MINERAL DIVERSIFICATION
1995 REPORT TO THE LEGISLATURE

Minnesota Department of Natural Resources

Minerals Division

March 1995

Pursuant to Minn. Stat. 93.002
Subd. 4 (b)

This report is available at various libraries in Minnesota. It may be purchased from the Department of Natural Resources, Minerals Division. For further information contact the Division's library in Hibbing, MN at (218) 262-6767.

1995 Minnesota Department of Natural Resources

Table of Contents

Letter From The Chair

Everyone should care about minerals because our lives and lifestyles depend on having a strong, viable minerals economy. We use minerals every day and depend on mineral in our homes, offices and factories. It is easy to take minerals for granted since most of us are only consumers of products made using minerals. We are not an active part of the mineral production process. However, for us to have titanium frames for our glasses, automobiles, and rechargeable batteries someone must:

- discover a mineral deposit,
- invest the capital and time to obtain environmental and reclamation permits,
- develop and operate a mine and its associated processing facility.

Minerals also provide jobs and tax base in rural areas which need the economic boost. Minerals in Minnesota is a one billion dollar industry supporting 8,000 Minnesotans directly, and perhaps another 10,000 indirectly. The taconite industry alone provides 96 million dollars per year in direct taxes, and royalties paid for state and county owned iron ore add some 6.6 million dollars to the Permanent School and University trust funds and taxing districts. In the last 100 years these funds have built to over 533 million dollars. A new copper/nickel mine might provide 950 jobs, and about 20 million dollars per year in taxes and royalties.

The state's mineral diversification program exists to generate information about the state's geology, new processing techniques, and improved reclamation methods that will allow deposits to be discovered and developed. The program is managed by the Minerals Coordinating Committee, which receives advice from three advisory committees. The program has had a number of successes over the last eight years.

In the Ferrous metals area the taconite process has been improved by diversification projects on pebble lime/dolomite, column flotation, flotation in magnetic fields, improved size classification, digital image analysis, and revegetation of taconite tailings. In the non-ferrous area detailed studies of the stratigraphy and structure of the gabbro has led to a resurgence of interest in the Duluth Complex. New developments in the grinding and flotation technology for copper/nickel ores has raised expectations for better grade and recovery during processing. Work in the industrial minerals area has led to leasing of three dimension stone quarry sites, and the opening of one quarry. The restoration of old sand and gravel pits using native grasses has been shown to be feasible, and low-grade kaolin production in the Minnesota River Valley has increased dramatically as has exploration for high-quality kaolin for the paper industry.

The most successful projects in terms of immediate economic benefit have applied to the iron ore industry, a mature and functioning enterprise. Excellent short-term benefits also have accrued from projects relating to industrial mineral commodities already under production in Minnesota. The projects in the area of non-ferrous metals have contributed substantially to the information base required for new mineral discoveries. Their economic impact has been relatively small and diffuse in the short run, but their ultimate value must be judged over the long run of the non-ferrous discovery cycle, which typically exceeds 30 years.

We can expand the state's production of minerals without creating long term extensive damage to the environment. Mineland reclamation can provide stable, hazard free areas, and reclamation research has given us many techniques for mitigation and control of materials that might cause air or water quality problems. We can have mining and a quality environment. The Mineral Diversification program has a demonstrated record of success, and MCC has the plan for extending the success to new commodity areas. Minnesota's untapped mineral wealth is an asset for future generations which must be developed wisely for their benefit.

William C Brice

Introduction

The Mineral Diversification program and the Minerals Coordinating Committee were created by the legislature in 1987 (MS 93.001 and MS 93.002). The overall goal of the program as stated in the Ten Year Plan was to "stimulate development of Minnesota's mineral resources". The authorizing legislation requires a biennial report to the legislature which describes progress in mineral diversification, and recommends future action and funding. This document is the biennial report for FY1996-97 which contains a summary of the projects and progress since inception of the program, and a justification for the actions recommended for the upcoming (FY1996-97) biennium and descriptions of recommended projects.

Executive Summary FY96-97 Diversification Plan

The Mineral Diversification program started on July 1, 1987 with an appropriation of $1,526,000. In December 1987 the MCC released a ten-year plan which was submitted to the legislature in January 1988. That plan identified the major priorities for minerals research which have been the basis for the Mineral Diversification effort over the last eight years. During that period the MCC has allocated $4.9 million to 55 projects in 11 mineral related areas. These studies are the foundation for the FY1996-97 strategy recommended in this report.

In the upcoming biennium the MCC member agencies will focus their efforts on those topics that appear to have the greatest likelihood for job creation in the short term. Therefore, the production of mineral inventories, resource assessments, and generation of regional level data will be curtailed in favor of development oriented efforts. The MCC believes past efforts have identified priorities so that specific strategies can be developed for each of the mineral commodities. The mineral diversification effort in the upcoming biennium will consist of three high-priority themes. These are:

- Supporting for iron ore value-added efforts of Minnesota mining companies,
- Improving the economic viability of known copper/nickel deposits in the Duluth Complex near Babbitt, and
- Completing the detailed mapping of the Virginia Horn area, a region with known occurrences of gold and other metals.

The MCC believes that other mineral topics also deserve attention, however, current budget constraints preclude extension of effort beyond the three mentioned above. As was previously noted, the first biennium's appropriation for mineral diversification was about $1.5 million, last biennium it was $750,000. This document requests $970,000 to coverthe work needed for the three priority topics listed above. If additional funds, above the amounts requested, were made available the MCC would allocate money to sand and gravel studies, development of information to support the recent interest in diamonds, and additional work in the dimension stone area.

Program Status

The following short discussion of the current state of knowledge and external factors provides the basis for the priorities listed above. This discussion will be separated according to the three priorities listed in the Ten-Year Plan. These are:

- To improve and extend Minnesota's iron industry
- To encourage exploration and development of non-ferrous metallic minerals
- To enhance Minnesota's industrial minerals industry

Mineral Diversification and its three objectives operate state-wide as Figure 1 shows.

"To Improve And Extend Minnesota's Iron Industry"

The ferrous area has been successful because an industry which needed specific help existed. Many of the projects funded were aimed directly at improving the quality or reducing the cost of taconite pellets made in Minnesota. The performance indicator for these projects is adoption by the industry. Digital Image Analysis has been adopted for particle size measurement, the use of pebble lime as a flux material has moved to plant scale testing, the CFS classifier will be tested in one of the plants, and magnetically assisted flotation is now undergoing extensive testing in the plants. Four out of six projects funded have had a direct positive impact on taconite operations. The second research area within the ferrous metals topic is value-added, i.e., production of direct reduced iron or other products. The first project funded under this heading was a small allocation to support the state's efforts on the COREX direct smelting process. More recently the work has been oriented toward development of DRI processes specific to Minnesota conditions and support of efforts to implement conventional DRI technologies in Minnesota. The development of one or more new DRI processes that make specific use of characteristics of Minnesota ore will take many years and large amounts of funding. Two possibilities have been identified. The first uses the energy boost obtained from the oxidation of magnetite to obtain temperatures high enough for rapid reduction of ore to iron. This process was conceived at the Coleraine Minerals Research Laboratory. The second is the reduction of low-grade natural ore containing about 40 percent iron followed by grinding and separation to obtain a commercial iron product. This process has been tested at Midland Research, and small scale tests showed some promise.

Currently much of the state's effort has been directed at implementation of conventional DRI processes at taconite plants. One project is underway at North Shore Mining Co., and the state's role in that effort is the development of a low-sulfur carbon source. The state has identified a process based on steam reforming of western coal which can produce a low-sulfur char product for DRI and a fuel gas that can be burned in a taconite pelletizing machine. The state hopes to have a federal Clean Coal Technology demonstration project moved to Silver Bay so that the process can be tested at a taconite plant. A second project at National Steel Pellet Company is just in the preliminary feasibility stage. The goal of that effort is to modify an unused pelletizing line to produce 200,000 to 400,000 tons of DRI per year.

"To Encourage Exploration And Development Of Non-Ferrous Metallic Minerals"

Much of the effort in this area has been expended on 1) regional scale (1:200,000) mapping and 2) geochemical studies. Seven mapping projects have been funded and the maps cover a large portion of the northern part of the state. The areas mapped were selected in cooperation with the exploration industry in Minnesota. It can be shown that exploration companies used the mapping efforts to target their leasing and reconnaissance work. However, the general level of exploration interest is down due to external factors like mineral prices, foreign incentives, and uncertainty due to the proposed revision of the federal mining laws. The mapping effort has significantly increased the knowledge about the bedrock which underlies Minnesota.

The Geochemistry projects, and specifically, the Glacial Till Geochemistry projects had a significant impact on leasing in the late 1980's. One of the projects actually found grains of gold in the till samples near bedrock, and generated many bids for mining units near the sampling points. However, subsequent exploration did not locate any mineralization worth a continuing effort so work on this topic was reduced in the later years of the program. Soil geochemistry remains a valid tool to identify "hot spots" in locations where the till is rather thin. In areas where the till is thick and has been laid down by several glacial events the issue is more complicated and less likely to identify nearby mineralization.

One of the tools that has proven quite effective is drill core examination and assay. The state's drill core library in Hibbing contains millions of feet of core obtained from exploration companies searching for deposits. In most cases the companies were looking for something specific and therefore overlooked other possibilities. For example, much of core taken while searching for copper/nickel deposits in the Duluth Complex contains oxide zones which were bypassed. Examination of the core found that some of these zones contained chromium and platinum group elements. The drill core library has been a fertile source of new geologic information. Therefore, the MCC has retained a consistent program of drill core examination and assay.

Historically, mineral processing did not receive much mineral diversification funding. A modest program on Ilmenite processing was initiated in 1987, but the results were not impressive so that line of effort was cancelled. However, two small basic research projects have had a larger impact. A small project on copper/nickel flotation conducted by Dr. Iwao Iwasaki from the Department of Civil and Mineral Engineering, found that grinding with mild steel balls contaminated the surface of the ore particles and inhibited flotation. His work led directly to the proposal contained in this report on Metallurgical Processing of Minnesota's Copper/Nickel Ores. It is believed that new technology based on Iwasaki's work might improve the separation of nickel, thereby improving the economics of the deposit. A second project on manganese in the Emily district showed that deeply buried high-grade deposits were likely in that area. That study lead to a significant investment in geologic interpretation and in-situ leaching by the U. S. Bureau of Mines.

