Reclamation of Abandoned Mine Spoils

in British Columbia, 1977-1978

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RECLAMATION OF ABANDONED MINE SPOILS IN BRITISH COLUMBIA

1977-78

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MINISTRY OF MINES AND PETROLEUM RESOURCES
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By: B.A. Como

L.M. Lavkulich

A.A. Bomke

J.M. Robbins

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B.A. Como

L.M. Lavkulich

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SUMMARY

The 1977-78 program consisted of two parts. The first part focused on the assessement of vegetation growth and soil forming processes taking place on abandoned mine spoils. The mines selected for this study were Coal Creek, Emerald, H.B., Hedley and Velvet. The first, Coal Creek, is an abandoned coal mine; the remainder are metal mines. In addition monitoring studies continued at Endako, Granby and Lornex. This was conducted to help verify some of the earlier findings.

The second phase of the program was a continuation of the weathering, microbiological oxidation and greenhouse studies initiated in 1976-77, as well as a study concerning P-fixation capacity of spoil materials.

The field studies on soil-forming processes and their effects demonstrated that organic matter (measured as organic-carbon) is accumulating in the surface layers of the mine spoil samples examined. Coal spoil seemed to respond most quickly to a build up of organic matter. This accumulation of organic matter helps build up the nutrient pool for sustaining a vegetative cover. Physical conditions for growth, particularly moisture availability were optimum at the Coal Creek location, but moisture stress was extreme on some of the metal mine spoils. Poor aeration, especially at Hedley is another growth limiting factor. Irrigation and/or fertilization and seeding in combination with deep ploughing would much improve the spoil as a growth medium.

In laboratory studies, a less obvious but still evident observation is that weathering has occurred in the samples examined, releasing nutrients. The beginning of the formation of clay minerals, notably vermiculite, supports this. In Coal Creek samples physical breakdown of the coarse faction is also occurring.

Phosphorus is the main limiting mineral nutrient in all spoil samples examined. An evaluation of the trace element content of spoil material and supported vegetation did not show any universal problem with toxicities. Low Cu:Mo ratios did occur. This could be a potential problem with ruminants feeding on the vegetation.

Section II presents weathering, microbiological, greenhouse and P-fixation studies. The weathering studies involve applying a technique of artificial weathering to spoil material with interest in prediction of long-term expectations in the field. The degree of weatherability of specific spoils as well as preferential removal of elements by leaching are discussed.

Microbiological studies discuss the ecology of iron and sulfur oxidizing bacteria in iron sulfide mine tailings and their fole in its oxidation. From the analysis completed it aopears that there is a relationship between kinds of organisms and the state of weathering of the tailings material. Increase in elemental sulfur content with a decrease in pH appears to be linked to microbial oxidation of iron sulfides.

Greenhouse studies concentrate on soil test evaluation, copper-molybdenum relationships and organic matter amendments concerning selected tailings materials. Comparison of soil tests on the various tailings are made and the best methods for each type are suggested. Cu:Mo ratios for selected tailings are found to be generally <2 which is considered potentially hazardous for ruminant consumption. Keeping N fertilizer rates at a moderate level decreases the concentration of Mo in plant tissue, with the result of raising the Cu:Mo ratio.

The effects on acid tailings of a variety of organic amendments show that short-term effects on plant growth are beneficial in all cases but that chicken manure decreases Fe and Cu concentrations in plant tissue. Sawdust was not found to be particularly effective.

Results of the P adsorption studies are only preliminary, for the method is only being developed. It was found, however, that the capacity of P-fixation (or adsorption) for a variety of spoil materials can be predicted over time. This allows more accurate fertilizer additions to be estimated so that excess P is not subject to leaching, and costs can be minimized.

1. INTRODUCTION

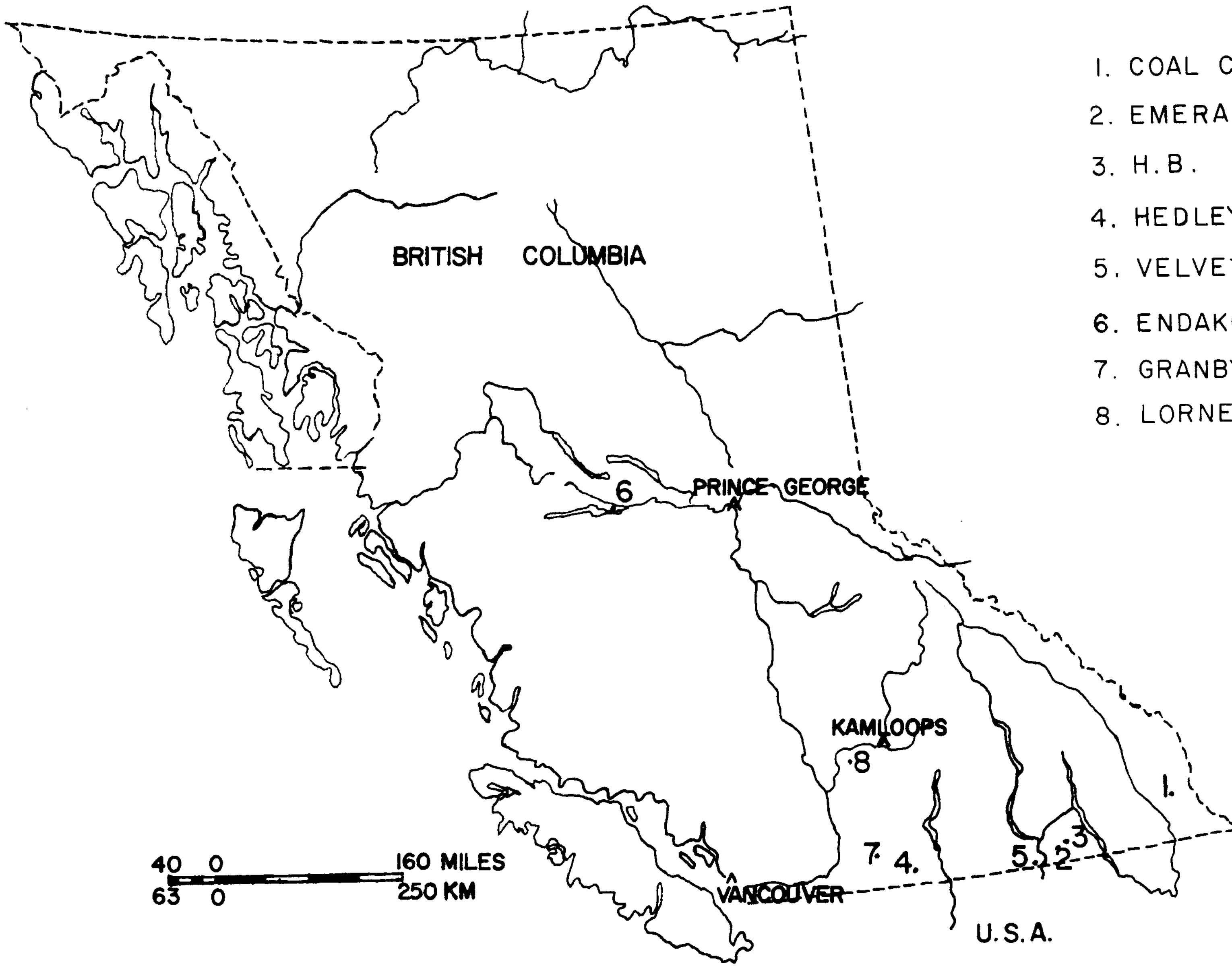
INTRODUCTION

This report is presented in two sections. The first section includes research conducted in the 1977-78 season. This involved assessment of revegetation and soil-forming processes occurring on old or inactive mine spoils. Included is qualitative and quantitative evaluation of vegetation presently established on spoil materials and general relationships existing between this vegetation and the chemical and physical characteristics of the spoils. Of prime interest is a better understanding of nutrient recycling and availability, toxicity and/or defficiency symptoms and organic matter accumulation related to formation of soils.

Five mine spoils were chosen as study sites. These were: Coal Creek, Emerald, H.B., Hedley and Velvet. These spoils represent a cross-section of types and ages of materials in a variety of biogeoclimatic zone settings. Three other mines were sampled for additional information on vegetation assessment. These were Endako, Granby, and Lornex.

The second section of this report includes a summary of studies initiated in 1976-77, but still in progress at the time of publication of the 1976-77 Tailings Research Report. The studies completed and summarized are: Soxhlet weathering of mine tailings, microbiological studies and greenhouse experiments concerning soil test evaluations. Further laboratory research on a few selected tailings is also presented dealing with P-fixation capacities.

FIGURE 1:1 : LOCATION OF STUDY SITES



1. COAL CREEK
2. EMERALD
3. H.B.
4. HEDLEY
5. VELVET
6. ENDAKO
7. GRANBY
8. LORNEX

- SECTION I -

2. DESCRIPTION OF STUDY SITES

DESCRIPTION OF STUDY SITES

1. General Description of Mines and Spoil Areas

A. COAL CREEK

In 1897, coal mining began at Coal Creek, in southeastern British Columbia. This was located 5 km up the valley of Coal Creek from the present townsite of Fernie (lat. 49° 03' N, long. 115° 03' W). The coal was mined, sorted and washed at the preparation plant in this location and was then removed via the company-owned railway. Good quality medium-volatile bituminous coking coal was processed. The coking ovens were in Fernie and the coke produced supplied many smelters in southern B.C. and the United States. Production occurred from 1910 to 1913. In 1942 Elk River Colliery was built just west of the previous Coal Creek Colliery in order to service the newer mines coming into operation. All operations ceased in 1958 as economic demand for coal decreased.

Coal Creek is physiographically part of the Fernie Coal Area. This is situated at the western edge of the Crowsnest Coal Basin, which is the coal-bearing portion of the Kootenay Formation. The coal beds at Coal Creek are located at the base of an elevated plateau at an elevation of about 940 m a.s.l. The creek is a tributary of the Elk River.

The climate of the area is cool and humid. Precipitation averages 108 cm annually with two thirds falling as rain. Temperatures range from an extreme minimum of -41.7°C to an extreme maximum of 36.1°C. The average frost-free period is 98 days: June 1st until September 7th.

Soils of the area are dominantly Dystric or Eutric Brunisols or Brunisolic Gray Luvisols. Where coal outcroppings are found, Dystric Brunisols are developing (L.Lacelle, personal communication, 1977).

The sampling sites were chosen on the basis of relief and vegetation cover (Appendix V). Much coal debris is found all along both banks of the creek as well as along the slopes of the narrow valley. Coal has been stockpiled in various locations near both the old and the new preparation plants. No areas are totally lacking of vegetation with the exception of steep-sided slopes and stockpiles where erosion is evident.

B. EMERALD

The Emerald mine is situated on Iron Mountain, only a short distance from the H.B. mine (lat. 49^{o} 06' N, long. 117^{o} 13' W). It began production in 1906 and was in operation sporadically until 1972. Originally lead and zinc ores were mined, but in 1942 it began production of tungsten, and the name was change in Invincible. The mine is located between Sheep and Lost Creeks at an elevation of 1340 m a.s.l. The tungsten mineralization is mainly scheelite disseminated in skarn. Ore zones are in flames originating in the granitic contacts, diminishing as they proceed into the altered argillite beds overlapping belonging to the Liab Group of Lower Cambrian Age.

Emerald lies in the same physiographic and climatic subdivisions as H.B. mine. The soils of the area are dominantly Podzols and Brunisols, formed under a mixed coniferous forest and grassland cover.

The surface of the inactive pond was totally dry this year whereas in the summer of 1976 there was standing water in the center. Vegetation cover is less than 10% and is composed to a large extent of alfalfa. The pattern of growth is similar to that of last year, being concentrated just outside of where the water had stood.

C. H.B.

H.B. is an underground mine located just south of Salmo in southeastern B.C.(lat. 49° 09' N, long. 117° 12' W). It extends north from Sheep Creek on Aspen Creek and south of Annie Rooney Creek at an elevation ranging from 762 m to 1672 m a.s.l. It was discovered in 1907, but production only began in 1955 with lead and zinc being the primary economic minerals.

H.B. is physiographically located in the Selkirks, which is a mountain range characterized by deep trough-like valley dissecting the mountains into several distinct groups. The very rugged and prominent peaks of the northern part of the Selkirks become more subdued in the Salmo area. Surficial geology is dominanted by the presence of much glacial overburden, for the region was heavily glaciated during the Pleistocene. Soils formed on the till and glacio-fluvial debris are dominantly Humo-Ferric Podzols and Orthic Dystric Brunisols (Surveys and Mapping Branch, 1973).

The orebody is contained within the dolomitized region of the Reeves limestone, in folds of a gently plunging syncline southward. Mineralization consists of sphalerite and pyrite with galena found in narrow bands and lenses in the dolomite.

Climatic conditions are typical of the southeastern interior. The frost-free period is only 71 days, with an extreme minimum temperature of -35.0^{o}C and an extreme maximum of 42.8^{o}C. Annual precipitation averages 63.0 cm, with approximately one third falling as snow.

The area sampled was a spill along the presently active tailings pond, at an elevation of about 700 m a.s.l. The tailings material is quite deep and has been deposited for a period of at least 4 years. There are intermittent layers of leaf litter throughout the profile, indicating a series of spills over time. The area is medium to well drained. As with Emerald, vegetation is concentrated leaving areas barren.

D. HEDLEY

Hedley townsite is located west of Keremeos, in south central B.C. (lat. 120^{o} 05' N, long. 49^{o} 21' W). It was originally a mining camp for the Nickel Plate and Hedley Mascot mining operations. The Nickel Plate mine (1904-1958) was for some time, the primary producer of lode gold in Canada. The Hedley Mascot mine was in operation from 1936 to 1949. Initially the Mascot mine tailings were sluiced directly into the Similkameen River. After sometime, however, they were impounded into a pond next to the river. These tailings are the location of one study area and are directly across the highway from Hedly townsite.

The Hedley Mascot was mined primarily for gold and to a lesser extent, silver, copper and arsenic. The orebody is of high-temperature replacement type with sulfides including arsenopyrite, chalcopyrite and pyrrhotite in a gangue of limestone silicates, or at their junction with porphyritic rocks.

The physiography of the area is diverse being on the boundary of the Thompson Plateau and the Okanagan Highland regions. The portion of the valley where Hedley is located is approsimately 1210 m wide and the valley bottom is 490 m a.s.l. The vally is bordered by steep-sloped mountains reaching elevations up to 1825 m a.s.l. Hedley is at the junction of 20 Mile Creek and the Similkameen River.

The climate of the area is mild, with low annual precipitation. Total yearly precipitation averages only 29.6 cm of which 21 cm falls as rain. Temperatures vary from an extreme minimum of -35.0^{o}C to an extreme maximum of 41.1^{o}C, with an annual mean of 7.9^{o}C. The frost-free period is from May 9th to October 9th, a total of 158 days. The growing season is about 200 days.

The Hedley area is considered to be non-agricultural. Soils are dominantly Eutric Brunisols formed on gravelly and stoney terraces along the valley floor (L.Lacelle, personal communication, 1977).

The pond itself is partially vegetated, particularly along the outside opposite the launder and towards the south. Grasses are dominant but herb, shrub, and tree species are also present. The pond is extremely well drained.

E. VELVET

The inactive Velvet mine is located 20 km west of Rossland B.C.

along the old Cascades Highway (lat. 49° 01' N, long. 117° 56'W). Operations commenced in the late 1800's and ran intermittently until 1962. Lode gold was the primary mineral extracted.

Physiographically, Velvet is situated in the Monashee Moutain Range. The mine itself is on the northwestern slopes of Mt. Sophia at an elevation of 1280 m. The tailings disposal area is on the valley floor near Big Sheep Creek at an elevation of 825 m.a.s.l.

The ore occurs in northerly trending replacement veins dipping steeply to the west and cutting altered volcanics. Mineralization includes copper and iron sulfides in a gangue of altered wall-rock and quartz.

The climate of the vicinity is typical of the southeast interior. Annual temperature extremes are -35.0°C and 42.8°C, with a mean of 7.8°C. Precipitation averages 63.0 cm annually, of which two thirds is rainfall. The frost-free period is from mid-May until late September, about 130 days.

Soils of the area are dominantly Orthic Dystric Brunisols formed on alluvial deposits (L.Lacelle, personal communication, 1977). The study area of the inactive tailings pond is bordered on one side by the road and on the other sides by a dam. Just outside the dam area is a slough. Vegetation is abundant in areas of the pond while totally lacking in others. Coniferous seedlings were occasionally found growing in the shade of larger cottonwoods. Drainage varied from good to poor.

2. Biogeoclimatic Zone Settings

The mines visited in the Salmo area represent the Western

Larch Subzone of the Interior Western Hemlock Zone described by Krajina (1965). Hedley mine is situated in the Ponderosa Pine-Bunchgrass Zone. Coal Creek and Velvet are both classified as being in the Interior Douglas Fir Zone.

3. Climate

Tables 2:1, 2:2 and 2:3 give data indicating climatic conditions for the 5 study sites. The information presented represents long-term averages monitored at permanent climatic stations nearest to all areas of interest. Differences in microtopography may have major effects on precipitation, temperature and frost-free periods and as a result, climate between the two may be variable.

Table 2:1 Selected Climatic Data-Precipitation

(Data from "Canadian Normals" 1941-1970, Environment Canada)

	*	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total	Elev-ation (m)
Coal Creek (Fernie)	Total	143.8	108.0	80.3	69.3	66.3	86.6	36.8	48.0	66.0	106.7	117.6	152.1	1081.5	1007
	Snow	99.6	58.7	39.4	19.1	1.5	0.0	0.0	0.0	0.3	8.6	48.5	93.2	368.9	
Emerald/H.B. (Waneta)	Total	79.2	53.8	44.7	32.8	57.2	64.3	32.0	34.0	34.0	53.1	64.8	80.3	630.2	670/1000
	Snow	61.0	33.5	13.2	1.0	0.0	0.0	0.0	0.0	0.0	0.3	20.3	49.8	179.1	(689)
Hedley	Total	27.9	16.8	13.2	21.6	31.5	37.1	29.0	29.2	18.8	18.0	21.3	28.2	292.6	538
	Snow	24.1	11.9	4.6	0.8	0.0	0.0	0.0	0.0	0.0	0.5	9.1	24.1	75.1	
Velvet (Rossland)	Total	108.0	73.2	66.0	53.6	76.7	84.8	37.8	45.7	43.7	77.7	94.0	111.0	872.2	731
	Snow	85.9	62.2	42.2	9.1	2.5	0.0	0.0	0.0	0.3	9.7	48.3	84.3	344.5	(981)

*Rainfall measured in mm, snowfall in cm. Rainfall equivalent is 1cm snow ≈ 1mm rain

Table 2:2: SELECTED CLIMATIC DATA-MEAN DAILY TEMPERATURE (°C)

(Data from "Canadian Normals" 1941-1970, Environment Canada)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Yearly
Coal Creek (Fernie)	-8.3	-4.6	-1.8	4.7	9.7	13.2	16.4	15.5	10.8	5.6	-1.0	-5.8	4.5
Emerald/H.B. (Waneta)	-4.7	-1.1	2.6	8.1	12.4	15.8	19.7	18.9	14.6	8.1	1.5	-2.3	7.8
Hedley	-5.2	-0.6	3.3	8.3	13.1	16.5	19.8	18.7	14.7	8.1	1.2	-2.7	7.9
Velvet (Rossland)	-6.0	-2.7	0.3	6.0	10.8	13.9	18.1	16.8	12.8	6.3	-0.6	-3.8	6.0

Table 2:3: Selected Climatic Data-Extreme Maximum and Minimum Temperatures (°C)

(Data from "Canadian Normals" 1941-1970, Emvironment Canada)

		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Yearly
Coal Creek (Fernie)	MAX	10.6	12.2	17.2	26.7	32.8	36.1	35.6	35.0	31.7	25.6	15.6	12.2	36.1
	MIN	-39.4	-40.0	-31.7	-20.0	-7.8	-2.2	0.0	-1.1	-18.3	-24.4	-32.2	-41.7	-41.7
Emerald/H.B. (Waneta)	MAX	10.6	16.7	24.4	32.2	36.7	40.0	42.8	40.6	37.2	32.2	15.1	13.3	42.8
	MIN	-31.7	-30.0	-17.8	-13.9	-3.9	-2.2	0.6	0.6	-6.7	-17.2	-17.8	-35.8	-35.0
Hedley	MAX	11.1	15.6	23.9	31.7	37.8	37.8	41.1	40.0	35.0	31.1	22.2	14.4	41.1
	MIN	-32.8	-32.2	-26.1	-10.0	-3.3	0.0	3.9	0.0	-5.0	-14.4	-23.3	-35.0	-35.0
Velvet (Rossland)	MAX	8.9	10.6	19.4	26.1	33.3	33.9	37.8	37.2	33.9	26.1	14.4	12.2	37.8
	MIN	-30.0	-27.8	-25.0	-16.7	-5.6	-1.1	1.1	1.7	-10.6	-17.2	-21.1	-26.1	-30.0

3. METHODS AND MATERIALS

METHODS AND MATERIALS

1. Field Methods

The choice of mine sites to be studied was based on the accessibility of the mine spoil, the quality and quantity of the vegetation presently established and on the degree of soil development observed. With the exception of Coal Creek, all sites chosen were tailings ponds or tailings spillage areas. Every spoil has been inactive for a period of at least 4 years and in some cases, for up to 30 or 40 years.

Spoils were sampled for indications of soil-forming processes evident in their characteristic, physical and chemical parameters. Vegetation was sampled to assess quality and quantity and to determine it's relationship to the soil-forming processes and nutrient recycling. All sampling locations are presented on the maps located in Appendix V.

A. Sampling of Spoils

At each of the 5 mine areas visited a "vegetated" and an "unvegetated" pit was dug. The location of the "vegetated" pit was chosen on the basis of the most established vegetative cover on the spoil. The "unvegetated" pit was located where there was the least vegetation present.

Pits were dug to a depth beyond rooting and a bulk sample of each major layer was sampled for laboratory analysis. For each layer sampled, a sub-sample was taken for a bulk density determination. Either the excavation or the core method of sampling was used, depending on the type of material being sampled (small corer used; D=2 cm). A general soils description was made for each pit, including Munsell colour-coding and hand texturing.

Photographs were taken of the sample area and background. These are for use as visual compliments to demonstrate the physical character of the sites as indicated in Appendix V.

B. <u>Sampling of Vegetation</u>

a. Identification of plant species present on the ponds was made. A 5 m area around each "vegetated" pit was staked out and species composition of this area was recorded.

Additionally, a number of plant species common to the tailings pond and the background areas were sampled for qualitative analysis. These plants were collected in paper bags and at least a 10 g dry weight equivalent was sampled. For tree and shrub species, only leaves and petioles were sampled. For herbs and grasses, the whole plant to the base was collected.

Plants were sampled randomly, from both within the 5 m area and otherwise. In the background, random plants were also sampled, but ususally from one side of the pond and far enough away as to prevent contamination from tailings material. Due to differing biogeoclimatic locations and/ or differences in species planted on individual tailings ponds, the same species were not always collected at all of the mine sites. Often only a few species were present on the spoil in quantities large enough to sample and these were not always found in the background area. This limited sampling alternatives.

b. At Endako, Granby and Lornex, only representative samples from the pond and background areas were taken. Endako samples were collected from the berm at the north end of tailings pond No.1. Granby samples were taken from the inner boundary of the northwest dam. The only vegetation subsisting at Lornex was on the research plots on the Emergency Pond.

2. Sample Preparation

The spoil materials were air dried immediately upon return from the field. Each sample was sieved and in cases where there was a >2 mm portion, samples were weighed and % coarse fraction was calculated. Roots were also removed in sieving.

Vegetation was washed and oven dried (80°C) immediately upon return from the field. The plants were then ground in a Wiley mill to <1 mm and stored in paper envelopes (no boron analysis conducted).

3. Laboratory Methods

Apart from bulk density, texture and color measured *in situ*, analyses of mine spoils and vegetation were conducted in the laboratory. Chemical analyses of mine spoils included: pH, total elemental analysis, avaialable nutrients, heavy metal release, cation exchange capacity, Acid Amonium Oxalate extractable Fe, Al, Si and Mn, phosphorus, sulphur, nitrogen and carbon. Physical analyses included: water retention, particle size analysis, particle density and porosity.

Analyses of vegetation included: total elemental analysis available nutrients, heavy metal release, phosphorus and nitrogen.

All routine chemical and physical analyses were conducted employing standard methods as outlined in Black (1965). Total elemental analysis is determined by the Buckley and Cranston method (1971). The following cations in solution for all the mine spoils and plant samples were determined using atomic absorption spectroscopy: Na, K, Ca, Mg, Fe, Mn, Al, Si, Cd, Cr, Co, Cu, Mo, Ni, Pb, Ti, Zn.

New and non-routine methods of analysis, such as are involved in Section II studies are described in their respective sections.

4. RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

1. Field Studies-Mine Spoils and Vegetation

The inactive mine spoils studied in this report are similar in nature to the wastes being presently created by active mining operations. The primary differences lay in the changes occurring over time, under the influences of biogeoclimatic factors. Some spoils have been inactive for 25 years, while others for only 5 years. Vegetation, to some degree, is present at all sites.

In some instances, formal revegetation procedures were apparent in the spoil, while natural invasion by native species was totally responsible for revegetation on others. The location of the spoils in differing biogeoclimatic zones as well as the variety of parent materials presupposes the variability of vegetation found between sites. Appendix V contains maps which indicate specific sampling sites for each mine spoil studied.

A. COAL CREEK

Unlike the other 4 study areas visited the Coal Creek spoils sampled were composed of a variety of mine waste types, not just strictly inactive tailings. These spoils were almost completely revegetated, apart from unstable, eroding slopes. No evidence of cultivation was found and plant species present were not typical agronomics. The climate, elevation, topography and particular nature of the coal seemed suited to support a plant community.

Three sites were sampled, where distinctly different spoil-vegetation relationships were evident.

The "tailings pond" site was located on the valley floor in an area that was used as a settling pond for coal fines resulting from the washing process. Drainage was moderate to poor, with shallow ponds of standing water being formed in some places. Vegetation was plentiful being a combination of weedy-type herbs and grass species and legumes. The roots of the legumes were generally found to be lacking N-fixing nodules. Grasses were primarily timothy, redtop and red fescue. Evidence of over-grazing was indicated. A few cottonwood, aspen, willow and spruce individuals were growing on the pond as well as a limited number of Douglas' maple and saskatoon.

The profile of the pit in Figure IV:1 shows the development of an Ah horizon. Below, the typical layering of the coarse and fine fraction characteristic in tailings deposition can be seen. The coarse fration was composed of fine gravel-size fragments while the fines were dominantly silt-size particles. Dense, fine roots were congested in the surface few centimeters, and fewer, but more coarse roots were found lower in the profile. In some cases, the roots were growing horizontally along the layers instead of penetrating to lower depths. This was likely a function of layering, with roots following the coarse layers horizontally instead of penetrating the more compacted fine layers where moisture is less available.

The "dry grassland" site was characterized by an open and exposed location and a much more coarse textured parent material. The site was somewhat elevated and drainage was good. Plant cover was limited to more drought resistant, weedy-type herb species and grasses as shown in Figure IV:2. Bull thistle, bladder campion, sweet clover, fireweed and rabbit-brush were common herbs and grasses were predominantly redtop and red fescue. Problems of water stress were evident at this site.

Layering of the parent materials was found in the "tailings pond" site, but the coarse fraction was composed of much larger coal fragments. Gravel-size fragments were horizontally stratified with finer textured materials. The Ah horizon was much deeper than at the previous site and this is likely due to two reasons: first, deeper penetrating and more abundant roots are found at this site because of water stress; this results in a deeper organic layer; secondly the freer drainage allows for downward translocation of organic matter in the profile. The presence of an Ah_2 horizon indicates this.

The "forested" site was the site having the most lush vegetation. Drainage was moderate although the site was situated on a slightly elevated ridge. Figure IV:3 and 4 demonstrate the variety of vegetation present, and the more coarse tree roots in the pit face. Predominant plant species noted were trembling aspen, cottonwood, sweet clover, red fescue and timothy.

The parent material at this location had a high percentage of coarse coal fraction. In comparison to the "dry grassland" site, the fragments were of a less uniform size. In the lower portion of the pit, the fragments were of the cobble-size range, while nearer the surface the coarse fraction was mainly composed of gravely-size fragments. Rooting was plentiful with many fine and medium roots in the upper profile and more coarse tree roots down to a depth of 70 cm. The association of plentiful roots with the diminishing fragment size of the coal suggests that roots may be significant agents. in degrading the larger coal fragments. The Bm_1 horizon is one indication of this occurrence.

B. EMERALD

Emerald study site is an open, exposed tailings pond situated in a locale of moderate climate. It has only been inactive for 5 years and as a result is still draining. Until recently, a pond of standing water was in the center, but the dropping water table has now drained it. Vegetation on the pond is not well established despite the adequate temperature and rainfall, and is restricted to pockets bordering the center. This growth pattern is indicated in Figure IV:7. Seeding and fertilization were carried out in 1973 just a year after mining operations ceased, and in 1976 there was a variety of vegetation to be found. Growth seemed to be progressing and the particularly cool an and moist season was an advantage. Conditions for growth were more borderline in 1977, however and the vegetation observed was more restricted in location, less in variety and had more symptoms of deficiency and drought.

Alfalfa was estimated as being 70 % of the vegetative cover.

Birdsfoot clover, sweet clover and timothy were also species well represented. Trees present included cottonwood, trembling aspen and alder seedlings. Rare individuals of other herbs were also found. The lowering of the water table is no doubt limiting species survival as the water supply diminishes for the less drought-resistant plants.

The spoil material was well drained but still found to be saturated in the lower portion of the profile. Where vegetation was subsisting, there was a very shallow organic layer forming. Root development was generally shallow being very congested in the upper 23 cm (Figure IV:5 and 6). All roots were fine and spreading horizontally in the more porous layers. The roots have changed the massive nature of the top few centimeters of the spoil to form a surface horizon with a granular structure underlain by a horizon with a play structure. Compaction was much reduced in these root-rich surface horizons.

The "unvegetated" pit had a thin platy surface horizon but no other signs of soil development. No obvious visual indication was evident to offer an explanation for the lack of vegetation observed on parts of the pond surface.

C. H.B.

H.B. spoil is almost identical in location to Emerald. The type of spoil, however, is very different and the area studied was actually a shallow tailings spill about 5 or 6 year old as Figure IV:9 points out. Vegetation on this spoil was almost totally accounted for by horestail, excluding the research plot. Redtop was the only other species present to any significant extent. Debris from launder construction plus logs and branches were scattered all over the spoil. In their vicinity there was found to be a wider variety of vegetation represented due to the higher nutrient-supplying capacity of the decaying wood. No problems of available moisture were found on this spoil, but preferential growth patterns were again characteristic.

Figure IV:8 illustrates the great vertical variability found in the "vegetated" pit. A thin Ah horizon was developing, with roots growing in clumps causing a wavy boundary. Mottling along root channels was evident throughout the entire pit. The organic layers found intermittently down the profile indicate the deposition of the spoil was in a number of stages with some organic buildup occurring between successive spills. Most of the roots in the lower profile were dead and decaying being roots of plants from buried vegetation.

The "unvegetated" pit was a heterogeneous as the "vegetated," including layers of organic matter in the profile. A lens of material from 23-41 cm deep was not tailings, but fine gravels.

D. HEDLEY

Hedley mine spoil was the site studied where the most extreme drought conditions existed. The pond is located on the valley floor in an area considered to be non-agricultural. Cultivation was undertaken at some time in the past, as tillage lines in the growth pattern of the grasses indicate. The northern portion of the pond was almost totally void of vegetation while the south had a variety of tree herb and grass species as illustrated in Figure IV:11. The grasses were dominantly crested wheatgrass and were congested around the outer boundary of the western and southern edges of the spoil. Herbs such as sweet clover, Russian knapweed and goldenrod were randomly dispersed in the south center and east parts of the pond. Trees and shrubs were few but cottonwood and saskatoon individuals were tall and well established. The pattern of growth showed deeper rooting species grew closer to the launder while grasses were more prevalent in the finer textured materials further towards the edge. The odd Douglas fir and ponderosa pine were found growing in the shade of the deciduous trees. Even at the time of sampling in early summer, grasses and herbs were dry and going to seed.

The "vegetated" site had an Ah horizon that was poorly defined. The amount of organic matter accumulation was small considering the length of inactivity of the pond (Figure IV:10). The structure of the surface was granular except in bare patches where it was single grain. The effect of rooting was evident to the bottom of the platy horizon at a depth of 26.5 cm. Below this point, compaction was great, to the point of being too difficult of excavate with a shovel.

Roots were abundant and fine near the surface but consisted only of masses of micro-roots below about 9cm. The micro-roots likely assist in breaking up the extremely compacted layers, but this process is slow and has not proceded to any great depth in the many years of vegetation development.

