TAILINGS REVEGETATION EXPERIENCE AT COMINCO LTD.

METAL MINES IN BRITISH COLUMBIA AND THE NORTHWEST TERRITORIES

COMINCO LTD.

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A fellow "reclamationist", with experience primarily in coal mine reclamation, recently commented that revegetation of tailings was less of a challenge than coal mine waste because tailings were relatively uniform and limited in area. In terms of certain factors, such as particle size and slope conditions, this may be true; however, as I hope to illustrate, tailings and tailings properties which influence plant life can be extremely variable, and not only among sites but within tailings deposits and with time. Cognizance of this fact is an important prerequisite to development of effective and efficient tailings revegetation programs and to the formulation of realistic guidelines, standards or regulations for tailings reclamation.

Information to illustrate variability in climate, mineralogy, chemical and physical characteristics, factors limiting plant growth and in cultural techniques for mitigating growth limiting factors and establishing vegetation on tailings from Cominco mining properties at Benson Lake, Pinchi Lake, Salmo, Kimberley, Pine Point and Yellowknife is presented.

1. Variability in Tailings Characteristics and Factors Limiting Plant Growth

Cominco mining properties are distributed among several biogeoclimatic zones in British Columbia and the Northwest Territories which represent a wide range of climatic conditions which influence plant growth (1, 2, 3) (Table 1). Economic and gangue minerals as well as size of the tailings deposit vary among mining properties (Table 2). At some properties, more than one type of tailings exists. In most disposal sites, partial segregation or redistribution of the various mineral and size fractions occurs during deposition resulting in a deposit with variable chemical and physical characteristics both over the surface and with depth. Variation in tailings characteristics can develop over time as result of modifications in mining, milling and disposal techniques and physical, chemical and biological reactions which occur within the tailings deposit following exposure to the atmosphere. The variation in tailings physical and chemical characteristics, evaluated to assess the suitability of tailings as growth media for plants, and more specifically, to identify potential growth limiting factors, is demonstrated (Tables 3, 4, 5). Available supplies of essential plant nutrients, tailing reaction, salt concentrations, total S, calcium carbonate equivalence, cation exchange capacity, particle size distribution, particle and bulk density and available moisture holding capacity vary both within and among tailings deposits and with time. The specific relationships between certain tailings physical and chemical characteristics as determined by analytical techniques and the potential for sustaining plant growth on tailings are not well defined. However, by comparing tailings values with those of soil with known plant growth potential, at least the nature, if not the degree of severity, of certain growth limiting factors can be identified.

Growth limiting factors associated with Cominco tailings include: deficiencies of one or more essential plant nutrients including N, P, K, Ca, Mg, B and possibly others; extremes of acidity and possibly alkalinity; excessive concentrations of salts and, in areas of limited precipitation, moisture stress (Table 5). Surface crusting, formation of hard, impermeable strata, movement of tailings by wind action and limited pore volume are growth limiting factors observed during site inspection. Usually more than one growth limiting factor has been identified within a specific tailings disposal area. Some care and caution must be exercised when sampling tailings and interpreting analytical data. Sampling sites should be representative of the range of conditions existing near the surface and with depth. Chemical and physical characteristics of recently deposited tailings containing reactive sulfide minerals can change substantially within a short time period and may continue to change for an indeterminate period to time. Under semi-arid conditions, salt concentrations near the surface of saline tailings deposits change during the growth season, generally increasing during periods of low precipitation and high evaporation.

2. Amelioration of Growth Limiting Factory Associated With Tailings

Improving tailings as a growth medium for plants is one of the first alternatives considered in developing a revegetation plan. Other alternatives include selection of plant species having tolerance of specific growth limiting factors and covering the tailings with a more suitable medium. Experimenting with alternative techniques for ameliorating chemical and physical conditions which severely limit plant growth on tailings is a major part of Cominco's reclamation program. However, in most situations encountered to date, selection of specially adapted plant species in combination with improvements to the growth medium, either by addition of amendments or by covering with a less toxic growth medium, may be required for effective and efficient reclamation.