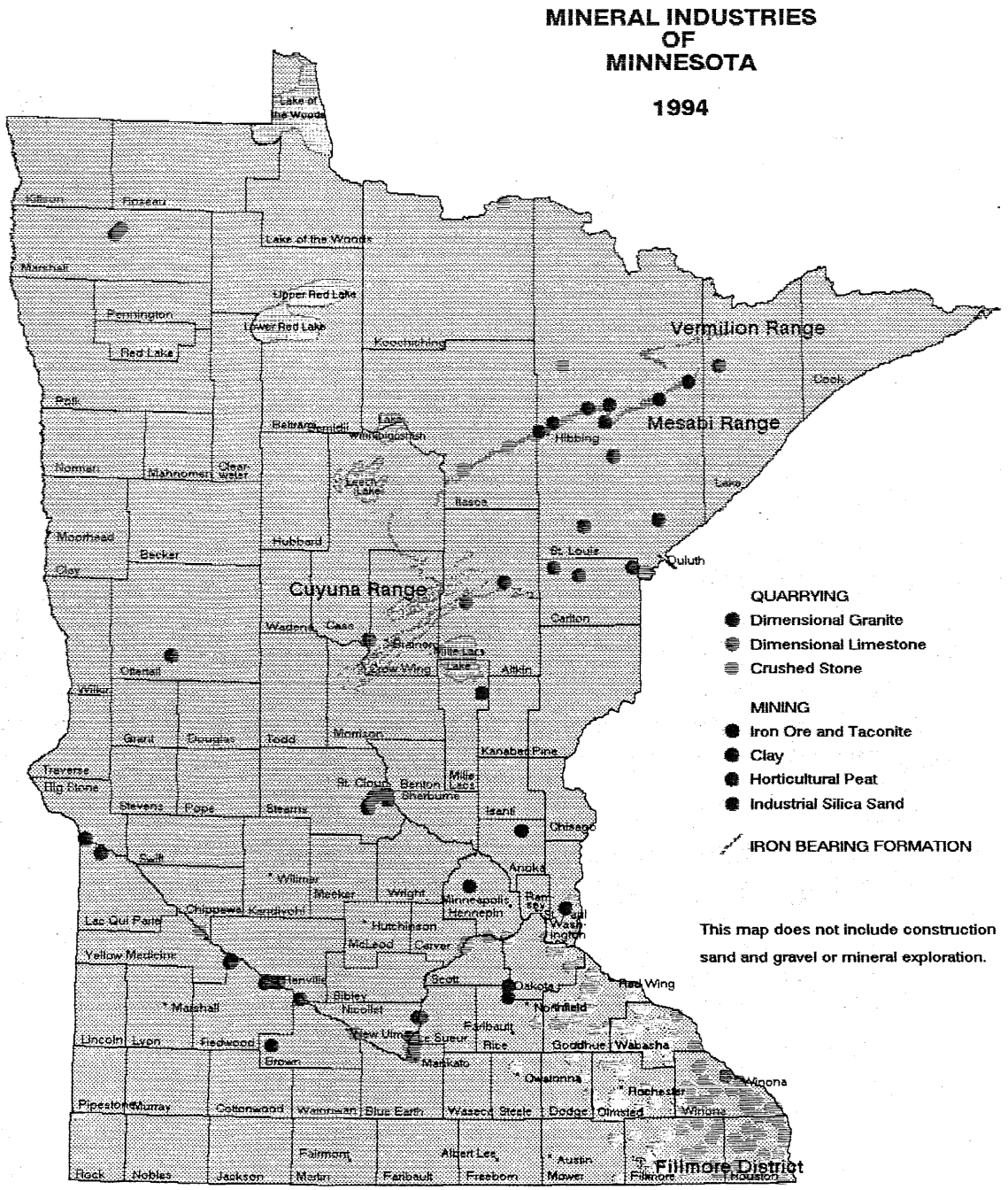

FIGURE 1.

"To enhance Minnesota's industrial minerals industry

The industrial minerals topic consists of two major areas: sand and gravel studies and mineral surveys. Sand and gravel inventory has been funded for six years. In that time three counties have been completed and inventories in two counties are now underway. The maps produced show where high quality gravel deposits are likely to be located in the county. The maps are being used by county planners, developers and road builders for zoning, planning and construction. All of the recent maps have been produced using geographic information systems (GIS) technology, so they can be transmitted in digital format, and used at different scales. The other project area is sand and gravel restoration. This topic is becoming more important as counties become more interested in the reclamation of old gravel pits. One of the more interesting findings is that gravel pits can be restored with natural prairie vegetation. This concept is currently undergoing large-scale testing in Clay County, and more work on this approach is expected in the FY1996-97 biennium as an LCMR project.

The mineral survey projects fall into three major product categories: Carbonate rocks, clays, and dimension stone. The dimension stone inventory project has been particularly successful. Work over six years has identified 18 sites, three of which have been leased by the federal government. Two sites have been opened, and one of those is in production with the second expected to begin production in 1995. Several other sites on state land will be the subject of the first lease sale under the state's new industrial minerals leasing rules. This sale is expected in mid 1995. While the number of jobs created remains small, they are in areas where a small number of jobs is important.

The clay evaluation effort has been aimed mostly at kaolin. It started with a product development project whose goal was production of material suitable for the paper industry. This goal was never achieved, but the project did generate private development interest. The MCC soon turned its efforts to resource assessment. Since 1989 personnel from NRRI have mapped a stretch of the Minnesota River Valley from just above New Ulm to Laq Qui Parle. This work has identified several areas of secondary kaolin which might be developed, and currently one company is engaged in a major effort to process Minnesota kaolin into products suitable for paper-making. Several firms have opened kaolin pits to obtain lower quality material for cement-making, and small scale kaolin production is now firmly established near Redwood Falls. The MCC also funded a small development project on the bloating clays found in Kittson County. The researchers found that the clay could be used to produce a light weight aggregate material. However, commercial development interest has not materialized.

The carbonate rock projects sample many of the formations in Southeastern Minnesota, and compared the results to known specifications. One of the formations that appears in several quarries near Stewartville has a chemical composition that would make it ideal for flux in the taconite industry. Investigations were begun to find a way to get this material to the plants in Northeastern Minnesota, however, transportation costs appear to be too high. The work on carbonate rocks has generated a significant data base that should be stable and usable for some time into the future.

Environmental Research

Environmental research has been a small but important part of the Mineral Diversification Program. The effort has been on reclamation of mined lands and two topic areas have been prominent, i.e. waste rock characterization and sand and gravel restoration. The metallic minerals waste rock characterization work augmented the state's efforts at the research site near Babbitt. The sand and gravel restoration work defined several reclamation techniques, one of which is restoration to native prairie. Both of these projects had a direct effect on the establishment of the Environmental Cooperative Research program.

The reclamation research component also supported the creation of a new research site near DNR's minerals office in Hibbing. This new site will allow studies on impact prediction and mitigation for both ferrous and non-ferrous mine wastes. Prediction is based on development of baseline information of how various wastes will behave in the environment. Mitigation relates to creation of new Best Available Technologies (BAT's) for reclamation of mined areas and treatment of mining wastes. Field scale studies are needed in these areas to verify their use in expected Minnesota conditions.

Funding History

Funding for mineral diversification has followed a generally downward trend since its inception in FY1988. In the first biennium the funding was divided between two appropriations. The first came from the general fund, and the second was a dedication of that portion of the mineral leasing revenue that reached the general fund. In 1989 the dedication was removed, but an amount equal to the mineral income was transferred to the general fund appropriation. The 1991 legislature appropriated a significant increase in funding which was subsequently lost in a special session, and in 1993 the agencies were forced to take a substantial funding cut. Cuts in mineral diversification have been unfortunate considering the success of the program.However, cutting other areas would have resulted in curtailment work central to the state's minerals management goals, and significant layoffs of state personnel.

Table I: Biennium

Biennuim	***Amount***
FY1988-89	$1,626,400
FY1990-91	$1,420,400
FY1992-93	$1,302,800
FY1994-95	$750,000

FY1996-97 Recommendations

The funding recommendations for the upcoming biennium are based on the priorities for mineral commodities developed by the MCC during the last eight years, the recommendations of the Governor's Commission on Mining and Minerals, and on the work of the Sustainable Development Task Force. The MCC believes it is possible to have mining and job creation, while protecting the environment for the benefit of future generations. The recommendations contained in this report focus on three topics. These are:

- Ferrous Value-added analysis to support the DRI efforts of Minnesota's taconite producers- $50,000
- A Duluth complex package which consists of the following projects:
    - Metallurgical Processing of Minnesota Copper/Nickel Ore- $400,000
    - Geologic Modeling of Minnesota Copper/Nickel Ores- $25,000
    - Intensive Investigation of Potential Mineralization Anomalies in the Duluth Complex- $195,000
- Intensive Mapping of the Virginia Horn Area- $300,000

The MCC believes that these projects have the greatest likelihood for short-term job creation. The $970,000 funding requested for the projects listed above, is $220,000 more than the amount appropriated for FY1994-95. However, it is $410,000 less than the average appropriated over the last four biennia. The MCC is requesting this level of funding as it believes the foregoing projects represent the best opportunity to achieve the mineral diversification goals set forth in the authorizing legislation.

Mineral Diversification in Minnesota

Program Overview

The Mineral diversification program has been funded through four biennia. The program is managed by the Minerals Coordinating Committee with advice from technical advisory committees whose membership corresponds to the goals stated in the ten year plan. The program started with broad goals to:

1) Increase the knowledge of the state's mineral potential;

2) Stimulate the development of mineral resources in the state; and

3) promote basic minerals research.

Using this framework the Minerals Coordinating Committee divided the universe of possible strategies into three categories, according to mineral commodity. The commodity groups and the specific objectives for each are as follows:

- Ferrous Metals: To improve and extend Minnesota's iron industry
- Non-Ferrous Metals: To encourage exploration and development of non-ferrous metallic minerals
- Industrial Minerals: To enhance Minnesota's industrial minerals industry

The coordinating committee established priorities for commodities so that the funding could be divided equitably. Since 1987 the ferrous area has received about 30 percent of the funds, the non-ferrous area about 50 percent, and industrial minerals about 20 percent. Several program areas were identified within each commodity group, and projects were selected to fit within program areas. During FY90-91 about ten percent of the appropriation was allocated to basic research. However, funding cuts in the last two biennia precluded any funding for this area.

In the next biennium the Minerals Coordinating Committee will keep the same Ferrous, Non-Ferrous, Industrial Mineral structure, but will use strategies which are commodity specific. This will allow the MCC to organize its recommendations around past successes and program strengths. The program will concentrate on work which should attract increased expenditures by industry. Examples of the kinds of projects which fit this strategy will be described later.

External Factors Affecting Mineral Diversification

During the last eight years developments in the global mineral industry have had an impact on this program. World-wide geological, economical, and political factors greatly affect Minnesota's competitive position in attracting exploration capital. At present, the sum of these weighs in favor of investment outside of North America. The developing nations of Argentina, Chile and Indonesia, to name three, are undertaking massive mineral inventory surveys in prospective geologic terranes. They have inexpensive labor costs and tax structures which are low by North American standards, and governments which are supportive of a developing mineral industry. Therefore, much venture capital that formerly was available for exploration

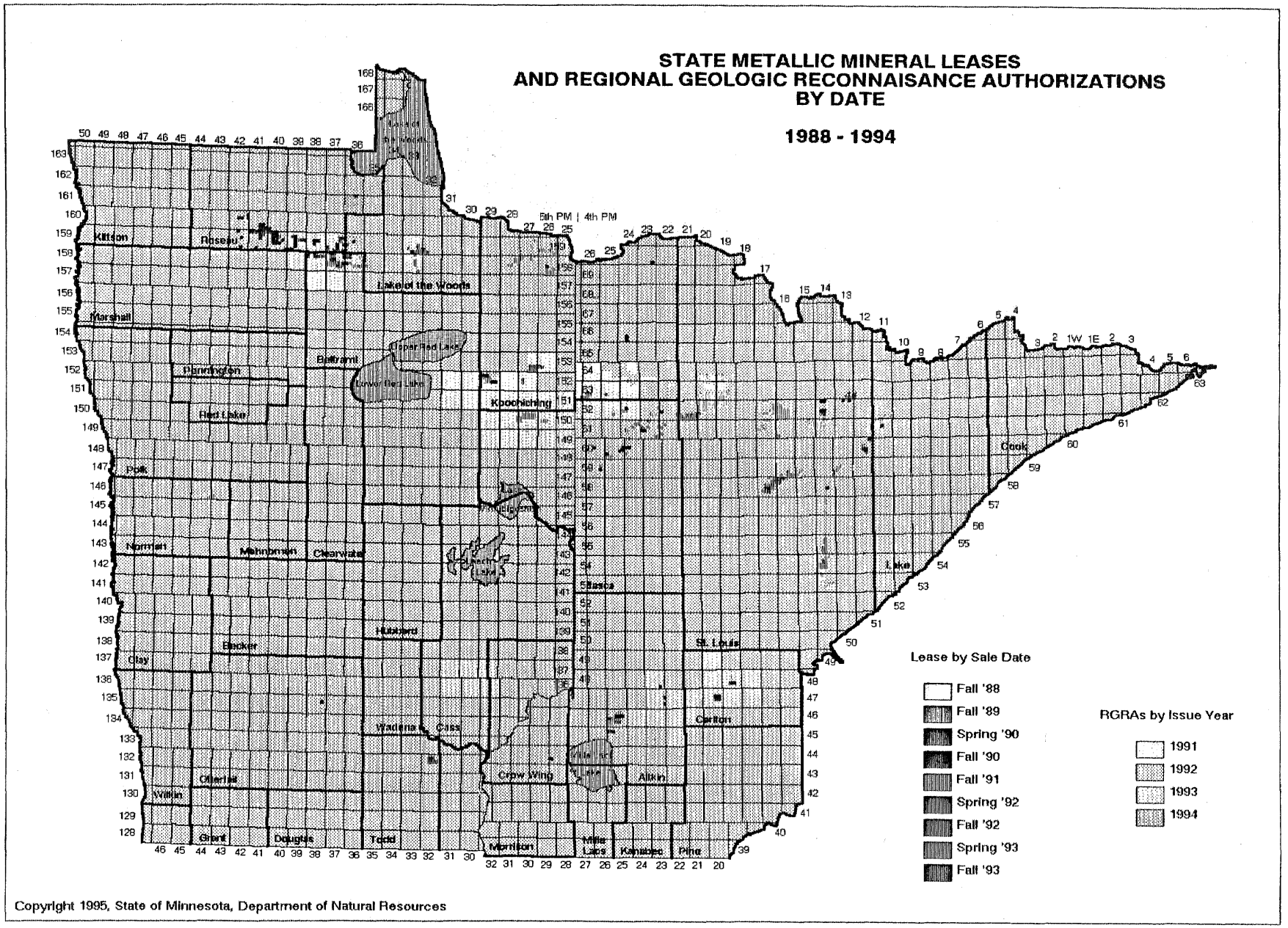

FIGURE 2.

projects in Minnesota is attracted to exploration in foreign countries. In addition to the foregoing, there has been a gradual shift of emphasis away from gold to base metals. Declining state funding may have also had an impact since budget limitations force the state to dramatically curtail its programs aimed at acquiring new geologic information.

