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VEGETATION OF MINE WASTE EMBANKMENTS IN CANADA

D. R. MURRAY

MINING RESEARCH CENTRE

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VEGETATION OF MINE WASTE EMBANKMENTS IN CANADA

by

D.R. Murray*

ABSTRACT

The main conclusions of this report are that revegetation of most mine wastes requires a well-planned program and that technology is available. The physical and chemical properties of some wastes are such that research is required to determine satisfactory revegetation procedures.

Canada is similar in many ways to other countries with respect to the physical texture and variety of its mining wastes and the associated problems of erosion and surface instability. Straw mulching, chemical binders, and wind breaks, as applied elsewhere with some success to control erosion, are used to some extent in Canada.

Reclamation: Revegetation: Mines Spoils: Bank Stability: Erosion Control: Acidity

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ABSTRACT - continued

Chemical properties of a waste depend a great deal on the geology and treatment of the ore. This is not unique to Canadian mines but the influence of environment makes it a significant problem. Climate influences the weathering of wastes to soils that are highly regional. Usually the revegetation program that suits one mine waste will not suit another even though the same ore is being mined.

Plant choice is very specific to Canadian wastes, and establishment of plants involves fertilization, seeding, and cultivation procedures. In any specific case, any one of a large number of factors relating to the development of either a program or, a reclamation sequence may be critical and these are discussed. If either a physical or chemical property is extreme, e.g. high acidity in sulphide tailings, research must be directed to finding a solution. Every case is different and must be approached systematically.

Direction des mines

Circulaire d'information IC 301

LA VÉGÉTATION DES TERRASSEMENTS MINIERS EN REMBLAI AU CANADA

par

D.R. Murray*

ABSTRACT

Les conclusions principales de ce rapport sont les suivantes: a) la révégétation de la plupart des remblais miniers exigent un programme bien conçu, et b) la technologie est disponible. Les propriétés physiques et chimiques de quelques remblais sont telles que la recherche est nécessaire pour déterminer les procédés de révégétation satisfaisantes.

Le Canada est semblable aux autres pays de bien des façons en ce qui concerne la texture physique et la variété de ses remblais miniers et les problèmes associés d'érosion et d'instabilité de la surface. Le paillage, les liants chimiques et les brises-vents, utilisés ailleurs avec un certain succès pour contrôler l'érosion, sont utilisés dans une certaine mesure au Canada.

Les propriétés chimiques d'un remblai dépendent beaucoup de la géologie et du traitement du minerai. Elles ne sont pas uniques aux mines canadiennes mais elles ont une influence significative sur l'environnement. Le climat influence la désagrégation des remblais dans des sols hautement régionaux. Ordinairement le programme de révégétation qui convient au remblai minier ne conviendra pas à un autre, même si le minerai exploité est le même.

Le choix végétal est très spécifique aux remblais canadiens, et la réussite du plantage dépend de la fertilisation, des semailles et des méthodes de cultivation utilisées. Dans tout cas spécifique, n'importe quel facteur relatif au développement soit d'un programme soit d'une succession de régénération peut être critique; ces facteurs sont discutés. Si une propriété physique ou une propriété chimique est extrême, i.e. haute acidité dans les résidus de sulfure, la recherche doit être dirigée pour trouver une solution. Chaque cas est différent et doit être abordé systématiquement.

Régénération: Révégétation: Déblais miniers: Stabilité du terrassement: Contrôle de l'érosion: Acidité.

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1. INTRODUCTION

Reclamation of waste embankments involves bank stabilization and revegetation. This report is concerned with establishing vegetative cover to stabilize the surface of a mine waste. In this context vegetation is any plant growth - grasses, legumes, trees, or shrubs.

Two types of spoil embankments are of interest. The first is overburden which is the top soil, subsoil, and other strata that must be removed to expose an orebody. Secondly there are tailings, which are the wastes, either wet or dry, from a milling operation.

This report describes the problem of spoil surface revegetation and why it is a matter of concern. It reviews methods of dealing with the problem outside of Canada and an assessment of the situation within Canada as it relates to the mining industry. Finally, possible solutions and directions of research are suggested.

2. THE PROBLEMS

A. Physical Properties

(i) Texture and Aggregation

The distribution of particle sizes in waste embankments is as varied as the components of the overburden. An embankment may consist of boulders, sand, silt, and clay; weathering by wind and water may reduce these to the minus 2-mm sands, silts, and clays that are of prime concern in revegetation work. The proportion of these particles in the embankment may be as low as 17%.

Strong material such as sandstone that does not weather readily hinders the formation of this soil fraction and consequently slows revegetation. Coarse-textured spoil allows the infiltration of water, thereby reducing surface run-off and erosion but causing an undesirably dry soil fraction.

Tailings, on the other hand, can have a very regular particle size distribution because of the milling operation. They are generally of a size acceptable for vegetation although their regular size and fineness make the surface more susceptible to wind and water eorsion. Fine particles reduce the pore space within the soil, water infiltration is reduced, and erosion is increased because of crusting of the surface. This is most pronounced when significant amounts of clay are present.

Equipment traffic compacts the soil, causing a loss of pore space. Infiltration of water is further reduced, so surface run-off and erosion are increased. The reduction in water infiltration reduces the leaching of salts from the spoil which slows the weathering process. Low pore space in the soil leads to low oxygen levels and the unavailability of essential nutrients to the plant. Biotic life is largely excluded from compacted soils, and root penetration into hard soil is slow at best.

Aggregation is the grouping of soil particles into stable structures. The individual particles are held together by strong clay or organic colloidal bonds and a stable aggregate will not break down when immersed in water. In a well-aggregated soil, compaction and erosion do not occur readily and the water-holding capacity of the spoil is increased. Water retention is important for flood control and plant growth during dry periods. Good aggregation is not essential for all plant growth, but, for advanced plants and trees, a well-aggregated soil is desirable.

The structural nature of tailings and overburden is such that they have little or no aggregation because of the lack of a particle adhesive or binder such as clay.

(ii) Surface Stability

With any waste embankment, the outer surface is exposed to the elements and undergoes physical and chemical weathering. This weathering process requires time and is essential to soil formation. The surface must be retained for two basic reasons: (a) the plants need a soil base to become established and (b) the chemical composition of the weathered surface is the most favourable for plant growth. The latter will be discussed further under Chemical Properties.

Wind can dislodge small particles of rocks, sand, soil, fertilizer, and seed and blow them with great force. Airborne seeds become desiccated or moved to undesirable growth areas. Plants on an unstable surface are covered by drifting spoils or subjected to undermining and sand blasting.

Water has a similar effect, so, if plant cover is to become established, the spoil bank must be mechanically stabilized.

B. Chemical Properties

(i) Acidity and Toxicity

One of the greatest problems in revegetation of mine wastes is the toxic acid condition of the spoil bank. Chemical weathering is the cause in most cases but it is also the process of correction. A mining operation exposes various minerals to air and water for the first time. Sulphides, especially of iron (pyrites), will oxidize and undergo biochemical leaching resulting in the formation of sulfuric acid. The acid attacks rock fragments to produce soluble salts which must be neutralized or removed by leaching. Weathering requires time and a spoil will only weather to a limited depth because the reactants, (air, water, minerals) are separated by oxidized material. Removal of this protective layer exposed more reactants and permits more oxidation and the creation of more acid, an unacceptable medium for growth. With time, however, natural leaching will render the weathered surface acceptable for plant growth.

Acid soils are unacceptable to plants for several reasons. Low pH does not permit bacterial life, required for nodulation on legume roots, to develop because the absorption tissue of the roots will not function at pH 2.0. Difficulties occur up to pH 4.0. Acid solutions also increase the availability and concentration of metal ions. Some ions in increased concentrations can be toxic to plant growth. They may, along with salts, alter the osmotic relationship between the plant root cells and the nutrient environment. This imbalance may make either the macronutrients, N, P, and K or some micronutrients unavailable to the plant because of an inability to absorb them into the plant tissue. Figure 1 illustrates the change in availability of some nutrients and how they can occur in toxic concentrations with changes in acidity.

In normal soil, there are vast quantities of mineral elements but they are not all available to the plant. The osmotic relationship between the soil solution and the cell solution permits only certain desirable nutrients to be absorbed. Highly concentrated salts affect the efficiency of this membrane, causing either the loss of cell material or the absorption of undesirable ions. Soil acidity is an important factor in determining availability and absorption of nutrients. Each spoil has its particular ions and concentrations in combination with acidity. Generally neutral soil pH 5 to 7 is required for plant growth. However this is only one of the requirements that must be met.

