# RECLAMATION OF ACID-FORMING MATERIALS IN THE COLORADO ALPINE[1]

by

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**Abstract.** Permanent reclamation of tailing and other acid forming mine wastes in the western United States has been largely a losing proposition. There have been few if any successes without actual burial of wastes with soil, overburden, waste rock or other material more amenable to reclamation. Rather than major breakthroughs, development of new techniques has been slow and steady. Revegetation of acid forming wastes with little or no soil cover is now probably feasible. Three key elements include the use of adapted plant species which are now becoming commercially available, lime and selective bactericide for controlling acid, and organic amendments such as manure or sewage sludge. Benefits of this type of reclamation often include reduced mobility of toxic metals and improvements in water quality. With a stringent regulatory regime for mine wastes impending under Subtitle D of RCRA, the importance of good, economical reclamation techniques will become critical to successful and profitable western mining operations.

## Ecological Setting of High Elevation Sites

Ecologists have long recognized that plant species tend to exist in fairly predictable distribution patterns. Conditions of climate and soils create selective pressure favoring certain species over others in any particular area. Species adapted to an area are recognized as a "plant community."

The landscape of the intermountain west is characterized by—among other things—rapidly changing topography. Distinct plant communities occur in different topographic zones. Distributions of such familiar plant communities as sagebrush, pinyon-juniper, scrub oak, mixed conifer, and alpine tundra are to a large extent a reflection of changes in elevation. Reclamation specialists use their knowledge of plant communities as a guide for selecting species which will be suitable for conditions at a particular site.

Great advances have been made in reclamation technology in the past twenty years. Probably the most significant of these has been the "domestication" of many species—especially native species—for revegetation, and the development of commercially available sources of seed and nursery stock. With the emphasis on diversity as a desirable (and in many instances a required) trait of reclaimed landscapes, it is not uncommon to see seed mixes containing twenty or more species. Such mixes would not have been feasible in the west more than ten years ago.

The alpine zone refers to the high elevation zone occurring above the treeline. Despite the progress that has been made in reclamation technology, reclaiming alpine disturbances remains problematic. Problems are exacerbated by harsh climatic conditions, marginal or unsuitable soils, and a short or non-existent supply of seed of adapted plant species. Results in Colorado, Alaska and elsewhere have shown a tendency for species adapted to lower elevations to decline in vigor following initial establishment when seeded in alpine environments. Good initial stands may eventually die out altogether. Especially on non-topsoiled areas, use of inorganic fertilizers can temporarily support improved agronomic species such as smooth brome and timothy, but when fertilization is curtailed, without the ability to cycle nutrients in the soil, stands may be lost. Plant litter may remain undecomposed in the soil for years because of low soil microbial activity.

## Acid Forming Materials

A complicating factor to contend with for reclaiming mining disturbances at high elevations is the frequent occurrence of acid forming materials. Such materials may

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include overburden, waste rock, below-grade ore, or tailing. A material is defined as acid-forming if the neutralization potential (as carbonate) is less than the acid potential (as sulfate). The basic geochemical mechanism is the same for all acid forming materials regardless of rock type—the oxidation of pyrite or other sulfides which can be generalized by the following equation—

$$(Fe, Pb)S_2 + H_2O + 3.5\ O_2 \rightarrow (Fe, Pb)SO_4 + H_2SO_4$$

Until not many years ago, the kinetics of sulfide oxidation in the environment were not well understood. It was then discovered that this oxidation reaction does not occur at a significant rate unless catalyzed by certain species of chemoautotrophic bacteria (*Thiobacillus*) which are ubiquitous in most environments. In the absence of bacteria, pyrite oxidation practically speaking does not occur. It is now known that four elements are required for acid formation—

1) sulfide mineral
2) oxygen
3) water
4) oxidizing bacteria

Eliminating any one of these will effectively halt the process of acid formation. Depending on the setting, the problem of acid formation may be characterized as a problem of acid mine drainage, mobilization of toxic metals, acid soils, or any combination of these. Most plant species will not tolerate the severe acid conditions which can result from the oxidation of pyrite. Studies have shown that liming treatments are not a permanently effective solution to this problem.

## Soil Microorganisms and Nutrient Cycling

In the past few years, a great deal of research has been conducted relating to the importance of "below ground reclamation", particularly the re-establishment of soil microbial populations and the nutrient cycles catalyzed by soil microbes. The importance of this has been especially recognized for cold regimes, where long winters and short growing seasons limit the rate of organic matter decomposition in the soil.

Early reclamation efforts under such conditions often made the mistake of utilizing non-native improved grass varieties and relatively heavy rates of inorganic fertilizer. As long as maintenance fertilization was kept up, the vegetation persisted. But it was soon noticed that under such management, that there would be a build-up of undecomposed plant litter on the soil surface and that as soon as maintenance fertilization was withdrawn, vegetation stands would be lost.