Institutional uncertainties have also contributed to a general decline of exploration in the United States. Companies are reacting to uncertainties regarding their long-term liability for environmental cleanup and reclamation. The lack of information on what will work in the long-term, and assessment of liability for past actions have placed a damper on domestic exploration. Also, the lack of resolution over changes to the 1872 mining law has affected Minnesota even though the state is not subject to the law. Finally, reductions in federal budgets have made it more difficult to develop information that would interest exploration companies.

Program Strengths

The Mineral Diversification program has several strengths which relate both to program operation and technical results. The program has shown the importance of research, long-term commitment and planning to ensure productive partnerships with industry. The program has developed a strategic focus and deserves to be continued.

In the area of program operation, use of the MCC structure has reduced duplication among the members and increased the amount of data integration which is reflected in the quality of the products. It has also reduced competition for state funding. The program has opened the way for joint funding of projects, and acquisition of funds from external sources. It also provides a forum for discussion and establishment of priorities in a complex setting that includes differing commodities, industries, needs and capabilities. Establishment of industry advisory committees has created a venue for the committee to seek validation of its programs by the users of the information. The program has also added an environmental focus to what might otherwise be purely technical or economic approaches. Success of the environmentally oriented projects funded provided support for creation of a new Environmental Cooperative Research program.

In the technical area, the program has generated capital investment by industry, created some new jobs, and perhaps most importantly, has been a significant factor in saving existing jobs. Ferrous research through Mineral Diversification and Iron Ore Cooperative Research program is now well established and well liked by industry. The ferrous programs have a solid record of success and many projects have moved from the laboratories into the taconite plants.

In general, the Mineral Diversification program has allowed researchers the freedom to take risks on new ideas that could not be justified under the stringent funding requirements of private industry. This has led to several significant breakthrough concepts for the iron mining and/or industrial minerals industries. The program has been a significant factor in generating interest in value-added processing of iron ore in Minnesota, and it provided the basic information that led to new quarries in northeastern Minnesota. As will be discussed later, one of the basic research projects provided the technical basis for a new approach to the processing of Duluth Complex copper/nickel ores.

Program Weaknesses

Work during the last eight years has also uncovered some program weaknesses. The more important ones relate to the Minerals Coordinating Committee itself and project selection. It has been stated on several occasions that the coordinating committee only funds its own ideas, and the continuation of project areas over several biennia creates an image of funding individuals rather than strategies. In addition, the general lack of specific goals has contributed to a feeling that the MCC has no consistent approach to mineral diversification. In some cases the organizations represented on the committee did not support the actions of the group or circumvented the MCC process in order to obtain direct funding for a particular initiative. Also, audits conducted by the Department of Natural Resources uncovered accounting irregularities at the University of Minnesota which hurt everyone associated with the program. In addition, the lack of geographic coincidence of geologic mapping and mineral resource inventory programs is a weakness which has been addressed in the FY1996-97 proposal.

The basic research component of the program generated very uneven results, and the method used to select basic research projects was questionable. The major problem was a lack of peer review in project selection. A couple of projects generated very good results, as was previously mentioned, but most did not lead anywhere.

While some of items listed above might sound like a damning indictment of the whole program, they were caused by a few instances which were isolated primarily to one of the original MCC member organizations. Many of the problems disappeared after the university closed the Mineral Resources Research Center. Recent financial audits were much better, and showed only minor cost deviations. In addition, the MCC has attempted to broaden its perspective by obtaining advice on its requests from industry oriented advisory committees. In 1994 the MCC was expanded to include the Pollution Control Agency, and the U. S. Bureau of Mines so that differing perspectives could be acquired. Finally, the MCC recently sorted though all of its foundation studies to identify those that have the best chances of success in a commodity specific strategy. The results of that work will be presented in the recommendations section.

Conclusion

In general, the most successful projects have been in the iron ore area. The industrial minerals projects were unexpectedly successful. While selection of areas for leasing by the minerals industry has been guided by results of the non-ferrous program, the general level of mineral exploration is down, due primarily to external factors. The existence of an industry which needed specific help worked to make the ferrous area successful. Identification of minable resources, and local control of solutions to problems like sand and gravel reclamation, provided a basis for the success of the industrial minerals programs. External factors dampened success in the non-ferrous area. Past results have caused the MCC to change its focus to concentrate on specific minerals and deposits to maximize the probability of increased mining.

Mineral Diversification- Overview of Program Results

This section of the report is organized according to the objectives of the Minerals Diversification Ten Year Plan. It presents the objectives, performance indicators, types of projects funded and project results.

- Ferrous metals: "To improve and extend Minnesota's iron industry"

The performance indicator in this area is adoption of the new technology by the taconite industry. The types of projects funded include higher risk taconite research like:

- the use of Pebble Lime for binder and flux,
- production of low-silica concentrates for potential use in DRI,
- Value-added research on DRI technologies specifically applicable to Minnesota,
- Energy saving approaches to crushing and grinding utilizing the Vertimill, high pressure roll mill, and/or Vibramatic mills, and
- Research on control of NOx emissions.

Research in this area has been particularly successful, perhaps because the targets are so well identified and results can be measured.

Work to achieve concentrates containing less than two percent silica resulted in plant tests of new flotation concepts which may be patented by the state. At least two flowsheets with operating costs near $2.00 per gross ton, and capital costs under $20.00 per annual gross ton were identified for each taconite plant. This work showed that Minnesota concentrates could compete with foreign ore on a quality basis which makes Minnesota DRI more likely. .

The use of Pebble Lime to replace limestone flux and bentonite binder has been tested at a plant scale at USS' Minntac plant. Additional larger scale tests are planned for mid-1995. If these are successful, the material may be commonly used to produce pellets in 1996.

The value-added research has supported a DRI project started by a taconite company, created a DRI project at another plant, and generated two interesting new technologies one of which uses natural ore. The state maintains a tracking system for value-added technologies to assess their applicability to Minnesota. In this regard the state has identified a coal gasification technology that might be used to produce synthesis gas for DRI technologies like MIDREX, or low-sulfur char for DRI technologies like FASTMET or INMETCO and fuel gas that might be used in taconite pelletizing. This work has made Minnesota DRI look more attractive.

Finally, preliminary testing of the high pressure roll mills looks quite promising. More testing is needed, but a combination of new coarse crushing technology, addition of a high pressure roll crusher, and new grinding technology might lead to a very different method for processing Minnesota taconite ores that could make our plants competitive for years into the future.

The Mineral Diversification Ferrous projects have been coordinated with the projects selected by the Iron Ore Cooperative Research program. Together these two programs have generated significant results like the adoption of fluxed pellets, use of digital image analysis, adoption of new methods like column flotation, and introduction of new techniques like Computational Fluid Dynamics.

- Non-Ferrous: "To encourage exploration and development of non-ferrous metallic minerals"

The performance indicators in this area include the number of active exploration companies and amount of exploration undertaken in Minnesota. The types of projects funded include regional scale geologic drilling and mapping, geophysical and/or geochemical studies, stratigraphic analysis, drill core examination and assay, ore deposit modeling, waste rock characterization for reclamation, data collection and organization, mineral ownership research and mineral processing research.

The areas mapped since 1987 include the Cook area, Koochibel (Koochiching, Itasca and Beltrami counties), Northwest Minnesota, the Penokean orogen, East Central Minnesota and several zones in the Duluth Complex. The Cook Area and Koochibel maps in particular have shown an ability to attract exploration interest. In 1991 the state initiated a "Regional Reconnaissance" program which allows companies to work in large regions to obtain a better depiction of the geology. To date 17 [RGRAs] reconnaissance agreements have been executed, and about 79 holes have been drilled to bedrock as a result of these reconnaissance efforts. Figure 2 shows the correlation between RGRA effort and leasing.

Obtaining a stratigraphic analysis of the basal zone of the Duluth Complex has been a major achievement. Prior to the work done at NRRI the layering of the complex was not understood, and the known deposits appeared to be akin to raisins in a pudding. The geologists now know that these deposits fit well defined occurrences in the geologic record. This work has provided a context for the search for higher valued deposits, and/or extensions of current deposits. It was one factor in the recent interest in the known copper/nickel deposits.

The geochemical efforts have been instrumental in identifying small areas with high levels of those minerals usually associated with metal deposits. Work in the basal zone of the Duluth Complex has been particularly fruitful. The sampling of drill core for gold and overburden drilling generated significant lease sales in the late 1980's. The geochemical and geophysical data has been combined into anomaly maps of an area in east central Minnesota, and the same thing is now being done for the Duluth Complex. It is hoped that these maps will identify areas that deserve close inspection.Geochemical surveys of the overburden in the northern part of the state have identified areas of high potential for gold and base metals.

One of the high priority project areas has been the logging, sampling and analysis of drill core acquired for the Hibbing Drill Core Library. Over 143,500 feet of core representing 898 drill holes have been logged since the program began, and these data are now available in data base format for use by geologists outside the state. The mineral indications found during the program have guided the work of the mineral industry. While this effort has generated much useful data miles of core remain to be logged before the library can be fully useful to exploration geologists.

The mineral diversification program has also provided funding for acquisition of computer hardware and software for geographic information systems and global positioning systems. These are not related to any individual project, but are generally useful across all project areas. The agencies have found ways to use real-time positioning to create data sets that can be coordinated with existing base maps. They have developed ways to use these tools in geologic mapping, assessment of reclamation progress, monitoring of exploration, and planning for restoration projects. The digital tools should have a significant impact on work methods, work planning and the costs of map preparation. Their applicability is only beginning to be felt. In a related area, the MCC supported efforts to obtain better information on mineral ownership to identify new areas for leasing by the state. In all some 106,818 acres were researched and 31,472 acres were added to the state's mineral interest.

In the mineral processing area one small basic research project has had a large impact. Dr. Iwao Iwasaki during his last year at the university identified a large problem with previous processing work on Minnesota's copper/nickel ores. He found that the use of mild steel balls for grinding had a negative effect on the flotation of metallic concentrates. This work has generated a major proposal to revisit copper/nickel processing in order to obtain better recovery and cleaner concentrates. This work will be described in more detail in the recommendations. Another small mineral processing project showed that the state's ilmenite deposits can be processed to obtain clean concentrates. Ilmenite is one of the raw materials used to produce titanium dioxide paint pigments, titanium metal, and high purity pig iron. This work led to major testing of an ilmenite extraction process at the Coleraine Minerals Research Laboratory, the results of which are still being evaluated. In a related area, a geologic research project conducted by Dr. G. B. Morey led to major study of innovative methods for extraction of manganese from base rock by the U. S. Bureau of Mines. One of the methods studied was in-situ leaching and the other was remote controlled mining using high-pressure water jet cutting of the ore. While this work appeared promising from a technical standpoint, it generated significant environmental concerns. The loss of federal funds essentially stopped all further progress.

- Industrial Minerals: "to enhance Minnesota's industrial minerals industry"

The performance indicators in this area include development of new or expanded mines, initiation of feasibility studies by industry, and the number of information requests received. The types of projects funded fell into three general realms: resource assessment, product development, and reclamation with resource assessment predominating.