The "unvegetated" pit was platy near the surface and the presence of dead decaying roots suggests that vegetation was at one time growing in this area. The lack of any real change in structure or colour indicates that the vegetation was not long-lasting. Lower compaction at this site, to at least a depth of 40 cm; may be responsible for better drainage less water availability and hence, lack of vegetation success.

E. VELVET

Velvet, like Coal Creek is an example of spoil that shows no sign of formal revegetation procedures (Figure IV:14). All vegetation present is naturally occurring. The pond is well drained in some areas, but the northern and western edges are poorly drained or submerged. These "slough" areas were not studied due to their inaccessibility.

Large patches of the well drained part of the pond remain barren. This prefential growth pattern was a very obvious characteristic of all of the study areas, with the exception of Coal Creek. No visible distinguishing features of the pond surface account for this pattern.

Tree species subsisting included alder, willow, cottonwood and aspen. Pine seedlings grew in shaded spots. Grasses were mainly redtop and timothy. Quite a variety of herb species were present but only in limited numbers. Horsetail and sweet clover were the most common.

The "vegetated" site was dominated by grasses. The dark colour of the tailings and concomitant higher temperatures attained near the surface may have some detrimental effect on the survival of vegetation (Figure IV:12). The Ah horizon was found to be very shallow with an abrupt boundary. Unlike any other study site, high numbers of earthworms were found, but in this horizon only. Rooting did not penetrate deeply, although some larger decaying roots were found lower in the pit. The roots were generally found to be growing horizontally in the 2 - 14 cm horizon.

The "unvegetated" site as indicated in Figure IV:13 is extremely variable in texture and layering. The very surface, sandy textured material appeared to be windblown as it was discontinuous and loose.

F. ENDAKO, GRANBY AND LORNEX

Endako, Granby and Lornex mine sites were only studied and sampled for vegetation. All showed problems of water stress. At the Endako site, only grasses growing at the base of the upper bench were subsisting, due to the collection of drainage water. All other grasses were dry and gone to seed. Beardless wheatgrass was about 90% of the vegetation cover at this site.

Granby tailings pond has been inactive for some time and vegetation was found to be minimal. Russian thistle was dominant on the eastern end of the pond while baby's breath was common along the dam slopes. Much debris has been piled over the surface of the pond and vegetation was beginning to invade where improved shelter and moisture exist.

Lornex emergency pond was very droughty with vegetation being limited almost exclusively to research plots. Defficiency symptoms were extreme and growth stunted.

G. CONLUSIONS

After studying the spoil and vegetation of the 5 major study sites, a number of general observations were made:

1. Whether or not cultivation had been practiced on the spoil, some degree of natural revegetation was occurring at every site.
2. Apart from cultivated species, all vegetation present on the pond must also be present in the background. This however, does not suggest a quantitative relationship. Often, the most abundant invading species are rare occurrences in the background.
3. The relative number of types of vegetation which do succeed on the spoil, as compared to those present in the background, is small. Only those species most adaptable to the conditions of growth on the spoil will reproduce and subsist.
4. Time of maturity for those species that are found on and off the spoil areas is often different. The full reproductive cycle may not be completed for species on the spoil, for water stress and nutrient problems may inhibit normal development. Many species growing on spoils

were stunted, dry and/or had coloration indication of nutrient imbalance.

5. As stated previously, species vaiability between ponds is great. A few notable exceptions, however, are found to appear on the majority of the spoil areas. These are cottonwood, sweet clover and timothy. Cottonwood is naturally invading, and sweet clover and timothy can be either seeded or are common enough in natural landscapes to be naturally occurring.

6. Grasses may or may not be the first invading species on spoil areas but they appear to be the most dominant quantitatively and of most importance in improving the spoil substrate as a growth medium. Rooting is fundamental in stability of these spoils as well as in improving structure, raising porosity and lowering compaction.

7. Generally the older spoil sites have more variety of species than the newer spoil sites. The number of individuals of each species may be few, however, or species subsisting may appear to have borderline survival conditions. For example, crested wheatgrass at Hedley shows symptoms of nutrient defficiencies as well as physical stresses, but have been subsisting in this environment for may years.

8. All spoils visited have preferential growth patterns whether or not cultivation is evident. Barren patches occur within areas of vegetation and some whole sections of spoil are unvegetated. Deep ploughing would help to lessen the vertical stratification of layers which inhibit drainage and vertical rooting as well as improve the massive structure of the spoil by lowering compaction.

2. Laboratory Studies

A. Mine Spoils, Vegetation and Mineralogy

While chemical properties of spoil materials may restrict vegetation quality, practical limitations of plant growth on these substrates are often more dependent upon the physical parameters. Most spoils discussed are inactive or abandoned mine tailings ponds. These tailings are firstly, of the sand-size particle range and secondly, composed of distinct layers of tailings as a result of the method of deposition and variability in crushing of the sediment, water and air and hence the degree of vegetation success is very strongly a function of these physical conditions.

Table 4:1 presents particle size distributions of the selected spoil materials. Analysis by the hydrometer method was not possible on coal samples because of the organic nature, so the silt and clay- size fractions of Coal Creek samples are indistinguishable. Wet sieving was conducted, however, to determine % sand-size versus % clay and silt-size fractions. Particle size tends to increase with decreasing depth in the profile. That is, the lower horizons have higher % sand-size particles than the surface horizons. This may be due to disintegration of the larger coal fragments by root action.

Emerald, H.B., Hedley and Velvet are more typical tailings materials in their variability of particle size. Velvet is more sandy in nature than the other spoils. There is no obvious correlation of finer textures near the top of the profile indicating effect of root action as was found at Coal Creek. Mineral sediments would not be broken

Table 4:1 : Particle Size Analysis of Selected Mine Spoils

Sample	Depth (cm)	Clay %	Silt %	Sand %	Textural Class
COAL CREEK					
Tailings Pond Vegetated	0-3.5	—— 20 ——		80	
	3.5-10	—— 42 ——		58	
	33-60	—— 8 ——		92	
	60+	—— 3 ——		97	
EMERALD					
Vegetated	0.5-15	19	76	5	silty loam
	15-23	6	77	17	silt
	28-34	1	45	54	sandy loam
	34 42	11	87	2	silt
	52+	28	32	40	clay loam
H.B.					
Vegetated	0-2	4	48	48	silty loam
	2-7	2	64	33	silty loam
	32-49	1	12	87	sand
	49-50	9	76	15	silty loam
	56-67	22	14	64	sandy clay loam
	67-83	5	27	68	sandy loam
HEDLEY					
Vegetated	(litter) 0-2	12	69	19	silty loam
	0-9	16	75	8	silty loam
	19-26.5	31	42	27	clay loam
	26.5-35.5	31	38	31	clay loam
	63.5-68.5	3	69	28	silty loam
	68.5-91.5	8	66	26	silty loam
VELVET					
Vegetated	0-2	10	31	59	sandy loam
	2-14	3	37	60	sandy loam
	14-17	34	53	13	silty clay loam
	67+	33	16	51	sandy clay loam
Endako Bulk		5	19	77	loamy sand
Lornex Bulk (Emerg. Pond		10	34	56	sandy loam
Sullivan Fe Oxidized Bulk		4	20	76	loamy sand
Sullivan Gypsum Bulk		5	20	55	sandy loam
Sullivan Si Oxidized Bulk		4	39	57	sandy loam

down by root action with the ease that coal materials would. Also, Coal Creek had a larger percentage of coarse fragments which are more susceptible to fragmentation.

The differences in particle size fractions in the layers of the mineral spoils indicate potential problems concerning infiltration of water, hydraulic conductivity and aeration. The interfaces of these layers inhibit free vertical flow of water and thus, run-off, ponding and horizontal flow of water result. This is one reason for root development to be impeded and congestion of roots and rootlets to be characteristic. The root development follow water movement patterns and ease of penetration in more coarse textured layers. Bulk density is a function of mineralogical composition, compaction and % organic matter content. Generally, deeper in a profile more compaction and lower % organic matter is expected. This results in increased bulk density. Normal mineral soils have bulk densities ranging from 1.00 g/cc to 1.60 g/cc depending on composition. Organic soils often have bulk densities of less than 1.00 g/cc. Particle density is strictly a function of mineralalogical composition. Variability is less than for bulk density, averaging 2.60 g/cc to 2.75 g/cc and less for organics soils or coal. Porosity, and aeration are parameters calculated from the particlular particle sizes, bulk densities and particle densities of each spoil material. Adequate porosity is around 50% of the total volume. Water and air of variable proportions occupy these spaces.

Tables 4:2 and 4:3 give results of bulk densities and particle densities for selected mine spoils. Table 4:4 gives porosity, water content of spoils at field capacities and aeration. Related water

Table 4:2: Bulk Densities of Selected Mine Spoils

Sample	Depth (cm)	Bulk Density (gm/cc)
COAL CREEK		
Tailings Pond Vegetated	0-3.5	0.75
	3.5-10	0.80
	16-19	0.63
	33-60	0.98
	60+	0.63
EMERALD		
Vegetated	0.5-15	1.62
	15-23	1.20
	28-34	1.20
	34-42	1.42
	52+	1.54
H. B.		
Vegetated	2-7	1.56
	32-49	2.19
	49-50	1.56
	56-67	1.46
	67-83	1.60
HEDLEY		
Vegetated	0-9	1.07
	19-26.5	1.50
	26.5-35.5	1.20
	63.5-68.5	1.85
	68.5-91.5	2.16
VELVET		
Vegetated	0-2	1.46
	2-14	1.98
	14-17	2.03
	67+	2.05

Table 4:3 : Particle Densities of Selected Mine Spoils

Sample	Depth (cm)	Particle Density (gm/cc)
COAL CREEK		
Tailings Pond Vegetated	0-3.5	1.89
	3.5-10	1.39
	16-19	1.33
	33-60	1.60
	60+	1.53
EMERALD		
Vegetated	0.5-15	3.03
	15-23	2.94
	28-34	2.98
	34-42	2.98
	52+	3.20
H. B.		
Vegetated	0-2	2.84
	2-7	2.93
	32-49	3.25
	49-50	2.99
	56-67	2.99
	67-83	3.00
HEDLEY		
Vegetated	0-9	2.58
	19-26.5	2.96
	26.5-35.5	2.94
	63.5-68.5	3.07
	68.5-91.5	2.96
VELVET		
Vegetated	0-2	2.68
	2-14	3.63
	14-17	3.61
	67+	3.62
Endako Bulk		2.69
Lornex Bulk (Emerg. Pond)		2.69
Sullivan Fe Oxidized Bulk		3.06
Sullivan Gypsum Bulk		2.47
Sullivan Si Oxidized Bulk		2.85

Table 4:4: Porosity and Aeration at Field Capacity of Selected Mine Spoils

Sample	Depth cm	Total Porosity cm	Field Capacity Water Capacity cm/cm	Aeration at Field Capacity cm/cm	%
COAL CREEK					
Tailings Pond	0-3.5	0.50	0.38	0.22	37
Vegetated	60+	0.59	0.06	0.53	90
EMERALD					
Vegetated	0.5-15	0.47	0.89	-	-
	52+	0.52	0.67	-	-
H.B.					
Vegetated	2-7	0.47	0.64	-	-
	67-83	0.47	0.59	-	-
HEDLEY					
Vegetated	0-9	0.59	0.42	0.17	29
	68.5-91.5	0.27	1.06	-	-
VELVET					
Vegetated	2-14	0.45	0.77	-	-
	67+	0.43	0.73	-	-

retention values of these selected spoils are given in Table 4:5. Available water storage capacity (AWSC) is a calculation estimating the quantity of water available to a plant growing on the material in question. It is the difference between field capacity (1/10 bar for more coarse textured materials) and wilting point (15 bars) - maximum water holding capacity of the material and the minimum water holding capacity whereby roots are still able to extract moisture.

Coal Creek is the exception in the pattern of physical characteristics of the spoil materials. It is organic and therefore has high porosity, low bulk density and particle density, as well as a low AWSC. The top horizons where soil development is occurring, store more available water due to higher porosity.

The other mine spoils are similar to each other in physical characteristics. Particle densities all tend to be higher than in normal soils. Velvet in particular has high values likely due to its composition of heavy minerals. Bulk density values are lower near the surface. It would be likely that porosity would increase near the surface due to less compaction, more organic matter and consequently lower bulk density. The porosity, however, stays constant with depth for all the spoils except Hedley. Hedley tailings were found to be extremely layered and very compacted under the top 20-30 cm. Particle size was fine and the structure massive below rooting. The variation in bulk densities of these layers reflects the presence of hardpans throughout the profile. The AWSC suggests that Hedley spoil is adequate for supplying water to the vegetation present on the pond. The

Table 4:5 : *Water Retention Data of Selected Mine Spoils

Sample	Depth (cm)	1/10 bar	9/10 bar	3 bar	15 bar	AWSC **
		gm/gm				
COAL CREEK						
Tailings Pond Vegetated	0-3.5	0.500	0.257	0.147	0.130	0.370
	3.5-10	0.397	0.104	0.066	0.054	0.343
	16-19	0.135	0.059	0.037	0.036	0.099
	33-60	0.136	0.059	0.035	0.036	0.100
	60+	0.094	0.052	0.030	0.031	0.063
EMERALD						
Vegetated	0.5-15	0.547	0.420	0.173	0.104	0.443
	15-23	0.405	0.110	0.090	0.064	0.341
	28-34	0.423	0.093	0.043	0.039	0.384
	34-42	0.466	0.365	0.136	0.078	0.388
	52+	0.433	0.112	0.042	0.033	0.400
H.B.						
Vegetated	0-2	0.389	0.139	0.058	0.055	0.334
	2-7	0.408	0.071	0.013	0.010	0.398
	32-49	0.170	0.035	0.008	0.007	0.163
	49-50	0.398	0.205	0.072	0.038	0.360
	56-67	0.357	0.052	0.011	0.010	0.347
	67-83	0.368	0.042	0.011	0.008	0.360
HEDLEY						
Vegetated	(litter) 0-2	0.424	0.162	0.162	0.136	0.288
	0-9	0.394	0.206	0.136	0.110	0.284
	19-26.5	0.481	0.281	0.128	0.081	0.400
	26.5-35.5	0.381	0.042	0.039	0.035	0.346
	63.5-68.5	0.456	0.123	0.044	0.034	0.422
	68.5-91.5	0.492	0.353	0.190	0.103	0.389
VELVET						
Vegetated	0-2	0.312	0.181	0.119	0.111	0.201
	2-14	0.387	0.105	0.031	0.019	0.370
	14-17	0.394	0.154	0.042	0.030	0.364
	67+	0.355	0.076	0.016	0.013	0.342
Endako Bulk		0.181	0.088	0.039	0.035	0.141
Lornex Bulk (Emerg Pond)		0.348	0.124	0.060	0.047	0.301
Sullivan Fe Oxidized Bulk		0.412	0.175	0.120	0.113	0.299
Sullivan Gyspum Bulk		0.384	0.155	0.197	0.195	0.189
Sullivan Si Oxidized Bulk		0.465	0.208	0.134	0.115	0.350

* 1 bar $\approx \frac{\text{joules}}{\text{Kg}}$ X 100 ** Available Water Storage Capacity

compacted layers may, however, strongly inhibit plant growth, for the pores may be very small in size and dominantly occupied by moisture. Poor aeration is the result.

Although Coal Creek spoils have lower moisture-retaining abilities and dark colour, growth is lush because of adequate rainfall in the area. Lesser rain would not only mean moisture stress problems but also overheating of the black-coloured coal and burning of the plants. Hedley in particular lies in an area of minimal rainfall, so lacks natural water avaialability. This inhibits plant growth, even though the substrate is theoretically able to support vegetation. Irrigation could rectify this. Aeration problems are evident in most of the spoils. This is probably caused by the lack of soil formation present in the substrates. They behave more like sub-soils where total pore space as well as the average size of the pores is generally much less. Lack of biological activity and rooting allow massive structure to subsist.

Endako, Lornex and Sullivan samples are discussed in the 1976-77 Tailings Research Report and are again used for studies discussed in Section I of this report (Lavkulich et al.,1976-77). More sample was collected this year for continuation of research and as a consequence, analyses of these samples are included.

Selected chemical analyses of the mine spoils examined are given in Table 4:6. With the exception of Sullivan tailings, the remainder of the samples have pH values of around 7 or greater. As is usual, pH measured in $CaCl_2$ is up to one pH unit lower than

Table 4:6 : Selected Chemical Analyses of Mine Spoils

Sample	Depth (cm)	pH (water)	pH (0.1M $CaCl_2$)	% N %	% C % (LECO)	CEC	Exchangeable Cations Ca^{++}	Mg^{++}	Na^{+}	K^{+}	% S %
						me/100g					
COAL CREEK											
Tailings Pond Vegetated	0-3.5	8.1	7.1	0.552	31.43	17.41	47.35	3.00	0.09	0.15	0.193
	3.5-10	8.2	7.1	0.959	73.89	3.31	4.06	0.82	0.05	0.06	0.325
	12.5-16	8.1	7.1	0.888	70.13	4.02	6.92	0.21	0.08	0.09	0.295
	16-19	7.9	6.5	1.19	79.69	2.42	2.16	0.51	0.06	0.06	0.478
	19-33	7.4	6.4	1.14	74.66	3.89	3.90	0.85	0.12	0.11	0.339
	30-33	7.4	6.3	0.921	77.42	3.67	4.55	0.64	0.10	0.10	0.297
	33-60	7.5	6.4	0.742	59.94	3.49	7.19	0.93	0.13	0.17	0.229
	60+	7.3	6.3	0.925	43.38	3.00	4.90	0.76	0.11	0.15	0.288
Dry Grassland	0-7	7.0	6.5	1.10	64.81	10.18	6.85	1.44	0.04	0.23	0.355
	7-21	6.2	6.9	1.11	76.09	1.83	3.71	0.51	0.02	0.17	0.396
	27-34	7.8	6.9	1.12	75.19	1.03	9.31	9.31	0.45	0.08	0.365
	34-60	7.5	6.8	0.696	49.42	4.62	10.80	1.91	0.03	0.30	0.259
Forested (litter)	2-0	7.3	7.0	1.14	37.39	3.36	32.04	5.76	0.02	0.77	0.276
	0-5	7.3	7.3	0.900	37.24	85.02	61.39	10.29	0.04	0.82	0.264
	5-16	7.8	7.1	0.642	53.27	14.54	14.18	1.81	0.04	0.18	0.269
	16-25	7.4	6.6	0.821	66.10	12.57	12.30	1.56	0.04	0.14	0.311
	25-70	7.6	6.7	1.04	68.55	9.67	8.54	1.42	0.06	0.15	0.378
	70+	7.7	6.7	1.01	65.93	4.92	5.83	1.07	0.05	0.16	0.329
EMERALD											
Vegetated	0-0.5	6.8	7.0	0.061	3.67	2.51	29.03	0.45	0.01	0.18	2.72
	0.5-15	6.9	7.2	0.010	3.84	5.46	40.16	0.97	0.06	0.17	2.32
	15-23	7.1	7.3	0.018	3.39	5.07	62.64	0.91	0.03	0.09	3.17
	23-26	6.9	7.2	0.029	2.82	2.82	69.01	0.76	0.03	0.05	3.85
	28-34	6.7	6.8	0.008	3.46	2.39	62.39	1.28	0.02	0.03	5.88
	34-42	7.3	7.3	<.006	4.76	5.47	19.05	0.74	0.03	0.11	2.08
	42-52	7.3	7.4	<.006	3.61	1.40	19.67	0.51	0.02	0.07	7.32
	52+	7.2	7.3	<.006	4.96	2.83	51.65	2.39	0.02	0.12	7.25
Unvegetated	0-1.5	6.0	5.9	0.021	3.13	7.56	70.25	2.25	0.02	0.07	0.837
	1.5-14.5	7.0	6.9	0.007	3.82	2.95	67.75	0.45	0.01	0.05	0.533
	14.5-38.5	7.6	7.2	<.006	4.07	2.23	65.25	0.35	0.01	0.03	0.380
	38.5-83.5	7.7	7.6	0.007	4.39	1.57	26.75	0.55	0.04	0.05	1.52
	83.5-90	7.9	7.8	0.007	4.20	6.22	29.00	1.70	0.02	0.14	0.227

(continued)...

Table 4:6 : Selected Chemical Analyses of Mine Spoils

Sample	Depth (cm)	pH (water)	Ph (0.1M $CaCl_2$)	% N %	% C % (LECO)	CEC	Exchangeable Cations Ca++	Mg++	Na+	K+	% S %
						me/100g					
H. B.											
Vegetated	0-2	7.5	7.2	0.107	11.29	2.03	17.42	0.62	0.02	0.03	2.18
	2-7	7.7	7.3	<.006	10.35	0.55	20.67	0.78	0.01	0.04	1.87
	7-10	7.7	7.3	<.006	9.23	0.67	20.05	0.84	0.01	0.03	2.66
	12-29	7.7	7.3	<.006	9.85	0.42	19.05	0.91	0.01	0.01	2.35
	32-49	7.5	7.1	<.006	9.74	0.48	12.55	0.93	0.01	0.02	8.41
	49-50	7.4	7.2	<.006	10.42	0.97	18.55	1.67	0.02	0.04	3.55
	50-56	6.8	7.2	<.006	9.87	0.70	19.30	1.17	0.04	0.05	2.51
	56-67	6.8	7.2	<.006	9.88	0.48	12.43	1.40	0.02	0.05	2.47
	67-83	6.8	6.8	<.006	10.06	0.45	15.18	1.03	0.02	0.05	2.45
Unvegetated	0-23	7.0	6.8	<.006	9.88	0.21	13.93	0.88	0.01	0.04	9.40
	23-41	7.1	7.0	<.006	9.71	0.42	11.93	0.62	0.01	0.05	11.9
	20-38	6.9	7.0	<.006	10.67	0.60	23.29	1.71	0.03	0.07	2.36
	38-56	7.1	6.9	<.006	9.54	0.30	12.18	0.51	0.02	0.08	0.731
HEDLEY											
Vegetated	(litter) 2-0	7.4	6.9	0.258	3.89	28.75	31.69	1.23	0.15	0.96	0.369
	0-9	7.6	7.2	0.098	1.59	5.56	44.35	2.51	0.06	1.14	0.040
	9-19	7.4	7.3	0.007	1.28	2.28	32.04	0.16	0.04	0.54	0.507
	19-26.5	7.3	7.2	0.006	1.52	9.13	62.39	0.21	0.10	0.39	0.828
	26.5-35.5	7.6	7.3	<.006	1.23	4.79	57.64	0.21	0.07	0.26	1.00
	35.5-43	7.5	7.3	<.006	1.71	16.74	51.15	0.42	0.17	0.32	0.478
	43-49.5	7.7	7.3	<.006	1.03	4.74	51.02	0.25	0.09	0.11	0.923
	49.5-63.5	7.6	7.3	<.006	1.81	11.01	48.40	1.05	0.36	0.79	0.317
	63.5-68.5	7.6	7.3	<.006	1.18	4.59	50.65	0.35	0.10	0.12	1.08
	68.5-91.5	7.5	7.4	<.006	1.54	11.27	55.89	1.13	0.38	0.30	0.370
Unvegetated	0-9	7.7	7.4	<.006	1.12	9.99	38.53	0.54	0.13	0.24	0.687
	9-15	7.7	7.4	<.006	1.24	14.02	49.40	0.66	0.20	0.32	0.719
	15-30	7.7	7.3	0.009	1.01	6.71	39.16	0.47	0.09	0.11	1.75
	30-40	7.7	7.2	<.006	1.12	8.35	51.77	0.78	0.14	0.18	1.46
	40+	7.6	7.3	<.006	1.37	12.83	66.01	0.68	0.35	0.26	0.952
VELVET											
Vegetated	0-2	6.9	7.1	0.246	4.02	15.82	22.86	1.73	0.10	0.40	0.419
	2-14	7.9	7.2	<.006	0.88	1.31	0.90	0.41	0.04	0.03	0.316
	14-17	7.7	7.2	<.006	1.28	1.07	12.30	0.58	0.02	0.04	0.428
	17-67	7.6	7.1	<.006	0.59	0.88	5.81	0.29	0.02	0.02	0.386
	67+	8.0	7.3	<.006	0.77	1.43	11.05	0.35	0.03	0.02	0.363

(continued)...

Table 4:6 : Selected Chemical Analyses of Mine Spoils

Sample	Depth (cm)	pH (water)	pH (0.1M $CaCl_2$)	% N %	% C % (LECO)	CEC	Exchangeable Cations Ca^{++}	Mg^{++} me/100g	Na^{+}	K^{+}	% S %
Unvegetated	0-0.5	7.8	7.6	0.013	0.87	2.24	44.28	4.38	0.39	0.44	1.61
	Surface Clay	8.0	7.5	0.010	1.22	3.28	20.04	1.28	0.08	0.15	0.449
	0-27	8.2	7.3	<.006	0.43	0.58	6.59	0.16	0.01	0.02	1.25
	36-42	7.8	7.4	<.006	0.75	1.43	19.42	0.70	0.03	0.07	1.10
	49-55	8.2	7.4	<.006	0.49	1.37	9.58	0.27	0.02	0.05	0.912
	55+	8.0	7.4	<.006	0.50	0.98	8.24	0.29	0.03	0.03	2.29
Endako Bulk		7.8	7.3	<.006	0.27	3.85	9.68	0.78	0.29	0.17	0.085
Lornex Bulk (Emerg. Pond)		8.0	7.8	<.006	0.35	4.24	18.17	0.84	0.67	0.31	0.016
Sullivan Fe Oxidized Bulk		2.2	2.2	0.007	0.10	1.94	18.05	1.21	0.22	0.04	11.73
Sullivan Gypsum Bulk		3.0	2.9	0.006	0.09	1.45	149.82	1.05	0.78	0.96	6.18
Sullivan Si Oxidized Bulk		2.3	2.3	0.017	0.10	8.20	55.3	1.85	0.26	0.02	1.82

that measured in water.

At Coal Creek the "dry grassland" and the "forested" sites had lower pH values at the surface than did the"tailings pond". Similarily at Velvet the "vegetated" site had a lower pH than the "unvegetated". This is probably the result of the more acidic nature of organic matter as it decomposes. In none of the examples was the drop in pH sufficient to cause concern about acidity problems.

Nitrogen values are low, with the exception of the spoil samples from Coal Creek. The latter samples reflect the organic origin of coal with its inherent nitrogen content. In the "vegetated" sites nitrogen was greater in amount than in the "unvegetated" sites, indicating that there was a beginning of a build up of nitrogen in the system. This was not as evident for total carbon with the exception of Hedley and Velvet. The carbon values for Coal Creek again reflect the nature of the spoil.

The presence of vegetation at the sites examined has increased the cation exchange capacity (CEC) of the spoil material. Obviously the presence of organic matter due to the vegetation has increased the spoils ability to adsorb cations (nutrients). The increase in CEC of the "vegetated" sites decreased with depth following the decrease in carbon with depth. This is exemplified particularily at Hedley and Velvet.

Exchangeable cation data are more variable. Calcium is the dominant exchangeable cation. At the high pH values observed the exchangeable calcium was greater than the measured cation exchange capacity. This is the result of the method of measurement. In measuring cation exchange capacity, soluble cations are also determined. Exchangeable magnesium is next in abundance but much lower in quantity than exchangeable calcium. Only Hedley shows an increase, at the surface, of exchangeable magnesium. The remaining results are variable with no trends indicated. Exchangeable sodium and potassium are low in all samples investigated. No descernible effect or trend can be attributed to the presence of vegetation.

With tbe exception of H.B. and Sullivan, total sulfur is less than 1%. At H.B. the "unvegetated" tailings had a higher amount of sulfur than the "vegetated" site. In these cases pH tends to be lower when total sulfur is greater; the results, however, are not conclusive.

Table 4:7 give the results of available nutrients and some metals that were extracted from the mine spoil samples. In general available P was low in all samples examined. The only potentially toxic samples for available elements were Cu at Velvet and Pb at the "unvegetated" site at H.B. Ca, although variable in amount among samples and with depth, was the most dominant available nutrient. Calcium was followed by Mg and then K in metal mine tailings but Fe was more prevalent in Coal Creek spoil as well as in Endako and Sullivan. With the exception of Pb, as mentioned above, none of the mine spoils appeared to have toxic amounts of available metals. From the results it is obvious that P is lacking and needs to be added as a supplement.

Table 4:7 : Available Nutrients of Mine Spoils

Sample	Depth (cm)	Available P ppm	Available Ca (ppm)	Mg (ppm)	K (ppm)	Available with o.1N HCl Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Pb (ppm)	Cd (ppm)	Co (ppm)
<u>COAL CREEK</u>												
Tailings Pond Vegetated	0-3.5	38.3	38200	653.5	51.0	0.1	0.1	<.5	4.75	1.0	0.3	<1.0
	3.5-10	5.3	1055	108.5	27.5	3.5	5.5	634.5	21.5	2.0	0.2	<1.0
	12.5-16	3.0	1825	148.5	37.0	4.8	5.9	839.5	26.0	1.5	0.4	<1.0
	16-19	3.8	440	58.5	17.0	2.9	2.6	264.5	19.5	<1.0	0.1	<1.0
	19-33	6.0	900	123.5	29.5	4.6	5.3	559.5	38.5	1.0	0.3	<1.0
	30-33	12.3	995	83.5	27.5	3.4	4.4	574.5	12.5	1.0	0.4	<1.0
	33-60	6.3	2495	128.5	54.5	4.1	6.2	819.5	13.5	1.0	0.6	<1.0
	60+	9.8	1210	88.5	39.0	3.7	5.4	674.5	10.0	1.5	0.5	<1.0
Dry Grassland	0-7	16.5	1385	153.5	54.0	3.4	21.2	199.5	14.0	2.5	1.1	<1.0
	7-21	5.3	895	98.5	17.0	5.2	9.8	469.5	19.0	2.0	0.4	<1.0
	27-34	0.5	3975	108.5	18.5	3.9	8.6	484.5	5.0	2.0	0.7	<1.0
	34-60	0.3	5270	278.5	52.0	1.9	33.3	749.5	18.5	<1.0	3.3	1.5
Forest (litter)	2-0	54.8	11600	1298.5	490.0	0.1	9.5	3.95	33.5	<1.0	0.7	<1.0
	0-5	32.8	13000	1173.5	235.0	<.1	3.4	<.5	24.0	1.5	0.6	<1.0
	5-16	12.0	2695	238.5	34.5	6.5	15.9	234.5	7.50	3.5	0.8	1.0
	16-25	11.8	2985	223.5	47.0	7.4	24.0	324.5	41.5	4.0	1.0	2.5
	25-70	2.5	1925	183.5	49.5	7.8	32.3	244.5	31.5	5.0	1.1	4.5
	70+	<.3	1465	153.5	55.0	8.9	38.3	419.5	15.0	3.5	1.4	2.5
<u>EMERALD</u>												
Vegetated	0-0.5	21.8	39250	263.5	245.0	0.5	0.2	<.5	350.5	2.0	0.4	<1.0
	0.5-15	44.8	41300	333.5	166.0	0.2	0.2	<.5	397.0	2.0	0.4	<1.0
	15-23	6.0	39450	333.5	147.0	0.3	<.1	<.5	293.5	1.5	0.4	1.5
	23-26	1.5	25200	233.5	45.0	0.2	<.1	<.5	345.0	2.0	0.4	1.0
	28.34	<.3	30850	318.5	55.0	0.2	<.1	<.5	416.5	2.0	0.4	2.5
	34-42	60.8	37600	308.5	137.0	<.1	0.1	1.45	299.0	1.5	0.3	<1.0
	42-52	6.8	22050	168.5	57.0	<.1	0.7	42.45	321.0	2.0	0.3	<1.0
	52+	2.5	29450	418.5	91.5	0.1	0.3	<.5	399.0	2.0	0.3	<1.0
Unvegetated	0-1.5	0.6	16875	347.5	51.3	9.0	1.8	324.0	466.0	2.3	0.2	7.00
	1.5-14.5	0.2	29375	153.8	28.8	0.1	<.1	<.5	393.5	1.3	0.1	2.00
	14.5-38.5	0.3	31875	166.3	27.5	0.1	<.1	<.5	321.0	1.8	0.1	1.50
	38.5-83.5	0.6	46125	213.8	85.0	<.1	<.1	<.5	358.0	1.3	0.1	2.00
	83.5-90.0	1.7	56250	387.5	197.5	0.1	<.1	<.5	305.5	1.3	0.2	1.50

(continued)...

