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ASSESSMENT OF MINE SPOIL FOR THE ESTABLISHMENT OF VEGETATION

by

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INTRODUCTION

The assessment of mine spoil for the establishment of vegetation requires that information about the chemical and physical characteristics of the spoil be combined with that of the environmental setting of the waste material. In order to completely evaluate a spoil's ability to support plant life, factors of slope, precipitation, temperature and duration of frost-free period must be considered in conjunction with fertility, drainage, texture, available plant moisture, and salinity.

Though some general statements can be made about the qualities of mine spoil, some of the materials exhibit idiosyncracies which challenge reclamationists. The environmental setting is interesting in that much of it is artificial (e.g. topography and slope) and can therefore be manipulated to serve particular purposes.

This paper discusses the inherent variability of physical and chemical criteria in mine spoils and how these variables affect plant establishment and vegetative growth. Sampling strategy is also examined, as are analytical techniques crucial to plant growth appraisal, though the latter are included with a word of caution. As Mr. P. Christie previously covered the management of topsoil and overburden, only waste rock and tailings are considered in this paper.

FACTORS AFFECTING VEGETATION ESTABLISHMENT

The principal factors affecting seedling establishment and plant growth in mine waste rock and tailings materials are spoil stability, moisture retention, drainage, fertility, soil temperature, surface crust formation, heavy metal toxicity, pan formation in materials, salinity and acidity. Individually or in combination, these properties can threaten plant establishment and/or retard vegetative growth. Commencing with spoil stability, each of the properties will be discussed in terms of how it affects the opportunity for successful reclamation.

SPOIL STABILITY

The stability of deposited waste rock and tailings is of major concern to mine operators and reclamationists. For the operator, fitting spoil volumes into available areas to minimize land occupancy and disturbance is an engineering problem; whereas, the reclamationist is primarily concerned with spoil construction as a precursor to successful reclamation.

In general, waste rock and tailings provide a consistent environment for the establishment of seedlings, and a stable surface increases the possibility of vegetative growth. The irregular shape and size of the coarse fragments provide shelter from wind and water erosion for the germinating seedlings. Field observations have indicated that pockets between coarse particles act as microcatchments for moisture, nutrients, and fine particles. Such microhabitats can also protect young plants from the extremes of temperature.

Stability in waste rock piles is dependent upon the slope angle. If deposition results in a slope which is too steep, as may occur where a dump is steep walled to conserve space, a rock slide may occur. Revegetation will be impossible unless slope angles are reduced.

Instability has also been documented in dumps composed largely of sedimentary material. Sedimentary deposits are easily broken down, consequently they slump. Therefore, slope angles of dumps containing sedimentary host rock should be less than those which contain more competent materials.

In order to stabilize tailings materials, they must be supported by reinforcing structures or dams because they are subject to slumping when saturated with water. This tendency to slump is a direct consequence of the particle size distribution of the spoil. Tailings material is finely crushed rock that is deposited in the form of a slurry. This spoil is less than 2 mm in diameter and tends to be sand size. The stabilizing effect of coarse fragments combined with fines is absent in tailings. Recycling of excess water drained from the ponds helps to alleviate the slumping problem.

Instability also occurs on the spoil surface. Tailings are susceptible to extreme water erosion, and heavy rainfall rapidly scours the surface of the ponds, carrying away fines as a slurry. Immature plants are often buried or removed in the rivulets. Water erosion of tailings is under the scrutiny of government agencies. Environmental impact studies have included incidences where fines have been discharged into streams. The deleterious accumulation of fines in spawning grounds may smother fish eggs and bottom vegetation. The cardinal approach in preventing water erosion of spoil surfaces is to establish a vigorous and uniform vegetative cover.

Wind erosion is a common problem on dry tailings spoil devoid of vegetation. The level topography of impoundment areas offers no protection from air currents. Airborne particles have the effect of sand blasting plants seeded on the spoil. The rapid establishment of a vegetative cover will help to prevent particle transport. In some circumstances mulching, or the application of manures, soil and over burden have discouraged wind erosion.

MOISTURE RETENTION

The low moisture holding capacity of waste rock and tailings has caused some major problems in establishing self-sustaining plant communities on spoils in dry climates. Water retention is determined by particle size distribution and organic matter content. The water holding capability of organic matter is attributable to its high percentage of small pores, and the surface charges which hold onto water molecules. Organic matter can also increase the volume of small pores by binding together coarse particles such as sand. This favourable material is negligible or absent in both waste rock and tailings; therefore, the moisture retention characteristics of such spoil become a function of particle size distribution and coarse fragment content.

The moisture holding capacity of waste rock is substantially lower than that of tailings, because for equal volumes of both materials, waste rock has a lesser proportion of fines. Waste rock contains a fine fraction that is about 1.6 mm in size. Abrasion between coarse fragments during truck handling produces some of these fines. However, most fines are sand size, thus particle spacing is large enough to let water drain easily from the pores, leaving little available water for plants.