In the resource assessment realm, kaolin clay and carbonate rocks received the most attention with aggregate mapping and dimension stone coming in a close third and fourth.

A major effort at detailed mapping and assessment of the kaolin resources in the Minnesota River Valley and sections of central Minnesota was undertaken by the Natural Resources Research Institute in Duluth. This work identified large tracts which were likely to contain secondary kaolin. It also differentiated the kaolins according to the underlying rock types so that developers could have a basic understanding of the quality of the material.

The inventory of carbonate rock types in southeast Minnesota identified several deposits whose chemistry matched that needed for flux stone in the taconite industry. However, transportation costs from southern Minnesota remain as a significant impediment to utilization. The inventory led to consideration of the resource for several other uses, and it has become the foundation work for private firms interested in Minnesota's limestone and dolomite resources.

In the aggregate mapping area two counties were completed and two counties are underway. Diversification funding provided access to new mapping, data organization and data presentation techniques that will make future mapping much easier. Geographic Information Systems techniques have proven to be very useful in the production of final large scale maps, and the techniques have been adopted by local organizations interested in aggregate resources.

The dimension stone inventory started in the fall of 1989 was based on a request from the industry, but success was largely unexpected. The program has built on inventory techniques developed by mineral agencies in Canada and benefited from evaluations of identified prospects by the industry. Nineteen prospects have been identified, three of these were leased in cooperation with the U. S. Forest Service, and two of the sites were opened for test quarrying in 1994. Production started at one site in late 1994, and production is expected at the other site in 1995. This program illustrates what can be accomplished with new fieldwork, a long term commitment, and cooperation between government agencies.

Product development efforts concentrated on kaolin and bloating clays. The attempt to produce paper-grade kaolin was only moderately successful at a bench scale and so did not progress to pilot scale. Also, a private company began to conduct parallel research so the Coordinating Committee stopped its stream of effort to allow the private firm to progress at its own rate. The Kittson County bloating clays were tested at a pilot scale and products which met aggregate testing standards were made at Coleraine. This product needs a private developer but as yet no one has emerged to take a leadership role.

The reclamation projects concentrated on sand and gravel restoration. During the late 1980's a sand and gravel task force identified over 6,500 barrow pits, most of which are quite small. Of these some 4,000 are permanently closed, and in many cases reclamation was less than adequate. The state used the information gained to prepare a sand and gravel handbook which can be used by counties in their regulatory efforts. The document was published in 1993 and has since become quite popular with county zoning administrators. DNR employees are often asked to provide input and assistance to county processes. Identification of a large number of unreclaimed sites prompted the MCC to initiate a restoration program. It appeared that restoration for home sites, parks, and playgrounds were possible, and in some areas of the state restoration to native prairie was an economical course. This work has been expanded over the last few years and is now the subject of a major project on the Lake Agassiz beach ridges in Clay County.

Mineral Diversification Recommendations for FY96-97

During FY1996-97 the Mineral Diversification program build on knowledge gained in commodity specific studies conducted earlier. The project recommendations contained in this section are based on the expected funding level and supported by external endorsements. The MCC does not anticipate any great increase in funding, and has therefore, scaled the program to fit the expected appropriation. It has also listened to groups like the Governor's Commission on Mining and Mineral for guidance in project selection.

The funding cut absorbed in the last biennium caused a drastic reevaluation of the program. Program funding for FY1994-95 was cut by almost 50 percent from the average of the three previous biennia. This drastic reduction forced closure of some important research areas and curtailment of others. The result was an emphasis on ferrous metals value-added, regional scale mapping, drill core examination, and kaolin, and a shift away from product development and taconite processing research. The reduction also eliminated any possibility of opening new project areas.

During its review of the current situation, the MCC decided that a different approach to project selection should be used in the upcoming biennium. Rather than focus on information production for existing industries, or generation of information to attract exploration, the focus will be on short-term job creation and known deposits. The MCC is recommending that funding be concentrated in commodity areas that have the best chance for development, if technical obstacles yield to process and geological research. In so doing the MCC is following the advice given by the Governor's Commission on Mining and Minerals, and the Sustainable Development Work Group. The FY1996-97 recommendations of the Mineral Coordinating Committee are described below:

Ferrous Metals

Funding in this area will be reduced significantly to accommodate a new emphasis on known copper/nickel deposits. The Iron Ore Cooperative Research program is expected to continue, and University Trust Fund money will also be available for iron ore research, so state funding of iron ore research will remain significant. The one project remaining in the ferrous area will be:

- Value-added Analysis, $50,000
- Project funds will used to support ongoing DRI efforts at Northshore Mining and National Steel Pellet Co. The work at Northshore consists of finding a source of low-sulfur char reductant through steam reforming of western coal. This is a continuation of ongoing work. At NSPC the funds will be used to support evaluation of DRI production in an unused pelletizing machine. The personnel time needed for this effort will be supplied by the DNR general fund appropriation and diversification funds will cover travel costs, consulting contracts, sample analyses, purchase of reports, etc.

Non-ferrous Metals

Funding in this commodity area will be focused into two specific topics: intensive work on the Duluth Complex, in particular the known copper/nickel deposits and intensive geologic mapping of a region with known mineralization. All of the projects listed below were recommended by the Governor's Commission on Mining and Minerals.

Duluth Complex Package

- Metallurgical Processing of Ore from the Minnemax Deposit, $400,000

Basic research completed by Dr. Iwao Iwasaki at the University of Minnesota showed that ore grinding with mild steel balls reduced the selectivity of flotation, since the iron in the balls contaminated the ore surfaces and inhibited separation. It appears that all of the testing done by AMAX in the late 1970's may have been affected by this problem. MCC recommends revisiting this ore using new grinding and separation technologies. New ore samples will be taken, mineralogical investigation will be done and pilot scale amounts of material will be processed at the Coleraine Minerals Research Laboratory.Also, tests of hydrometallurgical processing which was not an object of past research will be initiated to determine whether a clean separation of nickel values can be obtained by those methods.

- Geologic Modeling of Minnesota Copper/Nickel Ores, $25,000

The existence of low-grade copper/nickel deposits in the Duluth Complex is well known. However, no one has found high-grade deposits even though the geology of the region suggests that such deposits might exist on either side of the contact with the Virginia formation. Data of the Duluth Complex will be compared and contrasted with conditions and ore controls in high-grade copper-nickel-platinum group mineral deposits to focus further exploration.

- Intensive Investigation of the Duluth Complex for Potential Mineralization anomalies, $195,000

Many independent studies of the Duluth Complex were conducted for a variety of purposes in the last ten years. Some investigators chose geochemical analysis, some geophysical, and a significant amount of effort was expended drilling for platinum group elements. Personnel assigned to this project will gather and process all of the available data combining it with the stratigraphic analyses already completed to identify areas of anomalous geology.

- Intensive Mapping and Drill Core Examination in the Virginia Horn Area, $300,000

The Virginia Horn, which lies in the fold of the Mesabi Range just east of a line between Virginia and Eveleth is an area of high mineral potential. The rocks of interest in that area are the Archean Greenstones, which are known to contain small amounts of gold and the footwall of the iron formation. However, the geology of the Horn has never been mapped intensively at a large scale, nor have the past mapping efforts been combined with intensive investigation of geophysical and geochemical anomalies. This project will start with a thorough evaluation of all past investigations, followed by geologic mapping organization of the data for ore deposit modeling. The result will be a detailed digital information package containing alteration data, chemical

analyses, geochemical and geophysical maps and a bedrock geologic map which pays particular attention to areas of potential mineralization. A package such as this will be valuable for mineral exploration and land use planning.

JUSTIFICATION: A detailed geologic map of the Virginia Horn and environs, Mesabi Range, will contribute to the resolution of issues related to the mining cycle from exploration through mining to mine closing and reclamation. EXPLORATION: The Archean rocks in the core of the Horn contain anomalous but uneconomic occurrences of gold. Modern remapping, integrated with data gathered by companies in earlier exploration cycles and with new geochemistry, could lead to significant new insights and a possible economic discovery. This possibility has significant land-use implications for the urban areas that surround the Horn. MINED-LAND HYDROGEOLOGY: The enriched "direct-shipping" ores of the Mesabi range were localized by faults and fracture zones in the Biwabik Iron-Formation which served as channel ways for the ore-forming fluids. Abandoned mines, many water-filled, now overlie these same fracture zones. Moreover, gravel-filled bedrock valleys are aligned with some fracture zones, leading to a situation in which ground water in the gravels communicates with surface water in the abandoned pits through fracture conduits in the bedrock. The design of appropriate water management strategies in and near the Virginia Horn will depend on the degree to which interactions of ground and surface waters in this profoundly disturbed mined land can be ascertained and understood. The relevance to land-use and associated environmental issues is obvious. RECLAMATION: Decisions concerning the ultimate disposition of mine pits and dumps should be guided, on a case-by-case basis, by their respective roles as recharge areas, discharge areas, or storage elements in the hydrogeologic system. Detailed geologic mapping will aid in these decisions to the extent that it elucidates the geologic framework of the hydrogeologic system.

The funding requested for the projects listed above, $970,000, is $220,000 more than the amount appropriated for FY1994-95. However, it is $410,000 less than the average amount appropriated in the three previous biennia.The MCC is requesting this level of funding because it believes the foregoing projects represent the best opportunity to achieve the mineral diversification goal as set forth in the authorizing legislation.

MINERAL DIVERSIFICATION PROJECT HISTORY FY1988-95

Prepared by: Minnesota Department of Natural Resources
January 1995

PROJECT DESCRIPTION	PROJECT MANAGER	FISCAL YEAR EXPENDITURES - $,000'S FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95	TOTAL
FERROUS PROJECTS										
Pellet Quality and Cost										
Digital Image Analysis	USBM		15.0							15.0
Novel Iron-making	MRRC			65.4						65.4
Improved Fluxed Pellets	CMRL			50.0	50.0					100.0
Process Temperature Control	CMRL			50.0	50.0					100.0
Improved Classification	CMRL						10.0			10.0
Phase II Low-Silica Concentrates	CMRL					50.0	50.0	25.0	25.0	150.0
Water Treatment for Flotation	CMRL					25.0	30.0			55.0
Value-added Technology										
COREX Direct Smelting	DNR	27.7								27.7
Technology Survey	DNR					10.0	10.0			20.0
Direct Reduction Research	CMRL/MID							37.5	37.5	75.0
Salt Roasting of Vanadium Ores	CMRL							12.0	12.0	24.0
Oxidation/Reduction of Magnetite	CMRL							10.0		10.0
NON-FERROUS PROJECTS										
Geologic Drilling and Mapping										
Cook Area Map	MGS	173.6	176.4							350.0
Koochibel Map	MGS			175.0	175.0					350.0
Northwestern Minnesota Map	MGS					150.0	163.0			313.0
Duluth Complex Stratigraphy	NRRI					75.0	71.6	50.0	50.0	246.6
Duluth Area Map	MGS					50.0	50.0			100.0
Quaternary Map of North Central MN	MGS					45.0	43.8			88.8
East Central Minnesota Map	MGS							120.0	120.0	240.0
Geochemistry										
Strategic Minerals	NRRI	98.0	98.0							196.0
Glacial Till	DNR	75.0	75.0	75.0	75.0					300.0
Bedrock	NRRI	31.0	69.0	50.0	50.0					200.0
Airborne Spectral Radiometry	NRRI		25.0							25.0
Gold in the Early Panokean Orogen	NRRI					12.5	12.5			25.0
Mineral Processing										
Concentration of Imenite	MRRC	30.0	100.5							130.5
Cu, Ni, and PGM Flotation	CME						3.4	8.0		11.4