(ii) Fertility

Plants require other nutrients besides CO_2 and water for formation of cell plasma. The macronutrients, nitrogen, phosphorous, and potassium (N, P, and K), as well as the micronutrients such as iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), baron (B), molybdenum (Mo), chlorine (Cl) and magnesium (Mg).

The macronutrients are needed in large quantities and in most cases are not present in the overburden or tailings spoil. Micronutrients are needed in extremely small quantities and, if they occur in higher concentration, could be toxic. Spoils may or may not contain all or some of these nutrients but generally most are present to some extent. A lack of macronutrients could cause complete crop failure whereas micronutrients may only deform or hamper growth.

Legumes do not require nitrogen but grasses do, and each plant has its own specific nutrient requirement which must be met. The nutrient content of the spoil must be determined and the deficient portions added as required in a form that will be available to the plant in the prevailing soil solution.

Besides air, water, and minerals, a soil must contain bacteria and fungi for successful establishment and development of the plant cover. Bacteria such as are required for nodulation on leguminous plants

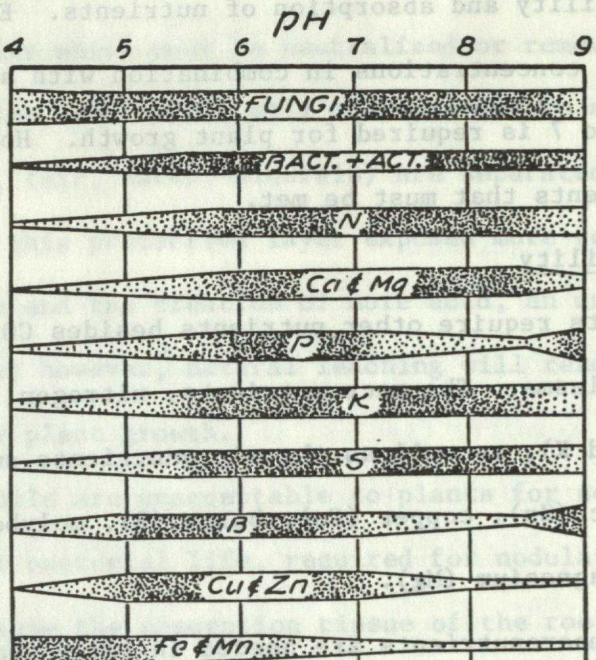

Figure 1: Diagram showing the relationships existing in mineral soils between pH on the one hand and the activity of microorganisms and availability of plant nutrients on the other. The width of the bands and the degree of shading indicate the zones of greatest microbial activity and the most ready availability of nutrients.

Apparently the availability of nitrogen depends in large degree upon the activity of microorganisms and the mobility of calcium and magnesium. Note that the satisfactory availability of phosphorus is restricted to a pH range of approximately 6 to 7. The wide ranges for potassium and sulfur are noticeably in contrast with that of the phosphorus. Also it is evident that the soil must be comewhat acid, say pH 6, if the trace elements, even if present in suitable amounts, are to show satisfactory availability.

Considering the correlations as a whole, a pH range of approximately 6 or 7 seems to promote the most ready availability of plant nutrients. In short if soil pH is suitably adjusted for phosphorus, other plant nutrients, if present in adequate amounts, will be satisfactorily available in most cases (86).

may be inoculated into the soil or seed but the bacteria must be able to survive in the soil environment (1). The need for correcting acidity for bacterial activity is shown in Figure 1. Humus or organic matter is the basic food for the biological life in the soil and this must be developed because most spoils contain very little organic matter.

C. Climate

(i) Macroclimate

Climatic conditions including temperature, length of day, length of growing season, presence of permafrost, amount and distribution of rainfall, prevailing wind direction and velocity, topography and altitude vary across the country. These factors cannot be controlled, so plants must be chosen to account for them.

(ii) Microclimate

Within the geographical limits of the spoil site, other climatic factors influence plant growth, e.g. direction of exposure and topography of the surface. Steep slopes hinder the use of conventional agricultural equipment and contribute to greater run-off and surface erosion. Undesirable ponding or flooding may occur on flat areas. Ponds on potentially acid spoils cause continued oxidation of the pyrites.

For germination, seeds need moist warm conditions. Seedlings and cuttings from nursery stock need moisture and shade to ensure a successful catch. The physical and chemical character of the soil is part of the microclimate that must be suitable for the selected plant. Air may also be considered part of the microclimate particularly where toxic gases such as SO_2 exist.

The microclimate must be satisfied not only for the establishment but for the maintenance of a vegetative cover. A mechanical surface stabilizer, for example, must last until the plant can bind the surface. High concentration of SO_2 can prevent plant growth, even though soil conditions are satisfactory. Extreme exposure to the sun may dry out seedlings and inhibit photosynthesis. This condition is common on light-coloured spoil surfaces where young plants are most susceptible to injury from excessive radiation (2).

D. Vegetation

(i) Plant Choice

All plants will not grow under all climatic conditions, so a plant that is suited to the existing conditions must be chosen. Climatic factors will restrict the types of vegetation adaptable to a geographic area and the topography of the site will determine the number of plants that can be grown. Steep high-altitude areas will not support a lush swamp plant and the converse is true.

The presence of several soil conditions, physical and/or chemical, may require that two or more plants be used in one spoil area. Time factors eliminate some plants because it takes too long for them to develop and become effective. Programs for eventual use of the land dictate the order of plant choice for a systematic improvement of presently undesirable microclimate conditions. This would lead to more productive vegetation in the future.

Plant choice might best be summarized by the selection criteria listed below; these are in addition to the ability of the plant to grow under the existing climatic and soil conditions in the area:

- insect and disease resistance;
- life span of plant and sward (annual, biennial or perennial);
- persistency under climatic stress (drought, flooding, cold, heat);
- growth habit (bunch, sod former, erect, prostrate);
- strength in competition; and
- mode of reproduction (vegetatively, sexually).

(ii) Planting Method

The choice of plant may restrict the use of some seeding methods, e.g. some should be just compacted into the surface. Seedlings must be put in by hand for best results. The presence of a slope would restrict normal agricultural tillage and seeding methods as would rough rock terrain. Mixtures of seeds add additional considerations because of individual depth or rate of application. Seeds like bromegrass cannot be seeded with the conventional seed drill as can other grasses and legumes. A variable soil would negate an overall treatment. The need for nutrients and organic matter or liming might hinder the immediate planting of seed. The method of planting must be chosen so as to give the most satisfactory stand of the desired sward for the present and for the future.

E. Other Factors

(i) Time

The weathering process takes time. For aesthetic reasons, the site should be masked and covered up as soon as possible. Pollution control and erosion control also emphasize speedy stabilization of the waste embankment.

The bank must be structurally stable and the weathering process completed. Correction of acid and nutrient conditions is required prior to seeding. Since time is required for germination and establishment of the vegetation, mechanical means have to be employed to control and microclimate during this critical period. This period varies from a few months to a few years. Seeds for grass cover may have to be established before light pulp trees could survive and subsequently provide shade for lumber-grade tree seedlings.

(ii) Program

Without previous experience, a successful solution is not always possible. The presence of unaccounted-for factors can lead to the eventual, if not immediate, failure of the vegetation. A green embankment can be killed by frost the first winter or eroded away after two years when the plant finishes its life cycle. For example, either throwing seed on the ground with no consideration for water and wind erosion or planting a mixture where the plants are so competitive that they kill each other off is defeating the purpose of revegetation.

Successful reclamation of waste embankments by revegetation is complete only after a detailed program has been set-up and followed to completion. The problems of revegetation are numerous and will be different for different spoils and possibly even for the same spoil bank. Figure 2 summarizes the basic overall problems to be faced by the revegetation team.

3. SOME SOLUTIONS

A. Physical Properties

(i) Texture and Aggregation

Changing the physical properties of an established waste embankment has been proven impractical and uneconomical. Correction, during the formation of the embankment, has given some satisfactory results which will be discussed later. The placement of excessive amounts of coarse rock on the surface where vegetation is expected should be restricted. A minimum of 20% soil (particles 2 mm or less in size) is necessary to support growth. However, vegetation will grow on a large range of textures -- agricultural crops are best-suited to a fine-textured soil whereas ground cover, e.g. trees and shrub growth, will grow on rocky areas (3,4,5).