2.1 Deficiencies of Essential Plant Nutrients

Plant growth on tailings is severely limited by deficiencies of one or more essential plant nutrients. All Cominco tailings evaluated to date have "plant available" nitrogen and phosphorus concentrations in the "very low" range (Table 3). Growth room investigations have confirmed that application of both nitrogen and phosphorus is essential for satisfactory growth of grass on tailings. "Available" potassium concentrations are generally in the "very low to low" range, however, eliminating potassium from a nutrient mix applied to tailings does not limit grass growth as severely as eliminating nitrogen or phosphorus. "Available" magnesium concentrations range from "very low" to "very high", however, as was observed with potassium, plant growth was not severely limited when magnesium was not added to tailings. Tailings deficient in magnesium are generally acid in reaction. Application of dolomite to improve tailings reaction will generally provide sufficient magnesium for plant growth.

In contrast to tailings, gypsum, a waste product of phosphoric acid manufacture, contains "very high" concentrations of phosphorus and satisfactory growth of grass and legume species was possible without addition of phosphorus. Grass growth on gypsum was, however, limited by deficiencies of nitrogen, potassium and magnesium. Alfalfa developed symptoms characteristic of boron deficiency when growing on gypsum limed with dolomite.

In addition to limiting growth of agricultural species, nutrient deficiencies restrict natural revegetation of non-toxic tailings deposits by native plant species. Application of a nutrient mix containing nitrogen, phosphorus and potassium to Pinchi Lake tailings initiated establishment of native herbaceous and woody plant species within the fertilized area. Similarly, native grass species have invaded fertilized experimental areas on slightly to moderately saline Con tailings in which seeded species did not establish or sustain growth. Growth of native species was observed on tailings supplied by nutrients released by mineralization of plant residues originating from vegetation growing adjacent to the tailings deposit and from decaying trees partially submerged within the tailings deposit.

Chemical fertilizers are a convenient source of plant nutrients for promoting growth on tailings. Growth room and field investigations have demonstrated that excellent plant growth can be established and sustained on non-toxic tailings by applying fertilizers. However, specific information for planning effective and efficient fertilizer use in tailings revegetation programs is limited. Improperly planned fertilizer programs can be costly in terms of wasteful use of an important limited resource, unnecessary applications and increased potential for surface and groundwater contamination. Fertilizer nitrogen can be lost as result of leaching, volatilization and denitrification. Careful consideration of nitrogen source, rate, time and method of application can minimize losses. Since tailings are generally coarse textured, with a very low cation exchange capacity, leaching of potassium and magnesium fertilizers from the root zone is possible. Phosphorus fertilizers react with mineral constituents of tailings forming reaction products of low water solubility. Following reversion, phosphorus is relatively immobile. Efficiency of phosphorus use is dependent, therefore, on solubility of the reaction product and position of the reaction product relative to absorbing roots. At the Land Reclamation short course, held at U.B.C. in March 1974, Dr. Beaton, Chief Agronomist at Cominco, presented an excellent discussion of soil-plant nutrient relationships together with general comments on more effective use of fertilizers in mine and mill waste revegetation programs (Table 4). Dr. Beaton's comments were based on many years of research and experience with fertilizer use in agriculture. To improve efficiency of fertilizer use in tailings revegetation programs, however, more research is required to improve fertilizer recommendations and application techniques.

In addition to improving the efficiency of fertilizer use, alternative sources of plant nutrients should be considered. Agricultural and municipal organic wastes, if conveniently situated, have potential as sources of plant nutrients, as well as for improving physical properties such as infiltration and retention of water. Care should be taken not to select organic residues with C:N ratios in excess of 20 to 25:1. Addition of substantial amounts of organic residues with wider C:N ratios would likely induce or aggravate nitrogen deficiency since available nitrogen in tailings would be used by micro-organisms responsible for organic matter breakdown.

Addition of plant nutrients can be reduced by establishing plant species with the capacity of symbiotic associations with soil micro-organisms capable of assimilating alternate or less available forms of a limiting plant nutrient. To illustrate, a significant deterioration in grass stands growing on tailings occurs when annual nitrogen applications are discontinued. This suggests a necessity for a maintenance nitrogen program for an, as yet, undetermined number of years to sustain satisfactory growth of grasses. Vegetation with a significant component of nitrogen-fixing species can, however, sustain satisfactory growth without maintenance nitrogen. The use of nitrogen-fixing plant species is a less costly alternative to a maintenance nitrogen program. Similarly, the availability of residual organic and inorganic forms of phosphorus may be increased by the selection of plant species capable of a symbiotic association with mycorrhizal organisms.