Table 4:7 : Available Nutrients of Mine Spoils

Sample	Depth (cm)	Avialable P ppm	Available Ca ppm	Available Mg ppm	Available K ppm	Available with 0.1N HCl Cu ppm	Zn ppm	Fe ppm	Mn ppm	Pb ppm	Cd ppm	Co ppm
H.B.												
Vegetated	0-2	1.8	21200	443.5	112.0	0.7	108.5	<.5	24.5	2.5	2.8	<1.0
	2-7	5.0	29500	468.5	26.0	0.2	22.8	<.5	22.5	2.0	1.7	<1.0
	7-10	1.0	24950	403.5	19.0	<.1	69.5	0.95	21.5	7.0	2.0	<1.0
	12-29	3.0	21200	403.5	35.0	<.1	16.0	0.95	23.5	3.0	2.0	<1.0
	32-49	1.0	14950	313.5	20.0	<.1	16.5	7.95	18.0	550	1.1	<1.0
	49-50	<.3	26700	808.5	54.5	0.1	225.0	<.5	28.5	3.0	3.0	<1.0
	50-56	4.3	14950	508.5	39.0	<.1	298.0	27.45	21.5	95.0	4.6	<1.0
	56-67	0.8	12850	478.5	25.5	<.1	126.5	55.95	26.0	125	3.0	<1.0
	67-83	2.0	13100	483.5	29.0	1.1	283.0	40.95	40.5	155	3.7	1.0
Unvegetated	0-23	0.8	5150	178.5	67.0	3.0	210.0	54.95	23.0	1000	4.9	1.0
	23-41	5.0	14000	253.5	34.5	1.4	115.0	64.45	28.0	450	1.9	1.0
	20-38	<.3	22800	958.5	72.5	<.1	328.0	.5	71.5	2.0	3.0	1.0
	38-56	2.0	16100	383.5	26.5	<.1	106.5	35.45	69.0	405	5.2	1.0
HEDLEY												
Vegetated	(litter) 0-2	22.0	9650	153.5	340.0	0.6	8.4	12.45	159.0	1.0	0.5	6.0
	0-9	13.8	14450	358.5	265.0	0.1	0.2	<.5	12.0	<1.0	0.4	<1.0
	9-19	13.8	26900	53.5	200.0	0.1	0.1	<.5	30.5	<1.0	0.4	2.5
	19-26.5	58.0	31950	53.5	107.0	0.1	0.1	<.5	26.0	<1.0	0.4	4.5
	26.5-35.5	5.0	26400	53.5	52.0	0.1	0.1	<.5	48.0	<1.0	0.4	6.5
	35.5-43	57.3	37250	93.5	93.0	0.1	<.1	<.5	25.5	<1.0	0.5	4.0
	43-49.5	6.8	22500	58.5	46.0	<.1	<.1	<.5	43.5	1.0	0.4	4.0
	49.5-63.5	89.8	34200	163.5	119.0	0.1	0.1	<.5	18.5	1.0	0.4	3.5
	63.5-68.5	9.8	29100	68.5	54.5	0.1	0.1	<.5	43.0	1.0	0.4	5.5
	68.5-91.5	90.8	39200	168.5	119.0	0.1	<.1	<.5	19.0	1.0	0.4	6.5
Unvegetated	0-9	4.1	28100	88.5	118.0	<.1	<.1	<.5	51.5	1.0	0.4	1.0
	9-15	57.3	30400	113.5	125.0	0.1	0.1	<.5	29.5	1.0	0.4	2.5
	15-30	18.3	22300	78.5	55.0	<.1	1.7	1.45	57.5	1.0	0.5	5.0
	30-40	22.5	26850	128.5	94.5	0.1	0.2	<.5	45.5	1.5	0.5	2.0
	40+	91.8	33250	103.5	115.0	0.1	<.1	<.5	17.5	1.0	0.4	4.0
VELVET												
Vegetated	0-2	4.5	79650	288.5	245.0	120.1	3.6	97.95	241.5	2.0	0.6	5.0
	2-14	<.3	54650	198.5	66.0	290.0	0.9	359.5	110.0	1.5	0.4	1.0
	14-17	<.3	6100	368.5	76.5	260.0	0.9	434.5	153.5	1.5	0.6	2.0
	17-67	<.3	4000	98.5	38.0	190.0	0.6	289.5	93.0	1.0	0.4	1.0
	67+	<.3	9050	103.5	31.5	43.0	0.4	859.5	128.0	1.5	0.4	<1.0

(continued)...

Table 4:7 : Available Nutrients of Mine Spoils

Sample	Depth (cm)	Available P ppm	Available Ca	Mg	K	Available with 0.1N HCl Cu	Zn	Fe	Mn	Pb	Cd	Co
			ppm			ppm				ppm		
Unvegetated	0-0.5	<.3	14700	688.5	210.0	260.0	2.1	41.45	80.5	1.5	0.5	<1.0
	surface clay	<.3	19500	378.5	136.0	230	0.1	1.45	132.0	1.8	0.5	1.5
	0-27	0.3	4700	53.5	11.5	510.0	0.7	224.5	82.0	1.5	0.1	2.0
	36-42	<.3	11350	173.5	81.5	9.9	0.1	3.45	137.0	1.8	0.2	2.0
	49-55	0.5	7750	58.5	52.5	19.6	0.6	319.5	87.5	2.0	0.3	<1.0
	55+	0.3	5850	63.5	38.0	43.5	0.8	509.5	89.5	1.5	0.3	1.0
Endako Bulk		8.1	4395	158.5	1320	5.5	2.3	1185.0	245.0	2.3	1.0	0.2
Lornex Bulk (Emerg Pond)		4.0	6195	158.5	180.0	58.5	3.3	154.5	175.0	0.8	0.2	1.0
Sullivan Fe Oxidized Bulk		<.3	2660	153.5	<.5	8.3	28.6	4650.0	13.4	16.3	0.3	1.5
Sullivan Gyspum Bulk		145.8	8625	178.5	375.0	1.6	5.8	225.0	13.5	5.3	0.2	1.0
Sullivan Oxidized Bulk		<.3	7015	273.5	14.5	2.1	28.8	1410.0	44.0	36.8	0.3	1.0

It is also interesting to note that the "vegetated" sites are beginning to concentrate P and in some cases Ca and Mg in the surface layers of the mine spoils when compared to the "unvegetated" sites. It thus appears that as vegetation becomes established an organic nutrient cycle is initiated. However, in none of the cases studied, does it appear that supplemental P is not needed. The "forested" site at Coal Creek seems to have developed the largest nutrient budget in the surface layers of all the sites examined. Although the results are preliminary in nature it seems that in some instances there is sufficient build up of plant nutrients to sustain vegetation without additional inputs. Obviously supplemental fertilization would promote a more rapid accumulation of the nutrient pool. It is also apparent that the more organic matter that is built up on the mine spoil, the better the nutrient capital is.

In order to asses the buildup organic carbon, the result of soil-forming processes, organic carbon was estimated by the Walkley-Black wet digestion technique for the samples from Coal Creek. In this evaluation (Talbe 4:8), Leco % C is a measure of total carbon and Walkley-Black the so-called organic-carbon or "active" carbon that has come from recent organic matter. The difference (Δ% C) is an estimate of the amount of carbon that has come from recent soil forming processes. Thus the smaller the Δ% C, the greater the amount of C of recent origin from organic matter.

It can be seen that in all the surface layers appreciable C has accumulated from the vegetation growing on the site. This is best demonstrated by the results obtained for the "forested" site

Table 4:8 : Difference Between Total % C (Leco) and % C of Soil Organic Matter (Walkley-Black) of Coal Creek Mine Spoils

Sample	Depth (cm)	% C LECO	% C Walkley-Black	Δ% C
Tailings Pond	0-3.5	31.43	10.78	20.65
	3.5-10	73.89	15.44	58.45
	12.5-16	70.13	12.72	57.41
	16-19	79.69	4.21	75.48
	19-33	74.66	14.08	60.58
	30-33	77.42	3.20	74.22
	33-60	59.94	4.18	55.76
	60+	43.38	2.78	40.60
Dry Grassland	0-7	64.81	13.88	50.93
	7-21	76.09	17.18	58.91
	27-34	75.19	16.21	58.98
	34-60	49.42	4.64	44.78
Forested	(litter) 2-0	37.39	30.58	6.81
	0-5	37.24	32.72	4.52
	5-16	53.27	7.01	46.26
	16-25	66.10	12.52	53.58
	25-70	68.55	12.72	55.83
	70+	65.93	12.14	53.79

at Coal Creek. In the 0-5 cm depth almost all of the C is "active". The same trends apply at the other sites but not quite so marked. In all cases organic carbon, as estimated by Walkley-Black, decreases with depth. This indicates that organic matter is slowly accumulating at the surface and should help to store nutrients and moisture. Further studies are progressing on these preliminary findings.

Analysis of the total elemental content of selected mine spoil is presented in Table 4:9. It can be noted that, as expected, Coal Creek has very low amounts of total Ca, Mg, K, Mn, Si and the heavy metals. The remaining samples have higher quantities of Ca, Mg, K, Mn and Zn. In a like fashion H.B. has the highest amount of Ca, a reflection of the host ore rock, and the highest amount of Zn. Velvet demonstrated the largest amounts of Cr of the mines examined. None of the samples examined had values of elements that are normally considered to be in toxic quantities (Lavkulich et al.,1976-77). The result of total elemental analysis are related to the values given in Table 4:7 for available nutrients.

Table 4:10 gives the results of acid ammonium oxalate extractable Fe, Al, Si and Mn. These extractions were conducted as a means of assessing whether or not the mine spoils are undergoing weathering with the release of amorphous weathering products.

Although the results are variable within a site, as well as among sites it can be seen that Fe is being liberated at the surface at the Coal Creek "tailings pond" and at the Coal Creek "forested" site. These are the sites with the lowest pH values. This is not evident at the "dry grassland" site. Similar trends are observed for

Table 4:9 : Total Elemental Analysis of Selected Mine Spoils

Sample	Depth (cm)	Ca	Mg	Na	K	Fe	Mn	Al	Si	Cd	Co	Cr	Cu	Mo	Ni	Pb	Ti	Zn
		%																
COAL CREEK																		
Tailings Pond	0-3.5	13.00	0.20	0.04	0.10	15.0	0.08	1.1	4				<.01				0.1	0.01
Vegetated	3.5-10	<.01	0.06	0.03	0.06	2.8	0.01	1.5	3				<.01				0.2	<.01
	16-19	<.01	0.03	0.03	<.01	1.2	<.01	0.9	2			<.001%	<.01				0.2	<.01
	33-60	0.14	0.14	0.05	0.34	6.6	0.01	5.1	9				0.01				0.5	<.01
	60+	<.01	0.09	0.05	0.29	6.6	0.01	3.5	7				<.01				0.4	<.01
EMERALD																		
Vegetated	0.5-15	9.56	1.76	0.31	0.55	9.1	1.60	3.0	12			<.001	0.04		<.01%	<.01%	0.3	0.02
	15-23	7.60	1.63	0.34	0.75	10.8	1.03	2.6	13	<.001%		0.002	0.07				0.3	0.02
	28-34	6.91	1.27	0.38	0.52	12.1	0.91	1.8	15			<.001	0.04				0.2	0.03
	34-42	9.86	1.59	0.30	0.75	7.8	1.20	3.1	13			0.001	0.03				0.3	0.02
	52+	6.26	1.20	0.16	0.31	21.4	0.84	1.3	12		<.01%	<.001	0.10				0.1	0.02
H.B.																		
Vegetated	0-2	18.80	9.70	0.03	0.08	2.9	0.05	0.2	2	0.001			0.01		0.02	0.13	0.1	0.24
	2-7	19.20	9.60	0.02	0.10	2.3	0.05	0.3	2	<.001			0.01		0.02	0.09	0.1	0.19
	32-49	13.00	6.00	0.09	0.15	15.8	0.03	0.2	3	0.009		<.001%	<.01	<.01%	0.01	0.69	0.1	0.93
	49-50	18.30	9.80	0.05	0.07	3.5	0.05	0.3	3	0.006			0.01			0.36	0.1	0.58
	56-67	17.30	9.20	0.08	0 07	4.6	0.04	0.3	2	0.005			0.01			0.15	0.1	0.37
	67-83	18.00	9.70	0.07	0.10	4.2	0.04	0.3	3	0.003			0.01			0.13	0.1	0.35
HEDLEY																		
Vegetated	0-9	1.69	1.68	1.88	1.14	4.8	0.13	6.3	19			0.007	0.01		<.01%	0.08	0.8	0.01
	19-26	8.54	1.80	0.49	1.00	7.5	0.33	3.0	16		0.03	0.004	0.02			0.09	0.5	0.02
	26.5-35.5	7.45	1.82	0.44	1.01	8.8	0.32	2.6	19		0.02	0.005	0.01			0.11	0.4	0.02
	63.5-68.5	9.77	1.95	0.32	0.67	10.4	0.42	2.4	17		<.01	0.006	0.01				0.3	0.02
	68.5-91.5	10.56	1.91	0.38	0.95	7.9	0.38	2.8	16		0.02	0.007	0.02				0.3	0.02
VELVET																		
Vegetated	0-2	0.67	2.60	0.36	1.00	24.9	0.11	3.2	13			0.090	0.09		0.02	<.01%	0.3	0.02
	2-14	0.55	3.40	0.24	0.53	37.9	0.09	1.9	11	<.001%	<.01%	0.194	0.14		0.06		0.2	0.02
	14-17	0.69	4.40	0.13	0.35	35.9	0.09	1.6	9			0.200	0.22		0.07		0.2	0.02
	67+	0.74	2.40	0.12	0.40	39.9	0.08	1.6	8			0.195	0.15		0.06		0.1	0.02
Endako Bulk		0.26	0.38	2.06	3.15	2.1	0.05	6.1	25				0.01	0.03			0.3	0.01
Lornex Bulk (Emerg. Pond)		0.45	0.28	2.30	1.30	1.1	0.05	6.2	25			<.001%	0.06		<.01%		0.3	0.01
Sullivan Fe Oxidized Bulk		0.10	0.29	0.09	0.13	34.9	0.11	0.8	3				0.02	<.01%		0.57	0.2	0.22
Sullivan Gypsum Bulk		13.60	0.03	0.03	0.05	0.5	0.01	0.2	8				<.01			<.01	0.3	0.01
Sullivan Si Oxidized Bulk		1.17	1.22	0.64	1.08	14.9	0.46	4.1	14				0.01			0.47	0.5	0.19

Table 4:10: Acid Ammonium Oxalate Extractable

Fe, Al, Si, Mn, of Mine Spoils

Sample	Depth (cm)	Fe	Al	Si	Mn
		ppm			
COAL CREEK					
Tailings Pond	0-3.5	12148	220	1400	428
Vegetated	3.5-10	1668	44.0	80	32.0
	12.5-16	2708	60.0	80	24.0
	16-19	748	16.0	<1	24.0
	19-33	2068	64.0	<1	36.0
	30-33	2268	40.0	80	20.0
	33-60	3348	56.0	120	20.0
	60+	2668	36.0	80	20.0
Dry Grassland	0-7	2268	164	80	24.0
	7-21	2428	108	80	28.0
	27-34	1388	44.0	40	7.6
	34-60	8548	92.0	160	68.0
Forest (litter)	2-0	3748	616	440	256
	0-5	4108	888	480	292
	5-16	7388	1316	1120	116
	16-25	5268	792	600	60.0
	25-70	1228	160	80	32.0
	70+	1308	48.0	40	20.0
EMERALD					
Vegetated	0-0.5	27560	1675	2400	1240
	0.5-15	18760	1836	2160	1356
	15-23	25560	788	1600	1096
	23-26	43560	316	1040	1084
	28-34	31960	260	920	864
	34-42	15960	1436	1520	1664
	42-52	7228	212	320	420
	52+	27960	516	800	1136
H.B.					
Vegetated	0-2	5308	48.0	200	1.2
	2-7	3588	32.0	<1	30.4
	7-10	3908	28.0	<1	4.0
	12-29	3428	20.0	<1	1.6
	32-49	1628	20.0	<1	24.0
	49-50	2908	40.0	80	32.0
	50-56	3068	44.0	40	3.2
	56-67	2628	24.0	<1	2.0
	67-83	3228	76.0	40	0.8

(continued) Table 4:10: Acid Ammonium Oxalate Extractable Fe, Al, Si, Mn, of Mine Spoils

Sample	Depth (cm)	Fe	Al	Si	Mn
		ppm			
Unvegetated	0-23	2428	20.0	80	44.0
	23-41	1548	32.0	80	36.0
	20-38	3228	56.0	80	7.2
	38-56	21160	4.0	<1	60.0
<u>HEDLEY</u>					
Vegetated (litter)	0-2	6148	1436	1480	476
	0-9	3388	1356	1560	464
	9-19	17560	1680	2800	172
	19-26.5	15960	1876	3200	196
	26.5-35.5	21160	964	2200	128
	35.5-43	13788	1508	2920	172
	43-49.5	17160	628	1640	116
	49,5-63.5	17560	1760	3200	172
	63.5-68.5	16760	752	1840	84.0
	68.5-91.5	14360	2156	3160	156
Unvegetated	0-9	12988	1756	2720	292
	9-15	17960	2396	3920	360
	15-30	15160	912	2000	252
	30-40	22360	1596	2800	200
	40+	17160	2036	3320	204
<u>VELVET</u>					
Vegetated	0-2	46360	396	920	296
	2-14	107960	204	520	248
	14-17	51160	276	440	244
	17-67	89560	148	360	128
	67+	106360	128	480	168
Unvegetated	0-0.5	55960	180	560	140
	Surface clay	27560	972	1440	352
	0-27	105160	68.0	400	112
	36-42	73160	464	640	140
	49-55	29960	248	280	76.0
	55+	46760	184	320	64.0
Endako Bulk		3348	492	640	144
Lornex Bulk (Emerg. Pond)		2948	580	600	124
Sullivan Fe Oxidized Bulk		92760	344	320	32.0
Sullivan Gypsum Bulk		308	232	440	2.4
Sullivan Si Oxidized Bulk		35160	576	240	76.0

Al, Si and Mn. It thus appears that soil-forming processes are active at Coal Creek, beginning differentiation of the mine spoils into "natural" soil.

The results at Emerald are not quite as evident. Only Si shows an increase at the surface, indicating some breakdown of the minerals occurring in the tailings. The remaining elements are variable exhibiting the effects of stratification of the tailings material. H.B. samples exhibit similar trends to those found at Emerald. It appears that these tailings have not had sufficient time to release weathering products that can be detected.

The results from Hedley reflect the dry environment of the area. Very little chemical breakdown has occurred since the tailings have been deposited. Again the results demonstrate the stratification found in the pond. Velvet samples give the same trends as were observed for Emerald and H.B.

It appears, therefore, that the mine spoil samples investigated have not had sufficient time to produce amorphous weathering products that could accumulate. There is, however, some evidence that weathering is proceeding.

B. <u>Vegetation</u>

Table 4:11 reports on the results of elemental analysis of vegetation samples collected during the study year. The samples were collected from both mine spoils and from vegetation growing on "natural" soils in the area so that regional comparisons could be made.

Table 4:11: Chemical Analyses of Vegetation

Sample	N	Ca	Mg	K	Na	P	Fe	Al	Mn	Zn	Cu	Mo	Cu:Mo Ratio
	%					ppm							
COAL CREEK													
Tailings Pond													
Cottonwood	2.40	1.28	0.332	1.31	2.75	1719	75	43	18.2	190	7.5	0.85	8.8
Sweet Clover (wh., yw.)*	3.21	1.61	0.460	1.34	2.13	2218	118	38	18.2	36.4	13.9	2.58	5.4
Timothy	1.29	0.18	0.131	1.42	2.46	1721	1312	42	18.9	69.3	12.6	1.68	7.5
Dry Grassland													
Cottonwood	2.10	1.78	0.593	0.92	1.02	1370	43	22	11.3	406	9.7	1.30	7.5
Sweet Clover (wh., yw.)	2.69	1.81	0.481	0.92	1.59	1482	113	75	23.0	45.5	8.6	2.14	4.0
Timothy	1.02	1.69	0.127	1.28	2.79	1098	53	74	11.6	49.6	10.6	0.84	12.6
Forested													
Cottonwood	2.50	2.37	0.502	1.60	0.635	2392	53	11	40.6	455	9.6	1.71	5.6
Saskatoon	1.93	1.77	0.474	1.45	1.01	4187	63	21	49.7	68.7	12.7	2.54	5.0
Sweet Clover (wh., yw.)	2.65	1.58	0.413	0.74	2.42	2137	75	53	29.8	36.2	9.6	2.56	3.8
Timothy	1.17	0.21	0.119	2.06	1.93	2194	47	32	20.0	43.1	12.6	1.26	10.0
Background													
Cottonwood	2.02	1.37	0.234	1.62	0.029	2848	244	413	31.8	121	9.5	0.85	11.2
Sweet Clover (wh., yw.)	2.56	1.88	0.413	1.10	1.82	2195	211	285	25.3	20.1	10.6	2.53	4.2
Timothy	0.813	0.19	0.084	1.37	1.94	1813	538	295	20.0	31.6	15.8	1.69	9.3
EMERALD													
Tailings Pond													
Alfalfa (purple)	1.73	1.93	0.199	1.39	0.026	973	328	63	651	40.2	10.6	2.54	4.2
Cottonwood	2.42	2.02	0.412	1.42	1.06	2988	484	43	941	512	17.2	2.58	6.7
Sweet Clover (wh.)	1.71	2.42	0.385	1.18	2.84	979	490	64	444	17.0	<1	6.81	-
Timothy	0.500	0.14	0.051	1.01	2.48	908	188	<10	398	13.6	13.6	0.83	16.4
Background													
Cottonwood	1.79	1.55	0.262	1.74	2.97	2536	128	75	116	218	7.5	1.71	4.4
Sweet Clover (wh.)	2.19	2.21	0.319	1.33	1.88	1431	214	64	220	19.2	7.5	5.98	1.3
Timothy	0.459	0.12	0.040	1.02	1.94	1132	126	<10	41.2	11.6	13.2	2.55	5.2
H. B.													
Tailings Pond													
Horsetail	1.29	3.28	0.255	2.63	2.75	1078	272	22	54.5	693	15.3	1.71	8.9
Red Top	0.500	0.28	0.081	0.96	1.16	336	42	21	53.5	209	10.5	<.80	-
Background													
Red Top	0.584	0.15	0.131	1.21	1.07	1545	137	53	70.4	37.8	7.4	<.80	-

(continued)...

Table 4:11: Chemical Analyses of Vegetation

Sample	N	Ca	Mg	K	Na	P	Fe	Al	Mn	Zn	Cu	Mo	Cu:Mo Ratio
	%					ppm							
HEDLEY													
Tailings Pond													
Cottonwood	2.02	2.09	0.300	1.32	1.74	990	234	32	220	253	12.8	1.70	7.5
Crested Wheatgrass	0.292	0.35	0.035	0.36	0.634	349	775	147	49.3	17.8	12.6	3.35	3.8
Russian Knapweed	0.448	0.85	0.090	0.60	1.45	780	1177	228	55.7	9.5	12.2	5.93	2.1
Saskatoon	1.42	1.24	0.374	0.93	2.82	825	698	148	1234	11.6	4.2	1.69	2.5
Sweet Clover (wh.)	1.75	1.29	0.271	1.11	2.45	1119	437	85	36.2	11.2	16.0	23.9	0.7
Background													
Crest Wheatgrass	0.854	0.26	0.052	0.86	1.25	1160	466	117	24.9	20.7	24.4	<.80	-
Russian Knapweed	0.854	0.86	0.159	1.00	2.62	1755	761	233	57.1	16.9	11.6	1.69	6.9
Saskatoon	1.54	1.33	0.419	1.11	2.67	281	314	73	102	23.0	7.3	2.51	2.9
Sweet Clover (wh.)	1.77	1.44	0.195	1.31	1.04	1280	74	<10	32.5	16.8	6.3	10.1	0.6
VELVET													
Tailings Pond													
Cottonwood	1.75	1.48	0.256	1.59	1.56	1473	244	53	60.4	152	7.4	4.24	1.7
Horsetail	1.90	2.14	0.464	2.47	0.040	2097	342	21	58.8	21.4	11.8	4.28	2.8
Timothy	0.500	0.20	0.068	0.82	1.18	586	136	31	22.0	17.8	17.8	<.80	-
Background													
Cottonwood	1.67	1.53	0.279	1.42	1.60	2383	253	127	56.9	172	10.5	2.53	4.2
Horsetail	1.29	2.02	0.384	2.85	2.54	3179	558	300	45.0	36.5	15.0	3.01	5.0
Timothy	0.646	0.14	0.084	1.33	1.56	1587	251	73	31.3	20.9	<1	1.67	-
ENDAKO													
Tailings Pond													
Beardless Wheatgrass	0.625	0.23	0.123	0.82	2.68	1049	161	107	135	8.6	12.8	129	0.1
Red Fescue	0.626	0.21	0.106	0.63	0.928	1724	223	138	244	11.7	18.0	41.6	0.4
Timothy	0.407	0.12	0.065	0.84	1.71	1031	138	96	109	9.6	17.0	40.0	0.4
Background													
Red Fescue	0.021	0.16	0.071	0.39	1.20	914	244	202	498	12.8	13.8	51.9	0.3
Timothy	0.334	0.16	0.079	0.81	2.30	1142	246	235	257	14.9	10.7	114	0.1

(continued)...

Table 4:11: Chemical Analyses of Vegetation

Sample	N	Ca	Mg	K	Na	P	Fe	Al	Mn	Zn	Cu	Mo	Cu:Mo Ratio
	%					ppm							
GRANBY													
Tailings Pond													
Baby's Breath	1.31	2.49	0.492	1.57	2.03	1435	306	222	108	17.9	29.6	4.22	7.0
Cottonwood	2.79	2.01	0.381	1.52	1.46	1276	170	85	104	25.5	13.8	4.25	3.2
Russian Knapweed	0.999	1.03	0.163	1.13	1.66	1361	188	84	49.2	10.5	11.5	2.51	4.6
Russian Thistle	1.40	2.15	0.399	4.39	1.75	1635	105	42	71.3	15.7	36.7	5.03	7.3
Sweet Clover (wh.)	1.81	2.03	0.266	1.55	1.61	1040	170	96	60.5	22.3	10.6	3.40	2.2
Background													
Cottonwood	0.788	1.94	0.348	0.67	0.986	1709	74	21	77.0	69.6	11.6	4.22	2.7
Russian Knapweed	1.06	0.69	0.170	1.18	0.992	2372	178	136	50.4	22.0	7.3	5.04	1.4
Sweet Clover (wh.)	2.13	1.01	0.276	1.21	2.71	1542	127	74	19.0	15.8	4.2	6.76	0.6
LORNEX													
Tailings Pond													
Sweet Clover (yw.)	1.25	1.63	0.207	1.09	0.065	871	157	262	49.3	16.8	48.3	72.2	0.7
Timothy	0.667	0.26	0.061	0.64	0.065	345	220	272	203	16.7	85.8	49.4	1.7
Background													
Sweet Clover (yw.)	1.52	1.76	0.403	1.24	1.76	1455	137	53	50.6	13.7	73.8	4.22	17.5

* wh.= white; yw.= yellow

It must be emphasized that only comparisons of vegetation growing on the "natural" soils and mine spoils are valid. In the Tailings Research Report 1976-77, a few vegetation samples exhibited Cu:Mo ratios of less than 2, which is considered to cause nutritional problems with ruminants. A further testing during 1977-78 was carried out to evaluate the earlier findings.

At Coal Creek there were no obvious differences in the elemental content of vegetation growing on mine spoils and the natural background except for P, Fe and Al. The concentration of P, Fe and Al was lower in the vegetation growing on mine spoils than in the background samples. There does not seem to be a problem with respect to vegetative chemical quality. The results do indicate that the vegetation growing on Coal Creek spoil have begun a rather well defined nutrient balance.

The results for Emerald again show that the amount of P in plants growing on mine tailings is less than in the background vegetation samples, especially sweet clover and timothy. Vegetation growing on the tailings had higher amounts of Fe, Mn and possibly Zn in comparison to the background samples. Only sweet clover had a Cu:Mo ratio less than 2.0. The remaining elements did not seem to show any trends and are within normal ranges found in plants.

The lack of sufficient vegetation samples at H.B. does not allow meaningful comment. The concentrations recorded do not seem to be outside the range commonly found for plant species. Again P content is lower in species growing on the mine tailings.

At Hedley, again P was higher in amount in the background samples than that found in vegetation growing on the abandoned tailings. The reverse was found for Fe. Again sweet clover was the only species having a Cu:Mo ratio of less than 2.0. Velvet exhibited similar results.

Endako vegetation was the only area exhibiting consistently low Cu:Mo ratios in both the background and mine spoil vegetative samples. This is consistent with the findings during 1976-77. In this region it appeas Cu deficiency is a regional problem for ruminant nutrition.

The results indicate, in general, that with the exception of P, vegetation growing on mine spoil has similar concentrations of elements tested for as vegetation growing on natural soils. In a few instances it appears Zn is found in higher amounts in vegetation growing on mine spoil, but it does not appear to be reaching toxic limits (500 ppm). Endako and Emerald are the only areas where the vegetation could contribute to hypocupracemia, a condition in ruminants, occurring when the Cu:Mo ratio is below 2.0.

C. Mineralogy

X-ray diffraction analyses were conducted on selected mine spoil samples. The samples were sieved prior to analyses and only the less than 200 mesh material was subjected to X-ray diffraction. In preparing the samples for X-ray analyses a number of pretreatments are necessary. These pretreatments can dissolve minerals like gypsum and to a lesser extent calcite and dolomite. Thus the results are an underestimate of these minerals: Table 4:12 gives the results of the X-ray diffraction studies.

At Coal Creek it appears vermiculite is forming from micas that were in the original spoil material. Kaolinite, quartz and mica are present in the unweathered mine spoil material.

At Emerald, vermiculite and chlorite are being formed at the surface, probably from the inherent mica of the tailings. The remaining minerals reflect the geology of the tailings, with a broad assemblage of primary minerals. The same seems to be the case at H.B. and Hedley, except that no evidence was found for chlorite at H.B. and no vermiculite at Hedley.

It is more difficult to draw comparisons for Velvet as there appears to be no differences with depth (assuming that mineral weathering decreases with depth). The remaining samples indicate relatively fresh minerals with abundant primary minerals present.

In summary, it appears that mine spoils are weathering to form secondary minerals especially vermiculite, probably from mica. As this continues, the material should move more towards a "natural" soil having better chemical and physical properties.

Table 4:12: X-Ray Diffraction Results (Mineralogy) of the Less Than 200 Mesh Material of Selected Mine Spoils

SAMPLE	CM	DOMINANT MINERALS
COAL CREEK		
Tailings Pond	0-3.5	vermiculite, kaolinite, mica, quartz, calcite
	3.5-10	kaolinite, mica, quartz
	16-19	vermiculite, mica, quartz, (kaolinite?)
	33-60	mica, kaolinite, quartz
	60+	mica, quartz
EMERALD		
Vegetated	0.5-15	chlorite, mica, amphibole, kaolinite, quartz, (gypsum?) calcite, dolomite, (apatite?)
	15-23	vermiculite, mica, amphibole, kaolinite, quartz, dolomite
	28-34	mica, amphibole, kaolinite,(feldspar?) quartz, calcite, dolomite, (apatite?)
	34-42	mica, amphibole, kaolinite, calcite, quartz
	52+	mica, amphibole, kaolinite, quartz, (feldspar?), calcite, dolomite
H.B.		
Vegetated	0-2	vermiculite, mica, amphibole, dolomite, calcite, quartz, feldspar
	2-7	vermiculite, mica, amphibole, calcite, gypsum, (apatite?), dolomite magnetite
	32-49	mica, amphibole, gypsum, calcite, (apatite?), magnetite, dolomite
	49-50	mica, amphibole, calcite, gypsum, (apatite?), magnetite, dolomite
	56-67	mica, amphibole, calcite, dolomite, apatite, magnetite.
	67-83	mica, quartz, gypsum, calcite, magnetite, dolomite
HEDLEY		
Vegetated	litter 2-0	chlorite, mica, kaolinite,amphibole, feldspar, quartz
	0-9	chlorite, mica, kaolinite,amphibole, feldspar, quartz, calcite

* Presence indicated

Table 4:12 (cont'd)

SAMPLE	CM	DOMINANT MINERALS
HEDLEY		
Vegetated	19-26.5	(kaolinite?), quartz, feldspar, calcite, dolomite, amphibole
	26.5-35.5	amphibole, feldspar, quartz, calcite
	63.5-68.5	amphibole, feldspar, quartz, calcite
	68.5-91.5	feldspar, quartz, calcite, magnetite, (apatite?)
VELVET		
Vegetated	0-2	chlorite, mica, (kaolinite?), quartz, feldspar, calcite, magnetite
	2-14	chlorite, mica, quartz, feldspar, calcite, (gypsum?)
	14-17	chlorite, mica, quartz, feldspar, calcite, gypsum
	67+	chlorite, mica, quartz, feldspar, calcite, gypsum
Endako Bulk		mica, kaolinite, quartz, feldspar, calcite*
Lornex Bulk (Emerg. Pond)		chlorite, mica, (kaolinite?) quartz, feldspar, calcite, (gypsum?) apatite
Sullivan Fe Oxidized Bulk		amphibole, feldspar, mica*, quartz, calcite*, (apatite?)
Sullivan Gypsum Bulk		amphibole, quartz, calcite, (gypsum?), apatite
Sullivan Si Oxidized Bulk		chlorite, mica, quartz, calcite*, (apatite?)

