BUREAU OF MINES RECLAMATION ACTIVITIES ON THE MESABI IRON RANGE, MINNESOTA[1]

by

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Abstract. Surface mining of iron ore on the Mesabi Iron Range in northeastern Minnesota began in the late 1880's, and continues today with production approaching 75 pct of our nation's iron ore. Mining and processing of low-grade iron ores results in hundreds of millions of tons of wastes generated annually, and these wastes must be stabilized against erosion. The Bureau of Mines began researching this problem on the Mesabi in the early 1980's with characterization studies of natural ore waste disposal sites, associated vegetative covers, and biological studies of mycorrhizal fungi relationships with coarse and fine taconite tailing materials. The interest in State reserves of low-grade copper-nickel ores during the 1970's and 1980's led the Bureau to research waste tailing revegetation and the movement of heavy metals associated with the waste materials.

With the reorganization of the Bureau in 1988, environmentally oriented research became a critical part of our mission and the Twin Cities Research Center began an extensive program of stabilizing wastes generated by the minerals-related industries. In Minnesota, vegetation research is in its third growing season of extensive study concentrating on the stabilization of coarse taconite iron ore tailing with organic waste soil amendation, and with the utilization of mycorrhizal fungi.

This presentation summarizes the Bureau's individual and cooperative research efforts in the reclamation of Minnesota mining wastes.

Additional Key Words: mining wastes, reclamation, revegetation, soil amendments.

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Introduction

Surface mining of iron ore on the Mesabi Iron Range in northeastern Minnesota began in the late 1800's and continues today with fully 75 pct of the nation's domestic supply coming from the Range. High quality natural ores, consisting primarily of hematite, were mined initially. As time progressed, industrial requirements

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increased, ore grade decreased, and the natural ores required processing to result in an acceptable, competitive product. Processing resulted in large quantities of waste tailing being produced for disposal in vast storage basins.

Since most of the iron formation was covered by glacial overburden, large quantities of this rock/soil mixture were removed and stored in waste piles. In addition, large quantities of lean ore (low grade natural iron ore not acceptable as direct shipping ore and not economical to process) were also removed and stored in hugh "Mesabi Mountains" across the Range.

As the natural ores began playing out in the 1950's, the industry began constructing large treatment plants to process taconite, a hard, siliceous rock containing 25 to 30 pct magnetic iron oxide as finely divided magnetite. At one time the rated capacity of the Range was over 65 million Mg of taconite pellets per year, and Minnesota's iron ore industry was faced with the annual disposal of more than 200 million Mg of iron ore wastes as overburden, coarse tailing, and fine tailing, in disposal sites requiring stabilization.

Minnesota Natural Ore Waste Characterization

In the early 1980's, the Bureau undertook a study to characterize Mesabi glacial overburden dumps and natural iron ore tailing basins, and to identify the type and degree of vegetative establishment on these structures (Nater, Bickel, and Borovsky, 1984). The dumps ranged in age from 0 to 74 years (years since last disturbance) and the tailing basins from 2 to 36 years.

At each of the 133 overburden sites and 36 natural ore tailing sites characterized, soil samples were taken for analyses and vegetative cover was evaluated. Limitations to vegetative growth were identified and fertilizer recommendations were made, and changes in soil properties over time were identified (Nater, Bickel, and Borovsky, 1984). Results were as expected, with the bulk density and pH decreasing with age and the organic carbon content increasing with time. Most of the overburden and tailing sites were adequately revegetated, mainly through volunteer growth. In fact, some overburden piles were difficult to identify with almost natural tree, grass, and shrub regrowth.

Lean ore piles on the other hand are of more concern because of their relatively steep slopes and small flat benches. However, nature has a way of reclaiming the slopes of even these formidable structures, with trees first and then grasses and shrubs. Given enough time, they almost appear to be part of nature.