Aggregation has been introduced by direct addition of organic matter but this is expensive and not always successful. Colloidal organic matter and clays hold the soil particles together; the organic matter must be decayed to form a colloid. Straw, hay, resins, bitumen, wood chips, and broiler litter have been tried. Excessive application hinders the development of plants and immediate aggregation is not accomplished (6). The use of soil on slopes is ineffective because of the weak soil-spoil particle attraction (7). The solution generally accepted is the development of aggregation and soil structure from plant deposition over several years of growth (8, 9).

Compaction of spoils is accomplished during emplacement of tailings, i.e., tailings pond permits the settling of the slurry solids. After closing and draining the tailings compound, the spoil can be worked as a soil material. Clay slimes, found in the waste from phosphate mines, are too moist for vegetation and their maximum solid content is about 35%.

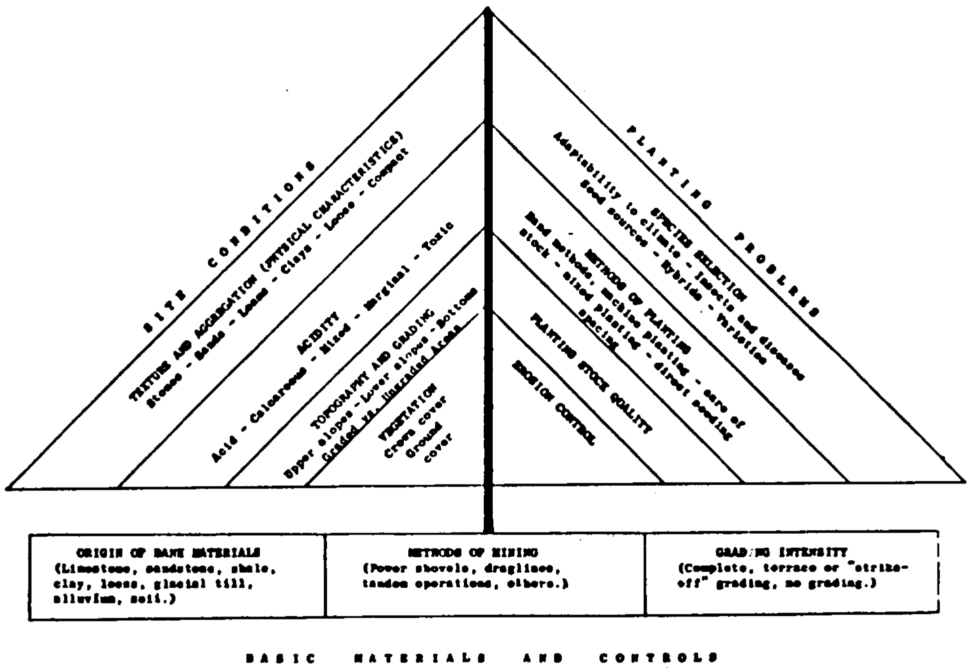

Figure 2: A. Summary of Problems in Revegetating Strip Mined Land following Limstrom (87).

Mixing the slime and sand simultaneously in the same ponding area permits the sand to settle with and to compact the clay, releasing the bound water. The result is a waste containing 70 to 80 % solid which can be handled for revegetation (10, 11).

Compaction by grading is minimized by site planning and waste handling. During strip mining, strike-off grading of the overburden is sometimes used to improve the stability of the crests for vegetation (12). Where grading is necessary the harrowing of the surface allows grasses and legumes to become established. Planting of legumes like alfalfa or birdsfoot trefoil eventually breaks up the sub-soil and subsequently increases the success of tree seedlings (13).

(ii) Surface Stability

Rock dumping, sludge dumping, oil films, and flooding have all been tested but their stabilizing effects are temporary. Vegetation has been a very effective long-term stabilizer of the surface against wind and water erosion. The surface, however, must be stabilized to permit the establishment of vegetation. Soil dumping has been successful but only on level or almost level topography -- one to four feet of soil must be applied because the soil is easily eraded from the waste by water (7, 14, 15, 16).

On slopes, solid windbreaks have been tried but these are quickly covered and rendered ineffective. Snow-fencing reduces wind erosion but does not entirely stop water erosion and seeds are washed into ridges near the fence. The snow-fence did catch snow, and, consequently, moisture infiltration into the soil was increased (2, 7, 17).

Growth with snow-fences has been twice that with no fence when tried in Wyoming, U.S.A. (18). In South Africe, reeds have been used for the purpose (7, 19). The reeds are bundled and planted in the embankment to form a network of small paddocks on the surface. One mile of reeds per acre of spoil used in 18 ft. x 18 ft. paddocks on a 27° slope provides adequate surface stabilization for establishment of vegetation. The reeds do not have to be removed and add to the organic matter of the spoil.

Mulches as surface stabilizers have been tried in other parts of the world. The intention is to increase the cohesion or aggregation of the surface of the soil. Hay and straw proved somewhat effective but needed discing to embed them in the embankment. Although the surface sometimes dried out more (6, 9, 20), results indicated that the use of hay mulch and snow-fences was six times better than without and three times better than snow-fencing alone (18). Other mulches such as resin, sodium silicate, latex gelatin, wood chips, bark, limestone chips, and animal litter all worked with varying degrees of success in trials but were both impractical and uneconomical. A growing mulch achieved by planting mature plants was unsuccessful (21) because the plants were quickly covered with drifting sand or tailings. Excessive mulching proved detrimental to seedling germination and establishment (8). It was found that 10 to 20 % of the soil surface should remain exposed for satisfactory results (6). Jute netting as a mechanical stabilizer is considered to be better than both mulching and snow-fencing. The addition of an adhesive or surface stabilizer emulsion gave excellent results (9, 17, 18).

The use of asphalt, latex, and bitumen emulsions in proper concentrations has led the way in temporary stabilization. They not only hold the surface against wind and water erosion but also allow the infiltration of water. Evaporation is reduced and the dark colour of the emulsions reduces high radiation reflection and raises the temperature of the soil to assist germination. In addition, seedlings grow through the emulsion cover and establish before the stabilizer disintegrates (2, 7, 9, 17, 22, 23, 24, 25). Table 1 lists different mulches and chemical stabilizers and their effects on plant emergence and survival (9). Dean, Dolezal, and Havens (22) summarize some as follows:

1. Sodium silicates having ratios of 2.4 to 2.90 SiO_2 to 1 Na_2O were more effective than those having ratios greater than 2.90. Application of 0.5 lb per sq ft of sodium silicate was effective in stabilizing fine-sized tailings. Calcium chloride was an effective additive to sodium silicate, whereas ferrous sulfate was not. Use of 0.03 lb per sq ft $CaCl_2$ permitted reduction of sodium silicate from 0.5 to 0.1 lb per sq ft while producing good stability.
2. Calcium, ammonium, and sodium lignin sulfonates, as well as redwood bark extracts, were all effective surface stabilizers at 0.05 lb per sq ft.
3. Cement and milk of lime additives were effective in stabilizing the surface when applied at the rate of 0.2 lb per sq ft.
4. Coherex, a resinous adhesive, furnished good wind-resistant tailings surfaces when applied in quantities as small as 0.09 lb per sq ft, but good resistance to water jet testing was not achieved until approximately 0.46 lb per sq ft was applied.
5. Compound SP-400, Soil Gard, and DCA-70, elastomeric polymers, produced wind- and water-resistant surfaces in all quantities tested from 0.09 to 0.92. All were exceptionally effective on sandy tailings and produced satisfactory results on both acidic and basic tailings.
6. Pyrite treated with sulfuric acid was an ineffective stabilizer under all conditions evaluated.

TABLE 1

The Influence of Various Mulches on
Grass Seedling Emergence and Survival (9).
following Zak (9).