2.2 Acid Tailings Reaction

Normal growth of most plant species *is* severely limited on soil with a pH less than 5. Very few species of plants can survive on soil with a pH less than 4. Weathered tailings from Cominco's Benson Lake and Sullivan properties have a pH in the range of 2 to 3.5. Development of an extreme acid reaction in tailings is generally the result of chemical and biological oxidation of iron sulfide minerals, forms of which have been identified in all Cominco tailings materials. An extreme acid reaction can develop relatively soon after deposition and exposure to the atmosphere. For example, freshly deposited sulfide tailings have a neutral to slightly alkaline reaction, however, within a matter of a few months, extreme acidity may develop. The severity of the acid reaction is dependent, in part, on relative quantities of reactive iron sulfide minerals and minerals capable of neutralizing acid generated during oxidation, such as calcite and dolomite. The phytotoxic effects of extreme acidity can be alleviated by application of appropriate quantities of liming materials such as calcite, dolomite, hydrated lime and marl. However, analytical techniques normally used to estimate "lime requirement" of acid soils do not provide a realistic estimate of "lime requirement" of acid or potentially acid tailings (Table 6). Less convenient and relatively long term incubation and growth studies have demonstrated that the lime requirement of acid tailings is extremely high relative to that of acid soils and that it bears no relation to tailings pH. For example, quantities of $CaC0_3$ required to maintain a near neutral reaction throughout a combined growth and incubation period of one year, were 40, 97 and 125 mg/gm of Benson Lake tailings, Sullivan oxidized siliceous tailings and Sullivan oxidized iron tailings, respectively. Converted to tons per acre-foot, the values are equivalent to 92, 185 and 301 tons per acre, respectively. The amount of $CaC0_3$ required to maintain a near neutral reaction in fresh actively oxidizing siliceous tailings appears to be greater than that of oxidized siliceous tailings. Addition of 110 mg $CaCO_3$ per gm of fresh siliceous tailings was not sufficient to prevent tailings pH from dropping to 5.5 during a 54-week growth and incubation period. Without addition of $CaCO_3$ tailings pH decreased from 6.2 to 2.6 during the same period.

Oxidation of iron sulfide minerals can also result in increased salt concentrations, surface crusting and formation of hard impermeable strata at or near the tailings deposit surface. Revegetation of acid tailings, therefore, requires amelioration of other growth limiting factors which, in some instances, may be more difficult and costly to mitigate than the acid reaction. Sullivan iron tailings are a case in point. In addition to nutrient deficiencies and an extremely high lime requirement, iron tailings are strongly saline and have a hard, impermeable layer, up to 3" thick, either at or within nine inches of the surface. Effective incorporation of liming materials is essentially prevented by this adverse physical condition Tailings immediately below the impermeable layer are unoxidized, saturated and thixotropic, with insufficient bearing strength to support equipment. As an alternative to improving iron tailings as a growth medium, a less toxic industrial waste from Cominco's fertilizer operations at Kimberley is currently under evaluation.

Gypsum, referred to earlier in this presentation, is disposed of on land immediately adjacent the iron tailings disposal area and has potential as a relatively low cost material for covering iron tailings. Gypsum also has an extremely acid reaction, however, relative to iron and siliceous tailings, the lime requirement is low. Growth room studies have demonstrated that nitrogen-fixing legume species alfalfa, birdsfoot trefoil and alsike clover, will grow satisfactorily on gypsum limed with 15 mg of dolomitic limestone per gm of gypsum and fertilized with up to 155 ppm potassium and 4 ppm boron. In field investigations initiated in the spring of 1976, birdsfoot trefoil, rambler alfalfa, hard fescue, tall wheatgrass, western wheatgrass and crested wheat-grass established satisfactorily on gypsum limed with the equivalent of 6 ton/acre-foot of hydrated lime. Increasing hydrated lime rate to 18 ton/acre-foot did not improve seedling establishment and growth during the first year, however, gypsum pH was maintained at a higher level of 7.4 compared to 6.0 for the lower lime rate. Application of up to 22 ton/acre-foot of dolomitic limestone did not raise gypsum pH above 5 1. Only grass species established satisfactorily on gypsum limed with dolomite. In addition to low lime requirement, gypsum is non-saline, "very high" in available phosophorus and does not possess the undesirable physical characteristics described for iron tailings. Gypsum does, unfortunately, contain minor amounts of fluoride. Legume and grass forage grown on gypsum limed with hydrated lime and sampled at the end of one growing season contained 80 to 310 ppm fluoride-F. Plants and plant products usually range from less than 1 to 16 ppm fluoride-F (5). Fluoride contents considered safe for animal consumption range from 30 to 400 ppm fluoride-F and depend on the form of fluoride and the type of livestock (5, 6).