Ecologists observed that vegetation loss could often be prevented with the use of live handled topsoil and species—typically natives—which were not dependent on high fertility levels in the soil. Thus it became possible to re-establish the below ground ecosystem of beneficial heterotrophic bacteria, fungi, actinomycetes, as well as animal populations, upon which the above ground vegetation was dependent. With adequate organic matter in the soil and thriving microbial populations, permanent establishment of vegetation under harsh climatic conditions, including the alpine and subalpine zones of the intermountain west, became much more feasible.

## Sunnyside Basin Test Plots

High in the San Juan mountains of southern Colorado, Lake Emma achieved notoriety years ago when the lake bottom—which had been undermined—collapsed into the mine workings below. It was fortunate this near-disaster took place on a Sunday, and no lives were lost.

At the Lake Emma site, about 20 acres have been affected by mining related surface disturbances. One of these disturbances is a large drainage channel which was built after the lake bottom collapsed to divert snowmelt and precipitation runoff away from the glory hole. Material excavated from the construction of the drainage channel, including lake sediments, have been deposited around the lower periphery of the former lake site. Other disturbances include two ore producing open pits above the former lake site. Waste rock from these pits has been stockpiled in various locations. Topsoil has also been salvaged and stockpiled. Surface disturbances from past mining operations long since abandoned are also evident.

Ultimately, waste rock, overburden and other materials will be used to backfill the Lake Emma glory hole. Adjacent disturbed areas will be regraded and revegetated. The reclamation of Lake Emma—and of all other mining disturbances in Colorado since 1976—is governed by the Colorado Mined Land Reclamation Act. Under this Act, a mining operation is required to have an approved permit for all mining and reclamation activities. These requirements are enforced by the Colorado Division of Mined Land Reclamation and the Mined Land Reclamation Board.

The Lake Emma site is above timberline at about 12,200 feet in elevation. Characteristic of high elevation sites, it is an area of high snowfall and a short growing season.

Recognizing the potential difficulty of revegetating mining disturbances at Lake Emma, the Sunnyside Gold Corporation has undertaken a program of revegetation field plot trials. Twelve plots, covering a total area of 2,500 square feet, were constructed and seeded in late August, 1988, by IMS Inc. The purpose of these plots is to test revegetation on three growth media using various amendments (or treatments).

The field plot trials at Lake Emma have been designed to address the problems of acid formation, nutrient cycling, and plant species adaptation. The study comprises four plots on each of three growth media, for a total of 12 plots. The media are (I) lake sediments, (II) lake sediments covered with six inches of fresh topsoil, and (III) waste rock covered with six inches of fresh topsoil. The four plots on each growth medium each comprise one of three treatments plus a control plot. Besides the (1) control, these treatments are (2) organic amendment (manure + peat moss), (3) organic amendment and pH control, and (4) organic amendment, pH control, and fertilizer. Each plot is 14 feet by 15 feet.

The plots are situated near the south end of the Lake Emma disturbed area, just above the outlet of the drainage diversion channel. The area is on fairly level grade in a location which will not be disturbed by mining activities. This area was selected in part because there is a clear boundary between waste rock on the south half of the area and lake sediments on the north half. Thus it was possible to have plots on waste rock and lake sediments in a contiguous area, and to spread topsoil on both in one operation. A bucket loader was used to place topsoil on the plots. The topsoil came from stockpiles recently constructed in connection with nearby open pit mining activities. Following rough grading of the topsoiled plots, all plots were hand tilled with a spade and pick-axe. Amendment materials, such as lime, manure and fertilizer were carefully spread on the appropriate plots according to the plot layout and design. Plots were then thoroughly hand raked to incorporate amendments into the soil and to prepare a smooth surface for seeding. All plots then were seeded with the same seed mixture and lightly raked. Seeding of all plots took place on August 31, 1988.

## Treatments and Seed Mixture

Each treatment, including the control, was applied to one of the four plots on each growth medium. All plots were seeded with the same seed mixture. Below are descriptions of each treatment and of the seed mixture.

TREATMENT 1—CONTROL. The control plots received no amendments. Each control plot was tilled, raked and seeded only.

TREATMENT 2—ORGANIC AMENDMENT. To each plot receiving this treatment, a 1:1 mixture of steer manure and sphagnum peat moss was applied at a rate of 10 ton/acre (field weight basis). The purpose of this treatment is to enhance the physical characteristics of the growth media, and to provide nutrients for plants and an organic matter substrate for soil micro-organisms.

TREATMENT 3—CONTROL OF PH. Treatment 3 consists of a combination of lime and a proprietary acidifying bacteria inhibitor manufactured by ProMac Systems, a subsidiary of B. F. Goodrich. This treatment was formulated by ProMac based on their sampling and analyses of lake sediment and waste rock materials from the site. Lake sediment plots (I and II) were limed with 1.5 ton/acre calcium carbonate equivalent; waste rock plots (III) received ProMac only and no lime. ProMac pellets and powder were applied to each plot in accordance with ProMac's specifications. Materials were broadcast evenly over each plot area at the following rates—

| | | |
|---|---|---|
| ProMac 2000SB | — | 198 parts |
| ProMac 2000PN | — | 84 parts |
| ProMac 2000PB | — | 119 parts |
| ProMac 2000PY | — | 99 parts |

Each of these ProMac materials is formulated to provide different controlled rates of release of bactericidal active ingredient. The active ingredient is selective for free living acid-forming autotrophic bacteria (e.g.,*Thiobacillus* and *Ferrobacillus*), but does not affect beneficial heterotrophic bacteria or other types of micro-organisms in the soil. Results with ProMac technology on acid coal spoil in the eastern United States have shown great promise for effective long term control of acidification. The product has only been on the market for a year and has been little tested in the west.