MINERAL DIVERSIFICATION PROJECT HISTORY FY1988-95

Prepared by: Minnesota Department of Natural Resources

January 1995

PROJECT DESCRIPTION	PROJECT MANAGER	FY88	FY89	FY90	FY91	FY92	FY93	FY94	FY95	TOTAL
		FISCAL YEAR EXPENDITURES - $,000'S								
Data Acquisition and Analysis										
Drill Core Examination and Assay	DNR	33.8	50.0	50.0	50.0	45.0	45.0	51.3	51.3	376.4
Minerals Data Base	MCC		50.0	25.0	25.0					100.0
Mineral Deposit Modeling	MGS		39.4	40.0						79.4
Gold Economics Study	NRRI		22.5							22.5
GPS Acquisition and Functionality	MCC						56.5	7.5		64.0
Environmental Research										
Reclamation Research	DNR			25.0	25.0	18.0	18.0			86.0
Mineral Management										
Improved Ownership Records	St. L County		50.0							50.0
Severed Minerals Identification	DNR			25.0	25.0	10.0	10.0			70.0
INDUSTRIAL MINERALS										
Aggregate Studies										
Sand and Gravel Inventory	DNR			20.0	20.0	20.0	13.5	20.0	20.0	113.5
Sand and Gravel Restoration	DNR					10.0	10.0			20.0
Mineral Surveys										
Carbonate Resource Assessment	CMRL	68.0	128.5	50.0	50.0					296.5
Clay Product Development	MRRC/CMRL	40.0	40.0							80.0
Dimension Stone Inventory	DNR			12.5	12.5	20.0	20.0			65.0
Minerals Forum	MCC		10.0							10.0
Kaolin in Central Minnesota	NRRI					30.0	30.0			60.0
Carbonate Beneficiation	CMRL					25.0	25.0			50.0
Transportation Study	NRRI					5.0	5.0			10.0
Kittson County Bloating Clays	CMRL					12.5	12.5			25.0
Kaolin Resource Assessment	NRRI							42.5	42.5	85.0
BASIC RESEARCH	U of M			50.0	50.0					100.0
FISCAL YEAR TOTALS		577.1	949.3	762.9	657.5	613.0	689.8	383.8	358.3	4991.7
BIENNIAL TOTALS		1526.4		1420.4		1302.8		742.1		

MINERAL DIVERSIFICATION PROJECT RECOMMENDATIONS FY1996-97

Prepared by: Minnesota Department of Natural Resources
January 1995

PROJECT DESCRIPTION	PROJECT MANAGER	*ALLOCATIONS - $000'S* FY1996	FY1997	TOTAL
FERROUS PROJECTS				
Iron Ore Value-added Analysis	DNR	25.0	25.0	50.0
NON-FERROUS PROJECTS				
Duluth Complex Package				
Metallurgical Processing	CMRL	200.0	200.0	400.0
Geologic Ore Deposit Medeling	MCC	12.5	12.5	25.0
Potential Mineralization Anomalies	MGS/NRRI	97.5	97.5	195.0
Mapping of the Virigina Horn Area	MCC	150.0	150.0	300.0
FISCAL YEAR TOTALS		485.0	485.0	
BIENNIAL TOTAL		970.0		

APPENDIX A

Minnesota's Mineral Potential[1]

Minnesota's mineral potential lies in a bedrock geology, formed of Precambrian and Post-Precambrian rocks. The state has a high mineral potential based on the presence of Precambrian rock, which is subdivided into five terrains: 1) the old gneiss, 2) the Superior Province, 3) the Penokean orogen, 4) the Sioux Quartzite, and 5) the Mid continent Rift System. The southern third of the state is unable to tap the Precambrian resource because it is covered by a younger layer of Phanerozoic sedimentary rock. The bedrock provide Minnesota with minerals resources, many of which have not yet been tapped.

The Precambrian bedrock supplies the state with invaluable mineral resources of ferrous metals. The **old gneiss** terrane, exposed primarily in the Minnesota River Valley, is quarried for dimension stone and crushed rock products. The **Superior Province** covers about one- third of northern Minnesota, providing industries with dimension stone and aggregate. These are not its most attractive features, however. Greenstone belts, composed of alternating layers of volcanic and sedimentary deposits that resemble gold and base metal terranes in Canada, have captured the attention of many exploration companies. The **Penokean Orogen** lies under most of the east-central portion of the state. It is abundant with volcanic, granitic, and mafic intrusive and sedimentary rocks, including the Cuyuna and Mesabi Iron Ranges. Explored for uranium and quarried for its hardness is the **Sioux Quartzite**, expanding across nine counties in the southwestern corner of the state. And finally, the youngest of the Precambrian terrains, the **Mid continent Rift System**, has potential for chromium, cobalt, copper, nickel, platinum group elements, titanium, vanadium, and other minerals. It contains the Duluth Complex, the largest U.S. reserve of copper and nickel.

Both the Paleozoic and Mesozoic rocks of the Phanerozoic provide southern Minnesota with valuable mineral resources. The **Paleozoic** terrain contains marine sandstone, shale, silica sand, and dolomitic limestone, while the **Mesozoic** terrain includes sandstone, shale, clay and gypsum. Its kaolin clays are presently mined for use in both the cement and paper industries.

1 Minnesota Department of Natural Resources Division of Minerals, *Resource Assessment*, October 1991.

Tapping The Resources Wisely

With Minnesota's geography bursting with mineral wealth, it boasts of having the leading taconite mining industry in the nation. Unfortunately, it admits to a slow recovery from employment layoffs in the 1980s and faces a pending decline in the steel-making market for taconite ore. In 1987, the legislature saw the need to strengthen the state's iron ore industry by reducing production costs and increasing product values. It also sought to tap its mineral wealth and stimulate the development of new mineral resources throughout the state. By diversifying its mineral interests, the state would expand its mineral economy, making it more stable.

To meet the state's needs the legislature established the Minerals Coordinating Committee (MCC) and charged it with the responsibility to, "provide for the diversification of the state's mineral economy through long-term support of mineral exploration, evaluation, environmental research, development, production, and commercialization (Minn. Stat. sec. 93.001)." Its task is to prioritize and recommend government activities that will produce the most "environmentally sound and diversified mineral economy.[2]" Consisting of directors from four agencies, the Department of Natural Resources Division of Minerals, the Minnesota Geological Survey, the Mineral Resources Research Center, and the Natural Resources Research Institute, the Committee also seeks assistance from various public agencies, industries, advisory committees, and academic and technical communities. It began its tenure by developing a long-term plan projected over ten years[3]. Throughout the ten years, the Committee is striving to meet three objectives:

1) to improve and extend the existing iron ore and taconite industry, focusing on production efficiency and added-value products.

2) to encourage exploration and development of non-ferrous metallic minerals, particularly those in continuous demand.

3) to promote and expand the state's industrial minerals industry, addressing five areas in particular: geological resource assessment, product development, industrial mineral markets, technical requirements, and government requirements.

While not a specific objective of the committee, basic research is a vital component of all three objectives. The committee acknowledges that without it, "needed insight on regional geology, mineral characterization, and specific mineral processing technologies may not be available to support future development.[4]" To encourage research, the MCC appointed to the University of

---

2 Wooden, Rebecca A. and Brice, William C., "Mineral Diversifaction in Minnesota," *Skillings' Mining* ***Review***, September 17 (1988):4.

3 Minnesota Minerals Coordinating Committee, *Minnesota Mineral Diversification: Ten Year Plan*, January 1988.

Minnesota's Earth Resources Subcommittee the responsibility of soliciting proposals for basic minerals research, proposals that would strengthen and expand the foundation upon which Minnesota could develop and promote its mineral economy.

Iron Ore Cooperative Research Program

In 1987, to address economic difficulties and further fortify the iron ore industry, the legislature appropriated funds for the establishment and operation of the Iron Ore Cooperative Research Program (IOCRP). This program funds research projects which aim to reduce production costs and improve taconite product quality. All appropriations granted by IOCRP are matched in some manner by the U.S. Bureau of Mines and private industry. In turn, all members[5] actively participate in the selection of projects to be funded and benefit from the data gained by the research.

Between 1987 and 1993 the IOCRP focused its research energies and funds in nine classification program areas[6]: Carbon Addition, Low Silica Concentrate Series, crushing and grinding, Digital Image Analysis, Blast Fragmentation Analysis, Oxygen Enrichment, Grate Corrosion, and Pellet Metallurgical Property Improvement. Within each of these areas are more specific projects under research at chosen laboratories. Each project is aimed at very realistic and practical impediments to low-cost, high-quality taconite production. Therefore, many projects are designed to meet companies specific needs.

---

4 Minnesota Minerals Coordinating Committee, *Minnesota Mineral Diversification: Biennial Funding Plan and Status Report* (F.Y. 90-91), January 1989.

5 Members include: MNDNR; U.S. Bureau of Mines; seven taconite companies: National Steel Pellet Company, Hibbing Taconite Company, U.S. Steel-Minntac, Inland Steel Mining Company-Minorca, Eveleth Taconite, LTV Steel Mining Company, Cyprus North Shore Mining Company; and six research facilities: Midland Research, Cliffs Mining Services' Hibbing Research Laboratory, the University of Minnesota's (U of M) Natural Resources Research Institute's Coleraine Minerals Lab, the U.S. Bureau of Mine's Twin Cities Research Center, the U of M's Corrosion Research Center, and the U of M's Mineral Resource Research Center.

6 For an explanation of each program area or project, refer to the MNDNR Division of Minerals' Iron Ore Cooperative Research 1987-1993, November 1993.

Cooperative Environmental Research

In 1993 the Legislature established the Cooperative Environmental Research Fund for the Minnesota Department of Natural Resource's (DNR) use in studying environmental issues associated with mining. Approximately two-thirds of the legislature's appropriation had to be matched one to one with non-state funds before it could be expended. The department was able to exceed the matching funds requirement, receiving from the taconite industry, Clay County, and the U.S. Bureau of Mines. The following projects were undertaken:

Financial Assurance Report. A study on how to effectively implement the financial assurance requirement of Minnesota's mineland reclamation statute.

Wetland Creation in Mining Areas. A study to examine the feasibility of creating wetlands on areas disturbed by taconite mining, with an emphasis on tailings basins. Demonstration wetlands will be built to verify watershed ratios, as well as necessary treatment to achieve functioning wetlands.

Gravel Pit Reclamation on Prairie Landscapes. A project to demonstrate the value of native prairie grass species in the reclamation of abandoned gravel pits on public lands.

Amax Rock Sampling and Analysis. A study to dismantle twenty-year old leach piles to examine the physical properties, mineralogy, and chemistry of the leached lean ores.

All of these studies will be completed by June 1995.

Additional Program Results Favorable To Mineral Diversification

- Mining-Related Laws Revised

In addition to the three programs previously discussed, measures have been taken in mining-related areas to support the mining industry and minerals diversification of the state's economy. Revision of laws and rules are some of those measures.

Metallic Minerals Leasing Rules. In 1993, a set of amendments were proposed to metallic mineral leasing rules that have existed since 1966. These rules were previously amended in 1982 and 1988. Annual and sometimes semi-annual lease sales have been held since 1988 for the leasing of state lands for metallic minerals. These state leases cover the base and precious metals (e.g., copper, nickel, zinc, gold, silver, platinum and palladium) except iron ore and taconite.

The amendments provide qualification standards for holding a metallic minerals lease, clarify the standards for eligibility to negotiate a lease, and establish a new optional method by which the commissioner may issue leases upon application under specified circumstances. There are several administrative changes, one of which is the removal of the requirement that an executive council member be present at bid openings for public lease sales.

Changes in the lease form include: increase in rental rates, modification of the royalty rate structure, formal review of exploration plans, and exploration site closure plans. The changes in the royalty rate will result in a slight decrease in the base royalty rate for lower grade deposits (most commonly base metal deposits) and a slight increase in the base royalty rate for higher grade deposits (most commonly precious metal deposits). Competitive bidding may result in an overall royalty rate higher than the base royalty rate.

After adoption of the amendments to the rules, the Department plans to hold another metallic minerals lease sale. It will likely be mid-1995 when the executive council is asked to approve the issuance of leases from the next metallic minerals lease sale.

NON-FERROUS RECLAMATION RULES. The completion of the non-ferrous metallic mine reclamation rules in 1993 allowed, for the first time ever, the mining of non-ferrous metallic minerals. Prior to this completion, the only type of metallic mining that could, by law, be conducted was iron ore and taconite mining. The non-ferrous reclamation rules prohibit mining without first receiving a permit to mine. Approval of a permit is based on plans prepared by the mine operator, provided the plans demonstrate that mining and reclamation will be conducted in a manner that will not adversely affect Minnesota's natural resources or endanger the health of its citizens.