Fines are not evenly distributed in waste rock. They are generally more concentrated near the top of the rock pile, since gravity draws the heavy coarse fragments towards the toe of the dump.

The volume of fines in waste rock spoil may be substantially increased when coarse fragments are broken down into fine particles. As noted previously, sedimentary spoil weathers fairly rapidly, whereas igneous and metamorphic rocks exposed to atmospheric conditions for long periods may become "rotten", crumbling under the slightest pressure.

Low water retention in waste rock results in droughtiness. The different sized coarse fragments create large voids in the rock dump which allows precipitation to leach through the pile, thus moisture is unavailable for surface vegetation. Drought resistant species or irrigation programs may be used to offset the effects of water deficiencies. An irrigation program will stimulate initial vegetation establishment, but may encourage moisture-loving plants that exclude drought resistant species. When the water supply is terminated, moisture-loving plants become water stressed. The addition of fines (<2 mm) to waste rock would serve to alleviate these water retention problems, provided that over-irrigation or heavy rain does not wash out the fines from the voids. Alternatively, mulches which tend to mat and/or bind may be added to waste spoil because they reduce evaporation and retain water.

Desiccation in vegetation due to low moisture retention, particularly in sand-size tailings, is common in dry climates. In such cases, the use of drought resistant plants or irrigation is required. As with rock spoil, any moisture-loving plants cannot survive without supplemental water. Surface ridging to provide microcatchment depressions in tailings impoundments may help to retain available moisture, or alternatively, mulches, soil and overburden laid on the surface or mixed into the tailings material have been known to improve moisture retention in dry climates.

Green manures may also improve the water-hoi ding capacity of tailings. Some companies in recognizing the pitfalls of irrigation in dry climates, prefer to irrigate solely to establish an initial ground cover; then, in the following season(s), the vegetation is plowed-in. However, the use of green manures is not always successful, because some reclamationists have observed moisture capacity improvements that were less than predicted. This occurred because the decomposition of the plowed-in plant residues was slower than that of the neighbouring undisturbed soils. Reduction in the rate of breakdown has been attributed to the absence of microbial decomposition.

Water retention problems may be less severe in tailings that contain a higher proportion of silt and clay sized particles, and consequently a more evenly distributed particle size. However, water retention is often not uniform over the pond surface, an unevenness which results from the segregation of similar sized particles into horizontal layers. During the deposition of the spoil, coarse particles settle near the inflow while the finer sizes are carried farther into the depressed areas of the pond. Planning of irrigation systems and species selection may be chaotic due to variability in the impoundment area. Deep cultivation of the surface (20-50 cm) may be required to establish homogeneity and thus make reclamation prescriptions simpler.

DRAINAGE

Desiccation of vegetation in tailings spoil can be made worse by the drainage characteristics of the impoundment area, based on the fact that tailings are usually well drained. Rainfall and irrigation water are rapidly removed from the surface as a result of the tailings' generally coarse texture and geographical setting in the design of the disposal area. Tailings ponds are often located in low areas and are gradually built and dammed at their open ends. Impoundment structures 20 metres high are not uncommon. The effect of a deep permeable material and the absence of a hydrologic barrier such as bedrock produces low water tables in the pond. The combination of a permeable material, the elevated position of the tailings surface and the low water table causes rapid drainage in tailings spoil.

FERTILITY

Waste rock and tailings are generally considered to have a low native fertility, because the basic nutrients required by plants are either negligible or absent. The deficiency of these important elements is attributable to the absence of organic matter, which plays a key role in the recycling of nutrients. The needed elements can be released into the rooting zone in a form available to plants only during the accumulation and decomposition of organic residues.

Development of a fertile system in mine wastes is retarded by the inability of the material to retain nutrients. The matrix of spoil generally lacks the clay size particles and organic substances, which provide charged surfaces that attract and bond nutrients. Fertilizers and/or the use of nitrogen fixing plants and green manures are commonly employed to alleviate low fertility in waste rock.

Research has been conducted on the use of native species to increase fertility. Ziemkiewicz (1979) studied the recycling of nutrients on coal wastes and found that native species possess a root-based cycle that returns a high proportion of the nutrients to the system below ground. Agronomic species on the coal wastes recycled 50 percent of their nutrients through their roots and 50 percent through detritus on the surface. The detritus system is less efficient and therefore retards fertility development.

SOIL TEMPERATURE

In some circumstances surface temperatures of spoil discourage seedling establishment. Unprotected seedlings are often scorched by excessive temperatures, a phenomenon common on black spoil such as coal wastes where the dark colours absorb heat. Temperatures as high as 70°C have been recorded at the air-spoil interface of coal wastes (Harrison, 1974). Surface configurations of rock waste influence soil temperatures. An uneven surface provides protection for plants during extreme heat and cold, including frost; for the level surfaces of tailings, mulching or ridging the upper 5 to 10 cm may partially control temperature and provide a favourable microenvironment for young plants.