Mulch	Mulch Rates per Acre	Plant Emergence[a] 6-28-62	Plant Survival[a] 10-9-62	Plant Survival[a] 5-22-63	Plant Survival[a] 7-1-64
Asphalt emulsion[b]	200 gal.	P	P	P	N
Asphalt cutback[b]	200 gal.	P	P	N	N
Elastomeric polymer emulsion[c]	700 lbs.	P	P	P	N
Polyvinyl acetate copolymer[d] and ammonium sulfate	69 gal. 55 lbs.	E	E	G	G
Polyvinyl alcohol solution[d]	300 gal.	G	G	G	G
Sodium silicate and ammonium sulfate	66 gal. 200 lbs.	E	E	G	G
Gelatin	1000 lbs.	P	P	N	N
Hay	2000 lbs.	P	P	N	N
Heavy jute mesh[e]	3/4" opening	E	E	G	G
Check no mulch		E	E	G	G

[a]E - Excellent, G- Good, F- Fair, P - Poor, N - Nothing. [b]Asphalt emulsion (Agricultural mulch E.A.P. 2005) and the asphalt cutback were supplied by Esso Research and Engineering Company, Linden, New Jersey. [c]Elastomeric polymer emulsion (Soil Set) Product of Alco Oil and Chemical Corporation, Philadelphia, Pennsylvania. [d]Polyvinyl acetate copolymer (Gelva Emulsion T.S. 70) and Polyvinyl alcohol (Gelvatol 1-60) are products of Shawinigan Resin Corporation of Springfield, Massachusetts. [e]Heavy jute mesh supplied by Ludlow Textile, Ludlow, Massachusetts.

7. Peneprime (a bituminous base product), amines, and dicalcium silicate were all effective stabilizing agents.

B. Chemical Properties

(i) Acidity and Toxicity

Acidity and toxic ions may have different origins within the spoil but they are in most cases interrelated. The correction of pH may, for example, remove or reduce either the concentration or the availability of the toxic elements, that is, pH correction may also lead to toxicity correction.

Correction of low pH caused by weathering and oxidation of pyrites (26, 27), is commonly done by lime neutralization. On acid-producing tailings, the acid may exist to a depth of 6 ft. into the waste pile with its maximum concentration at a depth of 1 ft. where exposure and oxidation are greatest (28). The addition of lime has been common practice in agriculture and it has been used to raise the pH of spoil from 4.6 to 6.4 within 10 weeks (29). Addition of lime to spoils has been between 0 and 24 tons per acre depending on the initial pH. It has been found that correction of pH above 5.5 does not appreciably increase vegetation establishment nor promote the growth of acid tolerant plants (30). A pH below 5.0 resulted in vegetation problems, and liming was not effective at pH 4.0 (31); for example, the addition of 16 to 24 tons/acre raised the pH temporarily from 2.5 to no higher than 3.0 (32). Excessive application of lime on some banks yielded toxic quantities of aluminum and manganese (6).

In South Africa, lime is used up to a maximum of 3 tons/acre (28). If this does not control the acid, leaching is employed to oxidize the surface. The acid salts are leached to below where they would interfere with plant growth. Figure 3 shows the variation in acidity in a slimes dam

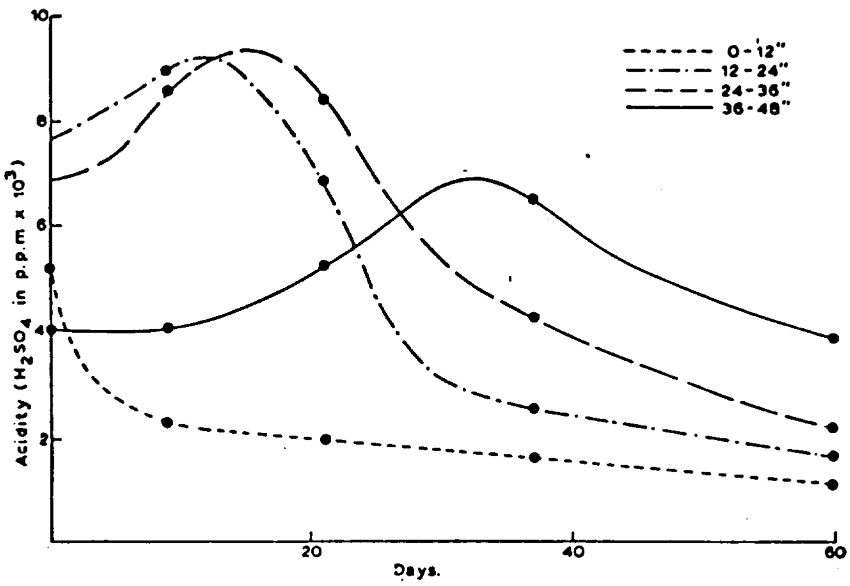

Figure 3: Slimes Dam Leaching - Change in Acidity at Various Depths with Time following James and Mrost (28).

that is being leached. Immediate vegetation will occur if soil has been leached to a depth of 12 inches (28). Rain leaches the acid from the soil surface but, during prolonged dry spells, moisture rises due to surface evaporation and capillarity, the acid returns to surface. The duration and intensity of the natural rainfall is not sufficient to leach adequately (7, 19, 26); flood leaching is impractical because of bank stability, but spraying can be practical. The water application rate should not exceed the infiltration rate, so the following system has been used:

1. loosen and smooth the surface to increase infiltration;
2. spread a mulch on the surface as a base for seeding and aggregate formation;
3. apply the spray for 2 or 3 days to leach the acid from the surface, heavy at first and then lighter;
4. seed the surface while acid at the surface is reduced; and
5. continue spraying for 3 weeks to leach the acid so deep into the soil that it will not rise to the surface during long dry periods (28).

The result of this procedure indicated that after 20 days acid was leached to a depth of 3 ft and that, in a 60-day period, the acid rose by only 15 in ; root growth does not exceed the leaching rate, therefore early seeding is possible; and controlled spraying for three weeks provides adequate moisture for the young seedlings. This method is so successful that vegetation can be maintained on the side of an active tailings dam to within 20 ft of the top (28, 33).

An alternative to leaching is to bury toxic material under the more desirable layers. A study in Kentucky suggested wind-rowing the toxic layers for strip mining operations instead of burial. Figure 4 illustrates the strata sampling for potentially toxic layers. The study concluded that rider coal or bone coal could be treated in this way but acid shale and sandstone were more difficult to identify and, therefore, could not be separated (16, 25, 34, 35, 36).

A practice in pits and quarries is to pile top- and sub-soil separately for replacement on the waste areas after mining. This is effective for flat surfaces but is difficult on slopes.

Toxic ions and salts may be removed by leaching. Increase in pH of the acid soil solution causes the formation of neutral salts and removal of high concentrations of toxic ions, therefore, the water can then leach the salts from the surface of the soil (27, 28, 37, 38).

On a small scale, salts and ions have been removed by the use of electrical potential difference techniques if pH correction and leaching had not performed satisfactorily. This electrical process of passing a current between 2 electrodes placed in the soil reduces the amount of exchangable Na and increases the movement of soluble salts towards the cathode. Water leaching is essential to effective salt removal. Although this process is expensive and has not been used on a large scale, it is felt that an economical large-scale operation could be practical (39, 40).

Other methods have been tried to control toxic ions. The placement of sand and slime in alternate layers tended to prevent the salts from moving up through the sand layers (2). Solar orientation leads to greater salt concentrations on the sunny side of spoil piles. This led to the construction of spoil piles with vegetation on the side opposite the

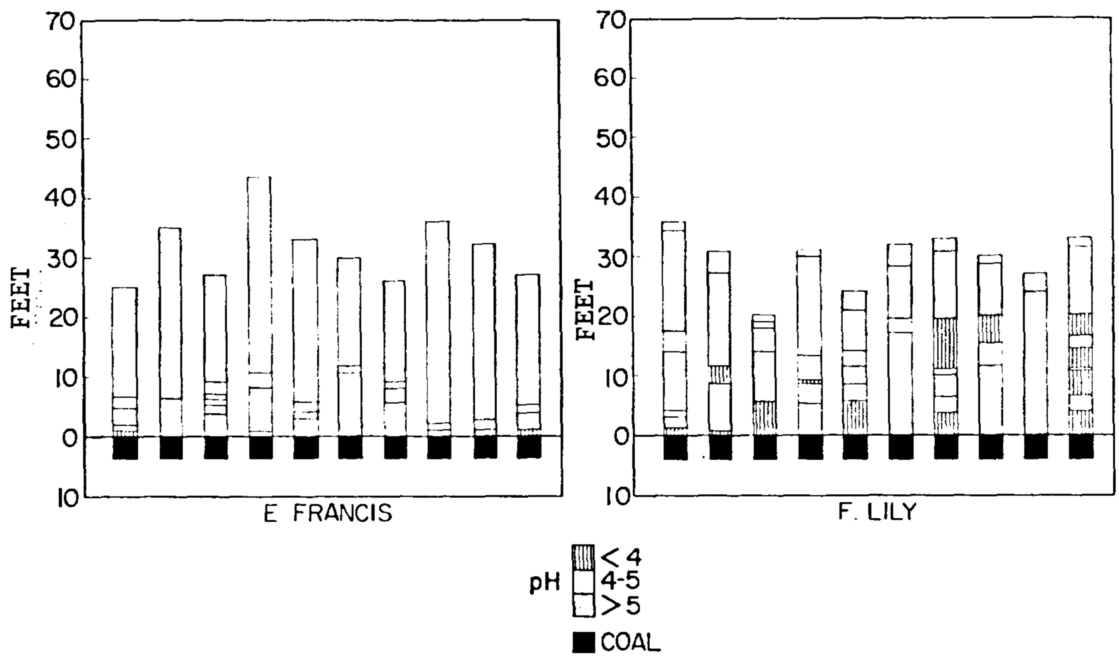

Figure 4: Locating Acid Strata above Kentucky Coal Seams by Horizontal Sampling for Strip Mining, following Berg and May (33).

sun (27). None of these latter methods have been proven on a large scale.