One of the chief elements of a non-ferrous metallic mineral mining permit application is a mandatory characterization of all mine wastes that are intended to be left after mining ceases. This characterization must identify all potential problems that the wastes could cause and the means that will be employed to resolve all potential problems. The reclamation rules also contain provisions for siting mine facilities; controlling erosion; providing safe slopes; measuring revegetation success; removing and cleaning site upon closure; and specifying long-term site maintenance, if necessary. Finally, the rules require mine operators to supply financial assurances for unforeseen reclamation problems, prior to permit issuance, relieving public funds of that burden.

TACONITE PRODUCTION TAX: RATES FROZEN. The Taconite Production Tax is a severance tax paid on concentrates or pellets produced by the various taconite companies. The taconite production tax rate for concentrates produced in 1993 remained frozen at $2.054 per taxable ton. The tax is levied on "taxable tons" which are the average tonnage produced during the current and previous two production years. The taconite production tax rate for concentrates produced in 1990 was $1.975 per taxable ton. The 1991 rate is the 1990 rate escalated by the percentage increase in the Gross National Product Implicit Price Deflator from the fourth quarter of the second preceding year to the fourth quarter of the preceding year. The rate was frozen at $1.975 for the 1990 production year. For production year 1991, the escalator was allowed to take effect which increased the rate to $2.054. Normally, the escalator takes effect each year unless the rate is frozen or changed by legislature.

The rate was frozen by the 1992 legislature at $2.054 per ton for production years 1992 and 1993. The 1994 legislature continued the frozen rate at $2.054 per ton for production year 1994 payable 1995.

TACONITE ECONOMIC DEVELOPMENT FUND EXTENDED (298.227). The Taconite Economic Development Fund was first created for production years 1992 and 1993 at a rate of 10.4 cents per taxable ton. The 1994 legislature extended the Taconite Economic Development Fund through the 1995 production year at the rate of 15.4 cents/ton established in 1993. Each producer's share can be spent for equipment, machinery or research and development in Minnesota on mining technology or taconite, iron, or steel production technology. A joint labor-management committee must agree on projects to be funded.

ECONOMIC DEVELOPMENT INCENTIVES. The 1994 legislature authorized the Iron Range and Resources Rehabilitation Board (IRRRB) to loan up to $10 million from the Economic Fund (2002) for construction and equipping of direct reduced iron (DRI) plants. The amount is limited to $5 million per facility and the loan authority expires December 31, 1995. The plant must be designed to produce iron upgraded to a minimum of 75 percent iron. This loan provision is also available to mineral producers subject to net proceeds tax (generally non-ferrous).

TAX RATE FOR DRI REDUCED. The 1994 legislature established a reduced production tax rate for DRI. For concentrates produced in 1994 through 1999, the rate is 25 percent of the normal production tax rate for the first 500,000 tons and 50 percent for any remainder. The three-year average will also apply to this tonnage.

- Governor's Task Force On Mining And Minerals

Many of the Governor's Task Force on Mining and Minerals' 1994 Recommendations echoed the Minerals Coordinating Committee's concerns to improve the iron ore industry, encourage the exploration of non-ferrous metallic minerals, and expand the state's industrial minerals industry. Highlights of those recommendations include:

Increased funding for bedrock geologic mapping. Modern mineral exploration is information based; exploration dollars from the private sector will be risked only in areas where geological data are sufficient for rational development of target concepts and exploration strategies. In much of Minnesota, the rock likely to host mineral deposits is covered by a blanket of glacial drift. This ubiquitous blanket makes it difficult to map the concealed rocks. Fortunately, aeromagnetic mapping and related investigations funded by the Legislative Commission on Minnesota Resources (LCMR) have provided regional data of exceptional quality to guide geologic interpretations. Building on the strong foundation of existing aeromagnetic maps with advanced interpretation, geologic test drilling and geologic interpretation can lead to production of high quality geologic maps in areas where present geologic maps are generalized and speculative. New geologic maps can be expected to stimulate exploration activity in the area, while providing the fundamental geologic data required for informed planning and decision making on other land use issues.

Therefore, the Task Force recommended funding of $400,000 per biennium for three bienniums for geologic framework mapping and $500,000 per biennium to complete the more detailed mineral potential and geologic study in selected areas; or $900,000 per biennium for three biennia and then $500,000 per biennium thereafter.

FUNDING FOR ENVIRONMENTAL RESEARCH. Environmentally sound development of the state's mineral resources and continued operations of the state's mineral industries require data on the prediction and mitigation of potential environmental impacts. Public-private cooperation in this research area is necessary to provide for sustainable development of the state's mineral resources.

The Task Force recommended funding LCMR proposals to 1) characterize iron mining wastes, 2) develop a plan to address aggregate resource supply and prairie protection for the beach ridge area of the former Glacial Lake Agassiz, and 3) examine effects of reclaiming non-ferrous tailings basins by converting them to wetlands. It also recommended that the IRRRB and the DNR explore with St. Louis County and the taconite companies the possibility of developing a municipal compost supply for re vegetating coarse taconite and other uses. Studies to determine natural pre-mining levels of metallics and contaminants in various water bodies that might be affected by future mining were also recommended.

FUNDING FOR FERROUS MINERALS RESEARCH. Continued state sponsorship of research is needed to protect the state's interest in its $2 billion per year iron ore industry. The Task Force recommends an additional $1.6 million allocation per biennium for ferrous minerals research to restore funding to traditional levels and to accommodate inevitable new studies to facilitate improvements in existing processes and new initiatives such as DRI and system economics.

CU-NI COMPANIES COOPERATION. The Copper-Nickel Resource Committee consists of parties having an economic interest or technical expertise in the development of Minnesota's copper-nickel deposits. It is working to determine the obstacles to the development of this large resource and report its findings and recommendations to the Task Force or Governor. The Technical Subcommittee of the Copper-Nickel Resource Committee reported its recommendations for an extensive metallurgical program and a limited geology program. Its recommended metallurgical budget is $440,000 with an anticipated timeline of 15 to 30 months. Its recommended geologic budget is $25,000 with an anticipated timeline of 12 to 18 months.

- Sustainable Development

In early 1993, the Minnesota Environmental Quality Board commenced the Minnesota Sustainable Development Initiative to address the ever growing concerns about the relationship between economic growth and environmental protection. The Minerals Team was one of seven teams formed under this Initiative. It was given the task to examine, "how we [the state of Minnesota] can explore and develop the state's diverse mineral resources, and efficiently use mineral products, in a manner that sustains both the economy and environment, without compromising the ability of future generations to meet their needs.[7]" The team studied and deliberated approximately nine months before reporting its *vision statement*, guiding *principles*, and *recommendations*.

To achieve its vision, "to balance [Minnesota's] needs for minerals, jobs, and protection of the environment...in the context of sustainable development and full cost accounting[8].", the team defined sixteen principles to guide the arrangement of its thirty-nine recommendations. The following is a brief explanation of four out of the five areas in which the principles and recommendations are ordered:

Encourage the use of *holistic management*, in which both critical environmental and cultural resources of the state are protected, recognizing at the same time the value of environmentally sound mineral development. A first step towards accomplishing this goal is to obtain an inventory of ecologically critical sites and mineral resources for intelligent land-use decisions and for incorporating the concepts of ecosystem and mineral potential into public and private planning.

Encourage recycling, reuse, and conservation so that our resources are used with the highest degree of *efficiency*. Metals, because of their inherent characteristics and their value, are highly recyclable, except where manufacturing processes have made this uneconomical. Products should be designed with the goal of recycling.

Develop a *sustainable* minerals *economy* to ensure quality jobs and minimal social disruption caused by mine closing. Several strategies may help to accomplish this, including increased knowledge of the state's mineral resources so the industry is not dependent on one metal, iron and local value-added processing so that the maximum economic impact from mining is kept in Minnesota.

Foster *strong and stable research*: environmental, geological, and metallurgical. It is critical that this research have long-term funding and that the research be accountable and directed to specific goals.[9]

---

7 Minerals Team of the Minnesota Sustainable Development Initiative, January 3, 1994, *Mining, Society, and* the *Environment*, p.1.

8 ibid., v.

9 ibid., vi.

APPENDIX B

Mineral Diversification Plan Project Results

This appendis contains descriptions of Mineral Diversification projects funded since program inception. It is organized according to the three major goals outlined in the "Ten Year Plan" using the sub-heading that were identified in that report. A single description is given in those cases where the work extended over more than one biennium.

- Objective 1: To Improve And Extend Minnesota's Iron Industry

  - Pellet Quality And Costs

DIGITAL IMAGE ANALYSIS. Stability, productivity and product quality in taconite processing require accurate particle size control throughout the concentration process. Accurate and timely particle size information allows equipment operators to do things like adjust cone crusher settings, adjust water additions, make binder and feed adjustments in balling drums, as well as modify blast parameters (such as the size of charge, the spacing of drill holes, etc.). The U.S. Bureau of Mines has been developing software and hardware packages for the operations at Minntac and LTV Steel Mining. Called digital image analysis, this computer-based, particle size monitoring system has undergone testing in both plants. The technique has significant potential for improving the control of particle size during the crushing and grinding process and improving control of moisture and pellet size in the agglomeration process.

IMPROVED FLUXED PELLETS. Production of fluxed taconite pellets is routine for two Minnesota companies and is being developed by two others. Raw limestone and dolomite are normally used for fluxed pellet production. This project seeks to build on that experience and to reduce costs by replacing the raw flux material with lime/dolomite hydrate or pebble lime.

The work has demonstrated that the substitution of lime/dolomite pebble lime for raw flux will reduce the additional energy required for fluxed pellet production by 50 percent. These energy savings will protect equipment and reduce excessive build-up of slag particulates. Furthermore, bentonite and organic binders can be totally eliminated, and the hydrate does not increase silica levels in the product, as the bentonite does. The use of the hydrate flux component can be accomplished with relatively minor adjustments to the plants. Encouraged by the research results, the USX Corporation is planning to run a full-scale plant test with pebble lime confirm fuel savings, reductions in the formation of NOx and productivity gains.

PROCESS TEMPERATURE CONTROL. This project was designed to evaluate the effect of water temperature on taconite processing at temperatures ranging from 45 to 120 degrees Fahrenheit, temperatures frequently found in Minnesota plants.

Batch and continuous grinding tests showed an increase of up to 10 percent in fines generation as temperature increased. However, it appears that classification efficiency decreased at the higher temperatures as a smaller percentage of the fines reported to the undersize or overflow. Flotation tests indicated better results as the temperature decreased, with the best flotation of silica occurring at 40 degrees Fahrenheit. Optimizing the temperature for various process unit operations should eventually provide economic improvements in taconite plants.

- Improved Classification.

PHASE II LOW-SILICA CONCENTRATE. Direct Reduced Iron research covers three areas: concentrate production, energy requirements, and innovative reduction processes. The low-silica concentrate project, which is being done at the Coleraine Minerals Research Laboratory (CMRL), aims to make Minnesota's taconite concentrate comparable with foreign ore by reducing silica levels to 2 percent.[10]

EFFECT OF PLANT WATER TREATMENT ON FLOTATION AND GREEN BALL QUALITY. The presence of high concentrations of calcium, magnesium, and sulfate ions in plant process water are known to have severe negative effects on flotation and pellet binder consumption. In addition, sulfate ions can contribute to accelerated corrosion. Since most taconite plants use extensive water recycle systems, a progressive build up of ions will result unless specific measures are taken to either prevent such accumulation or remove the ions from the system. Comprehensive water treatment to maintain or improve water quality is expensive, but can be justified if verifiable cost benefits from the treatment program can be demonstrated.

This project quantified the effect that water quality has on two critical process steps: flotation and green balling. Conventional water treatment methodology was used to prepare process water for bench-scale testing. The test work was based on plant water samples from three different taconite operations which were selected on the basis of preliminary water quality information and the interest of the plant operators. The data helped guide companies in the selection of the type of water treatment suitable for their plants and provide a preliminary cost-justification for the capital investment needed to bring water treatment technology on-line.

---

10 MN DNR Minerals Division, 1994. Minnesota Steel: A Blueprint for Progress. September, ix.

• Value-added Technology

NOVEL IRON MAKING. The project was targeted specifically at a new iron-making process conceptualized by the Director of the Mineral Resources Research Center. Its purpose was to complete preliminary material and energy balances, as well as operating and capital cost estimates in order to gain some insight into the technical and economic feasibility of the process.