SURFACE CRUST FORMATION

This phenomenon is specific to tailings ponds. Cracking and crusting are considered to be the result of wetting and drying cycles and the extremes of temperature. Such crusts may prevent the emergence and growth of seedlings and interfere with water movement down to the rooting zone. Cultivation can solve the crusting problem.

HEAVY METAL TOXICITY

A major pollution concern with mine spoil is the presence of heavy metals in toxic concentrations. Heavy metals can leach into the groundwater, thereby contaminating aquatic ecosystems and the drinking water supplies downstream.

Terrestrial wildlife habitats may also be polluted by toxic metals in spoil or in soils adjacent to mine sites. Vegetation growing on the materials can become contaminated through assimulation, converting them to damaging or lethal food for browsing animals.

Heavy metals can interfere with healthy maturity and growth of plants. Research by Berg and Vogel (1968), using greenhouse legumes, investigated heavy metal toxicities in acid mine spoil. While attempting to set up a visual index of metal toxicities, they found that excess soluble manganese and aluminum retarded normal plant development. Studies on the toxic effects of particular metals are complicated by the many chemical interactions which can occur. Results are dependent on the proportions of interacting heavy metals and the various plant species.

Metals frequently encountered in mine waste include zinc, copper, iron, lead, nickel, and molybdenum (Lavkulich et jil_., 1975-1977; Como, 1978; CANMET Pit Slope Manual, 1977). Incidences of more exotic elements such as arsenic, cobalt and mercury are also mentioned periodically in the literature (Mcllveen, 1978).

Gaseous toxins have also been documented. Sulphur dioxide and fluorides are hazardous to perimeter vegetation and soils; and trees, shrubs, grasses, etc. are singed by sulphur dioxide burns.

Management of toxic metal concentrations in mine spoil often includes liming. Liming renders most metals insoluble by raising their pH. Mulches have also been observed to raise the pH of a spoil sample and thus reduce its metal toxicity (Berg and Vogel, 1973). Organic matter is important because it can tie up metals and reduce metal concentration in spoil. The inclusion of metal tolerant plants in the reclamation program offers a feasible solution to these kinds of problems. Also, burial of contaminated spoil has been tried in an attempt to isolate toxic elements from the ecosystem.

PAN FORMATION IN MATERIALS

Tailings high in iron sulphides (pyrite and/or pyrrohotite) are associated with the formation of irreversible hard pans caused by the oxidation of iron sulphides. The resulting iron oxides complex tightly and solidly.

Growth of the pans occurs at the surface and at irregular intervals of depth, spacing and thickness where crevices expose underlying reduced sulphides to oxygen. In the consolidated state, bulk densities of the pans are high resulting in insufficient pore volume for the gaseous exchanges required by plants, and for root and water penetration.

Hydrology of the pond is also disrupted by the indurated horizons as evidenced by impediments to water vertical and lateral movement which results in broken and irregular flow patterns. Pan destruction by standard cultivation equipment has proven to be futile. One possible solution may be to cover them with soil or overburden.

SALINITY

Many mining companies have to take steps to overcome salt accumulations in fine textured tailings spoil, particularly in dry climates. Water movement is too slow to carry salts deep enough into the spoil before evaporation raises and concentrates them near the surface. The problem can be reduced by controlled sprinkler irrigation. If water is applied at a rate equal to the hydraulic conductivity of the material to be leached, salts can be moved deep into the profile beyond the range of high evaporation rates.

Salt tolerant species such as Bermuda grass and Western wheat grass may also be a practical means of vegetating saline spoil (U.S. Salinity Laboratory Staff, 1954). Extreme leaching or recourse to salt tolerant species may not be feasible in all cases, however. The formation of impermeable crusts on iron sulphide tailings spoil may nullify the application of these ameliorative techniques. The ferrugenous crusts prevent root penetration and vertical movement of water, and the salt concentration is extreme - Gardiner (1975) noticed that salt crystals extensively coat the surface of the spoil pond. Burying the spoil may once again be the best solution in this situation.

ACIDITY

Acid generating spoils have created difficult reclamation problems, particularly those related to plant establishment and the overcoming of heavy metal toxicities. Documented research has been undertaken mainly using acid coal wastes. The coal deposits in Kentucky, Pennsylvania, and Montana are high in sulphides. Pyrite is the dominant acid producer because the sulphur in pyrite is oxidized to sulphuric acid. Extreme acid production is also common in iron sulphide tailings. Some research studies have attempted to deter the oxidation of acid spoil to prevent the initial production of acid. Techniques such as flooding acid spoil and sealing it off with clay have been considered (Craze, 1977). Experiments have also been conducted to monitor factors which affect oxygen movement in spoil (Pionke and Rogowski, 1979). Kuja and Hutchinson (1979) approached the acid problem by examining unusual species of plants flourishing in low pH environments in the Smoking Hills of Cape Bathurst, N.W.T. They are hoping that these acid-resistant species can be used in reclamation programs on acid wastes.

Liming has been the conventional treatment for acidic spoil. However, liming is impractical on spoils which continually produce acids (Duncan and Wai den, 1975).