(ii) Fertility

In different waste embankments, it has been found that nitrogen and phosphorus are the two macronutrients in shortest supply. Potassium, K, the other macronutrient, is generally available in appreciable amounts (27, 41). The micronutrients, measured by plant tissue analysis or deficiency symptons, do not tend to limit growth. The exception is molybdenum which was limited in South African work (7).

Increasing the pH affects the availability of nutrients and leads to better assimilation of P, Ca, K, Mg, Fe, and Mn (29, 41). Correction of pH assists in correcting nutrient availability and in lowering toxic levels (42).

In loose spoils, leaching can remove nutrients, therefore several small applications of fertilizer are better than one large application (8). Slow-releasing fertilizers such as magnesium-ammonium phosphate are generally more effective for the same reason. A successful method used in Wales was the application of broiler litter. The small nutrient content was available to the plants and excessive amounts were not leached out. One quarter of the litter was wood shavings which provided organic matter for supporting biological activity and served as a mulch (8).

Biological activity is important for the assimilation of atmospheric nitrogen. Correct inoculation of the legume assists in fertilizing the soil with nitrogen, so there need be no further fertilization. An application of 4 times the required inoculation has been effective on pH-corrected spoils and is normal (43). Selection of plant species could also solve some nutrient deficiencies. Some grasses and legumes grow best in nutrient deficient soils, although nitrogen is always required by grasses.

Nitrogen is not required by legumes, so, if an inoculated legume is planted, the assimilated nitrogen can be used for increasing grass growth (44).

A wide variety of fertilizers and fertilizing rates have been tried after assessing soil deficiencies and plant requirements. Plant response to fertilizer has been extremely good and careful management of plants and fertilizers has led to rapid restoration of the fertility of spoil banks (44, 45).

C. Climate

The sprinkling system for leaching provided ample water for germination and because of application requirements, there was no surface run-off to wash the seeds or seedlings away. The addition of organic matter assisted with aggregation and establishment of a medium for bacterial growth (7).

Some surface stabilizers tend to darken the surface, so surface soil temperature increases with exposure to the sun and reflection of light is reduced. The warmth assists germination in cooler areas or seasons. The reduced reflected radiation assists plant metabolism because an excess of light tends to inhibit some biological activities associated with photosynthesis (2).

Besides soil and water, plants need air. To protect the plant from toxic materials in the air, monitoring devices have been set up to indicate the level of dust and/or sulphur. These in turn could be used to monitor milling operations and, possibly, to control the release of hazardous pollutants. High stacks have lowered the toxic levels at the ground surface (46).

D. Vegetation

(i) Plant Choice

Vegetation can be divided into two groups: the wild plants indigenous to the land prior to disturbance and the agricultural or commercial plants. The disrupted soil and the tailings, however, may not be suited to the pre-mining vegetation. The process of self-revegetation has proven extremely slow and spotty (7, 8, 41). Agricultural plants may adapt to the soil and climate. Adjustment of soil requirements has been successful because of the known growth and nutrient requirements. Availability of seed is also an important consideration. Greatest success has been obtained with agricultural plants.

Plant introduction trials were conducted in South Africa to develop a new variety by irradiation mutations. The results were less successful than the selection of agricultural plants and soil controls such as stabilization, leaching, and fertilization.

Work with hybrids has proven to be very successful in America but not under extreme pH or toxic conditions. Low-nutrient and acid-tolerant plants have been combined into vigorous hybrids. With corrected soil conditions, the use of hybrid poplars led to quick establishment. These trees grew 30 inches in a season while natural volunteer vegetation grew only a few inches (47, 48, 49).

Plant choice depended on land use. Trees were selected for rough areas not fit for agriculture (46, 50). A fast-growing litter-producing tree such as poplar and locust was first established (51). Subsequently these trees would act as shade trees for the slower-growing timber seedlings.

Varieties of trees have been mixed to protect against disease and for aesthetic reasons. Some trees are planted to provide food for wildlife which may move into the area (17, 52). If the land is to be used for crops, forages or cereals are chosen. This can be more difficult because of the lack of nutrients in the soil. The use of grass-legume mixtures is common for the first few years to develop some soil structure. This method implies annual maintenance such as fertilization, seeding, and cultivation. It is effective on top of tailings or flat terrain but, in some cases, 2 or 3 feet of top soil is required over the spoil before soil structure can develop (16).

The requirement for maintenance-free ground-cover has also led to the use of grass-legume mixtures. Nitrogen assimilation of the legume boosts the growth of the grass. Long-lived perennials with strong rhizome growth serve to hold the surface stable and to prevent wind and water erosion. Fine-textured grasses have been used to increase organic deposition necessary for soil development and fertility maintenance (6, 53).

Deep-rooted plants have been used to break-up a compacted sub-soil, e.g. alfalfa and trefoils are established prior to planting trees (13). It has been suggested that thick root systems prevent the oxidation of iron pyrites thereby reduce the acidity of the soil and spoil effluent (33). Sod-forming grass and legume mixtures have been used for this purpose.

The USDA Agriculture Handbook contains an evaluation of 56 grasses and 16 legumes for soil conservation (54). This would be of use in making preliminary choice of plants for mine spoils. Industries select plants tolerant of adverse physical conditions and low nutrient levels, whereas the spoil singles out those tolerant of acid and toxic ions (55). The choice of plants used in these trials are not listed here because in most cases the plants are not adapted to the Canadian climate.

In all cases, it has been shown that high-quality planting, stock seeds, and seedlings give the best results.

(ii) Planting Method

Two methods can be discussed - seed planting and seedling planting. Seed drills and other common seeders are suited to tillable soil and gentle topography. The value of common cultivation equipment is questionable. Where oxidizable pyrites exist close to the surface, cultivation exposes fresh spoil and compaction caused by the machinery limits weathering and root penetration (12, 44). Harrowing after compaction has been successful in establishing grasses and legumes (31). Levelling rough terrain so that agricultural equipment can be used on slopes eliminates the need for hydro-sprayers, but the problems of exposure of toxic material and soil compaction must be dealt with.

On rougher terrain where agricultural equipment cannot operate, seeding by plane or hydro-sprayer has been used. A mixture of seed, fertilizer, lime, humus, and a binder are applied, and although results are not as good as normal agricultrual methods, vegetation is established. The quantity of humus or mulch is a critical factor in this seeding method. Where two thirds or more of the surface is covered by hay mulch, plant growth is inhabited because the mulch blocks out sun and moisture (56, 57, 58, 59). Others have indicated that 80% to 90% cover is the limit for successful mulching (6). Broiler litter with no tillage was quite successful at 3 tons per acre with one-quarter wood shavings and a latex emulsion as binder. Growth was good and came through the emulsion cover (8).

Seedling planting must generally be done by hand for good results. It has been shown that rooted cuttings do better than non-rooted cuttings (48). This is the most common method used for reforestation and is very successful on well-weathered overburden. One suggestion for planting in acid spoil was the placement of the seedling at an angle such that the roots remain in the top 10 cm of the spoil bank but it has not been tried to any great extent (60).

E. Other Factors

(i) Time

Natural revegetation of a spoil may take anywhere from 30 to 100 years (41). This time has been shortened by starting revegetation before the mine has closed down, e.g. seeding of the outside of a tailings dam as it is being built.