* Presence indicated

5. GENERAL CONCLUSIONS

GENERAL CONCLUSIONS

Vegetation was found to occur on every spoil visited, but growth was invariably preferential over the spoil surface. Always, some natural vegetation was present even if cultivated species were evident. Species were not found to be quantitatively proportional to species in the background. Cottonwood, sweet clover and timothy were of very common occurrence at spoil sites whether or not formal seeding had been undertaken.

Physical signs of stress including symptoms of nutrient imbalance and/or water stress were often severe. At no site, however, was the vegetation found to reach toxic limits in heavy metal concentrations P was defficient in most case.

Generally, grasses were the predominant cover established. Older spoils had more variety of species present but not necessarily a greater number of individuals.

Physical limitations of all of the metal mine spoils were paramount. Coal Creek sites and particularly the "tailings pond" and "forested" sites were of little problem, either in the physical or chemical nature of the spoil materils. Variety of vegetation was great and the locale advantageous. At high elevations or in a low rainfall area, natural revegetation may not have been so successful.

The preferential growth pattern of vegetation growth is likely dominantly a factor of spoil physical and characteristics because no significant chemical differences were evident in "vegetated" versus "unvegetated" sites. At Hedley as well as Emerald, H.B. and Velvet improved structure, aeration and bulk density would allow for a more rapid vegetation cover to establish and result in accelerated soil-forming processes. Deep ploughing in combination with seeding and addition of anorganic amendment would help to alluviate many of the physical problems. Water stress at Hedley is severe and irrigation at least initially, would undoubtedly be required due to the arid climate. Emerald has only been inactive for a few years and is still draining. It may not be particularly stable at this point in time for supporting heavy machinery. The predominance of alfalfa subsisting on the pond and lack of presence of more shallow rooting species suggests that as the water table continues to drop, even the alfalfa may disappear.

Species choice as well as type of organic amendment are important factors take into acount if grazing is anticipated. None of the spoils exhibit extreme toxicity problems under normal circumstances (excluding Sullivan), but coupled with organic amendments which often have high concentration of heavy metals, potential problems can be seen. Use of species accumulating these metals can be avoided if such amendments are used.

Difficiencies in macronutrients is primarily with P. There is evidence of nutrient recycling, however, in surface horizons of "vegetated" sites and P and N buildup is noted.

Mineralogically, most spoils showed minimal signs of weathering. Clay mineral formation was occurring in the surface of "vegetated" sites however, and raised nutrient-supplying capacities result.

- SECTION II -

6. WEATHERING OF MINE TAILINGS

Weathering of Mine Tailings

1. Introduction

To plan techniques for reclamation of mine wastes, it is necessary to study the nature of the waste materials in detail. The weatherability of wastes such as mine tailings is of ultimate importance because of their characteristically high degree of chemical reactivity.

Tailings material is composed of ground waste rock that is a residual product of ore extraction. This material is not in chemical equilibrium with conditions at the earths surface. One result is that weathering will initially occur rapidly and as minerals alter and decompose, problems of contamination may arise in the surrounding environment. For example, toxic quantities of heavy metals may be released into water systems and be taken up by vegetation and animals, or extremely acidic conditions may be promoted as sulfide minerals oxidize. To help in the assessment of potential problems of reclaiming mine waste areas as well as planning productive reclamation projects, information concerning the long-termed behavior of these tailings is required.

One method of studying the weathering of tailings is by the utilization of the Soxhlet weathering procedure. This is a laboratory simulation of natural weathering conditions. The objective of the procedure is to speed up the weathering process and at the same time, create similar products that would be formed over a prolonged time span in actual field conditions. A more detailed understanding of the processes of soil-formation will hopefully be one outcome of Soxhlet studies.

In the 1976 research report, (Lavkulich et al., 1977) were discussed. Since this time, modifications of the procedure have been necessary, for this technique of artificial weathering is only being developed as a method of study for soil-size particles (Singleton, 1978). Weathering studies conducted for this years report largely utilize the selected tailings discussed in 1976. Analyses and descriptions for some of the unweathered tailings mentioned in this report have been previously published (Lavkulich et al., 1977).

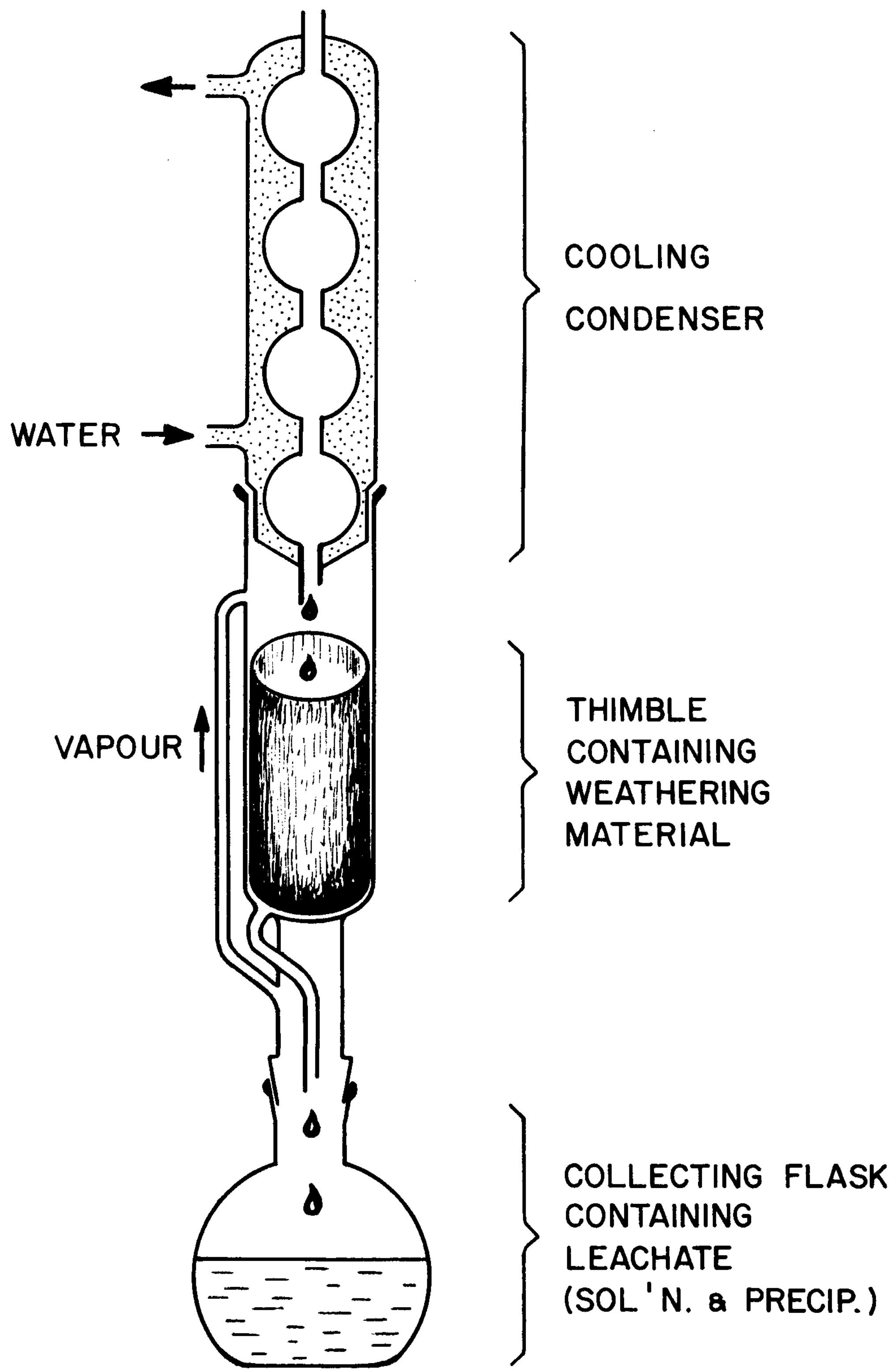
2. Method of Weathering

The Soxhlet is basically a column leaching apparatus. A column containing a thimble filled with the tailings material was placed upon a flask containing an extraction liquid. The flask was heated and as the liquid evaporated, it was condensed above the column and recycled as in Figure 6:1. The temperature at a point just above the thimble was regulated to 95 $\pm$ 2^{o}C in order to standardize conditions from sample to sample.

The thimble was filled and lightly packed with 150 to 250 g of sediment to be weathered. A small circular piece of filter paper is placed on the top to prevent the condensate from channeling and splash eroding the sample surface. The flask is filled with 300 ml of either distilled water or 0.3N acetic acid. The acetic acid solutions has the advantage of simulating more intense weathering

FIGURE 6:1

SOXHLET EXTRACTION APPARATUS



conditions. It creates a slightly acid environment as is found in areas of moderate to high rainfall. The buffering capacity and weak complexing ability of acetic acid are attributes also found in organic acids in natural systems.

The receiving flask contains a combination of the leaching liquid and any soluble constituents which have been removed from the sample. As these constitiuents are concentrated in the flask the solution becomes saturated and precipitation products are formed.

The solution and precipitation products were removed from the collecting flask weekly and were centrifuged to separate the solid and liquid phases. Fresh solution is then placed into the flask. Both elemental analysis of cations in the removed solution, conducted on the atomic absorption spectrophotometer, and pH of the solutions was taken weekly to monitor the changes in chemistry occurring over time. The precipitate phase was dried and weighed and may be characterized at a later date. The use of analytical methods such as X-ray diffraction and total elemental will supply information regarding the nature of the precipitate. Recrystallization of these amorphous compounds not necessarily present in the original weathered material.

At the end of 3 weeks, the thimble was removed from the apparatus material or "accumulation product" was divided into a top and a bottom portion by cutting the lower 5 cm away from the remaining upper portion, as indicated in Figure IV:15. This is done in order that any extreme vertical differences created by weathering may be detected during analysis.

The weight loss of the accumulation product varies with the particular sediment being weathered. The more inert tailings such as Lornex of Similkameen lose only 1 or 2 g while the extremely soluble Sullivan Gypsum loses up to 50% of its original weight by the end of the 3 week leaching period (Figure IV:14 and IV:18). The sum of the precipitate removed from the collecting flask and the cations in solution ideally account for the weight loss of the accumulation product. There is, however, high-temperature artifacts created around the inner edges of the flask. These artifacts are a function of the contact of the very hot flask sides with the free precipitate and the result is coatings of precipitate being deposited. The natue of these artifacts, and their relationship (ie. equilibria chemistry) to the precipitate is being studied by Singleton.

3. Results and Discussion of Weathering

A. Elemental Analysis of Accumulation Products vs. Originals

Total elemental analysis of the 0.3N acetic acid weathered and distilled water weathered tailings is presented in Tables 6:1 and 6:2. Table 6:3 gives the corresponding total elemental analysis for the origianl mine tailings. The relative quantities of elements found in the weathered materials compared to original materials indicates which elements are being removed from the weathering system. Lower relative percentages of elements measured in comparison to unweathered original tailings material indicate removal of those elements. Conversely, if percentages of the elements increase in relation to the original sample, those elements are accumulating.

A more intense leaching environment is found near the

Table 6:1 : Total Elemental Analysis of Soxhlet Weathered Mine Tailings

(0.3N Acetic Acid Weathered)

Sample	*	Ca	Mg	Na	K	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Ti	Zn	Fe	Al	Si
		%																
Bethlehem Fresh	Top	0.06	0.46	3.15	1.17	↑	↑	↑	0.14	0.01	↑	↑	↑	0.4	<.01	1.3	6.8	25
	Bottom	0.07	0.51	3.11	1.11				0.15	0.01				0.4	<.01	1.5	6.9	24
Brenda 0-8 cm	Top	0.37	0.62	2.66	2.37				0.01	0.03				0.4	<.01	2.5	6.7	27
	Bottom	0.41	0.67	2.37	2.16				0.01	0.03				0.4	<.01	2.8	6.7	25
Emerald 3 14.5-38.5 cm	Top	2.06	0.99	0.36	0.34				0.04	1.03				0.1	0.02	19.9	1.8	16
	Bottom	5.36	1.30	0.30	0.34	<.001%			0.03	1.13				0.2	0.02	15.4	1.5	14
Endako Bulk	Top	0.02	0.15	2.26	3.11				<.01	0.01			<.01%	0.5	<.01	2.7	6.5	25
	Bottom	0.02	0.16	2.04	3.07				<.01	0.01				0.5	<.01	1.8	6.4	24
Gibraltar Fresh	Top	0.32	0.88	2.10	0.95				0.11	0.04				0.5	0.01	3.7	6.4	26
	Bottom	0.27	0.84	1.99	0.85	↓			0.12	0.03			↓	0.5	<.01	3.5	6.5	25
H.B. Fresh Fines	Top	17.10	8.90	0.06	0.18	0.001	<.01%	.001%	0.01	0.04			0.15	0.1	0.28	3.7	0.4	3
	Bottom	17.50	9.00	0.05	0.19	0.001			↑	0.04	<.01%	<.01%	0.13	0.1.	0.28	3.3	0.4	3
Kaiser Fresh	Top	<.01	0.05	0.05	0.41	↑			.01%	<.01			↑	0.6	↑	0.7	5.0	9
	Bottom	<.01	0.05	0.05	0.40					<.01				0.6		0.6	5.0	8
Kaiser 0-26 cm	Top	<.01	0.02	0.03	0.03					<.01				0.2		1.0	1.6	3
	Bottom	<.01	0.01	0.01	0.05				↓	<.01				0.3		1.0	1.6	3
Lornex Bulk (Emerg. Pond)	Top	0.02	0.14	2.26	1.35	<.001%			0.04	0.01			<.01%	0.2	<.01%	0.9	6.9	25
	Bottom	0.02	0.15	2.31	1.31				0.04	0.01				0.3		0.9	6.9	26
Lornex Fresh	Top	0.03	0.07	2.04	1.65				0.13	0.01				0.2		1.2	5.7	26
	Bottom	0.03	0.08	2.07	1.58				0.15	0.01				0.2	↓	1.1	5.8	26
Similkameen 30-60 cm	Top	0.67	1.99	3.45	1.09				0.07	0.06				0.9	0.01	4.5	8.2	19
	Bottom	0.76	2.07	3.44	1.09				0.08	0.06			↓	0.9	<.01	4.7	8.2	18
Sullivan Fe Oxidized Bulk	Top	0.01	0.21	0.13	0.18				0.02	0.10			0.08	0.2	0.18	35.9	1.0	3
	Bottom	<.01	0.22	0.09	0.15	↓	↓	↓	0.01	0.11	↓	↓	0.33	0.1	0.18	36.9	0.8	3
Sullivan Gypsum Bulk	Top	no sample																
	Bottom	6.17	0.02	0.03	0.07	<.001	<.01	0.003	<.01	<.01	<.01	<.01	<.01	0.1	0.01	1.0	0.2	19
Sullivan Gypsum 36-50 cm	Top	no sample																
	Bottom	16.70	0.03	0.03	0.10	<.001	↑	0.023	<.01	<.01	↑	↑	<.01	0.2	0.01	0.2	0.3	8
Sullivan Gypsum 69-76 cm	Top	1.37	0.03	0.04	0.13	0.001		0.012	<.01	<.01			<.01	0.1	0.01	0.7	0.4	33
	Bottom	3.03	0.03	0.04	0.11	↑		0.014	<.01	<.01			<.01	0.1	0.02	0.9	0.4	27
Sullivan Si Oxidized Bulk	Top	0.03	1.15	0.81	1.22	<.001%	<.01%	<.001	0.01	0.46	<.01%	<.01%	0.08	0.5	0.18	15.9	5.2	17
	Bottom	0.09	1.13	0.69	1.18			<.001	0.01	0.43			0.50	0.5	0.17	15.0	4.9	15
Sullivan Si Fresh	Top	0.01	0.95	0.21	0.31			<.001	<.01	0.13			0.52	0.2	0.45	34.9	2.0	6
	Bottom	0.01	0.85	0.20	0.26	↓	↓	<.001	0.03	0.12	↓	↓	0.47	0.2	0.45	38.9	1.8	5

*Botton refers to the lower 5 cm of tailings in the Soxhlet thimble; the top is the remainder.

Table 6:2 : Total Elemental Analysis of Soxhelt Weathered Mine Tailings

(Distilled Water Weathered)

Sample	*	Ca	Mg	Na	K	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Ti	Zn	Fe	Al	Si
		%																
Bethlehem Fresh	Top	0.27	0.54	2.99	1.12		<.01	0.004	0.15	0.01	<.01	<.01		0.4	<.01	1.7	6.8	25
	Bottom	0.32	0.54	3.05	1.08		<.01	<.001	0.16	0.01	<.01	<.01		0.4	<.01	1.5	6.9	24
Brenda 0-8 cm	Top	0.47	0.67	2.29	2.17		<.01	<.001	0.01	0.05	<.01	<.01		0.4	0.01	2.5	6.8	25
	Bottom	0.50	0.65	2.24	2.17		<.01	0.086	0.01	0.06	<.01	0.04		0.4	0.03	3.2	6.7	25
Emerald 3 14.5-38.5 cm	Top	4.96	1.24	0.30	0.35		0.01	0.008	0.03	1.03	0.01	<.01		0.1	0.02	16.8	1.4	15
	Bottom	5.41	1.27	0.29	0.35		0.02	0.016	0.04	1.03	0.01	0.02	<.01	0.1	0.02	16.6	1.3	14
Endako Bulk	Top	0.07	0.29	2.03	3.21			0.003	0.01	0.04	<.01	<.01		0.3	0.01	1.9	5.4	27
	Bottom	0.12	0.31	2.00	3.02			0.004	<.01	0.04	0.02	<.01		0.3	0.01	2.0	5.2	27
Gibraltar Fresh	Top	0.36	0.81	1.95	0.82			0.050	0.13	0.05		<.01		0.5	0.02	3.5	6.8	23
	Bottom	0.36	0.86	1.96	0.79			0.071	0.12	0.05		0.03		0.5	0.02	3.6	6.9	25
H.B. Fresh Fines	Top	17.6	7.60	0.05	0.18			<.001		0.04			0.14	0.1	0.28	3.0	0.5	3
	Bottom	18.1	7.70	0.04	0.15			0.005		0.04			0.15	0.1	0.28	3.0	0.4	3
Kaiser Fresh	Top	<.01	0.11	0.04	0.35	<.001	<.01	<.001	<.01	<.01	<.01	<.01	<.01	0.6	<.01	1.2	5.2	11
	Bottom	<.01	0.15	0.03	0.48			<.001		<.01			<.01	0.6	<.01	1.0	5.5	12
Kaiser C-26 cm	Top	<.01	0.01	0.01	<.01			<.001		<.01			1.00	0.2	<.01	1.0	1.8	4
	Bottom	<.01	0.01	0.01	<.01			<.001		<.01			1.10	0.2	<.01	1.1	1.8	4
Lornex Bulk (Emerg. Pond)	Top	0.21	0.23	2.25	1.28			0.001	0.06	0.04	0.01			0.2	0.01	1.1	5.6	28
	Bottom	0.22	0.23	2.30	1.30			0.004	0.06	0.04	<.01			0.2	0.01	1.0	5.7	28
Lornex Fresh	Top	0.37	0.51	3.03	1.12			<.001	0.17	0.02	0.01		.01%	0.2	<.01	1.3	5.7	25
	Bottom	0.39	0.57	3.07	1.15			<.001	0.17	0.02	<.01			0.4	<.01	1.6	6.8	24
Similkameen 30-60 cm	Top	1.71	1.97	3.28	1.06			0.018	0.08	0.08	0.01			0.6	0.02	4.2	6.5	19
	Bottom	1.52	1.83	3.28	1.04			0.004	0.08	0.07	0.01			0.6	0.01	3.8	6.6	19
Sullivan Fe Oxidized Bulk	Top	<.01	0.23	0.09	0.12			<.001	0.02	0.11	<.01		0.32	0.2	0.17	37.9	0.8	3
	Bottom	<.01	0.21	0.21	0.22			<.001	0.02	0.10	<.01		0.51	0.1	0.15	35.9	0.8	3
Sullivan Gypsum Bulk	Top	no sample																
	Bottom	6.13	0.02	0.01	0.10			0.020	0.01	<.01	<.01		<.01	0.1	0.15	1.1	0.3	22
Sullivan Gypsum 36-50 cm	Top	17.6	0.30	0.03	0.10			0.019	<.01	<.01	<.01		<.01	0.1	0.01	0.2	0.2	5
	Bottom	18.5	0.34	0.01	0.02			0.021	<.01	<.01	<.01		<.01	0.1	0.01	0.2	0.1	4
Sullivan Gypsum 69-76 cm	Top	no sample																
	Bottom	3.24	0.33	0.03	0.08			0.021	<.01	<.01	0.02		<.01	0.2	0.01	1.1	0.4	28
Sullivan Si Oxidized Bulk	Top	0.02	1.20	0.77	1.16			0.003	0.01	0.52	<.01		0.44	0.5	0.18	15.9	5.2	16
	Bottom	0.03	1.17	0.78	1.17			0.001	0.01	0.51	<.01		0.51	0.6	0.18	15.9	5.1	16
Sullivan Si Fresh	Top	0.01	0.88	0.21	0.33			0.004	0.03	0.13	<.01		0.64	0.1	0.43	37.0	1.8	5
	Bottom	<.01	0.83	0.19	0.30			0.004	0.04	0.13	<.01		0.51	0.1	0.42	36.0	1.7	4

* Bottom refers to the lower 5 cm. of tailings in the Soxhlet thimble; the top is the remainder.

Table 6:3 : Total Elemental Analysis of Original Mine Tailings

Sample	Ca	Mg	Na	K	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Ti	Zn	Fe	Al	Si
	%																
Bethlehem Fresh	0.26	0.55	3.03	1.16	0.001		0.001	0.17	0.01	0.02	0.02	<.01	0.1	<.01	1.8	7.9	16
Brenda 0-8 cm	0.40	0.71	2.36	2.29	0.001		0.001	0.04	0.05	0.01	0.01	<.01	0.6	0.01	4.1	7.6	15
Emerald 3 14.5-38.5 cm	6.52	1.23	0.28	0.34	0.001		0.001	0.04	0.98	<.01	0.02	<.01	0.2	0.01	15.6	1.7	10
Gibraltar Fresh	0.30	0.83	2.05	0.81	<.001		0.001	0.11	0.04	0.01	0.01	<.01	0.5	<.01	3.5	7.1	17
H.B. Fresh Fines	17.29	5.78	0.02	0.19	0.003		0.001	0.02	0.04	<.01	0.03	0.09	<.1	0.32	3.0	0.1	<1
Kaiser Fresh	<.01	0.16	0.03	0.45	<.001		<.001	0.02	<.01	<.01	0.01	<.01	0.6	<.01	1.2	5.6	4
Kaiser 0-26 cm	<.01	0.02	0.03	0.06	<.001	<.01%	<.001	0.01	<.01	<.01	<.01	<.01	0.2	<.01	1.3	2.1	1
Lornex Fresh	0.07	0.18	2.13	1.75	<.001		0.001	0.27	0.02	0.01	0.02	0.03	0.3	0.01	1.7	6.8	19
Similkameen 30-60 cm	1.66	2.01	3.28	1.15	0.002		0.002	0.10	0.08	<.01	0.01	0.03	1.0	0.01	4.8	8.9	14
Sullivan Gypsum 36-50 cm	17.90	0.05	0.02	0.07	0.003		0.018	0.05	<.01	<.01	0.02	<.01	<.1	0.01	0.3	0.2	1
Sullivan Gypsum 69-76 cm	11.09	0.04	0.01	0.11	0.005		0.018	0.06	<.01	<.01	0.03	0.18	<.1	0.06	0.8	0.2	12
Sullivan Si Fresh	0.08	1.07	0.27	0.38	0.001		0.001	0.05	0.17	<.01	0.02	0.59	0.2	0.48	45.4	2.3	2

surface of the thimble and consequently, a comparison of top portions with the origianl materials indicate the more extreme differences. For example, it can be seen that in most cases, the percentage of Ca is much lower in the top portion of the weathered sample whereas the percentage of K and often Na are higher. The removal of these cations is less rapid because of their incorporation into the actual mineral structures, and hence they lack reactivity. Relative proportions of these elements in the top portion are changing with the time as Ca is depleted and K and Na are accumulated. Most heavy metals are not readily mobile in environments with pH >5.5, but some indication of movement downward in the profile is evident by higher values in the bottom portions. With 0.3N acetic acid, they tend to be slightly solubilized, due to the more acidic environment which results in higher solubility. Higher percentages of Al and Si in the top portion of the weathered material also reflects their slow solubility.

B. <u>pH and Nutrient Availability of Accumulation Products vs. Originals</u>

a) Tables 6:4, 6:5 and 6:6 give results of pH and avialable nutrients of the original unweathered and the Soxhlet weathered mine tailings. Nutrient availability by definition is pH dependent. As pH decreases, availability of the dominant cations increases. The 0.3N acetic acid solution as it is added to the leaching system is pH 2.7. It quickly depletes the major cations of the siliceous tailings such as Lornex and Bethlehem. In the acidic environment, the portion of exchange sites occupied by

Table 6:4 : Available Nutrients of Soxhlet Weathered Mine Tailings

(0.3N Acetic Acid Weathered)

Sample	*	pH H_2O	pH 0.1M $CaCl_2$	Available Ca (ppm)	Available Mg (ppm)	Available K (ppm)	Cu (ppm, available with 0.1N HCl)	Zn	Fe	Mn	Pb	Cd	Co
Bethlehem Fresh	Top	4.0	3.7	<.5	15.0	13.0	36.5	2.0	280	30.5	<1.0	<.1	<1.0
	Bottom	4.1	3.9	3.0	9.0	15.0	55.5	2.5	460	68.5	2.0	0.3	2.0
Brenda 0-8 cm	Top	4.3	3.9	<.5	20.5	89.0	10.2	5.6	1630	376	<1.0	<.1	2.0
	Bottom	4.5	4.1	<.5	21.5	113.0	5.1	4.4	980	199	1.0	0.3	2.0
Emerald 3 14.5-38.5 cm	Top	4.2	4.7	6865	103.5	4.5	0.2	7.9	3180	12699	3.0	1.1	8.0
	Bottom	6.8	6.5	20700	183.5	5.5	<.1	<.1	1.0	10399	1.0	1.0	8.0
Endako Bulk	Top	4.1	3.8	<.5	4.0	22.0	4.0	0.7	260	127	<1.0	<.1	1.0
	Bottom	4.1	4.0	<.5	4.5	23.5	3.7	1.1	490	156	<1.0	<.1	2.0
Gibraltar Fresh	Top	4.5	4.2	3.5	2.0	4.5	11.5	0.1	60.0	43.5	<1.0	<.1	1.0
	Bottom	4.4	4.1	<.5	1.5	1.0	12.3	0.1	80.0	38.5	<1.0	0.3	1.0
W.B. Fresh Fines	Top	7.4	7.3	19250	933.5	37.5	0.2	252	10.0	506	8.0	6.6	4.0
	Bottom	7.7	7.1	20600	868.5	60.0	<.1	418	<1.0	383	6.0	5.7	38.0
Kaiser Fresh	Top	3.6	3.7	↑	2.0	4.5	5.6	0.1	20.0	<.1	1.0	<.1	<1.0
	Bottom	3.6	3.7		3.0	4.5	10.1	0.8	30.0	<.1	2.0	<.1	<1.0
Kaiser 0-26 cm	Top	3.4	3.4		2.0	2.5	3.2	1.0	30.0	6.5	6.0	<.1	4.0
	Bottom	3.3	3.3		1.0	<.5	2.8	7.4	70.0	1.5	2.0	<.1	<1.0
Lornex Bulk (Emerg. Pond)	Top	4.1	4.0	<.5	1.5	12.5	24.4	3.3	200	146	<1.0	<.1	<1.0
	Bottom	4.1	3.8		2.5	17.5	30.7	4.1	340	192	<1.0	<.1	<1.0
Lornex Fresh	Top	4.1	4.0		2.0	9.5	32.0	4.1	60.0	128	<1.0	0.3	<1.0
	Bottom	4.2	4.0		1.5	8.0	94.0	1.9	120	174	<1.0	<.1	<1.0
Similkameen 30-60 cm	Top	4.0	4.2	↓	3.5	13.0	52.9	2.3	190	46.5	6.0	0.3	4.0
	Bottom	4.3	4.2	30.5	20.5	23.0	83.5	3.5	380	84.5	5.0	0.4	4.0
Sullivan Fe Oxidized Bulk	Top	3.5	3.8	2.0	1.5	.5	2.9	1.2	260	4.5	71.0	<.1	<1.0
	Bottom	3.5	3.7	47.5	3.0	34.5	3.1	1.6	370	5.5	2149	<.1	<1.0
Sullivan Gypsum Bulk	Top	no sample											
	Bottom	4.0	4.2	17850	1.0	20.0	3.1	1.9	60.0	4.5	2.0	0.4	2.0
Sullivan Gypsum 36-50 cm	Top	no sample											
	Bottom	3.6	3.8	8795	<.5	5.5	3.0	2.2	30.0	3.5	2.0	0.5	3.0
Sullivan Gypsum 69-76 cm	Top	no sample					1.2	1.9	240	7.5	9.0	0.5	3.0
	Bottom	3.1	3.4	373.5	<.5	7.5	1.8	1.7	240	28.5	6.0	0.7	3.0
Sullivan Si Oxidized Bulk	Top	3.3	3.9	<.5	7.5	11.5	1.7	1.6	320	28.5	69.0	<.1	1.0
	Bottom	3.7	3.9	2580	11.0	19.5	3.0	2.3	330	60.5	263	0.3	2.0
Sullivan Si Fresh	Top	2.7	3.1	10.5	10.5	2.5	5.4	2040	43980	119	84.0	6.8	15.0
	Bottom	4.1	3.8	5.5	7.0	11.5	27.4	1170	32980	116	134	6.9	12.0

* Bottom refers to the lower 5 cm of tailings to the Soxhlet thimble; the top is the remainder.