Minnesota Taconite Development

In the 1950's taconite mining and processing was initiated in Minnesota, and soon took over the iron ore industry, replacing the depleted natural iron ore. Eight large-scale operations sprung up over succeeding years (only seven remain) until the industry had a rated capacity of 65 million Mg of taconite pellets per year. Taconite is a hard, silica-based, iron-bearing rock, containing up to 35 pct total iron (25 to 30 pct magnetic iron). The ore must be ground as fine as face powder to liberate the magnetic iron oxide particles for concentration through extensive processing techniques.

The concentrate is then rolled into marble-sized balls and heat-hardened for shipment to the steel mills.

The current production level of the Range is about 46 million Mg of taconite pellets per year. To produce this amount in the seven operating plants, the industry must dispose of 80 to 100 million Mg of coarse and fine tailing material, and at least an equal amount of overburden or stripping material. Large waste storage basins are created to contain the tailing, and in some cases the main construction material used to encase the fine tailing is coarse tailing material removed early in the process. For example, the USX Minntac property near Mt. Iron, MN has about 26 km of these dams enclosing about 2,800 ha of fine tailing material.

In 1980, the Minnesota Department of Natural Resources instituted mineland reclamation regulations (State of Minnesota, 1988) to deal with existing and anticipated waste problems in the minerals industry. Under those rules, vegetation must be established on glacial overburden dumps, tailing basins, and glacial overburden portions of pit walls. The vegetation must achieve rapid stabilization and provide for long-term use of the area. After three growing seasons since last disturbance, a 90 pct cover consisting of living vegetation and its litter must exist on all areas except south- and west-facing slopes, and these areas must comply within five growing seasons since last disturbance. Within 10 growing seasons, the vegetation must be self-sustaining, regenerating, or at a stage of acceptable succession providing wildlife habitat, pasture, or timber land.

Wisconsin Taconite Waste Stabilization

Besides the characterization work described above, an interesting study took place in Wisconsin during the 1980's, that laid the groundwork for some of our current revegetation research. Thomas Hunt (1983) conducted a one-year effort in which a good stand of vegetation was established on the fine taconite tailing of Jackson County Iron Company near Black River Falls, Wisconsin. Jackson County, Wisconsin's only taconite iron ore operation, closed its doors in 1983. Their tailing basin was circular by design, with coarse tailing forming the outer dam to contain the fine tailing. Hunt used composted papermill sludge as a soil amendment, and various mulches, with very encouraging results. However, warned Hunt, first-year results must be interpreted cautiously as vegetative stabilization implies long-term survival.

According to Hunt (1983), vegetative stabilization is the ultimate goal of most reclamation. It is useful for aesthetics and wildlife habitat, but the main function is for immediate and long-term erosion control. Living plant roots and tops are the most effective protection from wind and water erosion. Vegetation reduces wind velocity, removes suspended particles from the air, reduces the impact of raindrops, retards water runoff, restrains soil movement, increases biological activity, improves tilth, encourages infiltration, increases water storage, increases organic litter, increases cation exchange capacity, and moderates pH and temperature.

Minnesota Copper-Nickel Waste Revegetation

During the three-year period of 1976 through 1979, the State of Minnesota undertook a $5 million study to determine the potential environmental effects of copper-nickel (Cu-Ni) mining and processing in northeastern Minnesota. A large resource had been identified and several companies were interested in development. Questions remained after the study, however, concerning the fate of heavy metals in the tailing when these wastes were stabilized through revegetation. Barr Engineering Company of Minneapolis was awarded a Bureau contract to answer these questions (Borovsky, Grigal, and Strassman, 1983).

With few exceptions, the chemical and physical properties of the Cu-Ni tailing fell within the range of typical Minnesota soils of the area, and within the range of most taconite iron ore tailing, such as those characterized at the Minntac and Eveleth properties and discussed later in this presentation. The Cu-Ni tailing lacked organic matter and was deficient in nitrogen, phosphorus, and potassium as was the taconite tailing. The Cu-Ni tailing had a higher soluble salt content than the taconite tailing, and higher levels of heavy metals such as copper and nickel. Some taconite tailing materials contained more manganese than did the Cu-Ni tailing.