Spoil is often buried in order to isolate the material from the environment. Some states in the U.S. exercise strict regulations to control the placement of acid producing wastes; for example, acid spoil must be buried under at least one metre of soil or overburden. However, covering a high acid-generating potential spoil with soil or overburden may result in contamination of the covering medium as acids migrate upward. A barrier of plastic or gravel could be used to separate acidic tailings spoil from the soil or overburden. Rock dump material from the mine site has been found to be a successful gravel barrier (Ames, 198U).

Table 1 summarizes the physical and chemical characteristics of waste rock and tailings deposited at mine sites. They are factors detrimental to successful vegetative reclamation and they must be considered in reclamation planning.

SAMPLING

This section outlines some strategies used in inspecting and sampling a site. They are not meant to be hard and fast rules, but they will serve as guidelines. Since mine waste areas vary in size, construction, configuration, and material, the reclamationist should make an on-site inspection. The spoil site should be traversed while looking for variations in material texture, colour, bearing strength differences and other factors that are important to plant growth. One common practice is to draw a small map of the disposal area indicating slopes, aspect and streams.

The heterogeneity of the tailings and spoil should be taken into account when sampling. Depressed areas of tailings ponds should be

Table 1

FACTORS AFFECTING VEGETATION ESTABLISHMENT IN MINE SPOILS

Waste Rock	Tailings
- 80% coarse fragments (gravels, cobbles, boulders)	- generally sandy texture (100% ~ 2 m)
- sandy texture (~ 2 mm)	- well drained
- rapidly drained	- unstable (to wind and water erosion)
- stable (to winds and water erosion)	- crust formation and cracking
- low organic matter	- hardpan formation
- low nutrient holding capacity	- differential layering
- low water holding capacity	- low organic matter
- low native fertility	- low nutrient holding capacity
	- low water holding capacity
	- low native fertility
	- heavy metal toxicites
	- acidity
	- salinity
	- toxic gases

sampled as well as the perimeter of the impoundment area. As noted previously, fines generally settle in low sections while coarser particles collect near the inflow of the tailings slurry. Ten sampling sites per hectare is recommended for spoil that is homogeneous (CANMET Pit Slope Manual, 1975). A standard grid pattern for site location can be used on uniform waste materials.

Once the sampling sites have been located, pits at least one metre deep should be dug. The depth requirement is based on the rooting depth of many plants, and is important in assessing potential water retention and drainage capabilities. It should be remembered that with cereals such as oats and wheat, root systems may penetrate to a depth of 1.5 to 2 metres; while alfalfa and other drought resistant plants, may sink their roots up to 5 metres.

Where vertical differences occur in the pit being sampled, the samples obtained for analysis should weigh 200 to 300 grams each (CANMET Pit Slope Manual, 1975). Field notes should include the locations of hard pans and impermeable layers, and describe variations of particle sizes and colours. The latter are significant because they indicate mineralogical and/or chemical changes in the spoil material.

ANALYSIS

The collected field samples should be analyzed to assess the potential of mine spoil for plant establishment. A list of tests as guides for the appraisal of spoils is given, and supplementary information is added where it is felt to be necessary. See also cautionary statement in the "Use of Standard Analysis on Mine Spoil" - the next chapter. Reference should be made to the CANMET Pit Slope Manual (1975) in order to compare results with the case histories of other mine waste analyses.

PHYSICAL ANALYSIS

Particle Size

By this method the fraction smaller than 2 mm is separated into the sand, silt and clay portions by weight. The analysis will provide data related to the stability and water retention properties of the spoil.

Water Retention

Water retention curves should be drawn. Points on the curve indicate the water storage capacity of the spoil, thus giving an estimate of the material's ability to store water to meet plant needs. Figure 1 presents the water retention measurements for three different horizons in the Endako (Central British Columbia) tailings. The water retention curve for an average loam soil has been included for comparison. The 96-100 cm layer of the Endako spoil has a higher water content than the average loam soil. The 96-100 cm horizon is dominant!/ silt and clay sized particles; whereas, the particle content of a loam is roughly 17% clay, 38% silt, and 45X sand. Because of the greater proportion of fine particles, in the Endako horizon, it has a greater moisture retention.

The Endako curves at 0-4 cm and 25.5-59 cm indicate the sandy nature of these horizons. The abrupt decline in the moisture contents at less than 1 bar is due to the rapid drainage caused by the high percentage of large pores. The low moisture content in the 3 to 15 bar range, represents the range at which water is available to plants.

