9

Revegetation of the Copper Cliff Tailings Area

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Mining and processing of metal-bearing ores produces vast quantities of hazardous waste material such as tailings, waste rock, slag, and flue dust (Freedman 1989). Of these, tailings (see Plate 16, following page 182), the materials that are discarded after the ore is separated by milling and flotation are probably the largest primary source of contamination associated with metal extraction (Salomons and Forstner 1988). Tailings often contain high concentrations of acid-generating sulfides and quantities of residual metals.

Tailings have produced serious disposal problems throughout the world. In some cases, tailings have been simply dumped as loose piles or even into rivers, such as at the Bougainville site in Papua, New Guinea (540 million tonnes in the Kawerong River) (Moore and Luoma 1990), or into the sea, such as at the copper smelter in Ilo, Peru (40 million m^3/year) (Young 1992). This irresponsible dumping has destroyed aquatic life over large areas. Fortunately, such practices are now relatively rare. However, even the more conventional land-based disposal of tailings in ponds creates substantial environmental effects through the production and escape of acid drainage water (containing high levels of dissolved metals). One of the largest hazardous waste sites in the United States is the Clark Forks complex, a copper mining area in Montana where tailings are stored in ponds that cover at least 35 km^2 and contain 200 million m^3 of waste. Seepage from the tailings ponds and airborne release of flue and surface dusts significantly increase metal concentrations in the Clark Fork River as far as 500 km from the site (Moore and Luoma 1990).

In Sudbury, the mining industries produce about 8–10 million tonnes of tailings per year. Depending on the operation, from 25–75% of the tailings are used to fill mined-out areas underground. However, because of the expansion of the ore due to blasting and grinding, not all the resulting tailings can be put back underground. A large amount, about 450 million tonnes, is therefore stored in ponds on the surface. At Copper Cliff alone, the tailings storage area covers 2225 ha (Fig. 9.1). In addition to the acid mine drainage problem (see Chapters 10 and 21), surface storage of tailings can produce serious dust problems once the ponds are filled and the material begins to dry out.

The need to control dust emissions from tailings areas has been appreciated by Sudbury operators for some time. In the past, temporary crops of fall rye have been seeded on the dry tailings, and various chemical sprays have been applied to bond the surface particles. However, in the early spring and late fall, weather conditions often produced a "freeze-dry" situation. This usually occurred when the surface of the tailings froze at night and then thawed rapidly during sunny days. The moisture released by thawing evaporated and was