The test plots were amended with organic fertilizer, seeded, and mulched with straw to protect emerging seedlings. Three seed mixtures were tested, each containing a legume and several perennial grasses. All seed mixes performed well in the field providing more than 70 pct cover on the average in the third growing season. Additions of peat or topsoil as soil amendments were not found beneficial and therefore not recommended for the Cu-Ni tailing revegetation.

In general, the concentrations of heavy metals such as copper, nickel, zinc, manganese, cobalt, chromium, and lead in grasses were below suggested toxicity levels for plants (Borovsky, Grigal, and Strassman, 1983). Legumes tended to take up more of the available heavy metals, perhaps somewhat related to the high fertilization rates causing an increase in tailing acidity, but all levels were well below the allowable for grazing animals, as given in Table 1, (Borovsky, Grigal, and Strassman, 1983).

Mycorrhizae Research

Trying to meet Minnesota's strict revegetation requirements in the case of coarse taconite tailing is a seemingly unattainable goal with the traditional approach to revegetation. Using another approach, inoculating the site with ecologically adapted, symbiotic fungi, the potential for establishing a vegetative cover and realizing the State revegetation mandate becomes a more reasonable goal.

Virtually all higher plants growing in natural habitats have structures on and in their roots formed by fungi, called mycorrhizae. The mycorrhizal structure is considered to be a mutualistic symbiosis, where both plant and fungus receive benefit from the association. Benefits to the host plant include increased nutrient uptake, drought resistance, protection against pathogenic organisms, and more tolerance for soil pH extremes, high soil temperatures, and soil toxins. The fungi, on the other hand, benefit from the host plant by receiving the nutrients necessary for its existence.

Mycorrhizae literally means fungus root. Functionally defined in layman's terms, it represents an mutually beneficial relationship between a fungus and a root system. Several types of mycorrhizae are recognized, the two most common are ectomycorrhizae, and endomycorrhizae or vesicular-arbuscular mycorrhizae (VAM). The ecto- associates itself primarily with woody plant root systems, while endo- associates itself with the roots of most wild and agronomic plants.

Under Bureau contract in the early 1980's, Stewart and Pfleger (1985) from the University of Minnesota's Plant Pathology Department looked at this biotechnology approach on the National Steel tailing basin to determine the feasibility of using ecologically adapted mycorrhizal fungi in the revegetation of iron mining wastes. Red and jack pine were tested with ectomycorrhizae, and alfalfa plus a variety of grasses were tested with the VAM.

Results indicated the both the ecto- and endomycorrhizae were beneficial in establishing and maintaining vegetative growth. Fertilizer additions increased plant response only in the year of addition. Organic matter added as the source of fungi also improved plant growth and survival.

Again under Bureau contract, Noyd, Pfleger, and Stewart (1992) began more extensive research in the late 1980's at the Minntac coarse tailing dam site, studying the population ecology and use of VAM for stabilizing coarse taconite tailing materials. In general, they set out to determine VAM species and spore numbers in undisturbed soils adjacent to mine sites and on reclaimed mine sites; to identify natural modes of spore movement into the tailing disposal area; and to examine the relationships between fungi, plants, and organic soil amendments used in the vegetative stabilization process.

Spore migration studies showed that the most likely vector of spore dispersal and immigration at the study site was the wind. Other potential immigration vectors included both large and small mammals. Of the five species of VAM discovered at the study site, Glomus intraradix was the most frequently encountered, and is being used for subsequent study.

Seventeen plant species native to northern Minnesota were evaluated for their potential use in revegetation of coarse taconite tailing. Five species were selected for their response with Glomus intraradix: Canada wildrye, Kalm's brome, big bluestem, little bluestem, and round-headed bush clover. These species were planted in a large-scale demonstration plot this spring and will be discussed later in this conference in the presentation by Robert Noyd (Noyd, Pfleger, and Stewart, 1992).

Coarse Taconite Tailing Revegetation Research

The stabilization of taconite mining wastes became a concern of the Bureau because of a reorganization in 1988 and the elevation of environmental technology efforts in our research program. The Division of Environmental Technology was created to deal with mineral-related environmental issues, and the stabilization of coarse taconite tailing in Minnesota was identified as one of these issues.