Natural weathering neutralizes acid spoils at about one pH unit in 20 years. The neutralization rate is most rapid in the first three years, therefore liming requirements are greatly reduced on spoil exposed for three years. However, if the pH of the bank is low, e.g. 2.5 to 3.0, even heavy lime treatment will not provide lasting pH reductions (13, 32). It has been stated that it takes 4 or 5 years, to allow for weathering, settlement, and acid correction, before vegetation can be established on a tailings dump. Another 10 years is required to develop a suitable soil and plant structure to permit lumber-grade trees to be grown. The vegetation between 5 and 10 years would be of the order of 20% trees and 80% grasses to 90% trees and 10% grasses (8, 28, 49, 61).

On the other hand, in South Africa, leaching permitted vegetation to be planted 2 to 3 days after the start of leaching.

Programs:

Revegetation programs vary widely because of local conditions. It is evident, however, that when the mining operation and the revegetation program were considered to be interrelated best results were obtained. That is, the program of reclamation was laid down before the mining operation began.

Aerial photography, soil testing, and climatic notations have all been used in developing programs (3, 35, 44). Comprehensive plans for revegetation and managing the area after vegetation is established are also common (6, 14, 16, 50, 51, 62, 63, 64, 65, 66).

Figure 5 and the following two outlines may best illustrate reclamation programs:

Program 1:
- investigate the limiting factors,
- develop methods to deal with them,
- apply the best solution, and
- control the results.

Program 2:
- application for the authority to work the mine including a plan,
- stripping and storing of top- and sub-soil,
- backfill, grading, and soil replacement,
- a five year reclamation for agricultural use, and
- return to productive land with careful management; (67).

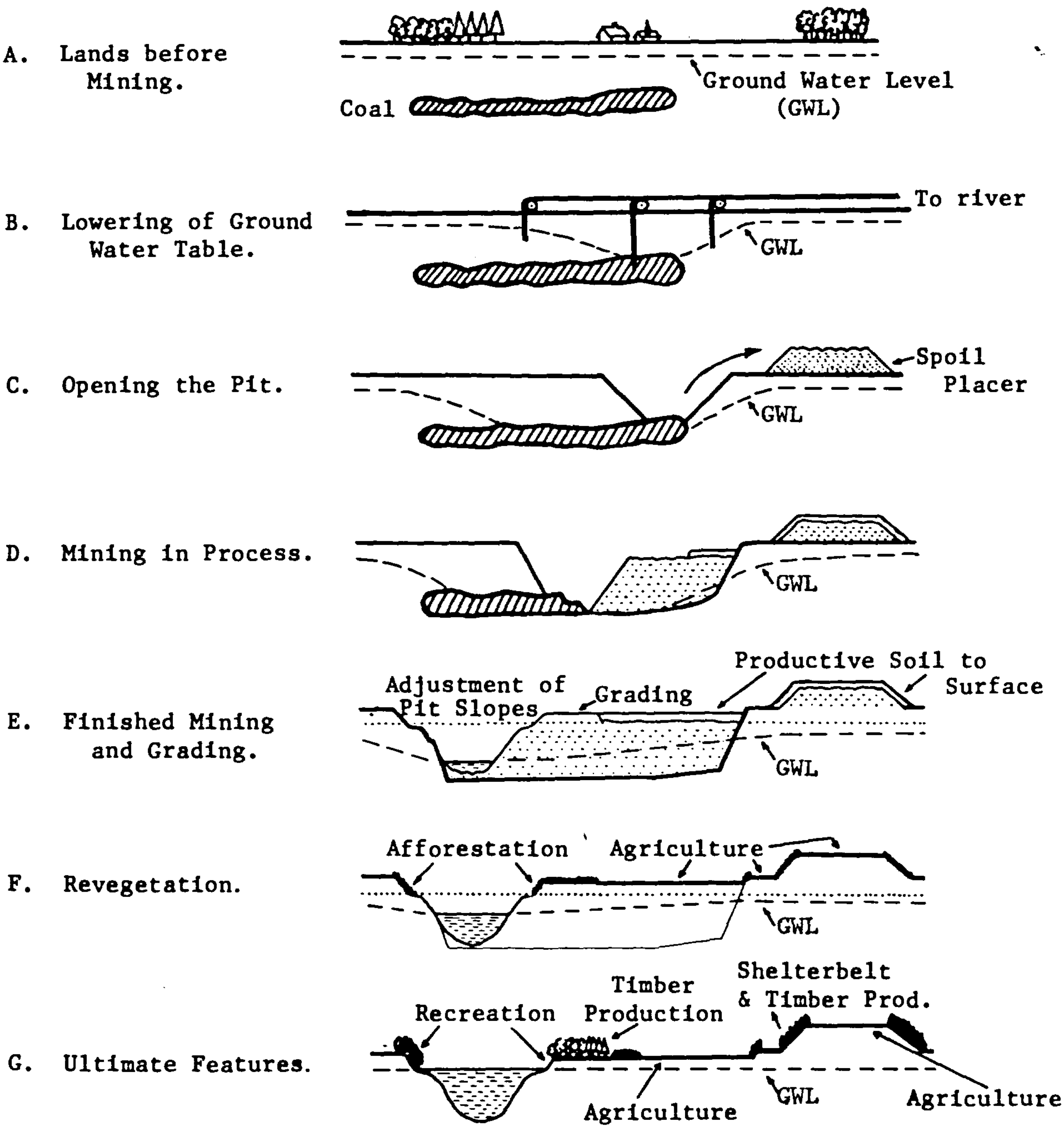

Figure 5: The History of a Man-Made Landscape.
Schematic Procedure of Brown-Coal Surface Mining to Finished Reclamation in Germany following Knabe (15).

4. THE CANADIAN SITUATION

A. Physical Properties

(i) Texture and Aggregation

Canada has both overburden- and tailing-textured spoils. In general, wet tailings in Canada can be drained so that the spoil can be worked by agricultural equipment and plants can be established. Because of the difficulty of establishing vegetation on active acid-producing tailings dams, the International Nickel Company (INCO) (39, 68) has dumped coarse rock on the slopes to maintain surface stability. This material does not improve the agricultural use of the slopes but small pockets are created between the rocks for vegetation to become established later.

To assist aggregation, some companies have tried adding soil. This changed the texture, covered the toxicity, and improved surface stability. Two to three inches of soil were spread over the tailings of a British Columbia base metal mine but the trial was not successful because of poor binding between the soil and the tailings. Aluminum Company of Canada is covering tailings with soil but most companies have discarded the concept because American experience suggests that 3 to 4 feet of soil is required for satisfactory cover. Over large areas this is an uneconomical procedure for establishing a soil cover.

Hollinger dumped sludge from a sewage disposal plant to establish growth on tailings (69). Fifteen to twenty acres were treated with the sludge applied before and after seeding. Separation of spoil and sludge did not occur and establishment of plants was good in both cases. Inco has successfully used a bituminous compound as a binder in a hydro-spray mixture that assisted aggregation for a short time (68).

Erocon has done a great deal of work on controlling the erosion of overburden and tailings. The slopes are graded down to about 25° which permits agricultural cultivation techniques.

Surface Stability

Wind and water erosion occur on Canadian spoils, and many mechanical stabilizers have been tried, i.e., Inco's coarse rock cover on slopes. The top of the slope presents no problem before it dries out. A sprinkler system was used to control this problem but, although it worked satisfactorily, it was not accepted as a long-term solution.

For flat surfaces and the graded slopes of Hollinger and Erocon sites, a roller-tamper was useful after the land had been cultivated and seeded.

Asbestos wastes have been sprayed with water as they leave the mill; this causes a hard stable surface on the dump. Because of the hardness, vegetation has never grown on these wastes. Other methods such as snow-fencing and tree planting have been used but these are used more for retention and stabilization of a snow cover than for soil stability.

B. Chemical Properties

(i) Acidity and Toxicity

Chemically, the spoils in Canada vary widely. An attempt is being made to shield potash wastes by planting trees on their perimeter, whereas the highly basic wastes from aluminum refining are covered with soil. Results of this work are not yet available. Extremely acid (pH 2.5 to 3.5) spoils as found in old tailings from base metal mines have not yet supported continuous vegetation (70). Acid migrates upwards through soil topping despite liming which provides only temporary relief. At Noranda, lime has been applied at seeding, but acidity returned to the surface after only two months as evidenced by dying patches of vegetation, and, by autumn of the same season, no vegetation remained. Present plans are to lime at 10 tons/acre in both the fall and the spring.