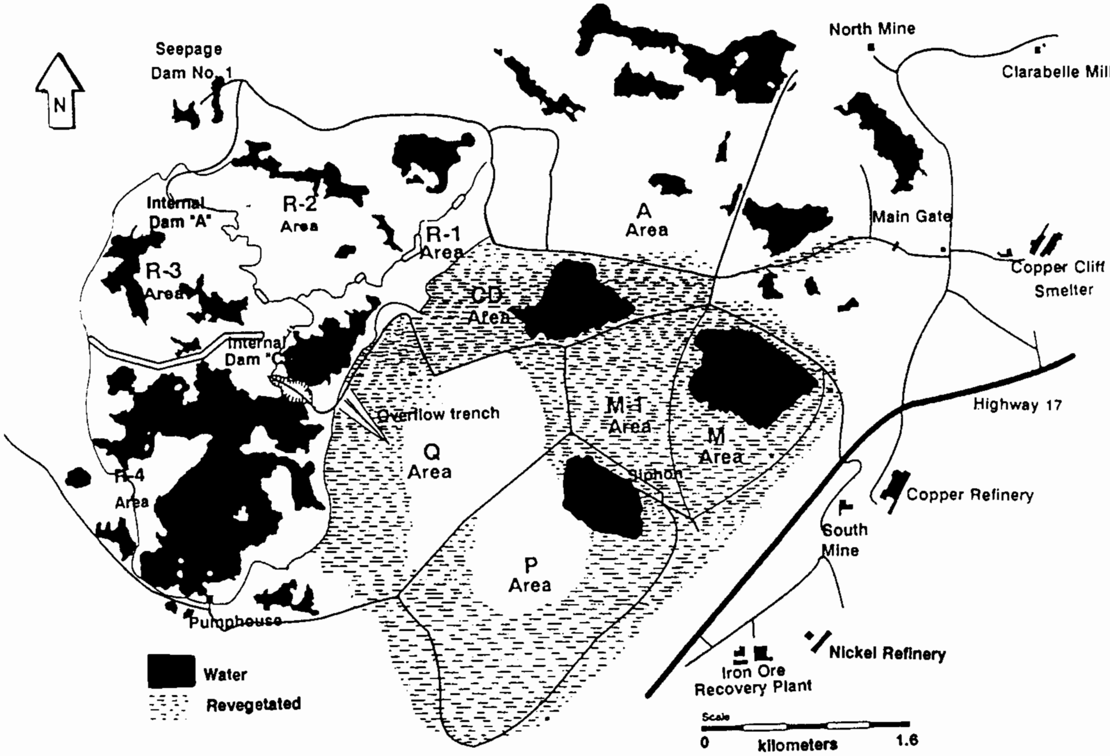

FIGURE 9.1. Diagram of Inco Limited's Copper Cliff tailings area.

not replaced by capillary action, leaving the particles dry and without cohesive binding. With winds of sufficient velocity, these particles readily became airborne.

A review of progress in preventing this dust problem by establishing a vegetation cover at the Copper Cliff tailings area is the topic of this chapter.

History of the Problem

By the late 1940s, the level of tailings in Inco's existing disposal areas at Copper Cliff were equal to or higher than the rocky hills of the local topography. Without shelter, the fine particles of the tailings frequently became airborne (Fig. 9.2). This blowing dust became a nuisance to local residents and adversely affected local industrial operations. For example, the dust contaminated lubricants in equipment and was an impurity that affected the product quality during electrolytic refining of copper.

Development of a Technique for Establishing a Vegetation Cover

It is not surprising that many of the early efforts (in the 1940s and 1950s) at establishing a vegetation cover met with failure. Fresh tailings had no nutritive value, limited water holding capacity, no soil structure, a low pH, and no organic matter (Crowder et al. 1982). However, eventually, from what often seemed like a trial-and-error process, some basic principles and procedures developed that made revegetation possible at the Copper Cliff site. These developments grew mainly from an experimental program begun in 1957 to test seed bed amelioration procedures in large plots. From these studies and earlier experience, it was recognized that the deficiencies of tailings as a growth medium could be overcome if the following principles and procedures were adopted:

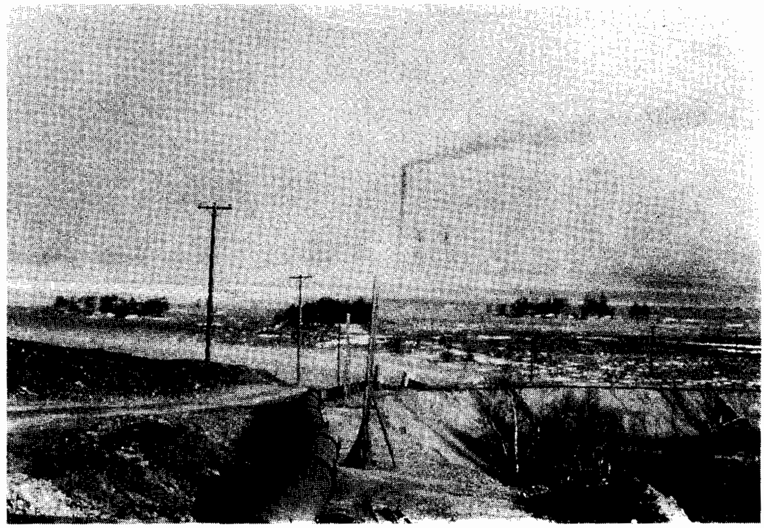

FIGURE 9.2. Before stabilization, the surface of Inco's Copper Cliff tailings area was susceptible to wind erosion. (Photo by Tom Peters.)