Table 6:5 : Available Nutrients of Soxhlet Weathered Mine Tailings

(Distilled Water Weathered)

Sample	*	pH		Available			Available with 0.1N HCl						
		H_2O	0.1M $CaCl_2$	Ca (ppm)	Mg (ppm)	K (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Pb (ppm)	Cd (ppm)	Co (ppm)
Bethlehem Fresh	Top	7.9	7.3	4315	17.0	30.5	315	3.6	580	899	1.0	0.7	3.0
	Bottom	8.0	7.3	5450	25.5	36.5	273	3.7	570	929	1.0	0.7	4.0
Brenda 0-8 cm	Top	8.3	7.7	5685	45.0	206.0	39.0	9.3	1040	2349	6.0	0.6	4.0
	Bottom	8.0	7.9	5660	41.0	204.0	39.7	8.1	980	2539	4.0	0.7	4.0
Emerald 3 14.5-38.5 cm	Top	7.0	6.9	22700	200.0	7.0	<.1	1.9	<1.0	7499	2.0	0.6	6.0
	Bottom	7.1	7.0	22950	180.0	8.5	0.1	0.9	<1.0	6999	1.0	0.7	6.0
Endako Bulk	Top	7.3	6.7	1755	120.0	26.0	16.6	4.7	1730	4369	3.0	0.3	3.0
	Bottom	8.0	7.1	3195	65.0	34.5	17.4	5.0	1710	4979	3.0	0.4	4.0
Gibraltar Fresh	Top	8.4	7.5	4050	30.0	4.5	299	3.9	520	1899	3.0	0.5	4.0
	Bottom	8.4	7.4	2295	24.5	5.5	312	3.5	430	1649	2.0	0.3	3.0
H.B. Fresh Fines	Top	7.7	7.3	23500	768.5	89.5	0.1	730	10.0	365	3.0	5.6	4.0
	Bottom	7.7	7.3	23850	788.5	89.5	<.1	610	<1.0	351	2.0	5.2	4.0
Kaiser Fresh	Top	7.3	6.5	460.0	130.0	8.0	19.4	8.6	860	241	2.0	0.3	3.0
	Bottom	7.3	6.8	910.0	130.0	9.5	34.0	11.1	1160	194	3.0	0.3	3.0
Kaiser 0-26 cm	Top	4.9	4.5	369.0	16.0	2.0	17.5	6.4	380	90.5	2.0	<.1	<1.0
	Bottom	5.5	5.0	333.0	22.0	4.0	15.3	5.9	370	101	4.0	<.1	<1.0
Lornex Bulk	Top	8.2	6.5	8150	60.0	19.0	150	7.5	460	4059	<1.0	1.0	5.0
	Bottom	8.3	6.6	9250	70.0	28.0	70.5	5.1	380	4049	<1.0	1.0	5.0
Lornex Fresh	Top	6.9	5.2	265.0	24.5	12.5	1560	10.8	730	2119	<1.0	0.4	2.0
(Emerg. Pond)	Bottom	7.3	6.1	595.0	25.5	19.0	1630	14.8	1020	2649	<1.0	0.4	3.0
Similkameen 30-60 cm	Top	7.4	7.2	13900	150.0	54.5	1.0	2.2	20.0	1509	1.0	0.8	5.0
	Bottom	8.2	7.7	15450	85.0	98.0	0.5	1.4	10.0	1459	2.0	0.8	5.0
Sullivan Fe Oxidized	Top	4.4	4.4	2.1	22.5	5.0	14.3	6.7	230	325	1779	<.1	<1.0
Bulk	Bottom	3.9	3.9	11.0	21.5	2.0	5.3	4.1	230	24.5	3449	<.1	<1.0
Sullivan Gypsum Bulk	Top	no sample											
	Bottom	5.2	4.8	8750	15.5	5.5	9.5	2.5	1070	39.5	8.0	0.8	4.0
Sullivan Gypsum	Top	5.0	5.3	16770	1.0	21.0	3.5	1.5	770	10.5	12.0	0.8	3.0
36-50 cm	Bottom	4.5	4.5	8355	1.0	4.5	2.6	0.9	570	10.5	8.0	0.7	3.0
Sullivan Gypsum	Top	no sample											
69-76 cm	Bottom	3.7	3.9	720.0	<.5	3.5	3.3	2.3	1090	20.5	2.0	0.8	3.0
Sullivan Si Oxidized	Top	4.6	4.2	4.7	110.0	16.5	18.7	18 2	270	174	2749	<.1	<1.0
Bulk	Bottom	4.2	4.0	13.9	105.0	23.0	7.1	11.6	310	162	2269	<.1	<1.0
Sullivan Si	Top	3.8	3.9	37.0	35.0	12.0	45.3	1160	30480	472	166	7.7	10.0
	Bottom	3.4	3.5	24.0	26.5	7.5	21.1	1360	31980	159	148	6.6	10.0

* Bottom refers to the lower 5 cm of tailings in the Soxhlet thimble; the top is the remainder

Table 6:6: Available Nutrients of Original Mine Tailings

Sample	pH		Available	Available			Available with 0.1 N HCl						
	H_2O	0.1N $CaCl_2$	P ppm	Ca (ppm)	Mg (ppm)	K (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	Pb (ppm)	Cd (ppm)	Co (ppm)
Bethlehem Fresh	8.6	8.2	2.0	7625	56.3	65.0	32.8	1.0	229	40.5	<1.0	<.1	1.0
Brenda 0-8 cm	8.4	7.7	<.1	7850	72.0	231	7.1	2.1	780	126	2.0	<.1	1.0
Emerald 3 14.5-38.5 cm	7.6	7.2	0.3	31875	166	27.5	<.1	<.1	<1.0	321	1.5	<.1	1.5
Gibraltar Fresh	8.5	7.5	1.3	4850	50.0	22.0	98.3	1.2	555	113	<1.0	<.1	1.0
H.B. Fresh Fines	7.9	7.6	0.3	31125	885	86.3	<.1	57.5	<1.0	15.5	2.0	2.7	1.0
Kaiser Fresh	4.3	4.0	0.8	1730	144	60.0	8.3	4.2	860	9.8	4.0	0.1	1.0
Kaiser 0-26 cm	6.0	5.7	7.0	645	23.0	21.0	8.1	3.8	360	4.9	1.0	<.1	<1.0
Lornex Fresh	8.5	7.3	1.8	890	23.0	45.0	6.32	6.6	1230	153	<1.0	<.1	1.0
Similkameen 30-60 cm	7.7	7.5	0.6	18750	328	272	14.0	2.0	<1.0	74.5	1.5	<.1	2.0
Sullivan Gypsum 36-50 cm	3.9	4.0	70.8	11375	2.5	28.8	1.1	0.4	149	1.2	2.5	0.2	<1.0
Sullivan Gypsum 69-76 cm	3.2	3.4	97.8	11125	5.0	91.3	1.3	1.3	204	0.7	2.0	0.1	<1.0
Sullivan Si Fresh	4.3	4.0	<.1	3350	263	65.0	104	354	15000	238	43.5	2.3	3.5

Data in Tables 6:4 and 5 show that in almost all cases there is more heavy metal availability in the distilled water weathered tailings, than in unweathered tailings. The least avialability occurs in the 0.3N acetic acid weathered tailings. The higher avialability in the unweathered tailings in comparison to the acetic acid weathered tailings shows that most of the available metals were removed by the acid leaching. With distilled water, not only is there no depletion of available metals but there is actually much higher availability than in the unweathered materials. This may imply that although the water weathering in a distilled water system creates more available metals as the product is weathered, these metals are not removed from the system. It is likely that availability of these metals is increased quite markedly by the 0.3N acetic acid, but since they are quickly leached out of the sample, this is not indicated in the availability data.

C. Fe, Al, Si and Mn Extracted from Accumulation Products vs. Originals

Fe, Al, Si and Mn is useful in supplying information concerning the degree of weathering of soils. By measuring the quantities of these elements extractable by a variety of extracting solutions, the accumulation of secondary products of weathering can be measured and distinguished from those inherited with the parent material. This information is of ultimate importance in the classification of soils.

The solutions used to extract secondary products are recognized as being indicators of specific forms of Fe, Al, Si and available cations such as Ca^{++} and Mg^{++} are replaced by H^{+}. The displaced cations are then subject to leaching by the percolating solution. The buffering ability of the acid keeps the pH relatively low. As the solutions is recycled, the H^{+} substitution for Ca^{++} and Mg^{++} continues.

Sullivan tailings are acidio by nature and as a consequence, nutrient availability is not strongly affected by the acetic acid.

Distilled water weathering has much less influenoe on removal of these cations. The neutral pH and lack of buffering ability of water minimizes the extent of cation displacement. The silica-rich as well as the coal tailings, however, are still found to be efficiently depleted of these cations. Sullivan tailings effectively lower the pH of the leaching solution by their own nature and the extent of available nutrient removal is not greatly different from the acetic acid system.

Most tailings materials found to be easily depleted of their available nutrients in either the 0.3N acetic acid or the distilled water weathering system can be anticipated to have poor nutrient-supplying capacities and therefore be relatively infertile. Sullivan tailings differ somewhat in that availability is low, but constant. The long-term nutrient-supplying capacity will be better, for depletion is less rapid.

b) With 0.1N HCl

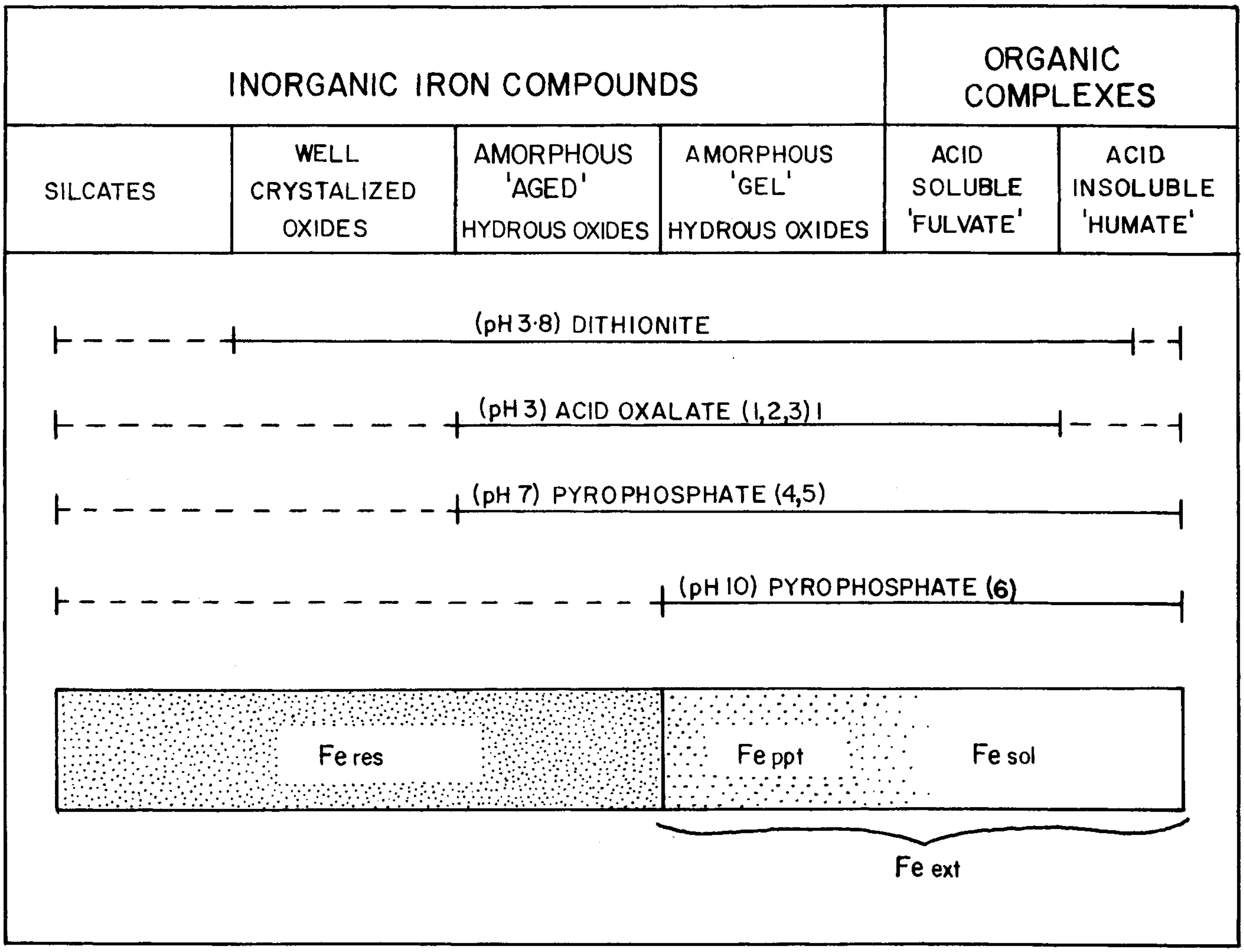
Nutrient availability with 0.1N HCl is significant in determining removal of potentially toxic heavy metals. Release of these metals indicates amounts that would be slowly available.

Mn present in soils. The relationship of the three extractants is presented in Figure 6:2. Sodium Pyrophosphate (pH 10) is used as an extractant of Fe and Al (Si, Mn) that is organically bound or that is in a very fine amorphous state. Acid Ammonium Oxalate extracts the above mentioned finely amorphous materials as well as those present in more stable amorphous compounds are hydrous oxides. Citrate-Bicarbonate-Dithionite (CBD) extractions measure both the preceding forms and more permanent, crystalline oxides of Fe and Al (Si, Mn). The methods of these extraction procedures are described in the Pedological Methods Manual (Lavkulich, 1977).

The value of applying these extraction procedures to mine wastes is in studying the chemical and physical breakdown and alteration occurring during weathering. As soil-forming processes progress, geologic materials such as tailings, are degraded and secondary products are created by dissolution and concomitent precipitation. These products tend to form coatings or discrete particles on individual grains known as free oxides. If these oxides remain in the system long enough, they tend to become stable or unreactive. As a result, the more reactive grains are in effect, protected by the inert coatings and particles. Qualitative and quantitative analysis of the free oxides allows recent products of weathering to be differentiated from inherited products.

Tables 6:7 and 6:8 indicate analysis of extractable Fe, Al, Si and Mn from the top and bottom portions of the 0.3N actic acid and distilled water weathered tailings. Table 6:9 indicates this analysis for the original unweathered tailings.

FIGURE 6:2: RANGES OF COMPOUNDS REMOVABLE BY DIFFERENT EXTRACTANTS*



———— EXTRACTION GOOD

(1) SCHWERTMANN, 1959
(2) KELLERMAN & TYSURUPA, 1965
(3) MCKEAGUE & DAY, 1965

— — — — EXTRACTION POOR

(4) KONONOVA & TITOVA, 1959
(5) KOSAKA & IZEKI, 1957
(6) DUCHAUFOUR & JACQUIN, 1966

* BASCOMB, 1968

Table 6:7 : Extractable Fe, Al, Si, Mn of Soxhlet Weathered Mine Tailings

(0.3N Acetic Acid Weathered)

Sample	*	Sodium Pyrophosphate Fe	Al	Si	Mn	Acid Ammonium Oxalate Fe	Al	Si	Mn	Citrate-Bicarbonate-Dithionite Fe	Al	Si	Mn
		ppm				ppm				ppm			
Bethlehem Fresh	Top	40	540	800	<1	656	408	120	3.2	650	775	<250	<3
	Bottom	70	570	500	<1	948	700	520	1.6	1150	850	<250	<3
Brenda 0-8 cm	Top	80	490	500	1	716	600	120	4.0	1150	375	<250	3
	Bottom	160	420	300	<1	1800	544	200	3.6	1850	350	<250	3
Emerald 3 14.5-38.5 cm	Top	6800	90	200	218	12000	376	360	508	77500	825	1000	1110
	Bottom	750	<10	300	436	14400	192	640	900	4850	175	1250	1223
Endako Bulk	Top	180	990	900	<1	640	592	80	3.6	2250	2900	250	<3
	Bottom	190	850	400	5	1120	732	200	6.4	2425	2225	<250	<3
Gibraltar Fresh	Top	30	150	300	<1	216	160	40	<.4	575	150	<250	5
	Bottom	30	160	300	<1	324	188	80	0.4	650	125	250	<3
H.B. Fresh Fines	Top	450	20	100	25	2200	88	120	3.2	3275	75	250	45
	Bottom	310	10	200	20	2480	76	160	23.2	2200	50	250	30
Kaiser Fresh	Top	100	230	<100	<1	800	272	40	<.4	525	950	<250	<3
	Bottom	200	220	<100	<1	320	268	40	<.4	525	650	<250	<3
Kaiser 0-26 cm	Top	400	260	<100	3	1960	108	<10	1.2	1575	50	<250	5
	Bottom	200	270	<100	1	1120	108	<10	0.8	1700	75	<250	5
Lornex Bulk (Emerg. Pond)	Top	130	1120	800	<1	428	800	160	3.6	1050	400	<250	<3
	Bottom	70	690	200	1	908	828	200	6.4	1775	350	250	<3
Lornex Fresh	Top	50	540	500	<1	272	352	40	2.0	2125	275	<250	13
	Bottom	40	490	300	<1	372	336	40	1.6	1875	300	<250	8
Similkameen 30-60 cm	Top	300	2690	800	<1	3600	3800	1280	10.0	4700	2925	1000	10
	Bottom	290	1770	500	<1	1280	1320	1040	13.6	2875	1850	500	10
Sullivan Fe Oxidized Bulk	Top	200	20	<100	3	6400	156	<10	2.0	142500	750	<250	130
	Bottom	190	20	<100	2	8800	152	<10	2.4	122500	675	1000	125
Sullivan Gypsum Bulk	Top	no sample											
	Bottom	170	20	100	<1	44	20	40	<.4	450	325	<250	<3
Sullivan Gypsum 36-50 cm	Top	no sample											
	Bottom	<10	10	800	<1	32	48	80	<.4	300	400	750	<3
Sullivan Gypsum 69-76 cm	Top	210	<10	1100	1	224	16	80	3.2	1050	50	250	<3
	Bottom	230	<10	600	<1	268	20	80	3.2	1075	75	250	<3
Sullivan Si Oxidized Bulk	Top	230	290	<100	<1	3080	528	80	4.4	107500	25	750	588
	Bottom	290	260	1600	3	4000	600	80	4.8	95000	25	2500	563
Sullivan Si Fresh	Top	32000	110	<100	2	40000	392	120	9.2	50500	25	<250	13
	Bottom	19000	30	<100	1	33600	252	120	7.2	64250	25	<250	40

* Bottom refers to the lower 5 cm of tailings material in the Soxhlet thimble; the top is the remainder.

Table 6:8 : Extractable Fe, Al, Si, Mn of Soxhlet Weathered Mine Tailings

(Distilled Water Weathered)

Sample	*	Sodium Pyrophosphate Fe	Al	Si	Mn	Acid Ammonium Oxalate Fe	Al	Si	Mn	Citrate-Bicarbonate-Dithionite Fe	Al	Si	Mn
		ppm				ppm				ppm			
Bethlehem Fresh	Top	70	120	200	<1	1040	444	640	21.6	1025	75	<250	28
	Bottom	50	60	200	<1	960	428	640	12.4	875	75	250	30
Brenda 0-8 cm	Top	90	70	200	41	2080	372	400	55.2	1500	125	<250	90
	Bottom	120	60	100	52	2560	396	480	48.8	1400	125	<250	88
Emerald 3 14.5-38.5 cm	Top	1100	<10	<100	259	15200	240	640	820	47500	250	500	1575
	Bottom	500	<10	<100	236	18800	196	760	740	47500	175	500	1150
Endako Bulk	Top	70	140	200	53	4040	812	760	204	2475	100	<250	123
	Bottom	70	90	200	53	3600	772	880	148	1550	75	<250	80
Gibraltar Fresh	Top	20	40	100	21	760	160	200	27.6	875	75	<250	38
	Bottom	10	50	100	16	760	168	160	60.0	800	125	<250	65
H. B. Fresh Fines	Top	310	20	100	19	2440	120	280	58.4	1400	<25	<250	13
	Bottom	360	30	<100	20	1840	60	120	30.8	2175	75	<250	38
Kaiser Fresh	Top	60	150	100	4	3280	160	160	19.6	2320	50	<250	15
	Bottom	30	90	100	<1	3080	80	120	19.2	1075	25	<250	13
Kaiser 0-26 cm	Top	60	40	100	4	2800	80	160	7.6	2625	<25	<250	<3
	Bottom	70	30	<100	3	2960	120	120	7.2	2500	75	<250	8
Lornex Bulk (Emerg. Pond)	Top	40	90	200	71	2680	704	720	120	1300	200	250	113
	Bottom	60	80	100	78	2640	680	720	104	1350	200	250	98
Lornex Fresh	Top	40	280	500	22	1520	200	240	118	1750	100	<250	125
	Bottom	20	180	400	19	2240	212	280	137	2375	100	<250	145
Similkameen 30-60 cm	Top	110	150	300	34	5960	1600	1720	61.6	2425	225	<250	33
	Bottom	120	160	300	36	6000	1560	1720	60.8	2350	225	<250	30
Sullivan Fe Oxidized Bulk	Top	60	20	<100	<1	4040	96	120	2.4	127500	775	500	88
	Bottom	50	10	<100	<1	3600	100	80	1.6	120000	600	500	85
Sullivan Gypsum Bulk	Top	no sample											
	Bottom	690	60	100	<1	1200	80	240	2.8	1175	75	<250	<3
Sullivan Gypsum 36-50 cm	Top	180	130	300	<1	440	216	240	0.8	575	<25	<250	<3
	Bottom	120	210	200	<1	340	300	280	0.8	400	200	<250	<3
Sullivan Gypsum 69-76 cm	Top	no sample											
	Bottom	820	130	300	<1	1040	112	160	4.4	2400	75	<250	<3
Sullivan Si Oxidized Bulk	Top	60	100	200	<1	2200	288	280	12.8	72500	2025	750	305
	Bottom	120	150	1500	<1	3240	364	280	9.6	90000	1900	1750	363
Sullivan Si Fresh	Top	4100	20	<100	5	41200	264	360	34.8	52500	525	250	78
	Bottom	4200	20	<100	36	37600	304	240	16.0	52500	625	250	58

* Bottom refers to the lower 5 cm of tailings material in the Soxhlet thimble; the top is the remainder.

Table 6:9 : Extractable Fe, Al, Si, Mn of Original Mine Tailings

Sample	Sodium Pyrophosphate Fe	Sodium Pyrophosphate Al	Sodium Pyrophosphate Si	Sodium Pyrophosphate Mn	Acid Ammonium Oxalate Fe	Acid Ammonium Oxalate Al	Acid Ammonium Oxalate Si	Acid Ammonium Oxalate Mn	Citrate-Bicarbonate-Dithionite Fe	Citrate-Bicarbonate-Dithionite Al	Citrate-Bicarbonate-Dithionite Si	Citrate-Bicarbonate-Dithionite Mn
	ppm				ppm				ppm			
Bethlehem Fresh	50	100	200	16	1120	456	760	12.0	800	125	250	30
Brenda 0-8 cm	160	150	200	48	2560	352	280	36.8	1150	25	<250	28
Emerald 3 14.5-38.5 cm	320	<10	<100	254	28800	136	440	704	40000	25	250	600
Endako Bulk	180	230	300	71	2800	636	560	116	2075	150	250	118
Gibraltar Fresh	90	90	<100	29	520	160	80	14.4	575	25	<250	23
H.B. Fresh Fines	460	<10	200	26	680	168	160	60.0	1225	25	<250	18
Kaiser Fresh	50	40	<100	<1	2400	92	40	13.6	875	50	<250	8
Kaiser 0-26 cm	30	10	<100	<1	3040	64	<40	10.8	1525	25	<250	3
Lornex Bulk (Emerg. Pond)	170	160	500	92	2480	600	680	96.0	1550	250	750	170
Lornex Fresh	50	70	100	26	2120	196	320	116	1925	100	500	68
Similkameen 30-60 cm	410	150	500	47	4480	1276	1200	65.6	2500	200	<250	50
Sullivan Fe Oxidized Bulk	280	110	200	4	104000	372	400	32.8	175000	400	1500	148
Sullivan Gypsum Bulk	160	210	300	<1	260	248	480	5.6	350	250	250	15
Sullivan Gypsum 36-50 cm	60	260	100	<1	200	348	280	<.4	375	325	500	<3
Sullivan Gypsum 69-76 cm	460	310	<100	<1	396	244	160	<.4	1000	300	250	<3
Sullivan Si Oxidized Bulk	950	100	3300	16	23600	620	360	54.0	102500	925	2500	530
Sullivan Si Fresh	7000	10	<100	126	42800	460	560	244	48750	325	500	200

Figures 6:3, 6:4, 6:5, 6:6 graphically represent some of the relationships found in these tables. It must be noted at this point, that only the top portions of the weathered materials are graphed in the above figures. This is due to the fact that more intensive leaching and higher temperatures are attained in the upper portion during weathering. The changes that are taking place in this portion can be more easily exemplified. One indication of this is the change in color observable after weathering. The top and very outer boundaries of the material in the thimble are often noticeably reddened. Also, it appears that some of the very fine material is slowly being translocated downward in the thimble (Figure IV:16).

Sullivan Si Bulk and Lornex Bulk are examples of two general types of tailings materials represented in the Figures 6:3, 6:4, 6:5 and 6:6:sulfide-rich and silica-rich. Sullivan Si and Fe tailings are composed of up to 80% sulfide minerals and are therefore extremely acid by nature. As they weather, they inherently form fine-grain materials. Emerald tailings are less fine grained, but are similar to these tailings in some ways. Lornex, on the other hand, is similar to Bethlehem, Similkameen and Brenda and is inherently more coarse-grained and inert material. Coal also tends to behave similarly to Lornex in many respects.

The sulfide tailings shown in the previously mentioned figues generally follow the predicted extraction pattern of CBD > Acid Ammonium Oxalate > Sodium Pyrophosphate. An important consideration to note is that with these tailings, all concentrations