2.3 Saline Tailing

Plant growth on tailings can be severely limited by high concentrations of water soluble salts. Salt concentrations in soils and other growth media are measured and expressed in terms of the electrical conductivity of the soil solution. Conductivities are usually measured on saturation extracts and expressed in terms of millimhos per cm at 25°C. Plants vary in sensitivity to salts and once concentrations exceed 8 mmhos/cm, only salt tolerant species such as several wheatgrass species, tall fescue, Russian wild rye, birdsfoot trefoil and sweet clover grow satisfactorily. At conductivities above 16 mmhos/cm, only a few very tolerant plants grow satisfactorily.

In addition to saline acid tailings, high salt concentrations occur in alkaline tailings at the Con mine at Yellowknife. Conductivities for 43 surface tailings samples collected in July and August 1976 ranged from 2 to 54 mmhos/cm and averaged 25 mmhos/cm. Eighty-three percent, 67% and 47% of samples collected had conductivities greater than 8, 16 and 24 mmhos/cm, respectively. Conductivities decreased with depth averaging 6 mmhos/cm below the surface foot. Discharge of saline mine water to the tailings pond has contributed to development of a saline growth medium. Subsequent evaporation of tailings moisture results in upward migration and accumulation of salts in surface layers of tailings.

In growth room studies, saline tolerant tall wheatgrass grew satisfactorily on tailings with a conductivity of 16 mmhos/cm. Leaching with 1 cm water per cm depth of tailings or addition of 75 mg peat moss per gm of tailings was necessary for growth of creeping red fescue, a less salt tolerant grass specie, to yield more than 50% of creeping red fescue yield on a non-saline agricultural soil.

Field studies on slightly to moderately saline tailings have demonstrated the capability of several grass species, including creeping red fescue, meadow foxtail, red top, reed canarygrass and crested wheatgrass to sustain growth for at least three years under severe climatic stress in the Yellowknife area The highlight of the 1976 field program, however, was the successful establishment of four grasses and one legume on tailings which had proven too saline for seeding growth during two previous years Favourable early season precipitation is believed to have contributed to establishment of salt tolerant tall and western wheatgrasses, cold tolerant arctared creeping red fescue and foxtail barley and a salt tolerant legume, birdsfoot trefoil. Incorporation of up to 40 tons peat moss per acre-foot did not improve germination of first season growth. At the end of the first growing season tailings conductivities were similar for all peat rates and were in the order of 20 to 24 mmhos/cm. A large deposit of peat exists adjacent the tailings disposal area and has potential for use as a tailings amendment on an operational scale if field studies demonstrate that peat moss is effective for reducing salt concentrations.

In addition, a visit to the Salt River alkali flats, in Wood Buffalo National Park, was made in mid-July and seed from a number of saline tolerant native plant species was collected for growth room and field evaluation

2.4 Accumulation of Potentially Toxic Metals by Vegetation Growing on Tailings

Tailings generally contain metals in quantities greater than normally found in non-contaminated soil. Monitoring vegetation growing on tailings for potentially toxic metals cannot be overlooked when assessing the suitability of tailings as a growth medium or, for that matter, when assessing vegetation as an acceptable tailings reclamation alternative.