1. Seeding should begin in the area closest to the source of the prevailing winds to minimize the covering or damaging of young plants by drifting tailings.
2. With sulfide ore tailings, sufficient agricultural limestone should be added to raise the pH of the seed bed strata to approximately 4.5–5.5. Half the limestone should be applied at least 6 weeks before seeding and the balance at the time of seeding.
3. The addition of adequate amounts of nitrogen, phosphate, and potassium fertilizers, to ensure plant establishment, should be made at the time of seeding. The amount of fertilizer should be sufficient to compensate for the loss of nutrient availability due to complexing with other elements (aluminum, iron, calcium, etc.) present in the tailings.
4. In a climate similar to Sudbury, grasses should be planted in the late summer to take advantage of cooler temperatures and available moisture.
5. Legumes should be seeded in the spring, with a power-till seeder, 1 or 2 years after the initial grasses have become established. A full season of growth, along with soil stabilization by grass roots, will provide protection for the legumes against the heaving effects of repeated surface freezing and thawing.
6. A companion crop (fall rye, *Secale cereale*) should be used to provide a quick protective canopy. This crop will reduce surface wind velocity and provide shade for the slower-growing grass seedlings. The companion crop also acts as a seed trap for wind-dispersed seeds from adjacent naturally vegetated areas.
7. Due to the lack of organic matter in the tailings and the subsequent rapid loss of nitrogen from applied commercial fertilizers, frequent small applications of a nitrogenous fertilizer should be made during seedling establishment. The use of a slow-release nitrogen fertilizer is another option, but its use is limited by the season and weather conditions.
8. Mulching (wood fiber, straw, shredded paper mixtures, etc.) should be used, especially when seeding wind-exposed areas or slopes with a south to southwesterly exposure. In areas exposed to the wind, a tackifier (asphalt emulsions, emulsion products from paint, adhesive, and forestry industries, etc.) should be added to the mixture being hydroseeded to stabilize the mulch cover (Brooks et al. 1989).
9. If a layer of natural soil is used to cover the tailings and provide a seed bed, the change in surface porosity, particularly on

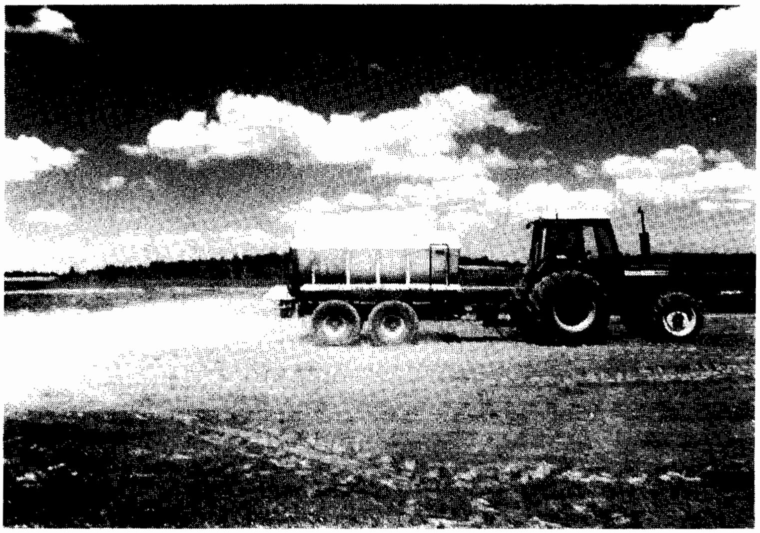

Figure 9.3. Spreading agricultural limestone on the tailings. (Photo by Tom Peters.)

slopes, must be considered. If the change in surface porosity is great, adequate drainage should be installed to eliminate water erosion.

While revegetation experience was being gained in Sudbury, other specialists throughout the world were also attempting to solve many of the unique challenges posed in the establishment of a vegetation cover on tailings (Marshall 1983; Dean et al. 1986; Australian Mining Industry Council 1987; Powell 1992).