FIGURE 6:3: EXTRACTABLE IRON FROM ORIGINAL AND SOXHLET WEATHERED MINE TAILINGS

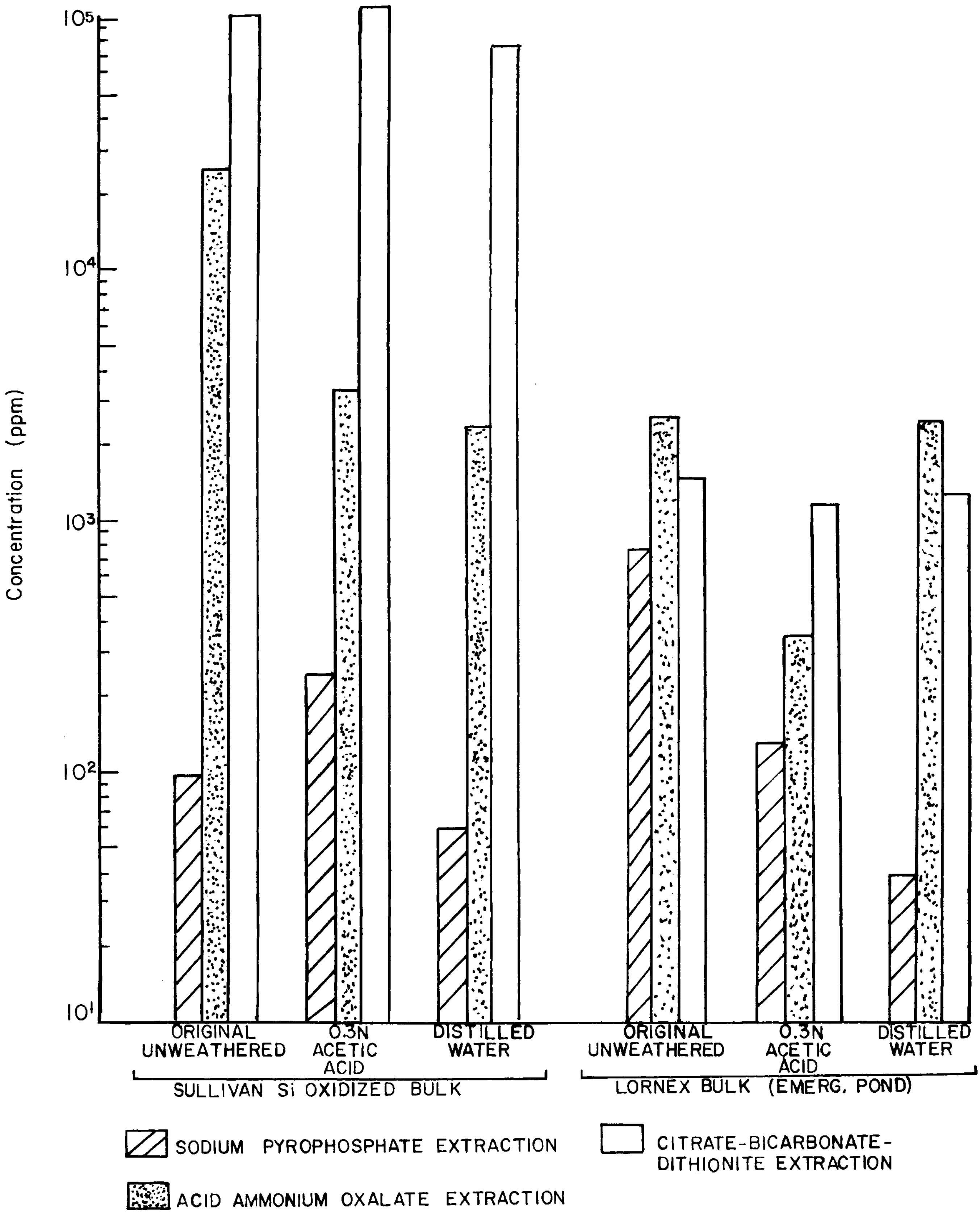


FIGURE 6: 4 : EXTRACTABLE ALUMINUM FROM SOXHLET WEATHERED MINE TAILINGS

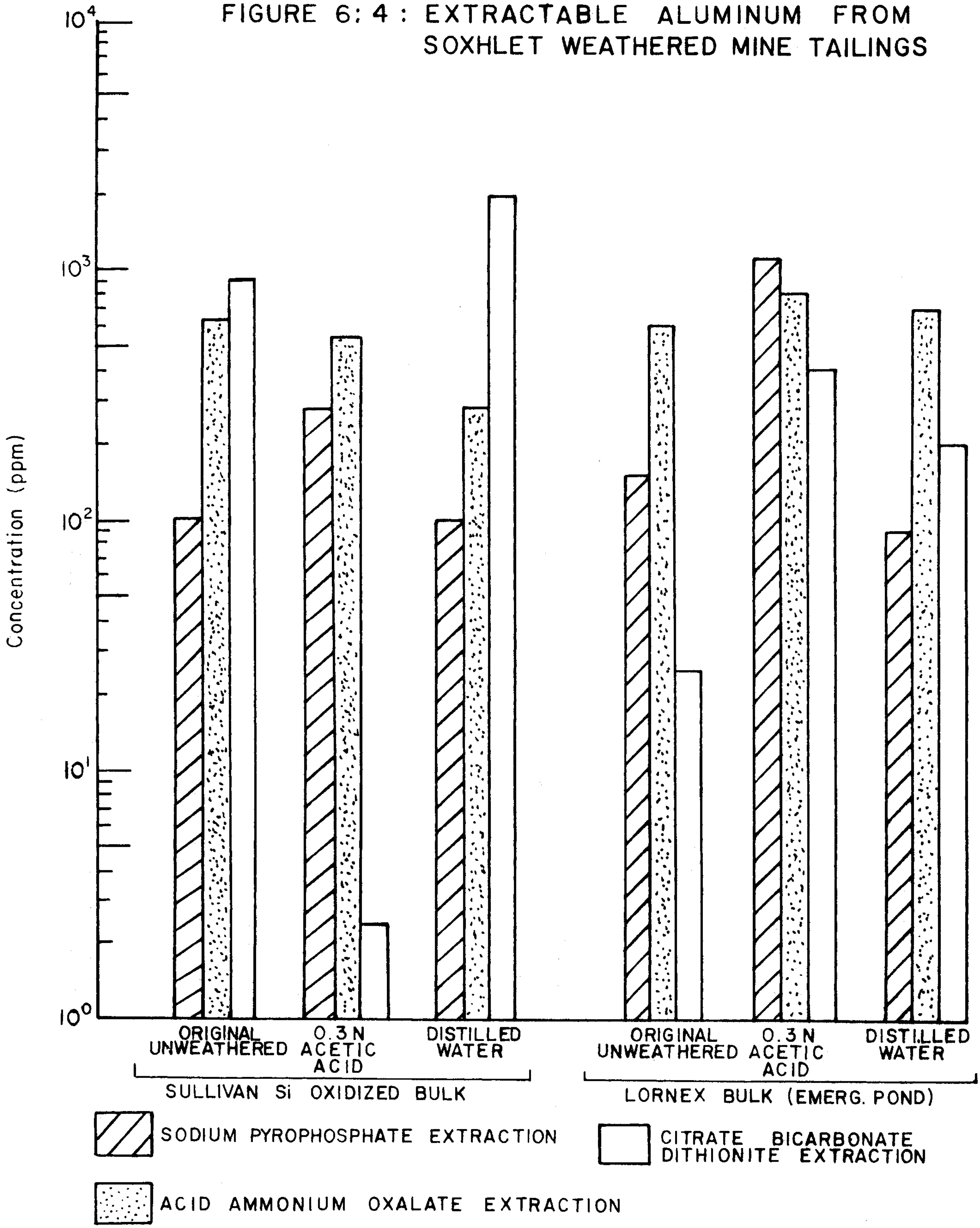


FIGURE 6:5: EXTRACTABLE SILICON FROM ORIGINAL AND SOXHLET WEATHERED MINE TAILINGS

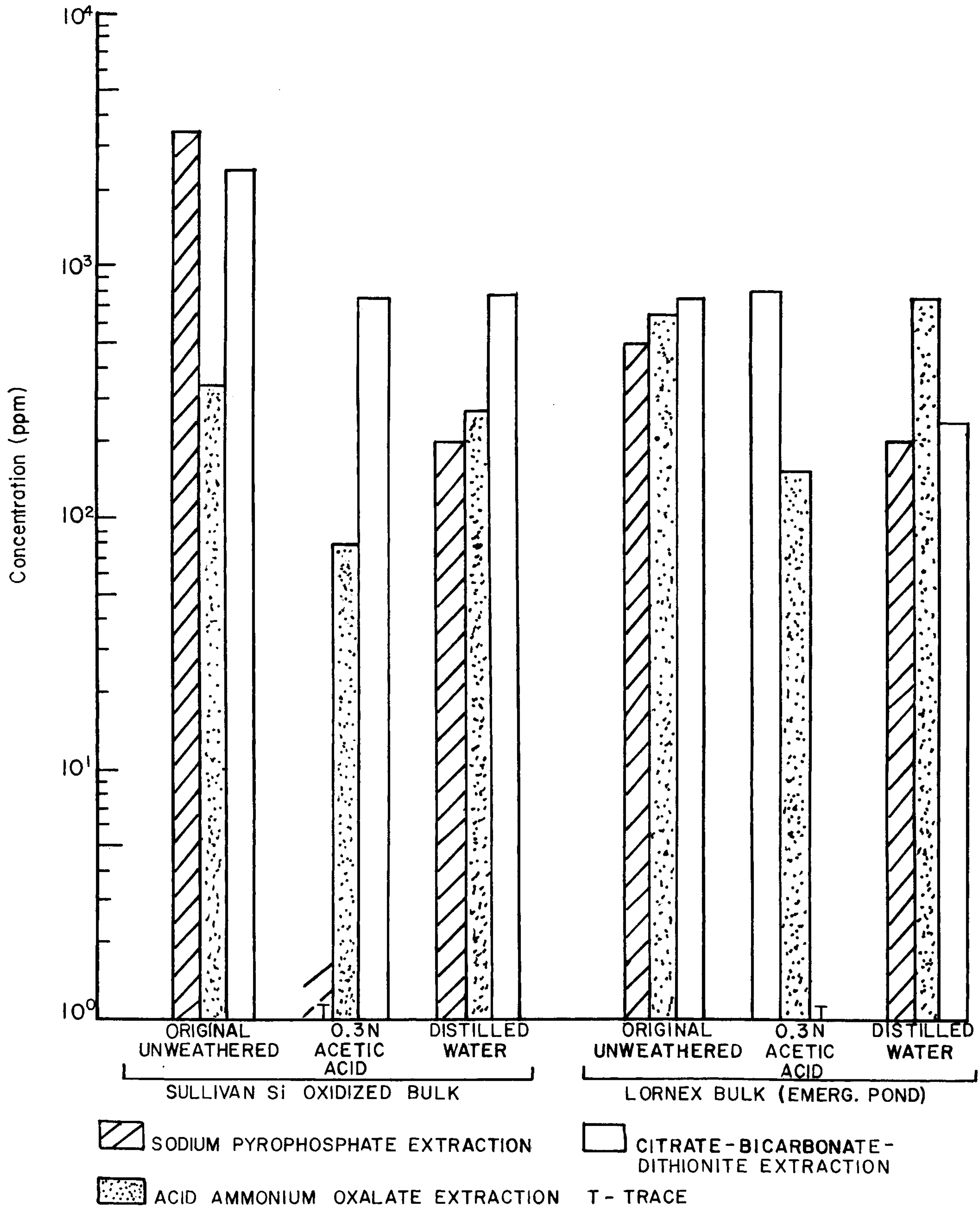
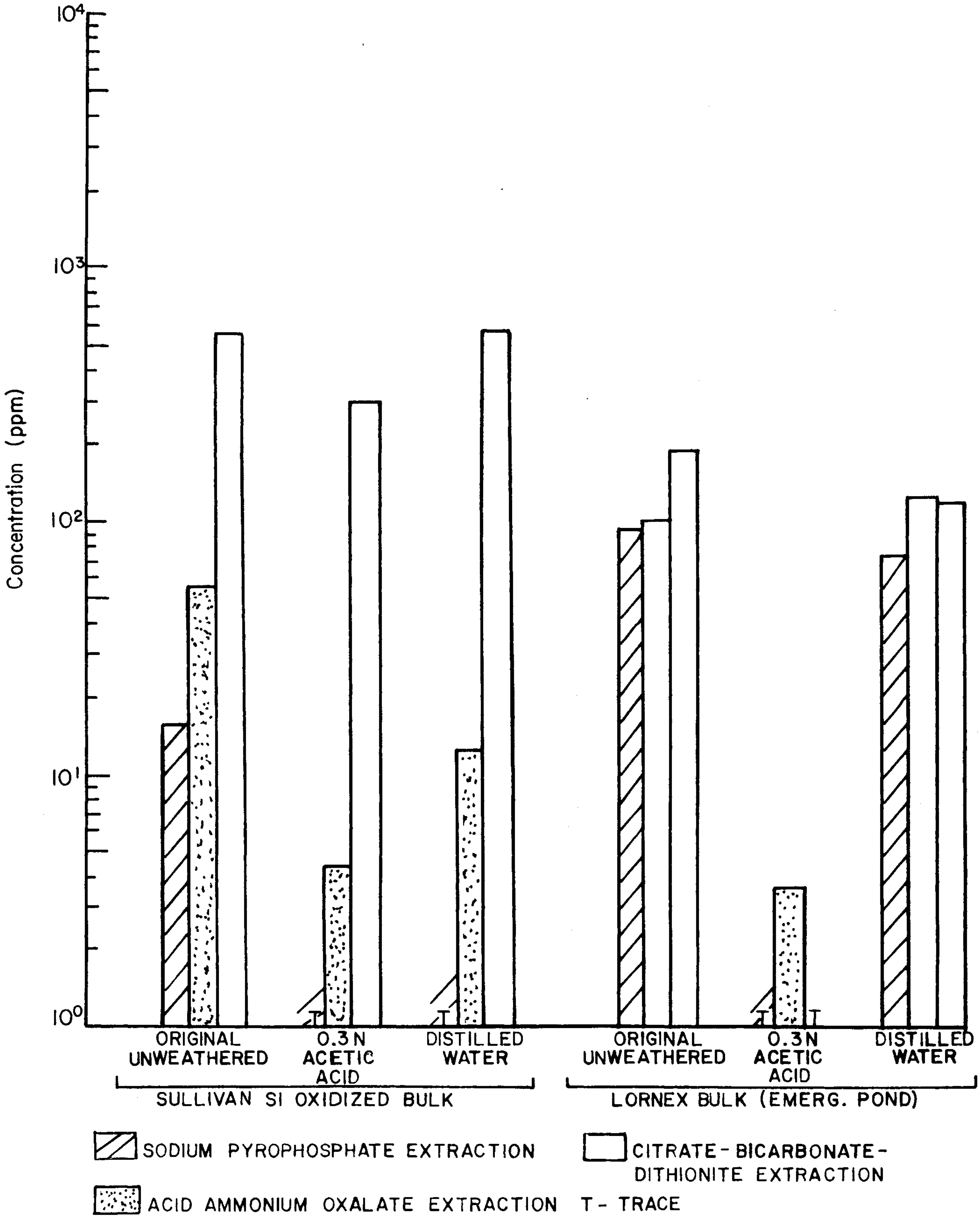


FIGURE 6:6 : EXTRACTABLE MANGANESE FROM ORIGINAL AND SOXHLET WEATHERED MINE TAILINGS



of the Sodium Pyrophosphate extractable Fe, and Al (Si,Mn) measured must be attributed to finely amorphous materials for there is no organic component. The scale of Fe extraction is much greater than for the other elements due to the extremely high quantities of Fe oxides present, particularly as well-crystallized coatings. Sullivan Si fresh is higher in amounts of non-crystalline coatings as indicated by the high concentrations of both Sodium Prophosphate and Acid Ammonium Oxalate extractable Fe. It has been crushed and weathering with consequent coating formation has not had a chance to occur. In time, it can be expected to behave in a similar manner as Sullivan Si Oxidized Bulk.

Al, Si and Mn conform to the patter of Fe extraction in most cases. The relative quantities extractable from the original and each case of the weathered material is similar, except that less Al is extracted with 0.3N acetic acid and higher Si is extracted for the original material.

The coarse-grained siliceous tailings do not follow the typical CBD > Acid Ammonium Oxalte > Sodium Phrophosphate extraction pattern, but instead Acid Ammonium Oxalate extraction seemed to be more significant. All concentrations of Fe, Si and Mn, but not Al, extracted are much lower than for the sulfide tailings. Fe and Al extraction for the 0.3N acetic acid weathered materials is relatively low as is Si extraction for the unweathered materials.

It is expected that the weathered tailings materials should be consistently higher in secondary products as the materials break down.

This was found, but at the same time, the quantities of these products are depleted as the leaching liquid removes soluble constituents from the system. The original tailings therefore, may seem to be higher in extractable Fe, Al, Si and Mn.

As these materials weather and elements are released, it is not strictly total removal that occurs. These elements may just be translocated or reassembled to form new compounds, resulting in qualitative change. The weathering process may solubilize compounds changing the well-crystallized oxides to less stable Acid Ammonium Oxalate or Sodium Pyrophosphate extractable forms. If little removal from the system occurs, the weathered materials may be similar to the original tailings in quantity of Fe, Al, Si and Mn but the distribution of compounds may be altered. If this is the case, a longer period of weathering would solubilize the coatings and remove them from the system. What is dissolved and removed by continuous hot leaching, perpetrates the inequilibrium of the solution-solid phases and promotes dissolution of the materials.

One other factor to be considered is that normally these extraction procedures involve grinding the sample to <.15 mm (100 mesh sieve). In analysis of the tailings for extractable Fe, Al Si and Mn, the material was not ground, but was just left as the <2 mm (10 mesh sieve) particle size fraction. This is because in this study interest is not in removal of all of the coatings, but to get some ideas as to what form coatings are *in situ* and how their relative amounts change in relation to weathering. For example, do the coatings on particles change from the more permanent hydrous oxides to a more soluble amorphous state after a period of weathering?

D. Analysis of Leachate

Tables 6:10 and 6:11 present analysis of leachate for weeks 1 and 3 for both the 0.3N acetic acid and distilled water weathered tailings. The pH of the initial leaching solution of distilled water is 5.6 while it is 2.7 for the 0.3N acetic acid. The change in pH measured weekly is an indication of changes occuring as soluble constituents are removed from the accumulation product. The leachate environment compounds forming change as soluble consitituents fluctuate between the solid and liquid phases (ie. solution and precipitate). This solubility equilibria is primarily a function of elements available in solution, pH, and temperature.

The pH from weeks 1 to 3 are good indication as to the ability of the tailings materials to buffer and therefore of their relative nutrient-supplying capacity. This data can be related to residual nutrient availability in the accumulation products (Tables 6:4 and 6:5). In most cases, Ca taken into solution was a factor of 10 to 100 times greater than minor elements and Mg, K and Na is solution varied largely with the material in question.

0.3N acetic acid weathering seemed to release higher quantities of heavy metals. This was not the case with Sullivan however, where distilled water released more. By looking at the pH of Sullivan's acidic tailings, it can be seen that their pH in water is less than in 0.3N acetic acid, hence raised solubilities. The production of sulfate is largely responsible for this occurrence.

Table 6:10: Chemical Analyses of Leachate of Selected Soxhlet Weathered Mine Tailings

(0.3N Acetic Acid Weathered)

Sample	*	pH	Ca	Mg	Na	K	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn	Fe	Al	Si
			ppm														
Emerald 3	week 1	8.4	11900	4.2	72.5	113	0.10	0.8	0.33	0.25	0.3	0.8	<.3	0.10	<.3	<.3	85
14.5-38.5 cm	week 3	8.4	8925	320	31.3	32.5	0.15	<.3	0.15	0.23	8.0	0.5	<.3	0.03	1.0	<.3	<3
Endako Bulk	week 1	5.7	5625	830	215	328	0.10	0.8	0.08	0.13	268	0.8	<.3	0.68	280	<.3	93
	week 3	3.8	95.0	136	200	218	0.03	<.3	<.03	0.43	7.5	4.3	<.3	1.38	825	21.0	348
H.B. Fresh	week 1	8.6	4698	1488	5.8	75.6	0.19	0.7	<.02	0.12	16.3	0.9	1.2	0.30	<.2	<.2	<2
Fines	week 3	7.3	4512	1.6	22.8	39.5	0.14	0.7	<.02	0.09	1.9	0.5	9.8	0.09	0.2	<.2	14
Kaiser Fresh	week 1	5.1	3188	1000	7.8	113	<.03	1.3	<.03	0.19	38.4	2.2	1.9	5.91	1773	0.6	219
	week 3	3.6	0.1	6.6	3.6	24.1	<.03	<.3	<.03	0.91	<.3	0.3	4.1	1.31	153	116	188
Lornex Bulk	week 1	7.2	9528	5.8	383	261	0.17	0.6	0.14	0.28	0.9	0.6	<.3	0.08	<.3	<.3	203
(Emerg. Pond)	week 3	3.6	200	55.3	286	69.4	0.03	<.3	<.03	53.1	11.5	<.3	<.3	1.36	164	16.1	514
Sullivan Fe	week 1	0.9	409	455	25.7	241	0.45	2.3	0.41	41.6	63.6	3.0	8.6	227	7864	334	477
Oxid. Bulk	week 3	3.4	25.0	177	27.7	34.1	<.02	<.2	0.05	0.11	37.1	0.5	21.0	38.0	818	24.3	614
Sullivan	week 1	3.5	1821	124	171	439	0.14	0.4	0.29	0.07	8.7	4.6	<.4	3.82	246	19.6	304
Gypsum Bulk	week 3	3.3	1311	11.1	16.4	53.6	0.07	<.4	1.57	0.11	0.5	<.4	<.4	1.18	146	47.5	214
Sullivan Si	week 1	1.9	650	1100	43.8	405	<.03	0.8	0.33	10.70	155	1.3	10.5	228	1938	125	275
Oxid. Bulk	week 3	3.4	700	268	33.5	95.0	<.03	<.3	<.03	1.7	38.0	<.3	18.0	14.0	460	32.8	625
Sullivan Si	week 1	5.7	840	772	32.0	372	0.10	0.8	0.12	0.04	302	0.6	<.2	1.08	11000	<.2	<2
Fresh	week 3	5.7	36.0	30.6	25.6	38.9	0.08	0.4	0.04	0.04	9.4	0.2	<.2	1.44	8400	<.2	<2

*Week 1 and week 3 refer to the solution removed from the collecting flasks after 1 week and after 3 weeks of weathering.

Table 6:11: Chemical Analyses of Leachate of Selected Soxhlet Weathered Mine Tailings

(Distilled Water Weathered)

Sample	*	pH	Ca	Mg	Na	K	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn	Fe	Al	Si
			ppm														
Emerald 3	week 1	8.8	1260	0.9	45.0	18.5	<.03	<.3	<.03	<.03	<.3	0.5	<.3	<.03	<.3	<.3	93
14.5-38.5 cm	week 3	9.2	1113	0.9	38.8	2.6	<.03	<.3	<.03	<.03	<.3	0.5	<.3	<.03	<.3	<.3	225
Endako Bulk	week 1	9.8	321	<.2	150	150	<.02	<.2	<.02	<.02	<.2	<.2	<.2	<.02	<.2	<.2	2
	week 3	10.6	35.7	<.2	667	36.7	<.02	<.2	<.02	<.02	<.2	<.2	<.2	<.02	<.2	<.2	69
H.B. Fresh	week 1	**	655	4.1	35.5	30.0	**	<1.4	<.14	0.14	<1.4	<1.4	<1.4	<.14	<1.4	1.4	14
Fines	week 3	**	698	0.2	69.5	15.7	0.02	0.2	<.02	0.07	<.2	<.2	<.2	<.02	<.2	<.2	< 2
Kaiser Fresh	week 1	9.8	71.6	<.3	36.9	71.6	<.03	<.3	<.03	<.03	<.3	<.3	<.3	<.03	<.3	<.3	44
	week 3	9.9	64.7	<.3	29.4	8.3	<.03	<.3	<.03	<.03	<.3	<.3	<.3	<.03	<.3	<.3	134
Lornex Bulk	week 1	9.9	239	0.2	245	187	<.03	<.3	<.03	0.76	<.3	<.3	<.3	<.03	<.2	<.2	8
(Emerg. Pond)	week 3	10.7	37.9	<.2	56.6	12.6	<.03	<.3	<.03	<.03	<.3	<.3	<.3	<.03	<.2	0.8	63
Sullivan Fe	week 1	1.0	343	504	39.3	83.2	0.84	3.4	0.66	37.5	59.8	5.0	9.1	300	5682	307	296
Oxid. Bulk	week 3	2.1	1.5	65.2	21.4	19.3	<.03	<3	<.03	0.14	7.3	0.7	9.1	8.86	157	1.1	341
Sullivan	week 1	2.5	1111	196	193	396	0.07	0.7	0.78	0.74	14.2	4.8	<.4	6.67	20.4	50.7	343
Gypsum Bulk	week 3	3.1	1578	1.6	11.1	10.2	<.04	<.4	<.04	<.04	0.4	<.4	<.4	1.44	115	13.0	89
Sullivan Si	week 1	1.7	644	822	28.3	478	0.36	1.1	0.33	4.83	114	2.5	9.7	192	833	289	1611
Oxid. Bulk	week 3	2.5	706	431	45.0	160	0.06	<.3	<.03	0.06	15.5	1.4	12.5	0.80	156	1.1	1222
Sullivan Si	week 1	4.3	246	900	38.0	324	0.06	1.4	0.08	0.20	326	2.6	<.2	1300	7200	<.2	193
Fresh	week 3	4.0	408	27.4	17.4	29.8	<.02	<.2	<.02	<.02	8.6	<.2	1.0	4.38	152	<.2	180

*Week 1 and week 3 refer to the solution removed from the collecting flask after 1 week and after 3 weeks of weathering.
** Not available

Generally, it was found that higher concentrations of elements were removed during the early stages of leaching (week 1) than in week 3. This is due to quick removal of highly soluble constituents. Pb and Si are exceptions and seem to be more soluble near the end of the leaching period.

Figure 6:7 points out from the leachate data, how weathering with 0.3N acetic acid differs from distilled water for the previously graphed Sullivan Si Oxidized Bulk and Lornex Bulk tailings. The concentrations in solutions represented are accumulated values of weeks 1, 2 and 3 of weathering. The differences are much more evident for Lornex Bulk with negligible amounts of Fe, Al or Mn solubilized with distilled water. The differences again, are primarily related to the low pH attained by the acetic acid.

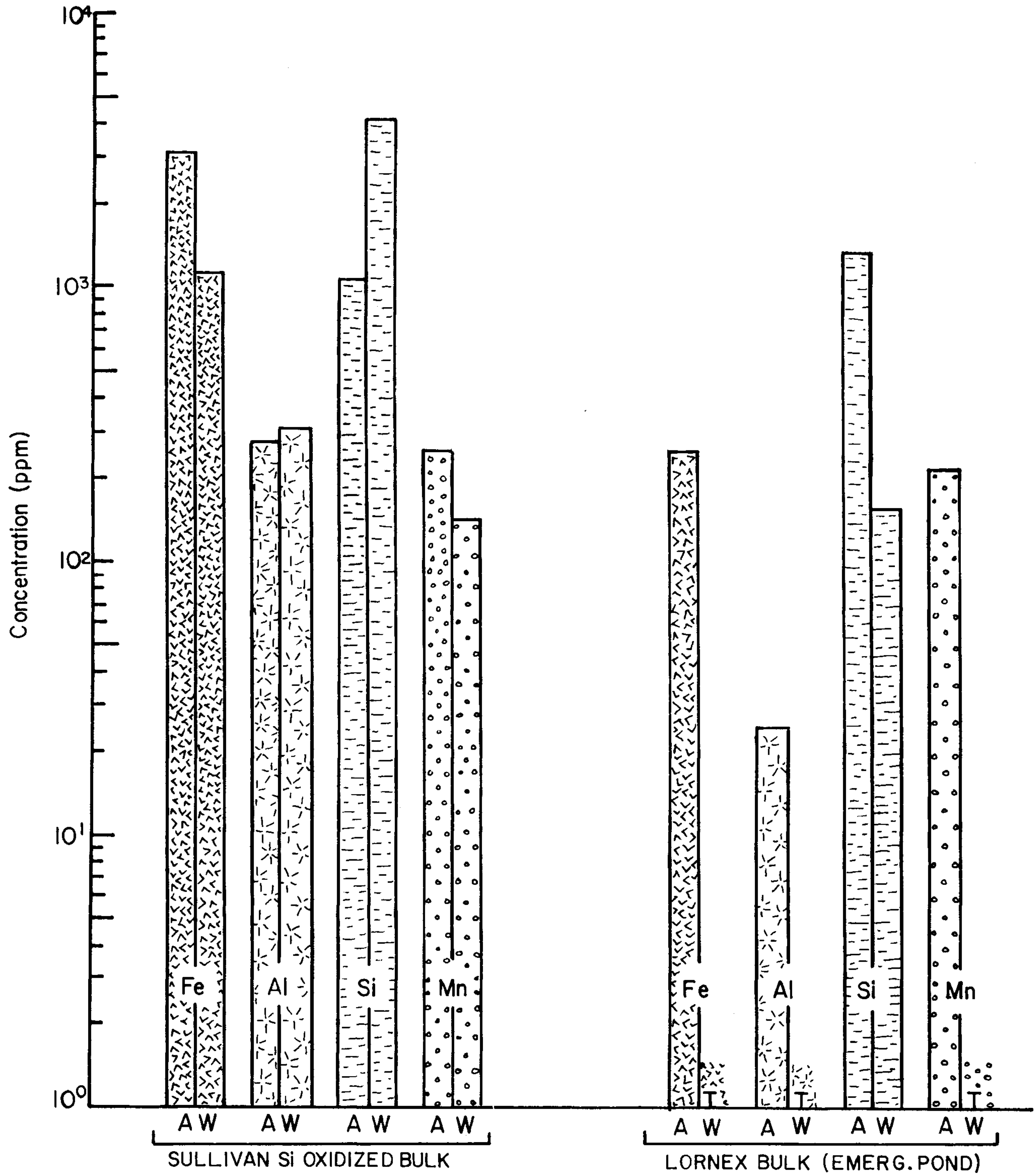
For Sullivan Si Oxidized Bulk, the acetic acid-distilled water differences are less dramatic because of the inherent low pH of the material. The pattern of solubility is about the same for both cases of tailings, with total quantities being greater for Sullivan.

C. Conclusions

The data presented in the preceding tables is an indication as to what information can become available by studying the weathering characteristics of tailings. It is expected that application to other types of waste materials would also prove useful.

Potential problems related to water quality, nutrient availability

FIGURE 6:7: CHEMICAL ANALYSIS OF LEACHATE OF SELECTED SOXHLET WEATHERED MINE TAILINGS



A - 0.3N ACETIC ACID WEATHERED

W - DISTILLED WATER WEATHERED T - TRACE

and/or toxicity, and also physical changes such as compaction or decreasing particle size can be approached from these kinds of analyses.

Some of the mine tailings presented in the tables are very unique: H.B. is neither sulfide-rich or siliceous; Emerald is sulfide-rich but has a less acidic nature than Sullivan ; Sullivan Gypsum is very soluble and has unrelated characteristics to Sullivan Fe and Si tailings; coal samples are low in nutrient status and inert. For this reason, it is difficult to make anything more than general observations and propose tentative relationships. (Figures IV:17 and IV:18)

Statistical analysis must be done to support these correlations and will be available at a later date.

Future studies in the application of artificial weathering techniques would be of value. Some areas of interest are:

1. Weathering for extended periods of time with continued monitoring of chemical and physical properties for spacific tailings types. This would supply further information concerning what further changes might take place
2. Actual time spans in a natural environment that might be comparable to the number of weeks of artificial weathering.
3. The effects of rate of percolation, temperature, leaching solution and controlled atmosphere variability. These are the predominant factors influencing final products.

7. METHODS OF MICROBIOLOGICAL STUDY

METHODS OF MICROBIOLOGICAL STUDY

The Ecology of Iron and Sulfur Oxidizing Bacteria in Iron Sulfide Mine Tailings and Their Role in its Oxidation

1. Introduction

The mining of metal sulfide deposits for economic minerals produces, as a waste, tailings high in ferrous sulfides which are impounded in the tailings ponds. The subsequent oxidation of these tailings results in the production of acid mine drainage, unless the acid produced is neutralized by inherent or added bases. This acid drainage if allowed to enter extant water bodies, is deleterious to aquatic life and to water quality for human purposes.

Previous work, reported in the 1976-1977 Tailings Research Report by the Soil Science Department at U.B.C., indicated that bacteria of the genus *Thiobacillus* are active in the oxidation of metal sulfides present in mine tailings. *Thiobacilli* appear to be among the initial colonializers and remain a significant portion of the population of micro-organisms as the tailings are weathered. However, this initial work did not attempt to quantify the relationship between the population or activity of these bacteria and the stages in the weathering process.

The study presently being conducted is designed to determine the weathering processes and the role micro-organisms, particularly *Thiobacillus* species, play in its oxidation. For this intensive study the Sullivan mine tailings containing iron sulfides were chosen. This choice was based on the previous finding of several species of

Thiobacilli in the tailings and effluent water and the high amounts of acid mine drainage from these tailings. Furthermore, it appeared from the small number of samples analyzed for the 1976-77 Tailings Research Report that there was a pH dependent succession of *Thiobacillus* species in the Sullivan tailings.

This study involved the collection of tailings samples from the Sullivan Mine at Kimberly, B.C. and subjecting them to microbiological, physical and chemical analysis. Thus far microbiolobical and part of the chemical and physical analysis has been conducted. Presentation of specific data is being withheld until the chemical and physical analysis of the data is performed. However, a number of general observations can be reported at this time.

2. Field Methods

A. Sites Sampled

Samples of Sullivan iron sulfide mine tailings were collected during the period of August 15th to 20th, 1977. Samples were collected from eighteen sites on the tailings. Sites selections were biased to include sites exhibiting several degrees of weathering and minerological composition. Waterlogged areas, slopes, and sites covered with ferruginous crusts were avoided for the sake of convenience.

In this study 120 surface samples were collected for laboratory analysis. Thirty samples were from the siliceous tailings and ninety from the iron tailings. Samples from the iron tailings included eleven samples from the 1948 tailings spill and nine miscellaneous samples. These latter samples later turned out to be organic matter crusts (four) and iron oxide deposits from old tailing fires (five). The sampling sites and the number of samples collected from each are outlined on the sampling site map. (Figure 7:1)

B. Sampling Methods

Five to eleven samples were collected from each area chosen for study. The samples were collected from the surface 2.5 cm of the tailings. The samples were chosen for their high degree of homogeneity. A metal coring ring was used to collect the samples. All samples were transferred to sterile plastic screwtop containers in the field and stored under refrigeration at 0^oC until analyses were conducted.

3. Laboratory Methods

A. Microbiological

To estimate the activity of the micro-organism in the tailings the population of each physiological group was determined by a dilution series method. The groups of micro-organisms quantified include fungi, acid tolerant heterotrophic bacteria, sulfur bacteria and iron bacteria. The media chosen for use in this study include:

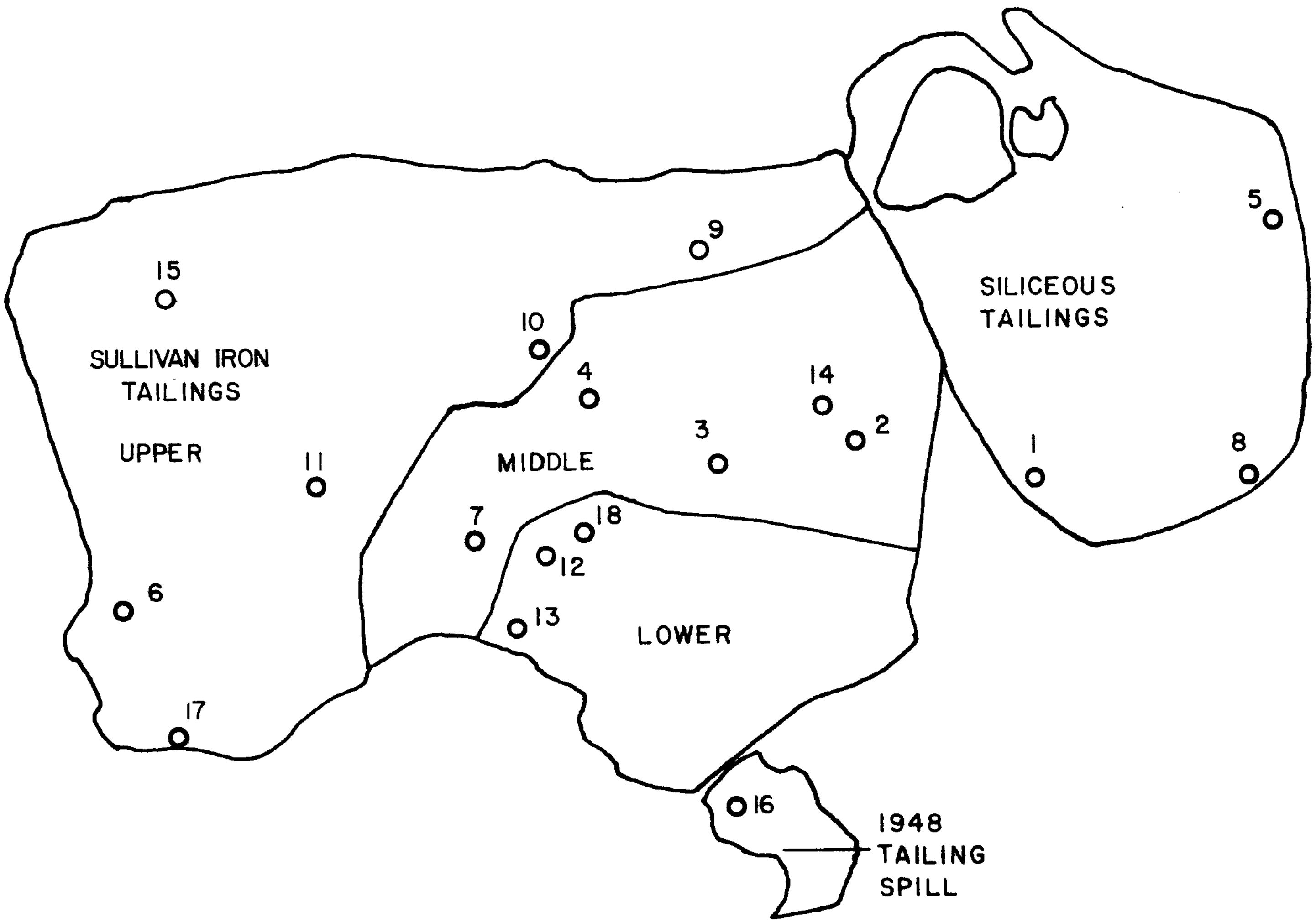
a) 9-K (Silverman and Lundgren, 1959) for iron oxidizing bacteria.

b) Thiosulfate (Vishniac and Santer, 1957) for sulfur oxidizing bacteria.

c) Allens + 0.1% glucose, 0.1% yeast extract and 0.1 mg cycloheximide. (Allen, 1959, as modified by Belly and Brock, 1974) for chemoheterotrophic bacteria.

d) Allens, but without cycloheximide (Allen, 1959, as modified by Belly and Brock, 1974) for heterotrophic fungi.

FIGURE 7:1: SAMPLE SITES OF SULLIVAN IRON SULFIDE TAILINGS



All incubations were carried out in test tubes at room temperature (18-26^{o}C) for 30 to 45 days. Tubes which appeared positive were confirmed by microscopic examination. Enumeration of these four groups was by the Most - Probable - Number (M-P-N) technique using the tables of Collens (1964). Populations of micro-organisms were expressed as the M-P-N per gram of dry tailings. All dilution series were carried out in triplicate. In the case of sulfur bacteria growing in thiosulfate media, the final pH of the media was determined. It has been found helpful by Hutchenson et al. (1969) in determining the species of sulfur bacteria carrying out the oxidation.

B. Chemical and Physical

Thus far the following chemical and physical analyses of the tailings have been conducted: pH, conductivity, elemental sulfur, % moisture, structure, texture and color. The latter four analyses were conducted on a subsample for moisture determination.

The pH was done on a 1:1 tailings extract by the method of Black (1965). Conductivity was done on a 1:2 soil extract as outlined by the U.S. Salinity Laboratory Staff (1954). Elemental sulfur was analyzed for using the method of Fliermans and Brock (1972). Structure, texture and color were done by procedures outlined by the Soil Survey Staff (1952). The tailings textures by the hand texturing method, are significantly finer in texture than other samples, collected by Morton (1976), using a particle size analysis method. Selected samples will be subjected to particle size analysis to evaluate the hand texturing results.

The hand texturing as well as structure and color determinations on the tailings samples were done so that correlations could later be done between these qualitative characteristics and quantative laboratory analysis. It is hoped that such an effort can assist the field worker in identifying the potential for acid production at specific sites on the tailings.

Presently mono- and disulfide sulfur is being determined by the methods of Smittenburg et al. (1974). Over the next two months total nitrogen will be done colorimetrically by Auto Analyzer and total sulfur by Leco induction furnace. These methods are described in the Methods. Manual (Lavkulich, 1977). Soluble sulfate sulfur will be determined by the turbido-metric method outlined in Determination of Sulfur in Soils and Plant Materials (1968).

Once a weathering sequence for iron sulfides has been worked out X-ray diffraction studies will be conducted on selected samples to qualitatively determine the dominant minerals in the various weathering stages.