TREATMENT 4—FERTILIZER. A slow-release nitrogen fertilizer developed for the turfgrass industry was used on all fertilized plots. The material is a proprietary form of granular urea formaldehyde sold as Blue Chip Nitroform by Nor-Am Chemical Co. This product is 38 percent total nitrogen (elemental basis). The material was broadcast evenly by hand over each plot to be fertilized in accordance with the study design. Application rate was 50 lb/acre elemental N. The advantage of this type of fertilizer is that it will not provide a large initial release of available nitrogen in the soil. The urea formaldehyde is gradually converted to an available form of nitrogen by soil bacteria.

SEED MIXTURE. The seed mixture shown in the following table was sown on all plots. Small lots of seed were obtained with the assistance of Wendell Hassell of the U.S.D.A. Soil Conservation Service. The mixture contains five grasses and one legume. Germination and purity test data were not available for all species, so seeding rates were not calculated on a Pure Live Seed basis. A relatively high bulk seeding rate (in terms of seeds per square foot) was used to accommodate anticipated low germination and establishment by some of the grass species. Seed for each plot was weighed to the nearest 0.1 gram. Seed was evenly broadcast over each plot by hand and lightly raked.

## Plot Study Results

After two growing seasons, the results of the test plots are very promising. Untreated plots (seed only) on non-topsoiled lake sediments are completely devoid of vegetation. Plots treated with organic matter and ProMac exhibit numerous grass and a few clover seedlings. Vigor of the plants in the treated plots is good, a hopeful sign that the long term survival of these plants will be good.

**Table 1. Lake Emma field plot trials seed mixture.**

| Common Name | Scientific Name | Seed ($ft^{-2}$) | Seed (lb/acre) |
|---|---|---|---|
| Tufted hairgrass | *Deschampsia caespitosa* | 50 | 1.4 |
| Alpine timothy | *Phleum alpinum* | 30 | 1.8 |
| Bering hairgrass | *Deschampsia beringensis* | 20 | 0.8 |
| Hard fescue | *Festuca ovina* var. *duriuscula* | 30 | 2.3 |
| Slender wheatgrass | *Elymus trachycaulus* | 10 | 2.3 |
| Dutch white clover | *Trifolium repens* | 20 | 1.4 |
| **TOTAL** | | 160 | 10.0 |

Soil samples were collected from the plots in the first and second years following seeding. Samples were analyzed at the laboratories of BFGoodrich in Akron, Ohio. A comparison of samples from ProMac-treated plots with samples from untreated plots clearly shows that populations of pyrite oxidizing autotrophic bacteria have been drastically reduced and that sulfide oxidation has been virtually halted. These plots will continue to be monitored in future years. Samples of waste rock taken from outside the plots which have received a yearly application of liquid ProMac also show minimal sulfide oxidation.

It must be emphasized that results from this type of study after only two growing seasons must be considered strictly preliminary. It is estimated that at least five growing seasons would be required to make any conclusions about the efficacy of the treatments. We have also proposed that plots continue to be monitored for a period of at least ten years to provide a more reliable long term picture of the potential for reclamation success at this site.

Nevertheless, based on these results as well as our experience from other sites and from scientific literature, it is now possible to elaborate a set of basic principals necessary for successful reclamation of acid forming sites in the alpine zone. These principles include the use of species adapted to the alpine zone, use of an organic amendment to provide a substrate for soil microbes, the use of ProMac and lime to control acid formation, and the lack of any mineral fertilizer.

## Regulatory Implications

Although the roots of modern reclamation technology go back to the days of the Dust Bowl and beyond, the present era in the western United States is little more than twenty years old. Technological advances have been spurred in large part by ever more demanding requirements for regulatory compliance. But more than a few such requirements have ironically been the result of innovations developed from within the industry—examples of the "now that they can do it we can require it" regulatory syndrome.

The old argument that the government could never require the industry to spend thousands of dollars per acre to reclaim land that was worth only hundreds of dollars per acre is little remembered. That argument was mainstream thinking at the time the mining industry was dragged into the Age of Environmental Regulation in the 1970s. Now it is necessary for the industry to prepare itself for a new wave of regulatory requirements in the form of more stringent ground and surface water quality performance standards (including testing of discharge waters for biological toxicity), and the regulation of mining wastes under something akin to Strawman II.

Under Strawman II, the control of acid forming materials will become much more critical in reclaiming mined areas. In general, treatments which are being tried at various projects such as lime, fly ash, kiln dust, calcareous sludges and the like represent temporary fixes at least. Unless the process of acid formation is halted, permanent control cannot be achieved. At this point the ProMac technology of BFGoodrich appears to be the most promising method to achieve this kind of control.