Current Program

The current tailings reclamation and vegetation program at Inco Limited in Copper Cliff differs greatly from the manual land reclamation procedures described in the previous chapter. It is highly mechanized, using a variety of heavy earth-moving equipment for leveling the site and standard agricultural equipment for surface preparation, discing, liming, fertilizing, and seeding.

Once the proper surface contour is established, to ensure drainage and permit the safe operation of equipment, surface treatments begin. Agricultural limestone is first spread and disced into the tailings surface (Fig. 9.3). On average, 25 tonnes of limestone per hectare are used. The seeding then begins in late July and continues until mid-September. At this time of year, moisture is readily available, and temperatures are more suitable for seed germination and seedling establishment.

Inco is now combining a straw mulch and a chemical binder on these freshly seeded areas as a surface stabilizer (Fig. 9.4). This combination of straw and chemical binders, over freshly seeded areas, has several benefits. The straw acts as a trap for seeds of local indigenous species growing on adjacent land. As it decomposes, the straw also acts as a much-needed source of organic matter in the tailings. The straw, obtained from local farmers, carries natural soil particles, which have lodged in it. This soil contains various soil microorganisms, which will, in turn, inoculate the tailings and accelerate the soil-building process.

At the time of seeding, additional agricultural limestone is spread and disced into the surface. A broadcast application of 8-24-24 (nitrogen-phosphorus-potassium) fertilizer at the rate of 740 kg/ha is spread and harrowed into the surface. A conventional farm seed drill follows. Fall rye is seeded at a rate of 60 kg/ha, as a companion crop, along with a grass seed mixture at the rate of 68 kg/ha. At the same time, this seed drill places additional fertilizer at the rate of 350 kg/ha in bands along the seed row. This is followed by a double-corrugated roller (cultipacker) grass seed-

FIGURE 9.4. Spreading straw mulch. Microorganisms in the mulch inoculate the tailings and hasten its development to a natural soil. (Photo by Tom Peters.)

er, which plants additional grass seed (22 kg/ha) and compacts the soil to provide a firm seed bed. After the initial germination, a slow-release nitrogen fertilizer is broadcast over the seedling area at a rate of 90 kg/ha. As part of the long-term maintenance program, additional limestone and fertilizer are applied, as required, based on soil tests. On areas that are not readily accessible, such as steeper outside slopes, or where conventional agricultural equipment cannot be operated safely, a hydroseeder is used for seeding and fertilizing.

The current grass seed mixture, depending on species availability, is 25% each of Canada bluegrass (*Poa compressa*) and redtop (*Agrostis gigantea*), 15% each of Kentucky bluegrass (*Poa pratensis*) and timothy (*Phleum pratense*), and 10% each of tall fescue (*Festuca arundinacea*) and creeping red fescue (*Festuca rubra*). The legume birdsfoot trefoil (*Lotus corniculatus*) is seeded the following spring to allow a full growing season for the young plants to become established (Heale 1991).

Soil Development

In a study conducted by Labine (1971), it was shown that approximately 10 years after seeding, a 2- to 3-cm organic horizon (A-zero) existed and the beginning of a podzolic profile was occurring in the treated tailings area. However, drainage at different slope levels affected soil profile development and resulted in the formation of iron pans at different depths (Peters 1988). This iron pan layer limited root penetration to cracks in the formation.

The Copper Cliff tailings, due to their deficiency of clay-sized particles, behave more like a sandy loam and are prone to moisture deficiency (Dimma 1981). Lacking colloidal moisture absorption, capillary action is the only physical means of retaining water in the tailings (Pity 1979). Maintaining sufficient levels of phosphorus is also difficult because of fixation of phosphates by the high levels of iron oxides in the tailings (Dimma 1981). However, this problem can be readily overcome by adjusting the application rate. This is one of the main reasons for recommending the high fertilizer application rate of 740 kg/ha at the Copper Cliff site.