4. Results and Discussion

Comparisons between selected chemical parameters and microbial populations are tabulated in Table 7:1. The sample values are averaged over pH range increments which are used as a general guide to the degree of weathering. The pH increments are 0.5 pH units in range and the increments are ordered by decreasing pH from 7.5 to less than 2.0.

Table 7:1: Correlation Between Degree of Weathering and Microbial Composition in Iron Sulfide Tailings Samples.

pH Range	Number of Samples in pH Range	Most Probable Number of Microorganisms/g Dry Tailings*				Elemental Sulfur % Dry weight basis	Conductivity mmhos/cm
		Acid Tolerant Heterotrophs	Fungi	Iron Bacteria	Sulfur Bacteria		
7.5 - 7.0	7	4X10^{6} (5)	2.5X10^{4} (6)	————	4.5X10^{6} (6)	0.33	1.96
7.0 - 6.5	6	4.5X10^{3} (2)	2.5X10^{4} (4)	————	3X10^{4} (6)	0.52	2.86
6.5 - 6.0	5	5X10^{3} (1)	4X10^{4} (5)	1X10^{3} (1)	7X10^{4} (5)	0.47	3.71
6.0 - 5.5	4	3X10^{3} (2)	3X10^{4} (3)	————	7X10^{5} (2)	0.82	4.08
5.5 - 5.0	4	2X10^{3} (1)	9X10^{5} (3)	————	3X10^{4} (4)	1.59	3.80
5.0 - 4.5	5	5.5X10^{4} (2)	1.5X10^{5} (4)	1X10^{7} (1)	5.5X10^{6} (5)	2.67	2.80
4.5 - 4.0	7	3.5X10^{6} (2)	————	4X10^{7} (2)	5.5X10^{6} (6)	6.28	2.62
4.0 - 3.5	9	1.5X10^{5} (5)	8X10^{4} (8)	3X10^{5} (6)	1.5X10^{6} (9)	8.87	4.87
3.5 - 3.0	5	5.5X10^{3} (2)	4X10^{5} (5)	1X10^{3} (1)	2.5X10^{5} (1)	2.64	10.76
3.0 - 2.5	3	8X10^{3} (1)	4X10^{5} (3)	4X10^{3} (1)	3X10^{3} (1)	3.37	6.33
2.5 - 2.0	57	5X10^{5} (29)	5.5X10^{5} (46)	2X10^{7} (14)	4.5X10^{5} (11)	1.99	>10.88
< 2.0	8	3X10^{4} (5)	7X10^{4} (6)	1X10^{3} (1)	9X10^{4} (2)	4.03	>12.7

* Numbers in Parenthesis refer to the number of positive samples/site

On the average, reductions in pH are associated with changes in elemental sulfur content and conductivity. As the pH decreases the content increases from 0.33% for pH 7.5 - 7.0 to 8.87% at pH 4.0 - 3.5. Below pH 3.5 the elemental sulfur content drops down to an average of 3.20%. This rise and then fall in the average elemental sulfur content with pH indicates that initially iron sulfides are weathered to elemental sulfur. As weathering proceeds the rate of iron sulfide oxidation is less than the rate of elemental sulfur oxidation resulting in a drop in the elemental sulfur content. In data on color of the samples verses pH not tabulated in this report, those with low pH values tended to have high hues and chromas. This indicates that there is a reduction in oxidizable iron sulfide content in these samples. X-ray analysis conducted on Sullivan iron sulfide tailings indicated that the mineral jarosite is the predominant product of the iron sulfide weathering process (Lavkulich et al., 1976-1977).

The data presented on conductivity verses pH indicates that conductivity tends to increase as the pH drops. Between pH 7.5 and 3.5 the average conductivity was less than 3.5 mmhos/cm. Below pH 3.5 the conductivity averaged over 10.

Microbiologically, there tended to be changes in the microbial population with decreases in pH. At high pH values acid tolerant heterotrophic bacteria, fungi and one species of sulfur *Tiobacillus Thioparus*, were found. However, numbers of acid tolerant bacteria and fungi tended to be low at the higher pH values. As the pH dropped below 5.0, high numbers of iron bacteria *Thiobacillus ferrooxidans* were often found.

Furthermore, the predominant species of sulfur bacteria changed with a reduction in the pH of the tailings.

Of the samples listed in Table 7:1 over 50 % of them have pH values below 2.5. The use of pH as an index of weathering is only useful for delineating differences in microbial population and chemistry of slightly weathered tailings samples. Those samples with pH values below 2.5 represent a wide range of weathering states. For this reason the samples and their aformentioned microbial and chemical parameters, have been averaged according to sampling site in Table 7:2. The ordering of the data according to the age of the tailings surface results in a clearerr presentation of the microbiological changes with weathering.

In the case of the iron bacteria *Thiobacillus ferrooxidans*, the smallest populations were found at site 1, 2, 3, 4, 5, 10, 12, 13 16 and 17. The first five sites represent relatively unweathered surfaces with pH values above that where *Thiobacillus ferrooxidans*' actively oxidize iron and sulfur. Of the latter five site, numbers 10, 12, 13 and 16 are the oldest and probably the most weathered sites sampled. Site 17 is composed primarily of iron oxide residues from an old tailing fire.

The lowest livels of sulfur bacteria are in samples from site 10, 16 and 17 and these samples also have low levels of elemental sulfur. Sulfur bacteria are also low in samples from site 15.

The populations of acid tolerant heterotrophic bacteria and fungi are related to the availability of oxidizable organic matter in the tailings. Heterotrophic microorganisms are low in samples from the relatively unoxidized and very unoxidized sites. In the former

Table 7:2: Microbiological and Chemical Characteristics of the Sites Sampled

Site Number	Number of Samples	Most-Probable-Number of Microorganisms/g Dry Tailings*				Elemental Sulfur	pH	Conductivity
		Acid Tolerant	Fungi	Iron Bacteria	Sulfur Bacteria	% Dry Weight Basis		mmhos/cm
1	10	2.7×10^{6} (4)	2.5×10^{4} (8)	———	3.5×10^{6} (9)	0.44	6.98	2.47
2	5	1×10^{4} (3)	3×10^{4} (4)	———	3×10^{4} (4)	0.70	6.72	3.39
3	5	———	3×10^{5} (5)	1.5×10^{3} (1)	5×10^{6} (5)	0.54	5.85	4.43
4	5	9×10^{3} (4)	1×10^{3} (1)	———	1×10^{4} (3)	1.87	5.13	4.26
5	10	1×10^{3} (1)	4.5×10^{5} (10)	———	3×10^{6} (8)	2.77	4.50	3.33
6	5	5×10^{6} (5)	1×10^{5} (4)	6×10^{7} (4)	5×10^{5} (5)	4.21	3.94	4.65
7	5	2×10^{5} (4)	2×10^{5} (5)	3.5×10^{6} (5)	4.5×10^{6} (5)	16.04	3.82	4.81
8	10	5.5×10^{3} (4)	4.5×10^{5} (10)	1.0×10^{6} (4)	3×10^{6} (8)	2.93	3.28	8.09
9	10	2×10^{4} (8)	5×10^{5} (9)	5×10^{4} (3)	1×10^{6} (3)	3.52	2.39	9.82
10	5	1×10^{4} (3)	2.5×10^{6} (5)	1×10^{3} (1)	———	1.21	2.20	6.46
11	5	6.5×10^{3} (3)	4×10^{5} (4)	4×10^{4} (3)	7×10^{5} (4)	2.77	2.10	10.84
12	5	5×10^{6} (3)	6×10^{5} (5)	2.5×10^{3} (1)	2×10^{5} (2)	7.80	2.07	6.93
13	10	1×10^{5} (7)	2.5×10^{4} (8)	———	3.5×10^{6} (9)	1.37	2.07	11.46
14	5	3.5×10^{4} (4)	2×10^{6} (4)	5×10^{5} (3)	5×10^{5} (1)	1.80	2.06	6.46
15	5	4×10^{3} (5)	2.5×10^{5} (5)	8.5×10^{4} (1)	———	3.01	2.06	11.46
16	11	2×10^{3} (4)	9×10^{3} (5)	———	———	0.17	2.04	10.58
17	5	4.5×10^{3} (2)	1.5×10^{5} (5)	1×10^{3} (1)	9.5×10^{3} (5)	1.10	2.01	10.0
18	4	9×10^{3} (2)	5.5×10^{4} (2)	3×10^{4} (2)	8×10^{4} (1)	1.53	1.85	> 18.0

* Numbers in Parenthesis refer to the number of positive samples/site.

case large populations of heterotrophic microorganisms have not had a chance to build up. In the latter case it is probable that there are low levels of organic matter in the samples. Analysis for organic matter content of the samples will be conducted if a suitable technique can be devised.

From the analysis completed it appears there is a relationship between kinds of organisms and the state of weathering of the tailings material. This is congruent with the changes or ranges of pH values found. The increase in elemental sulfur content with a decrease in pH appears to be linked to microbial oxidation of iron sulfides.

8. GREENHOUSE STUDIES

GREENHOUSE STUDIES

1. Introduction

Greenhouse studies were concentrated in three areas: a) soil test evaluation; b) copper-molybdenum relationships; and c) organic matter amendments. The first and third areas may provide information for improving estabilshment on mine tailings of vegetation and its subsequent fertilizer needs. The second area is of interest because of the potential effects on grazing animals of trace element content of forage grown on mine tailings. Greenhouse pot studies and chemcical analysis have been completed and results will be discussed.

2. Soil Test Evaluation

Chemical soil testing procedures developed for agricultural soils have commonly been used to predict fertilizer requirements for plants growing on mine tailings. Research in other regions has often shown a poor correlation between plant response to fertilizer addition to mine wastes and soil test results. The objective of our work has been to determine the effectiveness of soil tests commonly used in B.C. in extracting plant available P, K and Mg. N Soil test evaluation was not included since the tailings which were studied are consistently very low in nitrogen and do not provide the range in available nitrogen necessary to study plant response.

The extracting reagents and procedures used in this study are those used by the British Columbia Ministry of Agriculture Soil Testing Laboratory in Kelowna.

The objectives of the experiment were:

i) To evaluate Bray's P_1 extractant (0.03N NH_4F and 0.025N HCl) as an index of the availability of P in four sulfide tailings.

ii) To evaluate neutral 1.0N ammonium acetate extractant as an index of the availabilityof K and Mg in four sulfide tailings.

iii) To determine if Mg is a limiting factor for plant growth in the four tailings under study.

The third objective above represents a useful byproduct of the soil test evaluation study. Greenhouse work during the last two years has indicated that N, P and K are limiting to plant growth in some tailings, but no work has been done with Mg.

Mg is an element required by plants in relatively large quantities. Its availability to plants may be limited by low concentration in the growth media or high concentrations of other cations such as Ca and K. Ca is present in large quantities in most of the "non-acid" sulfide tailings, and K is often added as fertilizer in large quantities in revegetation programs.

The tailings used in this experiment were from the Lornex, Bethlehem, Gibraltar and Endako mines. The soil test P, K and Mg values for these tailings are given in the Table 8:1. The test plant was orchardgrass (*Dactylis glonerata L.*). The treatments include the following:

1.	N P K Mg	with:	N = 75 ppm
2.	N K Mg		P = 50 ppm
3.	N P Mg		K = 50 ppm
4.	N P K		Mg = 50 ppm

Table 8:1: Bray's P_1 Extractable P and 0.1N Ammonium Acetate Extractable K, Mg and Ca for the Tailings used in the Soil Test Evualuation Study.

Tailings	Bray P_1	K	Mg	Ca
	ppm			
Bethlehem	7.8	66.5	45.7	2700
Gibraltar	12.9	29.2	24.3	2148
Lornex	53.0	165.3	187.8	4148
Endako	74.8	74.3	62.8	2221

The tailings from Gibraltar and Bethlehem, which were lowest in available P by the Bray Method, gave dramatic increases in dry matter yield with P fertilization (Table 8:2). Yield results for the Lornex and Endako tailings were difficult to interpret. It appears that yields on the Lornex tailings (53.0 ppm available P) were somewhat less in the NPKMg treatment than the NKMg. Plants growing on the Endako tailings responded to P despite a high initial level of available P (74.3 ppm).

It appears from initial yield results that Bray's P_1 soil test detects tailings which are extremely deficient in P but is not effective in tailings with relatively high levels of available P. Additional yields were lower in the low P tailings than would be expected considering that the Gibraltar and Bethlehem tailings had available P levels of 12.9 and 7.8 ppm, respectively. With these levels, initial growth in this short-term study should have been better. In summary the Bray P_1 soil test is useful in establishing the general level of adequacy of P in tailings however, more information on P chemistry in tailings is required before it can be used to give precise fertilizer recommendations.

The ammonium acetate extractant predicted response to K reasonably well except with the Lornex tailings, which showed an available K level of 165.3 ppm but which gave little plant growth without added K. A slight yield increase was noted with the Bethlehem tailings, which had 66.5 ppm K, while the Gibraltar tailings, with 29.2 ppm K, gave little growth without fertilizer K added.

Three of four tailings gave slightly lower yields without Mg added; however, these responses to added Mg were quite small.

Table 8:2 : Dry Matter Yields of Orchardgrass from Soil Test Evaluation Study.

TREATMENT	TAILINGS			
	Lornex	Bethlehem	Endako	Gibraltar
	g/pot			
NPKMg	936	1292	1387	204
NKMg	1491	<10	977	<10
NPMg	83	985	1290	<10
NPK	1308	1088	1119	191

(Table 8:2). The Lornex NPK treatment actually yielded more than the NPKMg. This may be related to the fact that the initial Mg level of 187.8 ppm in the Lornex tailings was the highest of any of the tailings tested. Mg did not appear to be a severe limiting factor in the Lornex, Bethlehem, or Endako tailings; however, the low exchangeable Mg content (24.3 ppm) may indicate a potential problem in the Gibraltar tailings. This material gave very low yields and it appears that a growth factor (or toxicity) other than P, K or Mg is limiting growth. If this problem is corrected, than Mg will likely be a limiting factor to plant growth. In general, 0.1N ammonium acetate was adequate in determining which tailings were deficient in K, however, more work needs to be done on magnesium availability.

The plant analysis and uptake data (Table 8:3) were quite variable and were generally unrelated to nutrient treatments. This is perhaps due to the small amount of plant material produced in each pot.

Table 8:3 Concentration in Plant Tissue and Uptake of P, K and Mg by Orchardgrass Crop in the Soil Test Evaluation Study.

Tailings	Treatment	Concentration P	Concentration K	Concentration Mg	Uptake P	Uptake K	Uptake Mg
		%			mg/pot		
	NPKMg	.21	1.02	.27	2.0	9.6	2.5
Lornex	NKMg	.24	1.84	.18	3.6	15.1	2.7
	NPMg	-	-	-	-	-	-
	NPK	.37	2.45	.24	4.8	14.4	3.1
	NPKMg	.46	1.20	.33	5.9	15.5	4.3
Bethlehem	NKMg	-	-	-	-	-	-
	NPKMg	.54	2.38	.31	5.3	23.4	3.0
	NPM	.12	1.42	.25	1.3	15.5	2.7
	NPKMg	.25	1.19	.24	3.5	16.6	3.3
Endako	NKMg	.32	0.92	.36	3.1	9.0	3.5
	NPMg	.28	1.18	.31	3.6	15.2	4.0
	NPK	.35	1.13	.24	3.9	12.6	2.7
	NPKMg	Insufficient Sample					
Gibraltar	NPKMg	"					
	NPMg	"					
	NPK	"					

3. Copper-Molybdenum Studies

A. Experiment 1: AMELIORATION OF MOLYBDENUM (Mo) TOXICITY

A disorder of ruminants known as molybdenosis often results from the consumption of forage containing high levels of Mo or having low ratio of Cu:Mo. Laboratory analysis of samples of various forage species grown in reclamation projects at the mine sites has indicated that molybdenosis could be a problem. If ruminant animals use vegetation growing on the high Mo mine tailings for a significant portion of their diet, copper deficiency could result. The objective of this experiment was to determine the effectiveness of various soil amendments in lowering the Mo content or increasing the Cu:Mo ratio of plant tissue. Treatments include the following:

1. Control*
2. Gypsum 1 (6.2 t/ha)
3. Gypsum 2 (12.4 t/ha)
4. Ammonium Sulfate 1 (1000 kg/ha)
5. Ammonium Sulfate 2 (2000 kg/ha)
6. Copper Sulfate 1 (10 ka/ha)
7. Copper Sulfate 2 (20 ka/ha)
8. Sulfuric acid (17640 ppm)
9. Hydrochloric acid (13140 ppm)
10. Leached

The addition of sulfuric and hydrochloric acids to acidify the tailings was done because Mo availability has been shown to decrease with increasing acidity.

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* All treatments received 75 ppm N, 50 ppm P, and 75 ppm K as $Ca(NO_3)_2$, $Ca(H_2PO_4)_2$, and KCl, respectively. Endako and Bethlehem tailings were used.

Since the sulfate ion also tends to lower Mo availability, it was thought that sulfuric acid would have an effect in addition to acidification. However, the addition of sulfuric acid to these tailings resulted in the formation of salt crust (probably gypsum) on the surface and no seedling emergence was observed. This did not occur with hydrochloric acid and some seedling emergence was observed. Growth in these pots was poor, however. It is likely that these acidification treatments are too severe for immediate benefit to growing plants.

The treatments in which pots were leached with water prior to seeding resulted in extremely poor growth. The cause of this is not know at this time.

The gypsum treatments decreased dry matter yields in both tailings (Table 8:4). Gypsum increased tissue Mo concentrations in the Bethlehem tailings while slightly decreasing Mo concentration in the Endako tailings. This resulted in slightly lower Cu:Mo ratios in the Gypsum treated Bethlehem tailings and no change in the Endako tailings. Except for the 2000 kg/ha rate of $(NH_4)_2$ SO_4 on the Bethlehem tailings the $(NH_4)_2$ SO_4 gave considerable yield increases but did not consistently affect the Cu:Mo ratio in either tailings material. Cu SO_4 added as a soil amendment was not effective in increasing the Cu concentration in plant tissue.

B. Experiment 2: MACRONUTRIENT (N AND P) FERTILIZATION EFFECTS ON Mo CONTENT OF PLANT TISSUE

Heavy fertilization with NPK is a common practice in revegetation of mine waste materials. If Cu:Mo ratios or Mo content of forage grown on mine wastes is a potential problem, then the effects of fertilization on Mo uptake should be determined. K has not been shown to affect Mo

Table 8:4: Concentration of Cu and Mo and Cu:Mo Ratio in Orchardgrass in Molybdenum Amelioration Experiment.

Treatments	Bethlehem				Endako			
	Yield mg/pot	Tissue Concentration Cu (ppm)	Tissue Concentration Mo (ppm)	Cu:Mo Ratio	Yield mg/pot	Tissue Concentration Cu (ppm)	Tissue Concentration Mo (ppm)	Cu:Mo Ratio
Control	1258	39.3	5.5	7.1	1466	39.0	47	0.83
Gypsum (6.2 t/ha)	588	26.1	12.8	2.0	1007	27.8	42.3	0.66
Gypsum (12.4 t/ha)	833	53.2	13.1	4.0	816	32.3	37.3	0.86
Ammonium Sulfate (1000 kg/ha)	2090	71.2	8.3	8.6	2588	24.8	25.2	0.98
Ammonium Sulfate (2000 kg/ha)	1261	26.2	9.1	2.9	3011	36.3	30.0	1.21
Copper Sulfate (10 kg/ha)	1370	40.2	20.3	2.0	1200	39.3	25.0	1.57
Copper Sulfate (20 kg/ha)	1039	38.7	12.4	3.1	2107	30.3	123.0	0.25
Sulfuric Acid (17640 ppm)	0	-	-	-	0	-	-	
Hydrochloric Acid (13640 ppm)	<10	-	-	-	333	-	-	
Leached	<10	-	-	-	<10	-	-	

content in other work and is not included in this experiment. P and Mo are quite similar in their chemistry in the soil. Other researchers have shown an increase in Mo content with increased P fertilization. The effects of N fertilization on Mo uptake are not clear. However, N often causes a decrease in the concentrations of other trace elements. It was felt that N effects may be important enough to justify more work.

The objective of this experiment was to determine the effects of N and P fertilization of mine tailings on the concentration of Mo in plant tissue. The treatments consisted of two levels of N and three levels of P arranged in a factorial combination. N was applied at rates of 25 and 75 ppm and P at rates of 50, 100 and 150 ppm. N fertilizer greatly increased dry matter yields, while P had little effect (Table 8:5). P also had little effect on Cu or Mo concentrations in plant tissue. However, increasing the N rate from 25 to 75 ppm increased concentrations from a average of 3.8 ppm to 15.5 ppm for the first cut. Cu concentrations were not greatly influenced by N or P treatments, in either cut 1 or 2. Increasing the N rate decreased the Cu:Mo ratio from an average of 1.1 at 25 ppm N to 0.4 at 75 ppm N. With the exception of the highest P rate the Mo concentrations in the second cut were also higher where the highest N rate was applied. Regardless of N or P treatment, the Cu:Mo ratios were low. Cu:Mo ratios in this experiment were considerably less than 2 which is often quoted in the literature as being potentially unsafe (Miltimore, Mason, MacArthus and Carson, 1964), (Miltimore and Mason, 1971). If forage grown on tailings is to be grazed, care should be taken to keep fertilizer N rates at a moderate level.

Table 8:5: N and P Fertilization Effects on Dry Matter Yield Cu and Mo Concentrations and the Cu:Mo Ratio.

Treatment *	Cut 1				Cut 2			
	D.M. Yield mg/pot	Cu (ppm)	Mo (ppm)	Cu:Mo Ratio	D.M. Yield mg/pot	Cu (ppm)	Mo (ppm)	Cu:Mo Ratio
N_1P_1	989	4.9	4.8	1.0	2461	4.4	18.1	0.2
N_1P_2	738	3.8	4.4	0.9	2308	5.6	11.8	0.5
N_1P_3	1003	3.2	2.3	1.4	2278	5.1	50.1	0.1
N_2P_1	2070	4.9	15.4	0.3	3204	3.5	41.6	0.1
N_2P_2	1512	7.3	16.1	0.4	3318	4.8	43.1	0.1
N_2P_3	1879	8.0	15.1	0.5	3256	6.1	44.2	0.1

* N_1 and N_2 were added as NH_4NO_3 at rates of 25 and 75 ppm, respectively. P_1, P_2 and P_3 were added as $Ca(H_2PO_4)_2$ at rates of 50, 100 and ppm, respectively.

4. Organic Matter Amendments

Quite often physical properties of tailings may be more limiting than chemical properties, especially in drier regions of the British Columbia Interior. Improving moisture and aeration regimes of tailings may be quite beneficial in revegetation. The treatments given below represent avalable sources of organic matter for improving mine tailings.

1. Control*
2. Cow manure (10,000 ppm)
3. Cow manure (40,000 ppm)
4. Poultry manure (10,000 ppm)
5. Poultry manure (40,000 ppm)
6. Sawdust (10,000 ppm)
7. Sawdust (40,000 ppm)
8. Sewage sludge (10,000 ppm)
9. Sewage sludge (40,000 ppm)

Since the organic amendments were not added as fertilizer sources, NPK fertilizers were added to maintain plant growth as well as to aid microbial decomposition of some of the organic materials such as sawdust. Lime treatments maintained pH of the tailings between 7.2 and 7.5 during the experiment.

Early observations indicated the poultry manure delayed the emergence of the test crop (orchardgrass), possibly due to high ammonia concentrations. Even though emergence was delayed, final

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* All pots received 100 ppm N, 50 ppm P, and 50 ppm K as NH_4NO_3, $Ca(H_2PO_4)_2$, and KCl. Sawdust pots received and additional 100 ppm N. The pots also received 62,500 ppm $CaCO_3$ to neutralize any acidity produced.

Table 8:6:

Dry Matter Yields, N, K, Fe and Cu Concentrations with Addition of Various Sources of Organic Matter to Sullivan Tailings.

Source	Rate	Dry matter yield mg/pot	N	K	Fe	Cu	Mn	Zn
			%		ppm			
Control	--	481	1.03	1.55	1863	50	276	161
Cow Manure	10,000	597	1.51	2.70	2316	67	262	180
	40,000	1522	3.40	1.78	747	30	272	126
Poultry Manure	10,000	2725	3.82	2.40	784	28	396	166
	40,000	2742	7.17	2.98	834	36	191	165
Sawdust	10,000	735	1.98	1.90	1300	47	286	253
	40,000	451	1.86	-	3425	61	205	426
Sewage Sludge	10,000	831	1.22	2.20	4450	50	452	272
	40,000	1742	3.13	1.94	955	19	381	134

yields for poultry manure treatments were by far the highest of any of the organics used (Table 8:6).

With both cow manure and sewage sludge, increasing the application rate from 10,000 to 40,000 ppm greatly increased yields. The same rate increase for sawdust resulted in a decrease in yield, with 40,000 ppm rate being similar to the control. Even though the sawdust pots received a total of 200 mg N/Kg they were still probably deficient in N.

Some of tha above differences in plant response to organic amendments are likely due to the fertilizer value of the materials. The yield increases resulting from the 10,000 ppm rate of poultry manure, and the 40,000 ppm rate of both cow manure and sewage sludge coincided with increases in plant N content in all cases. In addition, the poultry manure treatments increased the K content of the plants. Ca and Mg concentrations in the plant tissue were not altered by any of the organic amendments. Since the plant N % in the sawdust treated pots was increased over the control pots by approximately 0.9 %, it does not appear that the lack of response to the sawdust was due entirely to N immobilization. It is possible that unless the physical state of a growth media is more severely limiting than in the Sullivan tailings, a growth response to added organic amendments may not be obtained in a short-term pot experiment. It appears in this experiment that the fertilizer value, especially N, overrode the potential beneficial effects of the organic materials. The benefits of organics are often of a long term nature and proper evaluation of physical benefits of these materials should be done in long term field trials. The fertilizer value of poultry manure, cow manure and sewage sludge can be important in the short term, however, other organics such as sawdust may have longer term effects on soil physical properties.

Another area of concern is the chemical composition of plants grown on the Sullivan tailings and the effects on these of the various organics. Plant analysis of orchardgrass tissue grown on pots treated with the above mentioned organic materials indicated that Mn and Zn conentrations were not affected by the organics. Fe and Cu levels, however, were generally decreased as plant yields were increased by both rates of poultry manure and by the 40,000 ppm rates of cow manure and sewage sludge. In summary then, the main effects of organic amendments on the trace elements measured, was to either have no effect or to decrease their concentration, probably by carbohydrate dilution.

5. Conclusions

i) The Bray's P_1 soil test allowed the separation of the two severely P-deficient tailings (Bethlehem and Gibraltar) from tailings with moderate P levels.

ii) The ammonium acetate extractable K was related to plant response to K in three of four tailings.

iii) Yields from three or four of the tailings tested were slightly lower in pots without Mg; however, severe Mg deficiencies were not observed.

iv) Addition of gypsum, ammonium sulfate, and copper sulfate as soil amendments had little effect on Cu:Mo relationships in plant tissue grown on Bethlehem and Endako tailings materials.

v) In the short-term study organic amendments such as poultry manure, cow manure and sewage sludge improved plant growth on the Sullivan tailings. Sawdust was not as effective as the manures and the sludge. These short-term effects were probably due to the fertilizer value of the manure especially N. Cu and Fe concentrations in plant tissue were decreased by poultry manure and the highest rates of cow manure and sewage sludge.

9. PHOSPHORUS ADSORPTION

PHOSPHORUS ADSORPTION

1. Introduction

Next to nitrogen, which is a limiting nutrient in mine spoils, phosphorus tends to be the major macro-nutrient for plant nutrition. Phosphorus is an essential plant nutrient and one that is relatively expensive to apply. Phosphorus reaction products vary with pH and with the chemical and mineralogical composition of the growth media. In some materials, phosphorus is adsorbed, when added as a fertilizer, and is rendered unavailable for plant growth; this is often pH-dependent. Also the fixation of phosphorus is time dependent; that is, added phosphorus may at first not be fixed into unavailable plant forms but with time the fixation process renders the added phorphorus unavailable. This has important practical ramifications not only in the amount of phosphorus fixation capacity but also the amount of phosphorus that should be applied in one application. For example, if a mine spoil has a high phosphorus fixation capacity then to supply plant available phosphorus it may prove more practical to apply fertilizer phosphorus in small amounts and at several times throughout the growing season so that the plant can absorb the phosphorus before it is fixed into an unavailable form.

To assess the phosphorus fixation capacity of selected mine spoils an experiment was conducted on representative samples. The experiment was conducted "aging" the samples for 48 hours and then repeated after "aging" the samples for two weeks. This was done to see if time was a factor in reducing phosphorus availability.

2. Methods and Materials

A standard solution of KH_2PO_4 was prepared in distilled water to produce a solution of 1000 ppm of P. The solution was standardized to pH 7.0. Aliquots of this standard solution were added to the selected mine spoil samples to cover the range of 0 to 300 ppm.

A. Method 1 - 48 hours

Five grams of mine spoil sample were placed in an acid washed 150 ml Erlenmeyer flask. Aliquots of the standard P solution were added to the samples giving an outside range of 0 to 300 ppm P. The solution was made up to 100 ml by adding appropriate volumes of distilled water. The flasks were covered with parafilm, and swirled for 48 hours on an oscillating shaker. The samples were removed and subjected to centrifugation at 3,400 rpm in an International No. 2 centrifuge. The amount of P remaining in solution was analyzed by the procedure of Dickman and Bray described in the Methods Manual (Lavkulich, 1977).

B. Method 2 - 2 weeks

Five grams of spoil were placed in an acid washed 150 ml Erlenmeyer flask. Aliquots of the P standards were added as in Method 1. The weight of the Erlenmeyer was recorded and the flasks were swirled as before. The samples were stored in the dark for two weeks for incubation. Following incubation, distilled water was added to bring the contents of the Erlenmeyer flasks to the previously recorded weight. The contents were subjected to centrifugation as before. Solution pH and P in solution were determined. The spoil material was washed with 20 ml aliquots of distilled water for a total of 100 ml; the resulting solution was analyzed for water soluble P. Following drying of the spoil samples, total P was determined.

The spoil samples selected for phosphorus adsorption studies consited of: (1) Tailings samples from Bethlehem, Lornex, Gibraltar, Emerald and Sullivan. (2) Spoil samples were selected from Kaiser.

3. Results and Discussion

Table 9:1 gives the results of the amount of P added to the various spoil materials as a standard P solution and the amount remaining in solution after 48 hours of reaction time. The tailings or spoils from the copper, molybdenum and coal mines did not exhibit a large P fixation capacity, as evidenced by the amount remaining in solution. (Bethlehem, Kaiser, Lornex, Gibraltar, Similkameen and Endako). Emerald tailings fixed a considerable amount of P as did the tailings from Sullivan. Sullivan gypsum had a low P fixation capacity. All the other samples of Sullivan tested had high adsorption capacities for P.

It appears that there is very little problem with P fixation in the copper mines, and the coal mine studied, as well as Endako (Mo). At these mine sites it appears one application of Phosphorus fertilizer in a rather large dose could prove satisfactory. However, care should be taken that excess P-fertilizers are not added to eleviate the

Table 9:1: Phosphorus Adsorption After 48 Hours

Sample	Added P ppm	Remaining P (Solution) ppm	Sample	Added P ppm	Remaining P (Solution) ppm
Bethlehem Fresh	0	0.6	Kaiser 0-26 cm	0	1.6
	5	4.7		5	6.7
	10	9.8		10	12.9
	15	14.4		15	17.2
	20	19.3		20	23.6
	25	24.0		25	26.6
	30	28.5		30	29.7
Emerald 1.5-14.5 cm	0	0.4	Lornex 0-10 cm (Emerg. pond)	0	0.0
	10	0.5		5	4.8
	20	0.7		10	9.7
	25	0.8		15	14.5
	30	1.5		20	18.9
	40	5.0		25	24.0
	50	10.3		30	28.7
	60	14.9			
	70	19.9	Lornex Bulk (Emerg. pond)	0	0.3
	80	21.6		5	4.7
	90	22.9		10	9.6
	100	26.2		15	14.5
				20	19.4
Endako 0-4 cm	0	0.1		25	24.3
	5	5.1		30	28.4
	10	10.1			
	15	14.9	Lornex Fresh	0	0.2
	20	19.6		5	5.3
	25	24.5		10	9.8
	30	28.2		15	14.6
				20	19.2
Gibraltar Fresh	0	0.0		25	23.8
	10	9.6		30	28.3
	20	20.1			
	30	29.5	Similkameen 0-15 cm	0	0.0
	40	39.8		5	3.0
				10	6.8
Kaiser Fresh	0	1.0		15	10.7
	10	10.5		20	14.8
	20	20.1		25	18.5
	30	30.0		30	22.2
	40	39.2			

Table 9:1: Phosphorus Adsorption After 48 Hours

Sample	Added P ppm	Remaining P (Solution) ppm
Sullivan Fe Oxidized Bulk	0	0.0
	20	0.4
	60	0.6
	80	1.1
	100	1.6
	150	6.0
	200	28.8
	250	60.0
	300	102.0
Sullivan Gypsum 1-5 cm	0	8.0
	5	10.7
	10	14.9
	15	18.8
	20	21.5
	25	25.2
	30	28.0
Sullivan Si-Fe 0-1 cm	0	0.2
	70	0.3
	80	1.9
	90	10.6
	100	14.7
	150	23.1
Sullivan Si-Fe 4-6 cm	0	0.0
	50	0.2
	70	0.7
	80	1.4
	90	2.3
	100	3.7
	120	8.6
	150	20.2
Sullivan Si Oxidized Bulk	0	0.0
	20	0.0
	40	0.1
	60	0.7
	80	1.6
	100	3.2
	120	
	150	17.7
	200	45.0
Sullivan Si Fresh	0	0.2
	100	0.2
	150	0.2
	200	0.2
	250	23.6
	300	68.0
	350	119

n.a. - Not Available

possibility of deep leaching of fertilizer beyond the growth zone of plants or into groundwater.