The theoretical material and energy balances indicated that the process did not have any conceptual flaws. However, the work did point out some rather difficult engineering problems which would likely require extensive large-scale test work. The MCC classified the project as speculative research worthy of additional investigation. However, the investigator was not able to secure private funding necessary to continue the project.

COREX. The COREX Process is a commercial success with a 330,000 ton per year plant operating in South Africa, a 600,000 ton per year plant operating in Korea, another on order for Korea, and a fourth which may be built in the United States by Geneva Steel.

The state, in cooperation with the AISI, sponsored the first successful pilot trial of the COREX process in late 1984. This led to an attempt by the state to have the first demonstration of the COREX technology built here using a combination of U.S. Department of Energy (USDOE) Clean Coal Technology I funds, state loan guarantees from the Iron Range Resources and Rehabilitation Board (IRRRB), and industry funding. The state's bid for the plant was rejected in place of one from Weirton Steel Company, but in 1987 the state received another opportunity to build the demonstration when Weirton dropped out of the process. At the time, a potential plant operator would have had access to about $82 million of public financing, which would have limited the private investment to less than $25 million. However, no company stepped forward to take the offer, so the federal money was reallocated to other purposes. The project proposal data show that the demonstration plant would have been capable of producing about 400,000 tons of pig iron per year at a cost of about $120 per ton. That price would be very attractive in today's market.

TECHNOLOGY SURVEY. The Minnesota Department of Natural Resources (DNR) tries to keep abreast of iron and/or steel-making developments in order to assess whether a particular technology should be pursued. A summary of this effort is maintained by the Division of Minerals. Contains the cost estimates of various technologies based on material and energy balances and estimates of capital costs that have been gathered over the years.

DIRECT REDUCTION RESEARCH. In 1993 The Research Priorities Subcommittee of the Taconite Enhancement Committee recommended three value-added research projects for funding under the Mineral Diversification and University trust Fund programs:

The oxidation/reduction and Metallization process concept is somewhat similar to FASTMET, except that carbon is not added to the pellets. The goal is to capture the heat from pellet oxidation to improve kinetics of a subsequent reduction reaction, which would take place on a circular hearth. If the work is successful, it could lead to a process that would yield a low-gangue, low-sulfur direct reduced iron (DRI) product which would be competitive with imported

products. A patent disclosure on this process has been filed by Dr. Rodney Bleifuss, Director of Coleraine Minerals Research Laboratory (CMRL) of the Natural Resources Research Institute (NRRI).

Lean Ore Oxidation (LEANOX), i.e., producing a metallized product from low-grade ores, has been looked at several times over the last few decades. Most of the significant work was done in the late 1950s and early 1960s before the taconite industry became firmly established. Metallization of the iron oxides is the easy part, but liberation of the product from the silica matrix has always been the stumbling block. Under conventional grinding methods, the softer iron material tends to smear onto the harder, more brittle silica/silicate material. Consequently, magnetic separation does not yield a clean low-silica product.

CMRL's research on the production of iron carbide from low-grade materials will be expanded to verify its reaction kinetics, iron oxide conversion, carbon deposition and liberation to achieve a low-silica end product. Lab scale equipment will be used to produce small batches of material for testing.

Present research for these programs is at the bench scale level, but if any of the initiatives yield promising results, the need for funding could escalate dramatically in FY96-97.

SALT ROASTING OF VANADIUM ORES. Vanadiferous-titaniferous ores are found in Northeastern Minnesota. Previous investigations have proven the feasibility of producing pigment-grade synthetic rutile concentrate from the nonmagnetic portion of these ores, but the economics of this process are marginal at this time. The objective of this program is to determine whether a second product (vanadium) could also be extracted, thereby making the entire process more economically attractive.

- Objective 2: To Increase The Probability Of non-ferrous Metallic Mineral Discoveries

  - Geologic Drilling And Mapping

Much of the non-ferrous mineral wealth of Canada, South Africa, Australia, and Russia come from Precambrian rocks similar to those in northern and western Minnesota. Geologic mapping of Precambrian rocks in most of Minnesota is hampered by a thick cover of Quaternary glacial deposits, and the generally inadequate state of geologic mapping here has been an impediment to exploration for non-ferrous minerals. A major step to deal with this problem was taken in 1979, when a world-class aeromagnetic survey of Minnesota was authorized and the first part of it was funded. Since then, aeromagnetic data have been combined with selective drilling for ground truth to produce credible geologic maps of prospective areas in several parts of the state. The following projects were supported with mineral diversification funds.

North-Central Minnesota

1. Geologic mapping in contiguous parts of Koochiching, Itasca, and Beltrami counties ("Koochibel" area), 1988-89 biennium. Mapping revealed hitherto unrecognized fault zones and volcanic rock units in greenstone-belt terrane west of the Vermilion district. The mapping prompted serious exploration for gold and base metals by several companies.

Publications: Minnesota Geological Survey maps M-67 (1990) and M-68 (1990).

2. Cook-Side Lake area, St. Louis and Itasca counties, 1990-91 biennium. Mapping extended coverage from the western limit of older mapping in the Vermilion district to the eastern boundary of the Koochibel map area described above. In this project also the mapping revealed previously unknown structures and rock assemblages of consequence to mineral exploration, and attracted exploration interest.

Publications: Minnesota Geological Survey maps M-775 (1991) and M-79 (1993).

Northeastern Minnesota

1. Central Duluth Complex, Lake and St. Louis counties, 1990-91 biennium. Mapping covered a block of ten 7.5minute quadrangles roughly between Isabella on the northeast and Toimi on the southwest. The work clarified a very complex intrusive history in the unexposed interior of the Duluth Complex and provided a rationale for locating oxide-rich segregations in igneous units that are potential sources for vanadium, titanium, and platinum-group metals.

Publication: Minnesota Geological Survey Open-File Report 91-4.

2. Duluth Complex, Duluth area, St. Louis County, 1992-93 biennium. Mapping covered several quadrangles in and near metropolitan Duluth. The rationale, from the mineral-deposits viewpoint, was that much could be learned about mineralizing controls by careful work in this accessible area. The information would transfer to poorly exposed areas elsewhere in the southern part of the Duluth Complex.

Current interest in the Duluth Complex as a probable host for platinum-group-element (PGE) mineralization has focused attention on peridotitic differentiates and highly evolved oxide-silicate residues. Both of these rock types occur near the city of Duluth, where relatively good exposures permit their detailed scientific study.

3. Duluth petrology project, St. Louis County, 1994-95 biennium. This project is an outgrowth and continuation of mapping initiated in the previous biennium. It became evident that more effort was needed to sort out the complex relationships among mineral phases in several rock units near Duluth if the controls on igneous differentiation (and the distribution of platinum-group elements) were to be understood. A program to extend field mapping near Duluth, conduct laboratory work on rock and mineral samples, and compile all data as GIS coverage is now underway. Final map compilations will cover work from the 1992-93 and 1994-95 biennia.

Northwestern Minnesota

1. Bedrock geologic map of northwestern Minnesota, Kittson, Roseau, Marshall, Pennington, Red Lake, Polk, Norman, Mahnomen, Clay, and Becker counties, 1992-93 biennium. Mapping revealed previously unknown relationships among rock units and regional structures in the extensions of three major tectonic subdivisions of the Superior Province of the Canadian Shield. Three poorly known greenstone belts are now known in sufficient detail to attract exploration interest. The Vermilion fault is now known to be a fault zone composed of several strands, and to have experienced a complicated movement history. The terrane north of the Vermilion fault is predominantly gneiss and plutonic rocks, not volcanic rocks as formerly thought.

Publication: Minnesota Geological Survey map M-80 (1994).

East-Central Minnesota

1. Geologic map of an area south of Lake Mille Lacs, west of the mid continent rift in several counties, 1994-95 biennium. The principal object are of this project is to produce a bedrock geologic map of a trapezoidal area in east-central Minnesota that is the northwestern half of a quadrilateral bounded by latitudes 4507'30"W and 4615'00"W. This study area includes some of the least understood Precambrian geology in Minnesota. Much of the bedrock has been interpreted as Penokean granitoid intrusions, but signatures in the gravity and aeromagnetic data imply the presence of diverse rock types and structures. The area is of particular economic significance because it may include rock equivalent to the Penokean metavolcanic rocks of the Wisconsin magmatic terrane that host significant deposits of base-metal sulfides. A reliable geologic map is necessary for systematic mineral exploration in east-central Minnesota.

Quaternary Mapping

"Koochibel" area, north-central Minnesota, 1992-93 biennium. A geologic map that shows the distribution of glacially deposited surficial materials was prepared as an adjunct to the bedrock geologic map of the same area (see above). The mapping of glacial material was facilitated by the abundant drilling conducted by companies and agencies in the area. It provides the stratigraphic framework for interpreting the occurrence and distribution of "indicator minerals" in the drift what were picked up by glaciers from mineral occurrences in the underlying bedrock. The science of tracing indicator minerals in glacial deposits back to their bedrock source has become all important element in exploration for gold and diamonds.

Publication: Minnesota Geological Survey map M-76 (1993).

- Geochemistry

Strategic Minerals.

GLACIAL TILL. This project is a continuation of an effort to identify the regional occurrence of gold and other metals in glacial till to stimulate further exploration in northern Minnesota and to assist the Department of Natural Resources in its land management role. Twenty new bore holes in Lake of the Woods County were drilled, sampled, and analyzed. A complete digital database of results is now available.

Analysis of the drill cores show that the Baudette area contains two distinctive buried landscapes that were unknown prior to this project. These results also immediately aided the development of the U.S. Geological Survey's Roseau bedrock map. In addition, there were many important mineral potential findings. Low levels of gold and five pathfinder elements and minerals were observed in the Rainy till of the eastern portion of the field area in the vicinity of the Baudette fault system. The new observations suggest a secondary kaolin clay deposit may be located in a buried valley near Baudette.

BEDROCK. The primary purpose of this project was to construct a data base of geochemical evaluations of Archean bedrock in fifteen counties. The work brought together all available data from several sources, filled in existing gaps in that data, and made the data available to the minerals industry on a county by county basis. The NRRI constructed a data base of 12,451 complete or partial analyses of drill core and bedrock outcrop samples, using published materials, unpublished materials, and data contained within the abandoned lease files of the DNR Minerals Division Hibbing office. The sample locations were also identified on digitized county maps.

GOLD IN EARLY PANOKEAN. Precious metal exploration is primarily confined to northeastern Minnesota. However, precious and base metal potential also exists in the early Proterozoic rocks of the Mille Lacs Group, the Animikie basin rocks, and perhaps in some of the Cuyuna Range rocks. The purpose of this project will be to provide a base from which exploration companies can make decisions on where to begin exploration.

McSwiggen, et al. (1989) indicate the presence of precious metals in these rocks, but a comprehensive lithogeochemical evaluation has never been conducted. As was done for the Archean Bedrock Geochemistry project, this project will digitally georeference all known drill hole and outcrop geochemical samples.

- Mineral Processing

Ilmenite.

Cu, Ni, PGM Flotation. The Duluth Gabbro is a copper-nickel bearing deposit rock set in an environmentally sensitive area. At the present time deposits are considered to be only marginally economic. A technology which would allow for the separation of copper-rich and nickel-rich products, maximize PGM recoveries, and minimize the environmental impact of residual sulfides and flotation reagents in tailings would significantly improve the economics of developing the Duluth Gabbro. Such a technology would also be useful world-wide to solve problems encountered in the processing of complex (copper, lead, and zinc) sulfide ores. This project determined

the nature of the electrochemical interactions that occurred during grinding and integrated and correlated these findings with flotation behaviors. It showed that pervious test results may have been biased by iron contanimation of the sulfide partcle surfaces.