The most practical method of tailing stabilization appears to be the establishment of a permanent, self-regenerating vegetative cover, to reduce wind and water erosion, to satisfy the aesthetic needs of the public, and to provide food and shelter for wildlife. Fine taconite tailing is readily stabilized through standard revegetation techniques employed across the Mesabi Iron Range. Several producers however, remove a coarse tailing product early in the process that is used in the construction of dams to contain the fine material. Coarse tailing is subject to the same State reclamation regulations as is the fine material, but because of its structure it cannot retain moisture and therefore cannot support the required level of permanent vegetation.

Fiscal Year 1989 Research

The development of a permanent vegetative ground cover for coarse taconite tailing became the subject of extensive reclamation research at two Minnesota sites: the U.S. Steel-Minntac Plant near Mt. Iron, and Eveleth Mines near Eveleth (Norland and Veith, 1992). Minnesota cooperators on the project in addition to the mining companies were the Minnesota Department of Natural Resources - Minerals Division in Hibbing, the University of Minnesota - Natural Resources Research Institute in Duluth, and Recomp, Inc. of St. Cloud.

To provide an idea of the magnitude of the problem, Minntac has constructed coarse tailing dams stretching more than 26 km in length, 150 m in width, and 9 m high. Eveleth also has a hugh fine tailing structure encased in a coarse tailing dam.

In 1989 the Bureau began to research the revegetation of coarse taconite tailing with a study at Minntac using organic wastes as soil amendments. The theory behind adding organic residue to the mining wastes is that organic matter acts as a slow-release fertilizer source of macro- and micro-nutrients necessary for plant nutrition and microbial growth. Organic residues can also affect tailing fertility indirectly by increasing the cation-exchange capacity, buffering pH changes, and increasing microbial populations. The organic residues can also tie up heavy metal ions that otherwise might leach into the groundwater, increase the soil water-holding capacity, improve soil structure, improve heat absorption capacity, and add some of the essential plant nutrients through the biological processes of decomposition, fixation, oxidation, and reduction.

Fiscal Year 1990 Research

Testwork was expanded in 1990 to investigate the effects of both type and age of organic amendments on vegetative response at both the Minntac and Eveleth sites (Norland and Veith, 1992).

Testwork at Minntac evaluated the response of vegetation to the age of organic amendments. The test design was a 3x3x3 factorial using municipal solid waste (MSW) aged 45, 90, and 180 days in windrow, and 18-46-0 inorganic fertilizer. The randomized block design included control plots and three replications, for a total of 90 individual 2.5x4-m plots (Norland and Veith, 1992).

Eveleth testwork was more extensive than that at Minntac, and evaluated the influence of type of organic waste on vegetative response. This design was a 4x3x3 factorial using four organic amendments (180-day old MSW with and without added disposable diaper residue, 180-day old composted yard waste, and reed/sedge peat), and 18-46-0 inorganic fertilizer. This randomized block design included control plots and three replications, for a total of 117 individual 2.5x4-m plots (Norland and Veith, 1992).

In both cases, a typical seed mix for the Iron Range was used, and all plots were mulched with hay and tacked down with netting to protect emerging vegetation.

When incorporating an organic waste as a soil amendment, one must analyze the deficiencies of the soil material to be treated and the available organics for incorporation, and select the most ideal combination. The organic amendments used should provide sufficient amounts of nutrients necessary for plant growth in the soil medium, and still be within the heavy metal limits allowed by regulatory agencies.

All composts used in Minnesota were within the limits established for Class I composts by the State. Class I composts must also be free from sludge or regulated industrial wastes, contain less than 1 pct by weight of contaminants (glass, plastic, and metal), and meet the heavy metal concentration restrictions shown in Table 2. Each compost used was well below these limits.

Results of the Minntac and Eveleth studies to date are covered in detail in a paper given by Norland (Norland and Veith, 1992) at this meeting. Soil quality at both sites improved with the addition of organic amendments. Soil fertility, total organic nitrogen, total organic carbon, and soil organic matter generally increased with increasing amendation.