Soil neutralization by leaching has not been emphasized in Canada because of the polluting effect of the effluent (70). One of the aims of revegetation in Canada is to establish a cover that will reduce infiltration of water and acid effluent. Ponds have been removed from tailings surfaces where acid seepage was a problem but maintained on alkaline spoils.

Base metal tailings present the widest diversity of problems although severity varies. Acidity is commonly close to the neutral zone, say pH 3.5 to 5.0, and may occur only in patches according to the amount and location of sulphides. Liming in these cases has proven to be very effective and best results have been obtained when the bulk of the lime was added well before seeding. International Nickel Company recommends liming in the early spring about two months before seeding and again, in lesser amounts, at seeding.

Liming is not the only method of reducing the acidity in spoils. In one case (68), improvements in refining operations have reduced the potentially acid-forming iron compounds from 45% to 30%.

Toxicity due to high ion concentrations is not a problem if pH has been corrected to above 5.0. This has been proven on less-acid spoils but strongly acid spoils have not been effectively neutralized, so it is difficult to say whether acidity or toxicity causes plant death.

Vegetation has been established on uranium wastes and current work is concentrated on removing radioactive pollutants that may enter the plant (70, 71).

Fertility and biological requirements:

Rio Algom and Erocon, like many other companies, apply 800 to 100 lb/acre of all-purpose 15-15-15 fertilizer at or before seeding. Top dressings of 200 to 300 lb/acre have been applied at the time of seeding, after cutting, or in the spring and fall.

Hollinger used sludge and milorganite as fertilizer (69); it is less subject to wind erosion than granular fertilizer.

The fertilizer per acre consisted of:

800 lb	20% Super Phosphate,
400 lb	60% Muriate of Potash,
2000 lb	Milorganite.

This was applied to spoil of pH 7.0 to 7.4 before hand raking and seeding. A top dressing of 400 lb/acre was applied the first fall but, subsequently, fertilizer has not been used and the stands have maintained themselves for several years.

Treatment of acid wastes has been developed by the International Nickel Company of Canada. They started out with high-volume low-value fertilizer and found it best to increase to lower-volume, higher-value fertilizer. The following illustrates their application:

Fertilizer	Prior to Seeding	At Seeding
4-12-10	1600 lb/acre	400 lb/acre
6-12-12	600 lb/acre	400 lb/acre
5-20-20	400 lb/acre	300 lb/acre

Annual maintenance involves application of 100 lb/acre of urea after freeze-up and 200 lb/acre of 5-20-20 after cutting. Annual liming and fertilizing are continued as insurance of a crop cover to reduce risk of failure (69).

There has been no indication of micronutrient deficiencies in the spoil. Inoculation of legumes has been normal procedure, with about four times the required amount inoculant being added with the seeds. Little has been done, about building up organic matter, other than the natural deposition by growing vegetation.

C. Climate

Canadian industries have faced climatic conditions realistically by selecting commercially used forage and cereal species adapted to the local climate. At high altitudes or in permafrost areas where no commercial crops are grown, wild trees and scrub growth are being planted but results are slow.

Thirgood attempted to identify portions of the macroclimate (72). He divided Canada into five regions:

1. Appalachian - Acadian,
2. St. Lawrence Region,
3. Canadian Shield,
4. Interior Plains, and
5. Cordilleran Region.

This classification included some geology and general topography of the area. Questionnaires sent out by the Department of Energy, Mines and Resources to Canadian mining companies provided more specific information about the mine sites (70, 73, 74). Data on rainfall, snowfall, and mean temperature extremes have been obtained. These sources have helped organize a revegetation program considerate of macroclimate.

Microclimate has been adjusted by correction of both physical and chemical properties of the soil. Snow-fencing, tree windbreaks, and companion crop stubble provide protection against frost-kill. Tree windbreaks have been established on the perimeter of Hollinger tailings (75) and have been successful in catching and holding a snowcover on the plateau of the tailings. INCO uses rye or oats as a companion crop leaving 10 to 12 inches to stubble, which is also effective (68, 76). Seeding just before a light rain provided good germination conditions.

Sulphur pollutants have been studied. Canadian industries releasing SO_2 are aware of its effects on plant growth and are erecting higher stacks and setting up devices to monitor the pollution level. In this way, industrial emissions can be controlled to below toxic concentrations (76). In British Columbia, Cominco has been planting trees where the pollution concentration has been corrected and is no longer dangerous to them. The installation of electrostatic precipitators has removed some fly ash and other possible pollutants (77).

D. Vegetation

(i) Plant Choice

Most of the plants chosen were agricultural species but some were natural vegetation or wild species. Wild or native vegetation slowly advanced onto some spoils, initiating their use as possible plants for revegetation.

Trees have been studied mainly for use on coal strip-mine overburden. A large variety have been grown and expect to be grown as the soil structure improves. They are scrub, hardwood, and softwood trees, generally grown in that order. Some poplar trees had reseeded naturally on the perimeter of tailings areas, and young poplars from the surrounding bush were transplanted to hasten tree cover. Trees, which are planted manually, have been chosen where agricultural seeding and hydro-seeding are not possible or practical.

Grasses and legumes are chosen mainly because their seeds are readily available and they solve the dust and erosion problem effectively. The plants have been chosen to tolerate acid, low-nutrient, and drought conditions and to form a fast persistent cover. Mixtures have been made-up to satisfy the varying conditions of a spoil bank but they tend to follow the forage mixture recommended for the area. However, in some cases, the shot-gun method has been used in which about ten grasses and legumes are broadcast over the spoil with the intention that the best adapted plants grow on the specific spoil area. Best results have been obtained, however, with a reduced number of well-selected species.

Table 3 lists trees, grasses,and legumes used for vegetation of spoil. Table 4 shows sample mixtures that have been broadcast on Canadian spoils. They are not listed in order of effectiveness because of the diversity of trials, sites, and mixtures. For minimum maintenance, however, a legume-grass mixture is much superior to grasses, trees, or legumes alone.

(ii) Planting Method

Seeding by plane, hydro-sprayer, and hand have all been practised in Canada with satisfactory results. These methods, however, have been used only if agricultural equipment could not be used because of steep slopes, rough terrain, or coarse, rocky spoil. The hydro-sprayer mixture consists of wood chips as a mulch, fertilizer, seed, and a bituminous compound as a binder. This lodges in the pockets between the rocks to permit plant establishment (68, 78, 79).

Hand planting of nursery stock is common on overburden spoil. As found in the U.S., grading the overburden reduces tree survival. Seedlings pre-established in peat pots have been planted in New Brunswick coal overburden. They seem to do best when the pots are sunk well into the bank, but a year or two is still required to confirm this (78).

Generally, Canadian industries seed by agricultural methods. This usually requires the grading of 45° slopes to 25° or 30°, which is relatively easy on tailings, so that cultivation and seeding can follow readily. Overburden is more difficult to grade evenly, therefore minimum grading and another seeding method are employed.

Planting mixtures are used to overcome the different chemical and physical properties at one site. The seeding of tree seeds along with grass mixtures has shown some progress, but the area can not be cut.

Irrigation was used as a surface stabilizer at one of Inco's spoil sites. Satisfactory results have also been obtained, without irrigation, by planting just before to a light rain.

Another planting method is the dumping of grass cuttings onto tailings. The seeds and humus supplied by the grass have allowed satisfactory establishment on gold tailings. This method, however, is so slow that direct seeding is preferable.