- Data Acquisition And Analysis

Drill Core Examination and Assay. Because of extensive overburden cover, drill core is the premier geologic sample reference regarding Minnesota geology. This project does reconnaissance relogging (describing) and sampling of the Hibbing Drill Core Library materials. The project purposes are: 1) to serve land use planning within the D.N.R.; 2) to encourage private exploration through better data access, and; 3) to serve government agency planning of future programs. This project is oriented toward identifying non-ferrous metallic mineralization, and features permissive of such mineralization. The new sampling and analysis of this project has been done to complement previous work of sample analysis. Results are made available in a digital format to allow for enhanced data handling and interpretation by customers, and GIS usage. Work areas include northern and central Minnesota, in several complex geologic terranes. Over 8 years, 898 drill holes have been described (783 logged in digital format) and 2277 samples have been analyzed. Favorable rock types, and anomalous base and precious metal assays, indicate a high probability for undiscovered economic mineralization. Mineral leasing has occurred on these lands, with active leasing still occurring in portions of the Duluth Complex and the present work area of central Minnesota.

- Environmental Research

RECLAMATION RESEARCH. Mine waste characterization and mine waste drainage quality prediction will be among the first environmental impact questions to address when non-ferrous mineral development begins in Minnesota. This information will be used to identify water quality controls required to protect the resources of the state.

Ten tailings samples from operating North American gold mines and two titanium tailings samples generated in pilot plant tests were characterized (particle size distribution, chemistry, mineralogy, etc.) and subjected to dissolution testing to determine drainage quality.

Static tests indicated that two of the samples were acid producers and that two others were marginal acid producers. However, acid produced by iron sulfide oxidation was neutralized by dissolution of calcium and magnesium carbonate. Additional dissolution of the same samples may deplete their neutralization potential, however, and so they could ultimately produce acidic drainage.

Continuing research seeks to answer questions raised in previous studies on long-term dissolution characteristics of reactive tailings, by determining the differences between reactive and non-reactive pyrites. In addition, the project seeks to determine the effect of temperatures and the length of dry cycle on dissolution. Methods of removing arsenic, antimony, and molybdenum from mine drainage will also be surveyed.

- Mineral Management

Improved Ownership Records.

SEVERED MINERALS INTEREST IDENTIFICATION. This project was established to determine the validity of existing state mineral rights ownership claims and to discover previously unknown state claims. Valuable information from a variety of sources other than the official county records was gathered.

Information was gathered from the records of USX Corporation, the mineral claims of Meridian Minerals, and the U.S. Forest Service for the Superior and Chippewa National Forests. Such "non-official" information can make valid state ownership claims for any particular parcel more or less likely. The state also used the official records to examine key title documents for several large minerals rights holders.

The total acreage researched during FY1990-91 totalled 126,000 acres. Diversification funding provided a 50 percent increase in the number of acres researched. The research results were used to prepare the list of minerals rights to be offered at public lease sales.

- Objective 3: To Enhance Minnesota's Industrial Minerals Industry

  - Aggregate Studies

SAND AND GRAVEL INVENTORY. Minnesota Statute 84.94 mandates that the DNR, in cooperation with the MGS, Minnesota Department of Transportation (MNDOT), and the State Planning Agency, identify and classify potential aggregate resources outside the seven-county metropolitan area. The statute also specifies that the program give priority to those areas of the state where urbanization or other factors may result in a loss of aggregate resources to development.

Mapping of aggregate resources requires data such as high-altitude photographs, geologic and soils maps, published reports, MNDOT test borings and domestic water well logs, and field work to verify interpretations.

Final maps are digitized for incorporation into state and county geographic information systems. Maps and accompanying reports provide valuable information to developing areas that wish to protect aggregate resources from future land use conflict. Additionally, the maps may be used for water planning and protection of rare or threatened native animal and/or plant species.

SAND AND GRAVEL RESTORATION. Minnesota ranks sixth nationally in gravel production. Figures for 1990 indicate 34.8 million tons of aggregate production in the state worth $89.4 million. Production was reported in 78 of 87 counties by 205 companies. According to an informal survey conducted by the DNR in 1991, there are about 1,600 active pits in the state. Another 2,500 are either permanently abandoned or only intermittently active. Most sites are mined without the benefit of a reclamation plan, resulting in problems that can include erosion, illegal dumping, safety concerns, and unauthorized activities.

Since 1987, the DNR, MNDOT, local government, and the industry have been working on reclamation techniques. Native prairie grasses seem particularly well suited to gravel pit reclamation. However, the cost and feasibility of the methods must be demonstrated in controlled tests given the fact that there are few examples of successful reclamation in the state.

BUFFALO RIVER STATE PARK. Gravel was mined out many years ago in short strips along an ancient beach ridge of Glacial Lake Agassiz and used in road and railroad construction. Between these strips are areas of undistributed vegetation that is good quality prairie. The Gravel Pit Reclamation and Prairie Restoration Project is in the process of restoring two former gravel mining areas totalling twenty acres to their original prairie vegetation. The work is confined to the areas distributed by previous gravel mining. The project area is surrounded by more than 100 acres of prairie and will complement the prairie vista image of the park entrance. Specifically, the project will:

- Delineate wetlands and identify sensitive wild flower species to be avoided.
- Remove old demolition material.
- Remove invading trees and shrubs on disturbed pit areas.
- Smooth and level 50 year old spoil piles left from gravel mining.
- Replant prairie grasses and wild flowers on the newly landscaped area using locally harvested seed.
- Control invading weeds, as necessary.

This first ever county/state partnership for reclamation and prairie will be a demonstration project. It will complement a recently funded LCMR project to develop and implement a plan to balance gravel production and native prairie restoration in Clay County, scheduled to begin in July 1995.

- Mineral Surveys

Carbonate Resource Assessment.

CARBONATE RESOURCE ASSESSMENT. Although it is well-known that all of southeastern Minnesota is covered by layers of carbonate rocks, no one had previously attempted a systematic sampling and analysis of the material. This project vehicle was used to sample over ninty naturally occurring or man-made outcrops in twelve counties. In addition, 14 holes were drilled in areas where channel sampling would have been very difficult. The sample data was correlated with the formations and other data to produce a regional representation of the carbonate rocks. The chemical data was compared to known product specifications to identify development possibilities.

The results have been used by companies, and quarry owners in southeast Minnesota to identify new prospects and new uses for materials from existing quarries. One of the more intriguing prospects is the use of material from the Stewartville formation as flux for fluxed taconite pellet

production. The material appears to have the correct chemistry. However, transportation costs may preclude its adoption by the taconite industry. It is expected that the data will become the foundation for much additional work in the future.

CLAY PRODUCT DEVELOPMENT. Although the clay deposits of the Minnesota River Valley have been known for decades, only recently have they been studied intensively to identify high-quality deposits. Today, the kaolin clays of the Valley are used only in the production of cement and bricks. Research conducted by the University will assist industry by locating the best quality clay in the Minnesota River Valley and central Minnesota.

Laboratory scale research to reduce particle size, and silica and iron contents have been successful and could now be pursued in larger scale tests. The resulting product is of a grade fine enough for coating paper, or any of the hundreds of other uses for kaolin clay.

Work at the University of Minnesota-Duluth, has helped narrow the parameters of exploration by determining the composition of parent rocks associated with the best grade of primary clay deposits. It has also pointed toward extensive secondary deposits which might be even more valuable.

DIMENSION STONE INVENTORY. A reconnaissance-level dimension stone inventory of crystalline rocks was conducted on government-owned and administrated lands in six northern Minnesota counties. Approximately 250 Middle Proterozoic (Keweenawan) and Archean outcroppings were evaluated with respect to joint spacing, color, texture, deleterious minerals, and size of extractable blocks.

Based on industry criteria, field investigations identified eight prospects and two inactive quarries that have potential for dimension stone development. These sites contain rock of a variety of color and texture, some of which is remarkably different from what is currently quarried or available domestically. Three sites have been leased and two of these will be producing by the end of 1995.

KAOLIN IN CENTRAL MN. The occurrence of kaolin in northern and central Minnesota is documented in drill holes and outcrops. However, very little of this material has been sampled for geochemistry, x-ray diffraction mineralogy, particle size analysis, or firing characteristics. While some kaolin clay samples were collected in central and northern Minnesota during the LCMR-sponsored clay study and the MCC study on the geologic and geochemical controls on the grade and distribution of clays, many new occurrences of kaolin clays have been identified in more recent drilling in the northern part of the state. Since the weathering episode that produced the kaolin clays in the southern part of the state was a state-wide event, good grade kaolin and other clays should also exist in the northern regions of Minnesota.

This project collected between thirty and forty samples from drill core and outcrops not sampled in the previous programs. These samples were analyzed for whole rock geochemistry. Particle size analysis, firing tests, and x-ray mineralogy were also conducted for comparison with previously analyzed samples from other areas of the state. A report of the findings was produced.

CARBONATE BENEFICIATION. This is a continuation of the original carbonate assessment program. The objective was to select some of the better limestone/dolomite deposits and subject them to standard beneficiation tests which would include stage crushing, high density scrubbing, screening, and hydraulic classification. There is reason to expect that these treatment schemes will reduce the percentage of diluents, primarily silica and alumina associated with intercalated shale and mudstone layers. This will improve the chemical purity of the limestone/dolomite and expand its market potential.

THE ECONOMIC IMPACT OF TRANSPORTATION COSTS IN THE POTENTIAL UTILIZATION OF KITTSON COUNTY BLOATING CLAYS AND THE MINNESOTA RIVER VALLEY KAOLINS. There are projects underway currently which seek to determine the potential of: 1) using the bloating clays found in Kittson County for the production of lightweight concrete aggregate, and 2) using the kaolin found in the Minnesota River Valley in the papermaking industry. As is the case with other industrial minerals, transportation costs will comprise a significant portion of the delivered price of each of these commodities. This project provided insight into effects transportation costs may have on the development of these resources by developing information on markets and market areas, and modes of transportation such as rail, truck, and possibly barge.

KITTSON COUNTY BLOATING CLAYS. The clays found in Kittson County, Minnesota are a part of the Pleistocene Sherack and Brenna Formations of Glacial Lake Agassiz. The bloating characteristics of the Kittson County clays were first identified during an LCMR-funded clay project. Evaluation of the bloating characteristics of these clays, based upon small samples, is currently being completed. Clays of this type may have application in the production of lightweight coarse aggregate used in the concrete and construction industry.

The Kittson County clays bloat at temperatures lower than any of the other Minnesota bloating clays. The Brenna Formation clays bloat better and have fewer impurities than the Sherack clays. Both clays outcrop and subcrop over a large area and within a few feet of the surface, making them readily accessible for open pit mining. The actual mining thickness of the clays exceeds 25 feet in most areas.

Currently, most lightweight aggregate (trade name: Arkalite) used by the construction industry in Minnesota comes up the Mississippi River by barge from West Memphis, Arkansas. It is possible that lightweight aggregate produced from the deposits found in Kittson County could be competitive with Arkalite provided that the raw material is suitable and the lightweight aggregate produced meets, or exceeds, ASTM standards.

KAOLIN CLAY RESOURCE ASSESSMENT. The occurrence of kaolin clays in the Minnesota River Valley between Redwood Falls and Fairfax has been studied in other MCC projects. This project continues the mapping of kaolin occurrences from Redwood Falls northwest through the recently-opened Belview mines, to Granite Falls, MN. Little geologic information is available on these clay deposits, their quality, or the controls on grades in the area.

This project will concentrate on mapping, sampling, and analysis of kaolin clays and associated bedrock. The samples will be analyzed for whole rock geochemistry, particle size analysis, and x-ray mineralogy and compared to samples from previous studies throughout Minnesota.

Basic Research

The purpose of this portion of the Minerals Diversification Program is to generate mineral research ideas by providing small amounts of money to faculty at degree-granting institutions in Minnesota. The money is then used for preliminary evaluations of promising geologic or mineral processing concepts. Projects funded in FY '90 - 91 included:

- Image processing for gravity and magnetic data
- Copper-nickel separation using reduced iron powders
- Flotation of platinum-group minerals from Duluth Complex minerals
- Identification of diamond-bearing Kimberlites in Minnesota
- Geology and petrogenesis of the Greenwood Lake area in Lake County
- Optimal production scheduling for non-ferrous operations in Minnesota

This research has had beneficial results. For example, the image processing work has lead to the production of several new maps based on existing data. The U.S. Bureau of Mines has become interested in work done on Duluth Complex minerals and has subsequently sponsored additional work in this area. Finally, the geologic work done in Lake County has substantially increased our knowledge of an area with high mineral potential.