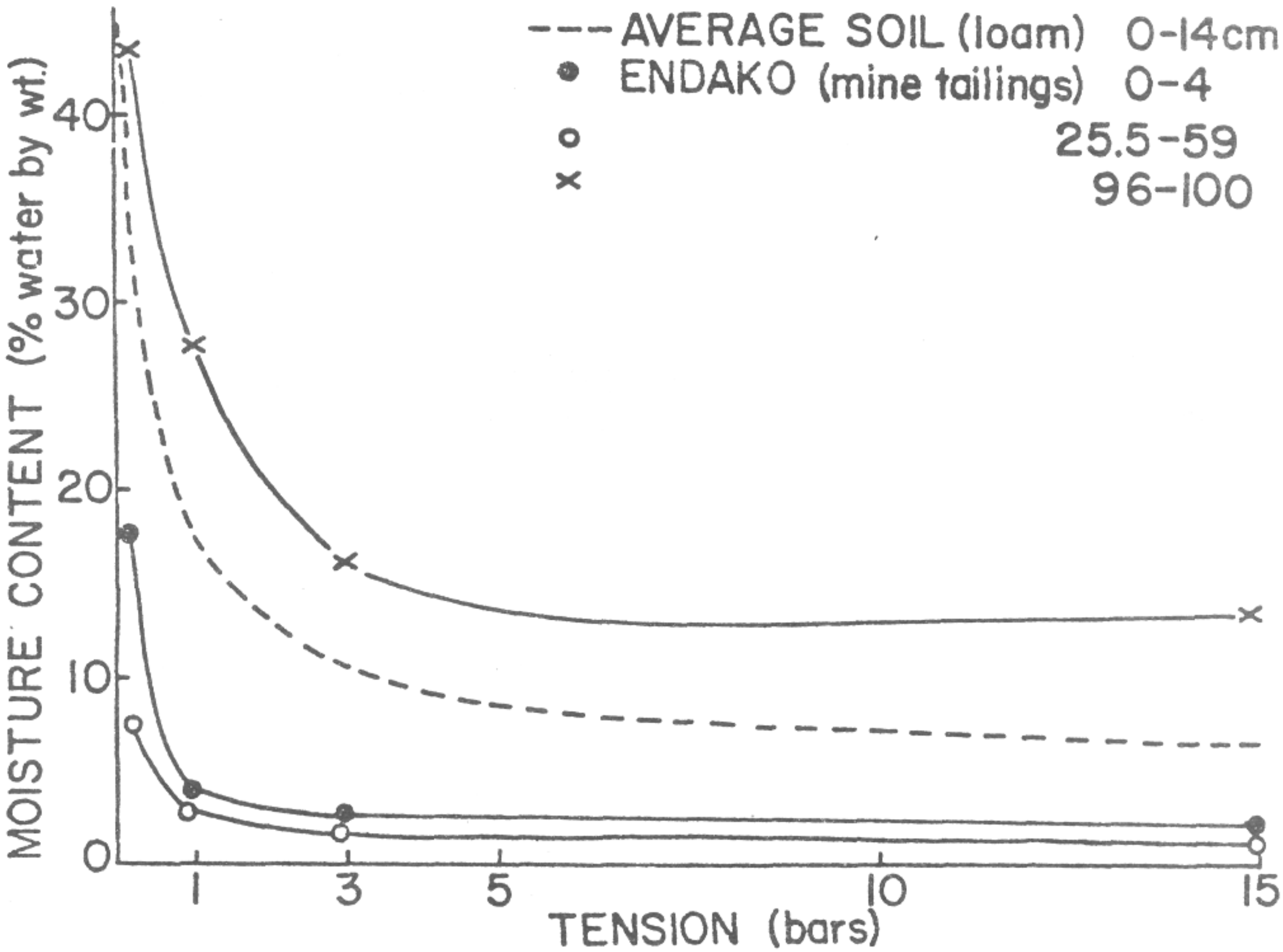
It is interesting to note that the Endako tailings material was not uniform throughout the sample pit, as evident in the three different curves used to represent three horizons. If the spoil had been uniform, all three curves would be superimposed.

Particle Density

The value of the particle density of the less than 2 mm size fraction

FIGURE 1

WATER RETENTION CURVES[c]



[c]From: Tailings Research, Selected Mines, British Columbia 1976-1977. (Lavkulich et al., 1977).

is important during particle size analysis because it enables calculation of the spoil porosity.

Bulk Density

The particle density included in the porosity evaluation, when combined with the bulk density, can be used to determine the degree of compaction or cementation in the spoil (i.e. porosity).

Bulk density measurements correlated with particle size analysis indicates the proportion of coarse fragments in the volume of rock dump spoil. This test can be performed on-site.

CHEMICAL ANALYSIS

Available Nitrogen, Phosphorus and Potassium - These primary nutrients should be determined by chemical analysis to assess fertility.

Soil Reaction - pH - This can be done in the field. Most plants prefer a range from about 5 to 7.

Salinity - Electrical conductivity values greater than 4 mmhos/cm are deleterious to most plants.

Extractable or Available Metals - The elements include iron, nickel, lead, cobalt, arsenic, cadmium and molybdenum. Excessive amounts of these metals may be toxic to plants and animals.

Cation Exchange Capacity - The test for cation exchange capacity is used to estimate a material's nutrient holding capacity.

Exchangeable Cations - The distribution of calcium, magnesium and potassium (nutrients necessary for plants) is ascertained in this analysis. These elements may interfere with one another or with other nutrients in plant uptake if they are present at certain proportions.