In contrast to the success at providing sufficient phosphorus, it has been difficult to maintain sufficient nitrogen levels for good plant growth. There was no organic matter in tailings and no microorganisms involved in organic matter decay. Therefore, there was no residual processes to tie up nitrogen from the fertilizer and slowly release it. In the early stages of establishing plants on the tailings, nitrogen had to be repeatedly added as need-

FIGURE 9.5. View of a revegetated area of the Copper Cliff tailings showing the managed gradual transition from a grass and legume cover to a re-established forest cover. (Photo by Tom Peters.)

ed. In addition to the fertilizer, nitrogen-fixing legume species, such as birdsfoot trefoil (*Lotus corniculatus*), were planted in an attempt to provide a continuous source of nitrogen.

Tree Planting

In the early 1960s, white birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*), and willow (*Salix* spp.) started to invade the grassed areas of the tailings from neighboring land. Mowing of the grassed areas was stopped to encourage the development of a natural tree and shrub cover (Fig. 9.5). In the early 1970s, test plots of trees and shrubs were also established. Based on their performance, a program to plant tree species was initiated (Box 9.1). Jack pine (*Pinus banksiana*) and red pine (*Pinus resinosa*) were two coniferous species selected for the tree planting program (Figs. 9.6 and 9.7). A deciduous species, black locust (*Robinia pseudoacacia*), has also been planted. Locust is a nitrogen-fixing legume, and it has adapted well to local environmental conditions.

Ecosystem Development

At the same time as the plant community was becoming established in the tailings area, various species of insects, birds, and small mammals began to colonize the area. In 1974, after consulting with local wildlife clubs, the decision was made to develop the reclaimed tailings area as a Wildlife Management Area. It was thought that this was the most suitable and practical end-use for the tailings area.

The abundance of wildlife at the tailings area has increased considerably in recent years. The rehabilitated area now supports a diverse community of bird species (Fig. 9.8). The species changed as the vegetative cover evolved from a prairielike grassland, to a scattered tree savanna, to a forest of indigenous species. Ninety-plus avian species have been identified, including 24 shorebirds, 3 gulls, 17 waterfowl, and various meadow- and wood-habiting species (Peters 1984). Eight species were ranked as provincially significant in that they were rare or uncommon (E. Heale, *personal communication*). Many birds nest and raise their young in the area, and the Copper Cliff site serves as a stopover point during spring and fall migrations.

Environmental Concerns

One of the major recommendations of the Wildlife Management Plan was to study possible contamination of the food chain. The

Box 9.1.

Inco Limited has carried out an annual tree planting program since the early 1960s. From 1978 to 1993, more than 900,000 tree seedlings were planted. To ensure that the number of seedlings of the desired species would be available for this program, the company began its own forestry seedling crop production in 1985. The growing of the tree seedlings underground developed from a joint Laurentian University–Inco Limited research project on the possibility of using an underground area of mines as a temperature-controlled, disease- and insect-free site for food production. Since 1985, 87% of the tree seedlings that have been planted out on local stressed land have been grown by the company. Seedlings are grown underground for 16 weeks, brought to the surface, and hardened off for 2 weeks before planting in the spring. The balance of the seedlings are grown in Inco's Copper Cliff greenhouse. Current annual crop production is 250,000 seedlings.

Red and jack pine seedlings are grown underground on the 4600-ft level of Inco Limited's Creighton Mine. At that level, the air is a relatively constant 24°C due to geothermal energy. (Photo by E. Heale.)

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metal content of the two principal grass species, redtop and Canada bluegrass, growing on the tailings fell within normal ranges for grasses (Rutherford and Van Loon 1980).

A 6-year study with mallard ducks (*Anas platyrhynchos*) fenced on the revegetated tailings found that metal accumulations were not a cause for concern. Meadow voles (*Microtus pennsylvanicus*) inhabiting the tailings were also found to have no toxic levels of heavy metals in their vital organs (Cloutier et al. 1986). Voles, along with deer mice (*Peromiscus maniculatus*), are important links in the food chain to red fox (*Vulpes vulpes*) and coyotes (*Canis latrans*), which inhabit the tailings area.

Other mammals that have been observed in this rapidly developing ecosystem are snowshoe hares (*Lepus americanus*), eastern chipmunks (*Tamias striatus*), red squirrels (*Tamiasciurus hudsonius*), beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), and black bear (*Ursus americanus*) (E. Heale, *personal communication*).