Vegetation grown on tailings at Cominco mining properties is being monitored for metals of concern to the specific area. As indicated earlier, elevated levels of fluoride accumulated in vegetation grown on gypsum. Vegetation grown on Con tailings contains arsenic in widely ranging concentrations from 10 ppm to 260 ppm. By comparison, vegetation grown on soil in the Yellowknife area ranged from 6 ppm to 44 ppm As. Grass forage grown on limed, actively oxidizing siliceous tailings in a growth room environment averaged 865 ppm Zn. Addition of the equivalent of 100 and 203 cons of sewage sludge per 1,000 tons of tailings increased Zn content of forage to 1,370 ppm and 1,814 ppm, respectively. In contrast, grass grown on limed siliceous tailings which has been exposed to atmospheric conditions for 30 or more years, averaged only 59 ppm Zn. Grass forage grown on an uncontaminated soil daring the same experiment contained 50 ppm Zn.

The mercury content of twenty-eight grass and legume forage samples grown on Pinchi Lake tailings during 1976 ranged from 0.1 ppm to 1.5 ppm and averaged 0.4 ppm. Mercury contents of terrestrial plants ranged from 10 to 200 ppb on normal soils and from 0.5 to 3.5 ppm in the vicinity of mercury deposits (7). Warren (8) reported mercury content of vegetation growing in the vicinity of mercury mineralization in *B.C.* ranging from 2.2 to 30 ppm.

The copper content of grass forage grown on Benson Lake tailings during the 1975 growing season ranged from 5 ppm to 40 ppm. Normal range suggested for plants is 3 ppm to 40 ppm Cu (5).

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Table 1: Geographic Location and Biogeoclimatic Zones of Several Cominco Mining Properties

Operation	Sullivan	Pinchi Lake	H. B.	Benson Lake	Con	Pine Point
Location	Kimberley	Ft. St. James	Salmo	Port McNeil	Yellowknife, N.W.T.	Pine Point, N.W.T.
Latitude: Longitude:	49°42'N 116° 2'W	54°38'N 124°26'W	49°8'N 117°10'W	50°21'N 127°14'W	62°27' 114°22'	60°49' 114°28'
Biogeoclimatic Zone	Interior Douglas Fir	Sub-Boreal Spruce	Interior Western Hemlock	Coastal Western Hemlock	Boreal Forest (Northwestern Transition)	Boreal Forest (Upper Mackenzie)
Climate	Montane	Sub-Boreal	Montane	Marine	Boreal	Boreal
Elevation (m)	1,020	720	884	152	152	205
Mean Annual Precipitation (mm)	378	470	762	3,200	254	330
May-September Precipitation (mm)	163	218	160	475	125	178
Extreme Minimum Temperature (°C)	-44	-49	-27	-13	-51	-52
Extreme Maximum Temperature (°C)	42	37	39	34	30	36
Mean Annual Length of Growing Season (days)	180-200	140-160	180-200	260-280	120-140	120-140

Table 2: Economic and Gangue Mineralogy and Areal Extent of Tailings

Operation	Economic Minerals	Gangue Minerals	Area (Acres)
Sullivan			
Iron Tailings	Pb, Zn, Ag	pyrrhotite, pyrite, galena sphalerite, quartz	594
Siliceous Tailings	Pb, Zn, Ag	pyrrhotite, pyrite, quartz, calcite, chlorite, mica, garnet, feldspar, tourmaline	276
KFO Gypsum	Phosphoric Acid	gypsum, phosphate rock, phosphate slimes, phosphoric acid, fluorosilicates	150
Pinchi Lake	Hg	calcite, dolomite, ankerite, quartz, sericite, graphite, cinnabar, hematite, pyrite, barite, stibnite, chalcopyrite	67
H. B.	Pb, Zn	calcite, dolomite, talc, tremolite, pyrrhotite, pyrite	61
Benson Lake	Cu, Fe	magnetite, andesite, garnet, pyrrhotite, calcite, epidote	7
Con	Au	quartz, ankerite, chlorite, carbonate, arsenopyrite, pyrite, stibnite, sphalerite	150
Pine Point	Pb, Zn	calcite, dolomite, pyrite, marcasite, galena, sphalerite, pyrrhotite	1,000