Soluble Salts - Data on the species and amounts of soluble salts present in a soil or spoil material are useful in preoicting their effects on plant health and growth.

Sulphur - The sulphur test is important in predicting the acid producing potential of spoil. This test requires separation of the sulphide from the sulphate form of sulphur.

USE OF STANDARD ANALYSIS ON MINE SPOIL

The previously outlined standard tests were developed for the analysis of soil material (Black et al., 1965). Caution should be used when adopting these techniques to mine spoil. Improper use or failure to make some necessary adjustments during the tests, will lead to erroneous results and, thus, perhaps invalidate any predictions. A few examples follow.

PARTICLE SIZE ANALYSIS OF MINE SPOIL

Particle size analysis illustrates the need to make adjustments in analytical techniques.

Particle size analysis is based on Stokes Law:

$$v = \frac{d^2 g (\rho_p - \rho_i)}{18 \eta}$$

where v = velocity

d = diameter of particle

g = gravity

ρp = particle density

ρ1 = density of liquid

η = viscosity of liquid

The proportion by weight of sand, silt and clay can be determined for a sample. The formula is based on the rate of descent of a particle of average particle density through *a* solution (water) of particular viscosity. This analysis must be modified when estimating the particle sizes of mine spoil, in order to compensate for the differences in particle density of certain mine wastes. For example, the iron tailings (Sullivan Mine, Kimberley, B.C.) have a particle density of 3.9 compared to the average soil particle density taken as 2.65. Failure to modify the standard method of this test, may result in a particle size analysis which gives a too high sand, and perhaps silt size fraction. The reason for the discrepancy is that the heavier but smaller particles will fall as rapidly as a sand size particle of average soil particle density.

In the case of coal spoil, fine particles float on water, consequently, new methods of particle size distribution need to be developed. One approach could involve the use of a less viscous solution so that the coal particles will sink. Kerosene has been suggested; however, if this or any other solution is used, the viscosity of the new medium will have to be incorporated into the Stokes Law formula.

ORGANIC MATTER IN COAL

The carbon content method of estimating the organic material in coal needs to be adjusted. The Leco method burns off all the carbon and ultimately yields a measure of "total carbon". The Walkley Black method is based on measurements of active or fresh organic matter as opposed to charcoal. However, this latter method has not been researched, and it is not known if the acids in the Walkley Black method break down the edges of the coal grains. Perhaps a combination of the two carbon methods may improve the technique of estimating organic matter in coal.

FERTILIZATION REQUIREMENTS

The relationship between crop production and fertilization has been correlated in agricultural soils. Similar trials are needed for mine spoil. Plant growth response to fertilization in agricultural soils is determined by phosphorus and potassium fixation as well as many other factors. Methods of testing phosphorus and potassium fixation in mine wastes should be established, supplemented by field trials and greenhouse experiments to measure crop response. Some related work has been undertaken (Como et al., 1978; Gardiner, 1978).

REPRESENTATIVE BRITISH COLUMBIA MINE SPOILS

Tables 2 and 3 identify some of the physical and chemical characteristics of mine spoil from four British Columbia mines. Data for an average soil (loam) is included for comparison.

The Kaiser (Sparwood, B.C.) mine provides an example of coal spoil. The Sullivan (Kimberley, B.C.) siliceous-iron tailings contains iron sulphides, and is therefore an example possessing a high particle density, high salt content and a potential for acid production. Lornex (Highland Valley, B.C.) and Similkameen (Princeton, B.C.) are examples of "average" mine wastes.

PHYSICAL CHARACTERISTICS (TABLE 2)

Particle size analysis for the Kaiser (Sparwood) mine tailings is incomplete, due to the lack of information on silt and clay size fractions. Perhaps this is indicative of the difficulty in particle sizing coal spoil.

Variation in particle density due to differences in mineralogy of the four spoils is evident.

Table 2

PHYSICAL CHARACTERISTICS OF REPRESENTATIVE B.C. MINE WASTE MATERIALS*

Sample	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	Texture	Fine < 2 mm (%)	Coarse Fragment > 2 mm (%)	Particle Density (gm/cm^3)	Bulk Density (gm/cm^3)	Total Porosity (%)	Field Capacity Water Content (cm/cm)	E.C. (mmhos /cm)
Average Soil (loam)	0-14	17	38	45	loam	90	10	2.65	1.33	46	.33	
Kaiser Tailings	0-26	—— 47 ——		53	-	100	-	1.37	-	-	-	.81
Sullivan Si-Fe Tailings	70+	2	31	67	sandy loam	100	-	3.34	1.86	44	.19	19.2
Lornex Tailings	78-98.5	8	44	48	loam	100	-	2.57	1.12	56	.37	2.0
Similkameen Waste Rock Dump		13	24	63	sandy loam	21	79	2.77	1.58	36	.11	

*Mine waste data from Lavkulich <u>et al</u>., 1977 and Lavkulich <u>et al</u>., 1975. Soil data from Brady, 1974.