FIGURE 9.6. Planting 14-week-old seedling conifer trees, which were grown underground in Inco Limited's Creighton Mine, on the Copper Cliff tailings area. (Photo by Tom Peters.)

FIGURE 9.7. View of a portion of the "CD" area of Inco Limited's Copper Cliff tailings, showing 30 years of ecosystem development. The area was revegetated with a grass and legume mixture in 1960, and the jack and red pine were planted in the early 1970s. (Photo by Tom Peters.)

FIGURE 9.8. A Canada goose at home on the "CD" area pond. Cattails and bullrushes were introduced into this pond in the early 1970s. (Photo by Mike Peters.)

Other Values of a Vegetated Tailings Area

The original objective of establishing vegetation on the tailings area was to stabilize the surface to control dust emissions. In recent years, the important and pressing problem of the quality of the drainage and seepage water from the tailings has become a major concern. There is an important research need for information on the hydrology of vegetated tailings areas, but at present there appear to be three ways that revegetated tailings can have an effect on the water quality problem:

1. by intercepting precipitation
2. by evapotranspiration
3. by forming an oxygen-consuming barrier of decomposing plant residues

The percentage of precipitation intercepted will vary with the density and the amount of the vegetative cover. Generally, dews are intercepted 100%, whereas only minimal amounts of water are intercepted during heavy rainstorms or during spring melt. In summer, the precipitation on vegetation evaporates and does not enter the ground to become seepage water. On sunny winter days, the stems of the vegetation also act as air passages in accumulated snow and thus increases the area exposed to the evaporation process.

Vegetation can remove a large amount of water through evapotranspiration and thus reduce the amount of water that infiltrates and leads to acid drainage. For example, it has been experimentally shown that to produce 454 g of dry matter, an alfalfa (*Medicago sativa*) plant transpires 364 kg water (Northen 1958). The water removed by evaporation from the surface or by evapotranspiration by the plants will not penetrate into the tailings to create acid mine drainage. However, less water may simply increase the concentration of dissolved constituents, a hydrogeochemical consideration that is part of the needed research in this area (M. Wiseman, *personal communication*).

The third means of preventing acid drainage is by blocking oxygen from reaching the sulfide material. The development of a thick root mass, along with a surface mat of decaying vegetation, may achieve this by acting as an oxygen-consuming barrier that reduces the access of atmospheric oxygen into the sulfide tailings (Peters 1988). In addition to the potential benefits of a vegetation cover, several other covers have been tested as a means of blocking oxygen and thus the production of acid drainage water (Spires 1975; Michelutti 1978). Falconbridge Limited has experimented with several different types of dry and wet covers placed on the tailings before attempting to establish vegetation. The dry covers (rock, gravel, etc.) have the benefit of preventing the upward migration of metallic salts, which can be toxic to vegetation roots. The wet covers, such as a covering of wetland vegetation, offer considerable promise as a more permanent solution to acid mine drainage by blocking oxygen and water penetration into the deeper layers of the tailings. The potential use of these wetland covers is the topic of the next chapter.

Summary

When faced with a challenging restoration job such as establishing a vegetation cover on a large sulfide tailings area, there rarely are textbook solutions that can be used (Bradshaw et al. 1978). Each site has its own unique problems and potential solutions. However, the main goal in tailings restoration is usually the same—to establish a maintenance-free cover. From our experience in Sudbury, the steps in achieving this goal were

1. **Establishment of initial plant communities using available species that are tolerant of factors characteristic of the tailings. These factors include drought, low pH, poor soil texture, and lack of organic materials and nutrients**
2. **Modification of the local microclimate to benefit plant establishment**
3. **Establishment of soil invertebrate and microbial communities. These assist in the soil building process and decompose naturally accumulating organic matter**
4. **Establishment of nutrient cycles**
5. **Establishment of a rich diverse plant community that can support wildlife and other natural assets**

While working along this path, the local practitioners must continue to monitor responses and be flexible enough to "adapt not adopt" the practices developed by others (Peters 1984, 1988).

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