Generally speaking, vegetation response at both sites was significantly improved with the addition of organic wastes and fertilizer, as measured by plant density (vegetative stems/m^2) and cover (percent of area covered by vegetation and its litter) (Table 3). In some cases, the higher rates of amendments were necessary to effect a significant improvement in vegetative response.

The highest rate of fertilizer resulted in no significant improvement over the medium rate, indicating that fertilizer addition can be kept to a minimum if combined with organic amendments. The high rate in our study was equivalent to that currently used on the Range in normal revegetation procedures.

Mature composted municipal solid waste with and without added disposable diaper residue, yard waste, and reed/sedge peat were all successful in establishing a vegetative cover approaching 60 pct after two growing seasons. This year is the third growing season, and we expect that the 90-pct cover requirement will be met with some of our organic amendment-fertilizer combinations.

Costs for the revegetation of Mesabi Iron Range coarse taconite tailing has not been addressed in this study, other than in a very cursory manner. Composted yard and municipal solid wastes may be readily available on the Range, if a market exists, for as little as a few dollars per ton at the compost plant. If used with organic amendments, the fertilizer cost should be half of the present rate. Transportation of the organic material from the compost plant to the mine site could perhaps be the major cost item.

The main benefit of this reclamation concept is that it will revegetate coarse taconite tailing with a single treatment, without additional attention, knowing that State regulations will be met. We also expect that this revegetation method will successfully compete with those presently used to stabilize the fine tailing on Minnesota's Mesabi Iron Range. Vegetation is flourishing on the test plots at these sites after two growing seasons, and within just a few inches outside the plots the tailing is bare.

Summary

In summary, the Bureau of Mines has been involved in the restoration of mined areas in Minnesota for many years. The current research on coarse taconite tailing using organic wastes to build soil materials and support vegetative covers, and mycorrhizal fungi to establish plant communities under extreme conditions, is very timely and promises interesting and economic approaches to compliance with State mineland reclamation regulations. Cooperators have been involved in this research from the beginning. Without their help, much of this would not have been possible.

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Table 1. Suggested Trace Metal Requirements and Toxicities for Livestock

Element	Species	Requirement ug/g Ration	Toxic Level ug/g Ration
Copper	Cattle	5-8	115
	Sheep	5	NA[1]
	Swine	6	250
Cobalt	Cattle	0.05-0.07	60
	Sheep	0.08	120
Lead	Cattle	NAp[2]	200
	Swine	NAp	80
Zinc	Cattle	20-30	900->1200
	Sheep	20-30	1,000
	Swine	50	2,000
	Horses	40	4,000

[1] NA, not available
[2] NAp, not applicable

Table 2. State of Minnesota Heavy Metal Limits Allowed For Composts and Soil Amendments (mg/kg) and Levels in Organic Wastes Used in the Study

Heavy Metal	PCA[1] Limits For Class I Composts	Yard Waste	MSW-W[2]	MSW[3]	Peat[4]
Cd	10	0.5	2.6	2.0	0.5
Cr	1,000	7.1	35.1	24.3	5.9
Cu	500	11	166	84	9
Pb	500	33	252	218	15
Ni	100	7.1	22.5	20.3	7.7
Zn	1,000	87	399	392	32

[1] PCA, State of Minnesota Pollution Control Agency
[2] MSW-W, municipal solid waste with 8 pct disposable diaper feedstock
[3] MSW, municipal solid waste with 2 pct disposable diaper feedstock
[4] Reed/sedge peat

Table 3. Main Effect and Interaction Significant Improvements - Plant Density and Cover, Minntac and Eveleth Coarse Taconite Tailings

Parameter	Minntac Density	Minntac Cover	Eveleth Density	Eveleth Cover
Organic Amendment Type	180-Day MSW[1]	45/90-Day MSW[2]	Peat	MSW-W[3]
Organic Amendment Rate	Med - High	High	High	High
Fertilizer Rate	Medium	High	Medium	High

[1] - 180-Day MSW, MSW 180 days in windrow
[2] - 45/90-Day MSW, MSW 45 or 90 days in windrow
[3] - MSW-W, MSW with 8 pct disposable diaper content in the feedstock