Table 3

CHEMICAL CHARACTERISTICS OF REPRESENTATIVE B.C. MINE WASTE MATERIALS*

Sample	Depth (cm)	pH (.01 M $CaCl_2$)	N (%)	Available P (ppm)	% OM (LECO)	C.E.C. (me/100g)	Exchangeable Cations Ca^{++}	Mg^{+} (me/100g)	K^{+}	% S
Average Soil (loam)	0-14	6.5	.25		4	14	17.6	8.0	17.4	.10
Kaiser Tailings	2-26	5.7	.35	7.0	100	2.8	5.5	.15	.13	.16
Sullivan Si-Fe Tailings	70+	4.0	.006	1.2	11.2	2.8	18.2	2.0	.14	7.39
Lornex Tailings	78-98.5	8.3	.006	1.1	.46	4.3	17.5	.35	.19	.02
Similkameen Waste Rock Dump		7.3	.008		.61	18.3	26.2	5.2	.33	-

*Mine waste data from Lavkulich et al., 1977 and Lavkulich et al., 1975. Soil data from Brady, 1974.

Under the table column heading, "coarse fragment", it should be noted that *79%* of the Similkameen waste rock spoil comprises cobbles and gravels.

Salt production through iron sulphide oxidation in the Sullivan siliceous-iron tailings is extreme (E.G. = 19.2 mmhos/cm), compared to an average sail (loam) and the other listed spoil materials.

CHEMICAL CHARACTERISTICS (TABLE 3)

The organic matter content of 100% for the Kaiser wastes material emphasizes the need to develop new techniques for measuring organic matter in coal spoil.

All the examples in this table, except the Kaiser coal spoil, have insufficient concentrations of phosphorus and nitrogen compared to an average soil (loam). In addition, cation exchange capacities are below average for these types of spoils.

CONCLUSION

The characteristics of mine spoil materials are variable and site specific. Assessment of the wastes prior to the establishment of vegetation necessitates combining information about the environmental setting of the disposal site and the physical and chemical properties of the spoil. Most mine waste materials are infertile, lack organic matter, and have poor water retention and nutrient holding capacities.

Complete assessments of collected samples must include thorough sampling programs followed by appropriate chemical and physical analysis. It is evident that further research into the development of new analytical techniques as "tools" for assessing mine wastes is required.

Finally, the reclamationist must recognize that some spoils exhibit unusual characteristics and, therefore, must be aware of the potential problems and how to overcome them.

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DISCUSSION RELATED TO S.E. AMES' PAPER

Si Brown - Acres Consulting Services Ltd.: You mentioned that most of the tailings have a high clay fraction.

Answer: No. A low clay fraction.

Si Brown: (Distorted recording. The question related to the existence of relatively high clay fractions in tailings.)

Answer: The clays are very important in soils. Clay particles are very small and their surfaces are reactive. They have charges that help to retain cations because the general surface charge of clays is negative. Because clay particles are small, the spoil has smaller pores, and the particles hold the nutrients and water more effectively. Sandy material is very coarse, so the nutrients generally don't adhere to the sand surfaces.

Questioner Unidentified: (Distorted recording. The question related to soil aeration as it pertains to the generally sandy structure of tailings.)

Answer: Tailings are generally on the sandy side, so one of the main problems with tailings is that they don't have very much structure. They don't have a buildup of organic matter, and the sandy grains haven't been weathered, consequently, the minerals important to plants aren't weathered out. As a result, although the particle size might not be too much of a disadvantage, the tailings are usually lacking in nutrients.

Niel Duncan - Energy Resource Conservation Board, Alberta: One of the problems with tailings is that perhaps only twenty percent is coal, and most of it is clay. Flocculant is added to try to settle the clay and some coal particles. Does this flocculant cause any problems with reclamation? Is there a flocculant which would respond better to reclamation than others?

Answer: I don't know much about the use of flocculants in coal. I think they might be a positive help because flocculants would promote structure and stability. If you flocculated tailings, they would have a greater potential structure. It depends, too, upon the chemical nature of the flocculant. If the flocculant is chemically adverse, then it wouldn't be advisable to use it. Adding organic matter would be a better approach. Although not usually available at a mine site, organic material could improve structure, help to retain nutrients, and enhance moisture holding capacity. Flocculants might help if the flocculating agent is used to flocculate the coal particles in coal tailings.

Niel Duncan: They try to coagulate the clay in larger sinks so that you have flocculant in the decant.

Answer: I understand.

Niel Duncan: I'm wondering if the utlimate ability to reclaim is a consideration in the choice of a flocculant?

Answer: It should be. But again, you should look at the chemical nature of the flocculant.

Jim Robertson - Acres Consulting Services: A number of chemical flocculants do in fact act by tying up cation exchange sites, resulting in a loss of complimentation.

Answer: That's correct.

Jim Meir - Byron Creek Collieries, Alberta: The basic consideration with waste dumps is the particle size. Have any studies been done on the breakdown time or the weathering time of the rock?