TABLE 2

Grasses, Legumes and Trees
Used for Revegetation of Spoil in Canada

Grasses	Legumes	Trees
Bromegrass	Alfalfa	Carolina Poplar
Canada bluegrass	Sweet Clover	Balm of Gilead
Timothy	Red Clover	Willow
Redtop	Alsike Clover	Black Alder
Kentucky Bluegrass	Birdsfoot Trefoil	Paper birch
Crested Wheatgrass	Crown Vetch	Ash
Creeping Red Fescue		Black Locust
Meadow Fescue		Black Spruce
Highland Bent		Colorado Blue Spruce
Kentucky No. 31(New Zealand Fescue or Chewing Fescue)		Red Pine
		Scotch Pine
Winter Rye		Jack Pine
Oats		Douglas Fir

TABLE 3

Examples of Seeding Mixtures Used for
Revegetation of Spoils in Canada

Mixtures Used by INCO (68)

1. 12-1/2 lb Mixed Grass Seed*
   12-1/2 lb Canada Bluegrass
   10 lb Alfalfa or Sweet Clover
   1-1/2 bu Oats
   8 lb Bromegrass

2. 12-1/2 lb Mixed Grass Seed*
   12-1/2 lb Canada Bluegrass
   10 lb Bromegrass
   1-1/2 bu Winter Rye

*Mixed Grass Seed
1 part Timothy
2 parts Redtop
1 part Kentucky Bluegrass
1 part Crested Wheatgrass
1 part Creeping Red Fescue
INCO (68)

Mixtures Used by Hollinger (69)

1. 30 lb Timothy
   20 lb Birdsfoot Trefoil
   1 lb Crown Vetch

2. 20 lb Timothy
   20 lb Birdsfoot Trefoil
   20 lb Kentucky No. 31
   1 lb Crown Vetch

Miscellaneous Mixtures

1. 20% Meadow Fescue
   15% Birdsfoot Trefoil
   25% Timothy
   10% Alsike Clover
   5% Highland Bent
   5% Redtop
   20% Doland Red Clover

2. Creeping Red Fescue
   Kentucky Bluegrass
   Redtop
   Meadow Fescue
   Birdsfoot Trefoil
   Timothy
   Alsike Clover
   Highland Bent
   Red Clover
   at 50 lb/acre

3. Kentucky No. 31
   Canada Bluegrass
   Crown Vetch
   Birdsfoot Trefoil
   Timothy

E. Other Factors

(i) Time

Canadian mining companies generally expect vegetation and establishment the season following completion of mining. Although this is the goal, it is not always achieved. Gold mine tailings have been easiest because of their basic or neutral pH. Their banks are seeded while the pond is in use to protect against erosion and the top is seeded at closure. Earlier seeding has been hampered by the high moisture content of the sludge and the structural instability of the embankment.

Hollinger noted that bank settlements started 11 years after the area was first opened and 17 settlements occurred over a period of 6 years. No further settlements have occurred in the past 22 years (75). Their site reclamation started with the closure of the mining operation; therefore, as seen at Hollinger, all significant settling has already occurred.

Correction of spoil chemical properties puts the greatest stress on time. With slightly acid spoil, liming in the spring at seeding has been adequate. With strongly acid spoil, the addition of lime prior to and at seeding permitted establishment of vegetation, but, within two months, burned patches began to show because of the upward movement of acid water. The next approach, by Noranda, was to lime heavily in the fall and spring as well as at seeding. A check in the fall would also be included. This has not yet been completed; therefore, results are not available. INCO limes in the spring about two months prior to seeding and claims fairly good success. They have been trying to vegetate acid spoils for several years.

Maintenance is varied; INCO applies fertilizer annually, but Hollinger applies top dressing the first two years only and then lets the sward maintain itself. Vegetation may be established in one season, but a self-maintaining sward is still unknown on Canadian base metal tailings.

(ii) Program

Individual companies have systematically approached the problem of revegetation for aesthetic reasons as "good citizens". Brenda Mines Ltd. (80) in British Columbia has done this on paper; its revegetation should be complete by 1991. Western coal companies have accepted reclamation as a part of the mining operation (81). Provincial governments have taken steps to establish reclamation standards but in most cases they are more interested in pollution control than in vegetation establishment (82, 83).

Mining companies frequently consider revegetation as an expendable outlay. The closer the mine is to civilization and public awareness, the greater the emphasis on making it look nice if nothing else. Far back in the bush of Northern Canada and in the permafrost regions there is very little programming because the companies are not pressed and technology is lacking.

The choice between self-perpetuating or annual maintenance has not been established by all companies. Most programs involve growing something to solve the problem in the hope that a great deal of maintenance will not be required. From questionnaires sent to mining companies, it was concluded that guidelines for reclamation would be desirable and advantageous but that legislation would not (70, 73).

5. SUMMARY AND RECOMMENDATIONS

Canada's revegetation problems are similar to those of other mining countries, but our climatic conditions demand different revegetation procedures.

With regard to spoil texture and aggregation, Canadian companies have put little emphasis on either mulching or addition of humus because of the expense. Wherever possible, the texture of the waste surface is kept close to soil size. With overburden, it is recommended that as much soil as possible be removed and replaced over the coarser material.

Surface stability by mechanical methods, especially asbestos, is detrimental to both the establishment and maintenance of a plant cover. Although these methods solve the problem there will eventually be a demand for vegetative cover, so, for that reason, non-vegetative, temporary stabilizers should not be encouraged. Emulsions are acceptable if they disintegrate and do not hamper plant growth. They are being tried in Canada and should be encouraged because they will be needed in the more difficult areas where slow-growing wild plants are the only possible vegetation.

The Canadian treatment of acid spoil is to apply lime, up to 10 ton/acre. Ponds on acid spoil are drained and the topography is altered to avoid ponding. Leaching has not been tried extensively because of toxic effluents but natural leaching plays an important part in weathering. It is considered that leaching would give more reliable, chemically stable spoil banks which would be more acceptable to vegetation on a long-term basis.

Nutrients are added by normal fertilizing standards and vegetation requirements. Although all-purpose fertilizers give good starting results, they should be studied closely. Nitrogen, for example, hinders the proper development of a legume and reduced amounts of it in the fertilizer would benefit both the grass and legume. On spoil, other than that used for agricultural crops, the annual use of fertilizer inhibits the establishment of a natural, self-sustaining vegetation.

The treatment of toxic spoil banks can hardly be improved. The best method of improving treatment is to change the mineral processing to reduce toxicity and increase the spoil's acceptability for vegetation.

Plants should be chosen from commercially available seed and nursery stock. The plant species, forage mixtures, and seeding rates should be suited to the area and as recommended by agriculturists; this is preferable to the shot-gun approach of seed application.

Mixtures for waste embankment reclamation have not always been forage mixtures because early germinating and fast-growing seedlings may squeeze out better seedlings, and may not withstand climatic stresses as well as slower-growing less-competitive plants. Therefore, mixtures should be analyzed before seeding. Articles similar to that of the Utah Agricultural Experimental Station would be useful in Canada (84). It gives a list of useful references for literature on vegetation and metal toxicity of mine wastes; the list could be expanded to include references on all aspects of plant choice.

Planting has been done mainly by agricultural machinery which is effective in controlling seed placement. However, it should not be forgotten that seeding can be done by air with no tillage. Grading is fine if it solves a pollution or aesthetic problem but, for non-toxic spoil, it may not give the best results. Rougher terrain has greater water-storing capacity and flood control properties than graded terrain. More emphasis should be placed on air seeding and hand planting of seedlings. Natural revegetation with grass or trees is a long process that might be acceletated by spraying seeds from the air to hasten the return of the land to production. Agronomic research could be done on areas subject to adverse climatic conditions and on testing the growth of hybrids of indigenous species. Next to soil factors, plant choice and seeding method are extremely important to successful revegetation on mine spoil.

Climatic conditions have been recognized in populated and agricultural areas, but mines are being opened in northern regions where agriculture is non-existent and where no way to vegetate soil above permafrost has been found. Therefore, non-agricultural plants are being tested at high-altitude and permafrost areas before site disturbance.

The reduction of time required for revegetation hinges a great deal on the planning before site disturbance. Guidelines for structural stability are good but guidelines for vegetation must be developed. These guidelines should not stop after establishing a vegetation cover but should continue with a view to benefiting both the industry and the community. Both annual-maintenance and maintenance-free vegetations should be covered by the guidelines. The former is best for agricultural crops, whereas the latter is preferred for reforestation and recreation areas. The revegetation program should be formulated prior to mining and followed through to completion.

The problem of vegetation of spoil is both financial and technological. The expense and lack of public pressure in the past have resulted in few, if any, revegetation attempts. Where practised, revegetation amounted to seeding and fertilizing neutral non-toxic spoil. For most spoil, the addition of lime and careful selection of plants will result in satisfactory vegetation. However, it will be financed voluntarily by very few, if any, mining companies. For high-sulphide-content tailings such as those discharged by Noranda and INCO there is a technology problem. Research should be done towards rendering such highly acid spoils fit for revegetation and towards producing less-acid spoils. Other abnormal environments such as high elevation and permafrost are still included in the technical problem section.

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