Table 3: Available Plant Nutrient Concentrations in Tailings

	Available Nutrients			
	NO_3=N	P	K	Mg
	ppm			
1. Sullivan Concentrator				
Iron Tailings-Unoxidized	<1	<2	<25-45	40-125
-Oxidized	<1	3-8	<25	<25-500+
Siliceous Tailings-Unoxid.	<1	2-3	<25-65	30-270
-Oxid.	<1	2-3	<25	500+
KFO Gypsum	<1-2	135	<25-65	<25
2. Pinchi Lake				
Tailings	<1-3	4-13	<25-100	45-500+
Tailings Slimes	<1	4	70	215
3. H.B.				
Tailings	1	2-9	<25	85-130
Tailings Slimes	1	5-14	<25	200-225
4. Benson Lake				
Tailings -1972	<1-3	<1-2	50-85	30-40
-1975	<1	2-6	<25	30-220
Tailings Slimes - 1972	<1	< 2	110	60
5. Con				
Con Tailings	<1	2-10	<25-80	50-500+
Negus Tailings	3-6	6-10	95-100	500+
6. Pine Point				
Tailings	<1	2	<25	150-275
Tailings Slimes	<1	2	<25	240

Table 4: Certain Chemical Properties of Tailings

	pH	Total S (%)	$CaCO_3$ Equiv. (%)	CEC (meq/100g)	ECe (mmhos/cm)
1. Sullivan Concentrator					
Iron Tailings-Unoxidized	5.8-6.1	34	25	1-3	2- 4
-Oxid.	2.0-2.5	7	0	1-6	2-36
Siliceous Tailings-Unoxid.	5.6-6.9	11	12	1-8	2- 5
-Oxid.	2.4-2.8	4	0	6	6-20
KFO Gypsum	3.5-5.0	12	0.5	1	2- 4
2. Pinchi Lake					
Tailings	8.0-8.6	0.2	43	1-3	1- 6
Tailings Slimes	8.1	0.1	52	3	1
3. H.B.					
Tailings	7.6-8.7	1.4	84	1	1- 3
Tailings Slimes	7.7-7.9	3	71	2	1- 3
4. Benson Lake					
Tailings-1972	6.4-7.3	4	6	2	2- 3
-1975	2.5-3.8	4	1	-	2-36
Tailings Slimes-1972	7.2	4	17	3	3
-1975	7.5	2	-	-	2
5. Con					
Con Tailings	7.6-8.3	0.6	21	-	4-54
Negus Tailings	7.7-8.3	0.8	24	-	2-45
6. Pine Point					
Tailings	7.6-7.9	10	25-68	-	3- 7
Tailings Slimes	7.3	-	-	-	4

Table 5: Physical Properties of Tailings

	Particle Size Sand	Particle Size Silt (%)	Particle Size Clay	Bulk Density (g/cm^3)	Particle Density (g/cm^3)	A.W.S.C. (%)
1. **Sullivan Concentrator**						
Iron Tailings-Unoxidized	33	64	3	2.4	4.3	16-20
-Oxidized	20-29	45-60	20-26	1.2	2.8	11-28
Siliceous Tailings-Unoxidized						
-Oxidized						
KFO Gypsum	-	-	-	1.0	2.2	29
2. **Pinchi Lake**						
Tailings	30-87	11-64	2-7	1.6	2.7	11
Tailings Slimes	0	81	19	1.0	2.7	-
3. **H.B.**						
Tailings	36-40	50-58	5-10	1.6	2.9	11
Tailings Slimes	0-1	87-88	11-12	1.2	2.9	24
4. **Benson Lake**						
Tailings	78-86	14-19	0-4	1.7	3.5	13
Tailings Slimes	47-58	38-49	4-5	1.6	3.4	35
5. **Con**						
Con Tailings	13	77	10	1.3	-	-

Table 6: Total S, $CaCO_3$ Equivalence and Lime Requirement of Selected Reactive Tailings Materials

	Initial pH	Total S (%)	$CaCO_3$ Equiv. (%)	Lime Requirement: $BaCl_2$-TEA (mg/g)	Lime Requirement: Incubation - Growth Tech. (mg/g)	Lime Requirement: Incubation - Growth Tech. (ton/ac.-ft.)	Final pH
Sullivan Concentrator							
Iron Tailings							
Oxidized	2.2	5.7	0	44	215	301	6.9
Unoxidized	5.8	36.0	25	2	n.a.	n.a.	n.a.
Siliceous Tailings							
Oxidized	2.4	2.5	0	25	97	185	6.9
Unoxidized	6.2	20.0	11		110+	268	5.5
Benson Lake							
Tailings	2.6	2.0	1	12	40	92	7.0