Answer: Dr. Lavkulich has a very good slide of interest to you. It shows a person holding a piece of rock and crushing it in his fingers. If you have a very rotten rock, it will break down even faster. Sandstones tend to break down more slowly than fine textured sedimentary rock. I don't know if much research has been done on the breakdown of rock. If the rock breaks down easily, you get more fines, and it is easier to reclaim because the fines are there. The fines help to hold the moisture and act partially as a seed bed for the seedlings.

Ernest Portfors - Klohn Leonoff Consultants: The slides you had of tailings, generally showed very dry sites. Have you ever considered a situation where whole tailings are recycled, sand fractions taken out for dam construction, and the storage of slimes? The slimes probably have a high water content.

Answer: These kinds of situations can occur. When iron sulphide tailings are deposited in the pond, they are wet, and become reduced. Their surface oxidizes and seals off the exterior, so the moisture remains below the surface. These slags are unstable if they have this high moisture load capacity. Are you thinking of a wetter climate?

Ernest Portfors: No.

Answer: If you are handling that kind of material, it is different than a lot of tailings. Particle size analysis, moisture, and probably some engineering properties should be done because the material doesn't appear to be very stable.

Questioner Unidentified: In your slides you showed tailings. You then proposed to mix them to get d homogenous horizon. You also showed a slide of a gravel bank. Then you proposed to add the gravel. Are you suggesting that all of those activities can be performed by any specific piece of land?

Answer: No. You have to chose your method according to your problem. The reason I put the gravel on was that the tailings were high in acids and some metals, and if you put overburden directly on top of them, the overburden might have become contaminated. Five centimeters of gravel is a very shallow layer, and I think most heavy equipment can't handle less than a foot. A gravel layer acts as a boundary between the tailings, which are contaminants, and the overburden. But I don't think you need gravel in a rock dump.

Peter Bradley: Do you require less topsoil if you place a gravel bed down?

Answer: In the long run you would because if you added a hundred feet of topsoil directly on to those kinds of tailings, you would probably pass away before the topsoil ever became contaminated. I'm not being facetious, but the moral support of the gravel is that it prevents contamination. The depth of overburden on top of a gravel layer should be determined according to the climatic conditions of the area. The gravel below an overburden layer could change the water movement and, if it were too shallow, it could produce a very dry soil. The use of gravel between overburden and tailings may be a problem in areas such as the west coast of Vancouver Island where it is very wet. Heavy precipitation would result in a water table forming on top of the tailings, which would seep into the gravel, and eventually into the overburden. So, the depths of gravel and overburden are dependant upon the climate and chemical and physical properties of the overburden. The reason for the gravel is to create a barrier rather than to lessen the depth of overburden; however, I think it would help to decrease the overburden depth, though. It's difficult to predict how far the contamination would seep upward into the overburden, if it was placed directly on top of the tailings.

Bill Herman - Pacific Soils Analysis Inc.: Does the vegetation grow into the barrier and then into the material below it?

Answer: I don't think the study has been going on long enough to determine that. Bob Gardner would be able to give you more information on that, I think.

Bob Gardner - Cominco Ltd.: The study was initiated in October of 1978, so there has been only one growing season. There has been some indication of contamination moving up into soil without the barrier. The barrier consists of one foot of coarse rock, which is a rock about two inches in size. There is no indication of any contamination moving through the barrier, to this point in time. Vegetation has established itself satisfactorily on the overburden that was placed over the top of the barrier. Those are the results to date.

Bill Herman: Have there been any pits dug to see how deep the roots go? It's great that the barrier is serving to keep the material from moving up, but is it going to keep the roots from going down?

Bob Gardner: The entire soil volume above the barrier should be available for root development, but I doubt very much that the roots will go into the very coarse material of the barrier.

Bill Herman: Do you think it is reasonable to put a vinyl layer below the barrier, keeping in mind that vinyl is not biodegradable?

Bob Gardner: Yes, this is probably another alternative which could be considered.

Ernest Portfors (to S.E. Ames): In your suggested chemical analysis I noticed you didn't include uranium as a trace element.

Answer: Perhaps you are thinking of the Okanagan. Uranium would be something to look for, and you can add it to the bottom of your list. The particular elements I chose were only examples. For instance, arsenic and mercury could be a big problem in Ontario. In a lot of mines they don't have such problems, but if you suspect that your mine materials might contain a certain element, they can be checked. You have to make sure that vegetation and animals that eat the vegetation don't take it up.

C. Guarnachelli - Hardy Associates Ltd.: You were showing slides of a sort of mine, and indicated that the top surface displayed massive leaching while the tailings in the lower part were less acidic. Is that correct?

Answer: If you get an oxidized iron pad forming on the surface that closes off the material from the air, the underneath material will still be reduced. These pads can be quite strong and uniform, since they're not broken. Below a certain depth - I think less than a metre - you can still find reduced tailings, even though the top metre is oxidized.

Questioner Unidentified: I think you indicated that acidity increased as you went down below?

Answer: No, not in the Sullivan mine tailings.