Emerald had a relatively high P fixation capacity but the percent fixed decreased as the amount initially added increased. It is possible that at Emerald the potential P fixation capacity could be reached and then more of the added P fertilizer would be available for plant growth.

All of Sullivan's tailings (with the exception of the gypsum pond) had a high P fixation capacity. It appears that the low pH of the Sullivan tailings coupled with the high iron content makes P fertilizers largely unavailable. This indicates, therefore, that before P is added as a fertilizer the acidity problem requires ameoloration.

Table 9:2 gives the results of the P adsorption experiment conducted with two weeks of aging (incubation). Again the samples from Bethlehem, Lornex, Endako, Kaiser and Sullivan gypsum showed little P fixation as evidenced by the amount of P remaining in solution after aging for 2 weeks. Also the pH values of the solution (after 2 weeks) was above 7.0 as was the pH of the spoil

Emerald and Similkameen exhibited a greater P fixation capacity (c.f. Table 9:1 and 9:2). Again Sullivan tailings exhibited the largest P fixation capacity, especially the Si-fresh and the Fe. In these cases the pH of the solution, after incubation, and the ph of the spoil dropped below 7.0, with the exception of Similkameen tailings.

A comparison of the amount of P fixed that was water soluble to that which was fixed in an available form by the mine spoils demonstrated similar trends, in that of the amount adsorbed (fixed), more was in a water soluble form with the spoil materials from Bethlehem,

Table 9:2: Phosphorus Adsorption After 2 Weeks of Incubation

Sample	Added P (Solution) ppm	Remaining P (Solution) ppm	Water Soluble P (Spoil) ppm	Available P (Spoil) ppm	Total P (Spoil) ppm	pH (Solution)	pH (Spoil)
Bethlehem Fresh						*7.00	-
	0	0.2	2.8	5.0	280	8.03	8.62
	10	9.4	16.6	13.8	560	7.89	8.62
	20	18.7	29.6	16.4	540	7.84	8.58
	30	27.7	38.6	21.0	500	7.70	8.79
Emerald 1.5-14.5 cm						*7.00	-
	0	0.0	1.2	0.0	300	7.48	7.29
	60	6.2	19.8	358	1220	7.13	7.13
	80	11.6	108	438	1500	7.00	6.83
	100	14.4	136	640	1700	6.83	6.60
	120	16.0	198	934	1940	6.93	6.56
	150	19.6	224	1475	2100	6.84	6.34
Endako 0-4 cm						*7.00	-
	0	0.1	0.0	5.0	580	8.06	8.46
	10	9.5	15.4	16.8	720	7.89	8.23
	20	19.4	25.8	22.4	640	7.67	8.53
	30	28.4	35.6	22.8	680	7.59	8.55
Kaiser Fresh						*7.00	-
	0	0.1	3.8	5.4	460	7.95	7.94
	10	9.2	27.2	16.2	560	7.89	7.82
	30	28.8	49.4	17.0	540	7.75	7.85
	50	49.0	67.6	24.6	640	7.57	7.89
	70	70.8	102	25.2	590	7.39	7.95

* Original pH of Solution.

(continued)... Table 9:2: Phosphorus Adsorption After 2 Weeks of Incubation

Sample	Added P (Solution) ppm	Remaining P (Solution) ppm	Water Soluble P (Spoil) ppm	Available P (Spoil) ppm	Total P (Spoil) ppm	pH (Solution)	pH (Spoil)
Kaiser 0-26 cm						*7.00	-
	0	0.2	0	12.0	600	7.33	6.94
	10	9.0	17.6	28.8	620	7.31	6.85
	30	28.2	38.6	42.2	580	7.20	6.93
	50	49.6	130.0	46.0	650	7.20	7.02
	70	70.0	176.0	45.0	700	7.18	7.05
Lornex 0-10 cm (Emerg. Pond)						*7.00	-
	0	0.2	5.0	6.2	380	7.91	8.68
	10	8.6	20.4	24.4	420	7.66	8.57
	20	18.0	43.4	31.4	440	7.95	8.74
	30	26.5	61.2	39.8	440	7.94	8.72
Lornex Bulk (Emerg. Pond)						*7.00	-
	0	0.2	5.4	7.6	420	8.07	8.39
	10	7.8	30.2	27.2	400	7.79	8.32
	20	17.3	42.8	36.6	440	7.80	8.25
	30	25.0	46.8	58.8	420	7.78	8.26
Lornex Fresh						*7.00	-
	0	0.2	4.0	5.8	480	7.86	8.35
	10	9.2	14.6	12.8	540	7.90	8.38
	20	18.8	26.6	17.8	460	7.72	8.47
	30	27.8	36.4	18.2	370	7.64	8.28
Similkameen 0-15 cm						*7.00	-
	10	5.6	23.6	47.0	1480	7.96	8.10
	30	18.6	104.8	90.2	1540	7.83	8.22

* Original pH of Solution

(continued)...   Table 9:2: Phosphorus Adsorption After 2 Weeks of Incubation

Sample	Added P (Solution) ppm	Remaining P (Solution) ppm	Water Soluble P (Spoil) ppm	Available P (Spoil) ppm	Total P (Spoil) ppm	pH (Solution)	pH (Spoil)
Sullivan Fe Oxidized Bulk						*7.00	-
	0	0.0	0.8	2.4	100	2.28	2.80
	60	1.1	39.2	387	1220	2.46	2.85
	80	1.4	53.8	520	1420	2.42	2.87
	100	2.6	62.2	568	1820	2.44	2.86
	120	5.6	-	617	2080	2.45	2.89
	150	10.4	61.2	748	2440	2.47	2.98
	200	25.6	52.6	840	3080	2.53	3.02
Sullivan Gypsum 1-5 cm						*7.00	-
	0	8.6	64.4	918	2480	5.22	5.43
	10	16.2	87.6	956	2580	6.00	5.78
	20	23.2	96.0	1174	2720	6.04	5.97
	30	28.1	93.2	1120	2740	5.53	5.85
Sullivan Si Oxidized Bulk						*7.00	-
	0	0.0	0.0	6.0	380	2.84	3.05
	60	0.4	3.2	123	1480	2.89	3.21
	80	0.6	4.6	211	1860	2.88	2.14
	100	4.5	11.6	318	2020	2.88	3.15
	120	8.3	22.8	377	2380	2.92	3.19
	150	16.6	46.0	507	2800	2.99	3.24
	200	54.8	65.2	608	3100	3.13	3.41

* Original pH of Solution

(continued)...

Table 9:2: Phosphorus Adsorption After 2 Weeks of Incubation

	Added P (Solution) ppm	Remaining P (Solution) ppm	Water Soluble P (Spoil) ppm	Available P (Spoil) ppm	Total P (Spoil) ppm	pH (Solution)	pH (Spoil)
Sullivan Si Fresh						*7.00	-
	0	0.1	1.6	0	180	4.61	4.51
	80	0.2	3.8	470	1500	5.25	4.27
	100	0.7	7.6	553	1920	4.98	4.30
	150	11.8	54.6	876	2360	4.83	4.49
	200	21.6	42.4	1251	2780	4.90	4.69
	250	47.4	54.0	1664	3340	5.34	4.91
	300	50.8	92.8	1609	4300	5.29	5.15

* Original pH of Solution

Lornex, Kaiser and Sullivan gypsum than from the other mine samples investigated. (Caution has to be exercised in interpreting these results as they are based on weight of spoil and not amounts in solution). Again Emerald and Similkameen tailings had a larger proportion of the fixed P in available form in the spoil material than in water soluble form. This was also true for the Sullivan gypsum material tested. Once again Sullivan Si and Fe tailings fixed the most P into water insoluble compounds.

Total P values for the tailings exhibited interesting results (again based on a weight basis). Bethlehem, Lornex, Endako and Kaiser all had values from 280 ppm to about 700 ppm with the average about 500 ppm; thus a relatively low amount of natural plus fixed phosphorus is in an unavailable form to plants. All of the other mine samples fixed the added P in a form that is believed to be unavailable for plant growth.

A graphic comparison of the amount of P fixed after 24 hours and 2 weeks is presented in Figures 9:1 to 9:16. With the exception of Sullivan, all mine samples studied increased the amount of P fixed following aging. The results obtained for Sullivan can not be explained readily. At the lower concentrations less of the added P is fixed after incubation for two weeks than after only 48 hours. At higher amounts added the two curves converge. The types of reaction products formed require further elucidation.

FIGURE 9:1
PHOSPHORUS FIXATION CAPACITY
BETHLEHEM FRESH

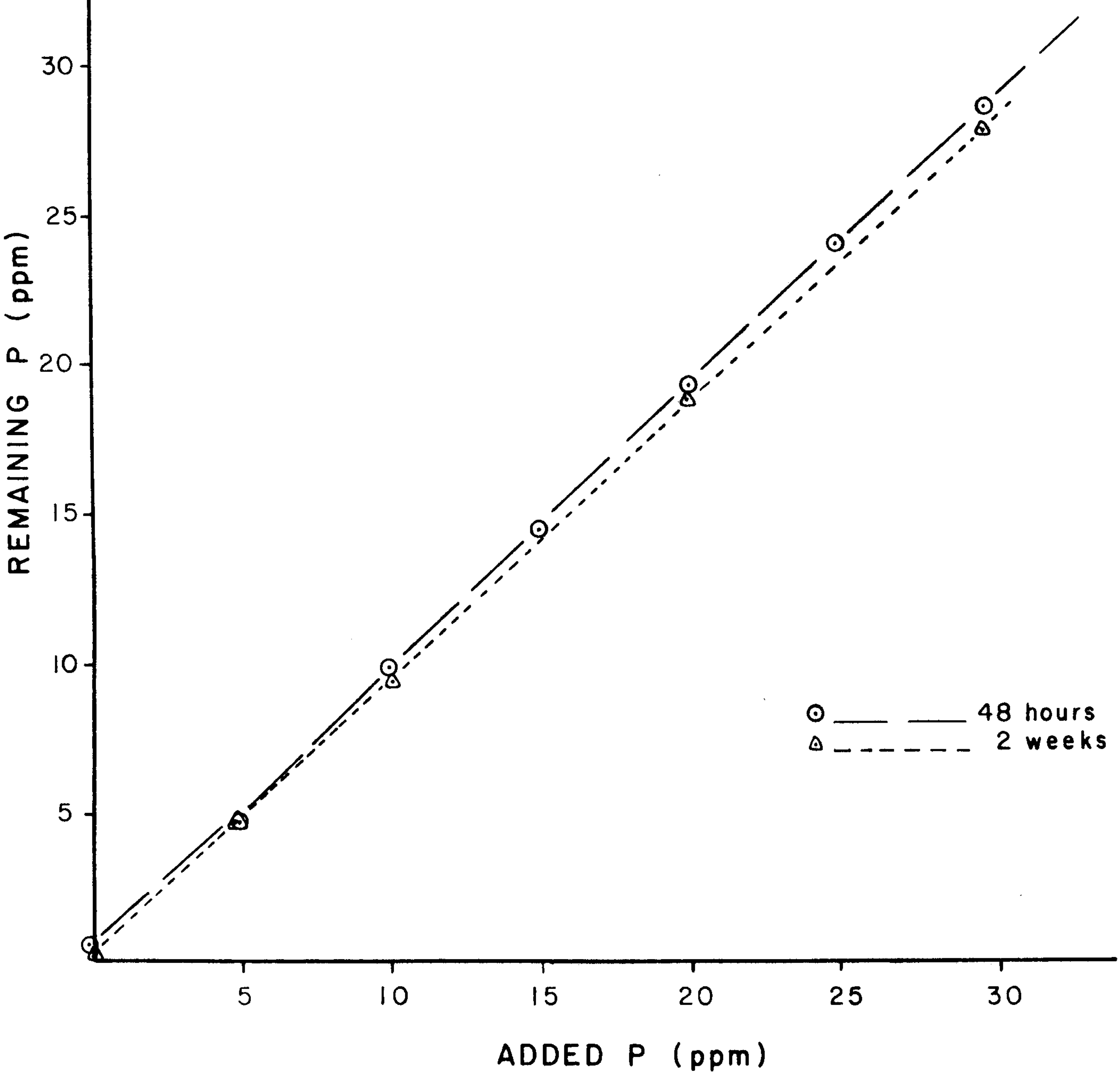


FIGURE 9:2
PHOSPHORUS FIXATION CAPACITY
EMERALD 1.5 - 14.5 cm.

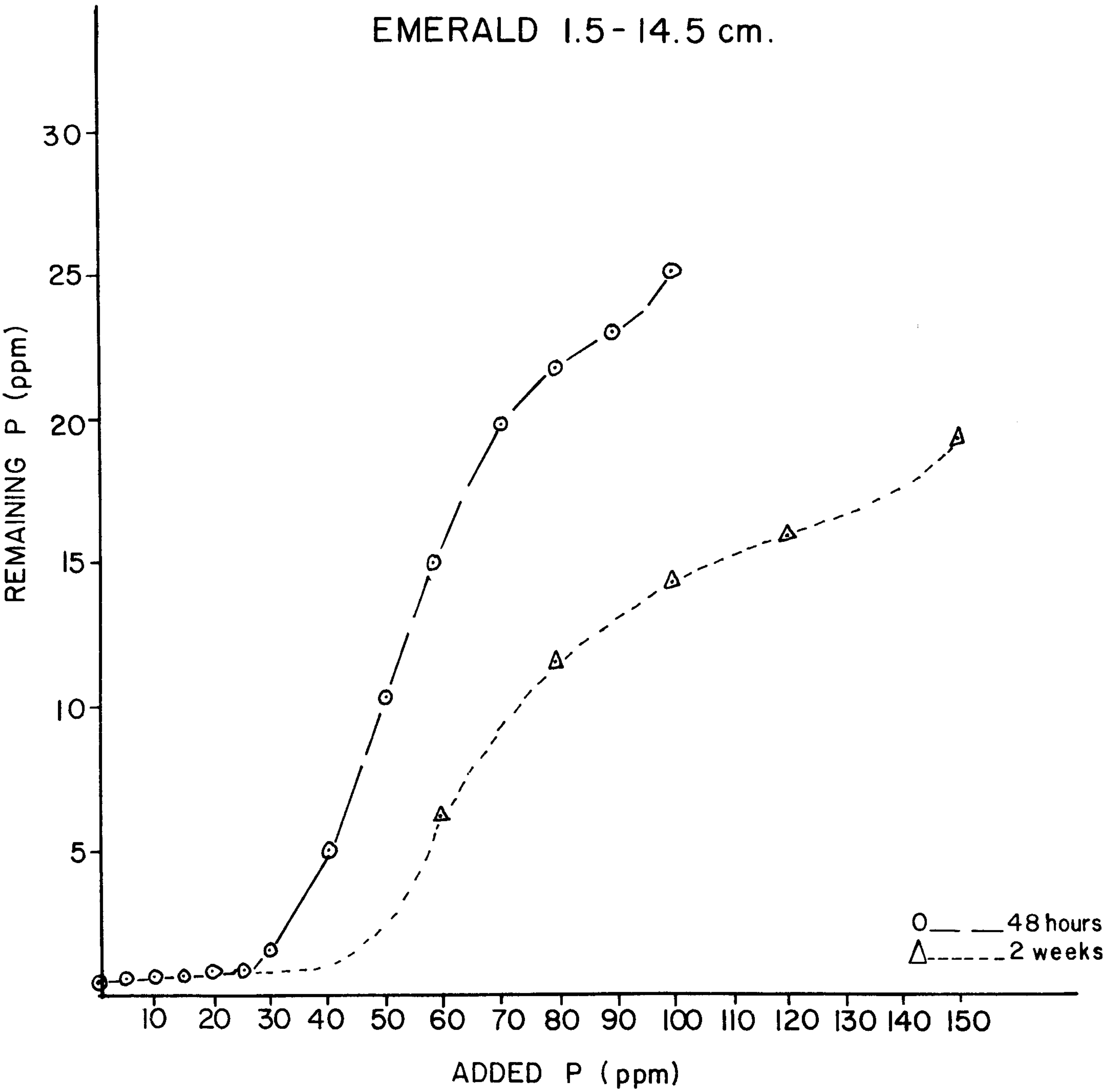


FIGURE 9:3
PHOSPHORUS FIXATION CAPACITY
ENDAKO 0-4 cm.

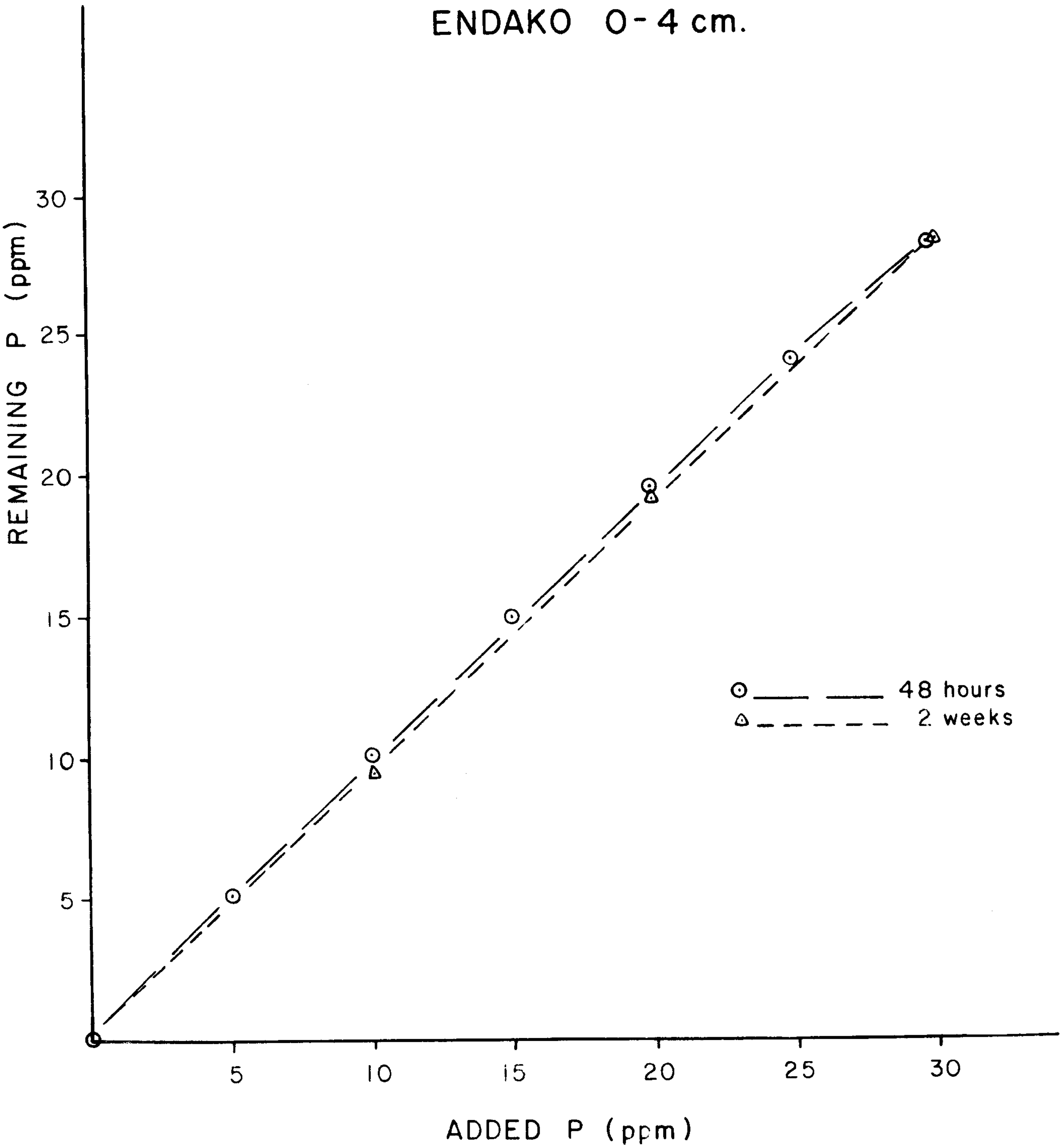


FIGURE 9:4
PHOSPHORUS FIXATION CAPACITY
GIBRALTAR FRESH

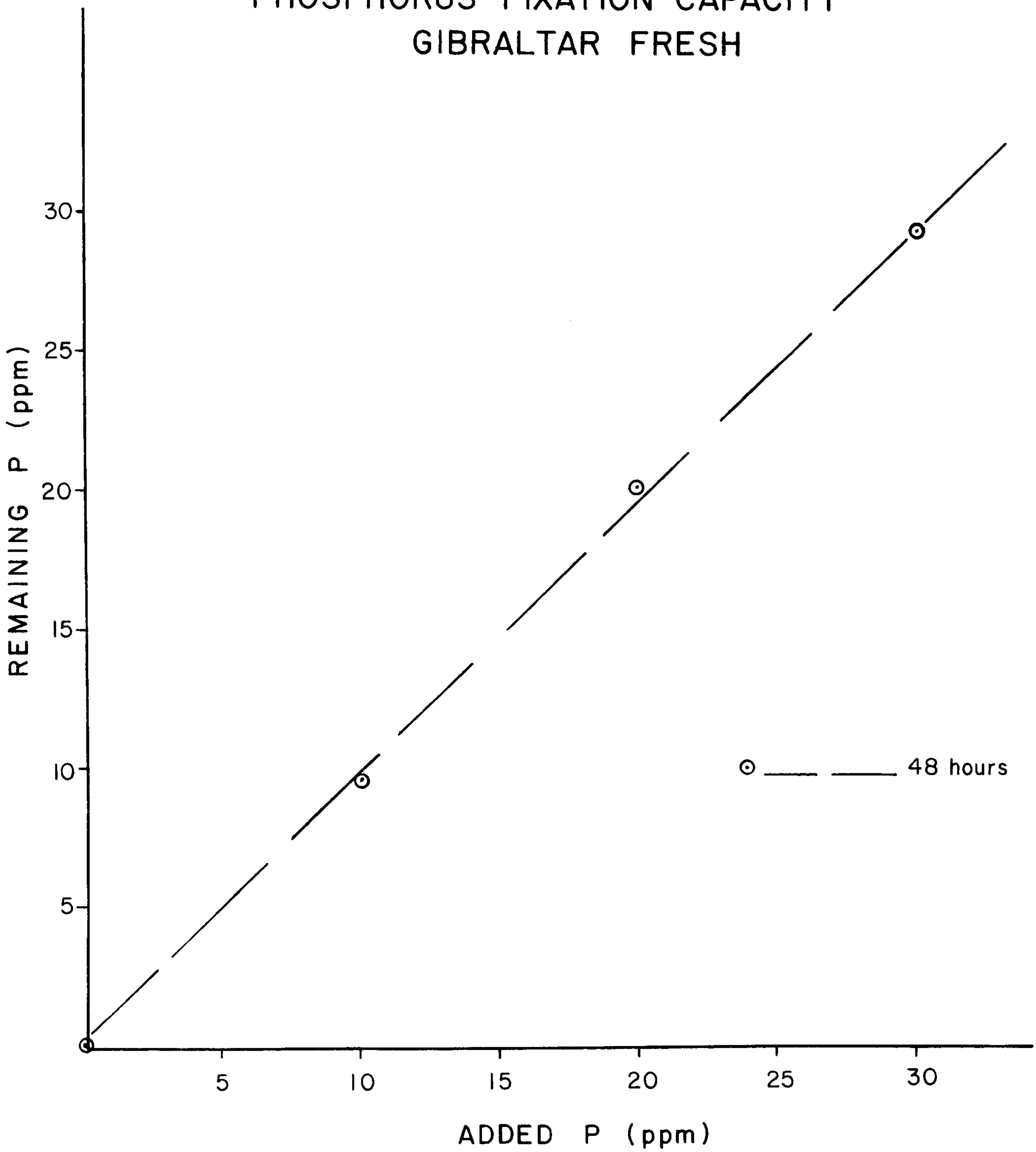


FIGURE 9:5
PHOSPHORUS FIXATION CAPACITY
KAISER FRESH

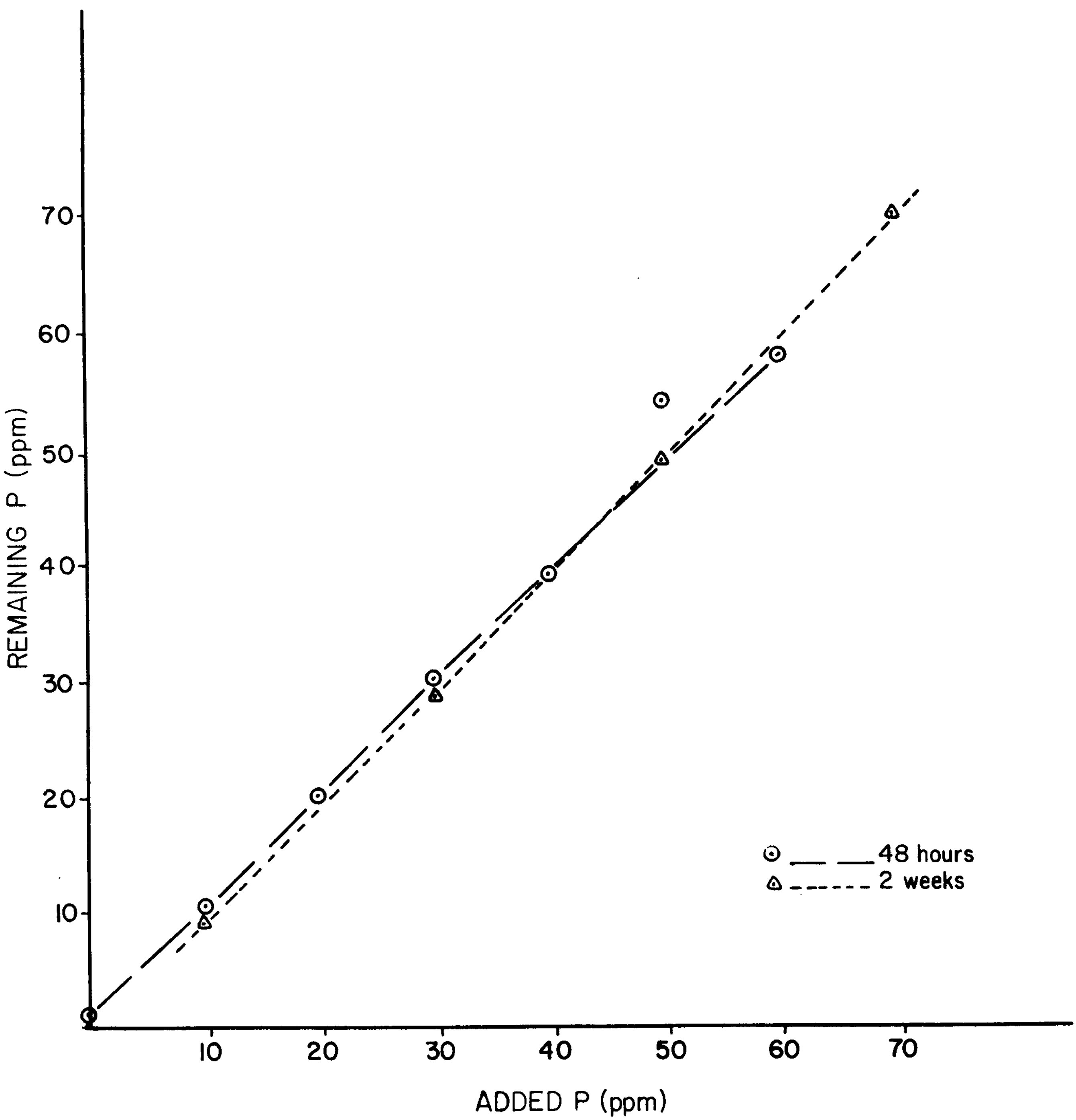


FIGURE 9:6
PHOSPHORUS FIXATION CAPACITY
KAISER 0-26 cm.

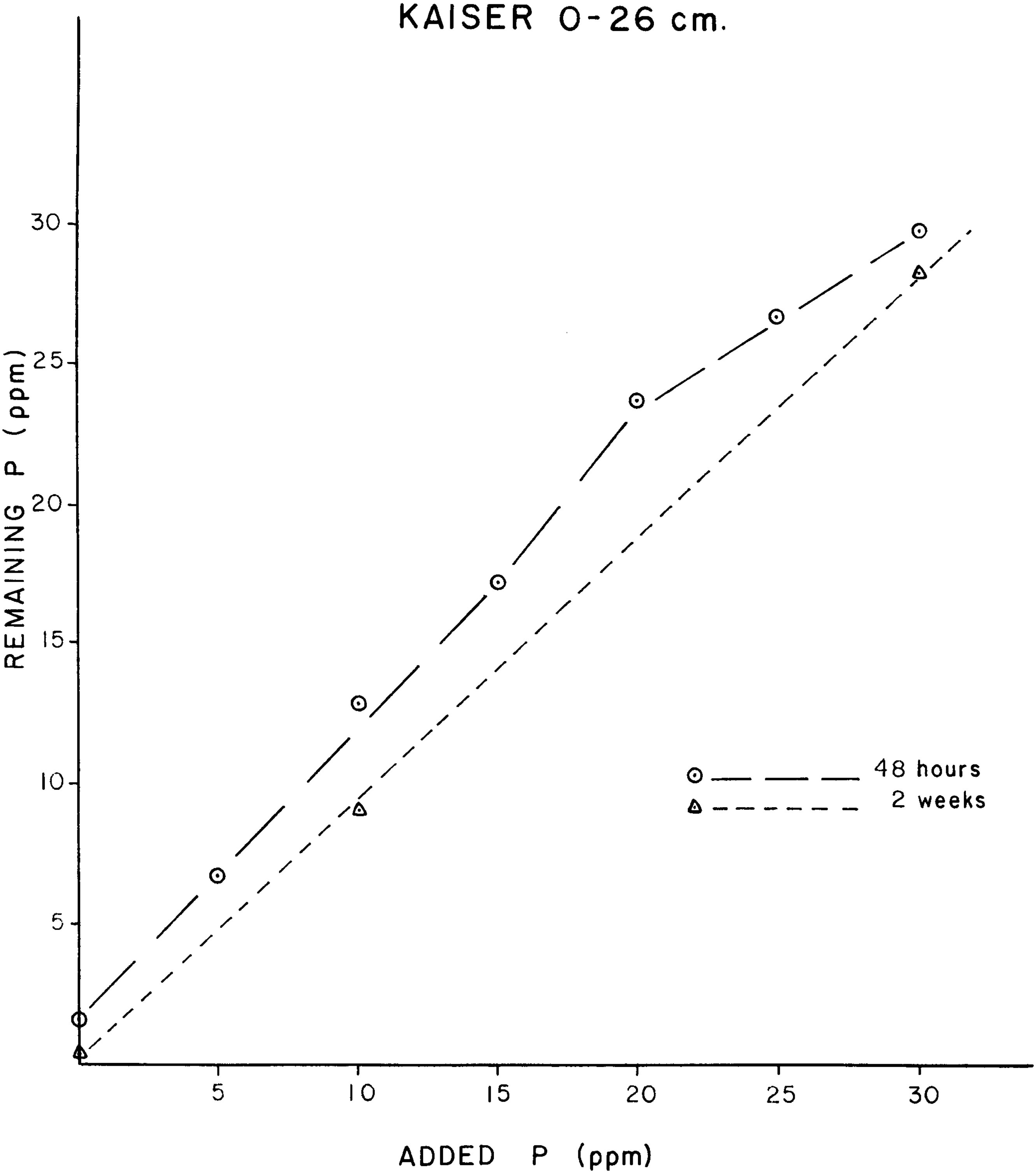


FIGURE 9:7
PHOSPHORUS FIXATION CAPACITY
LORNEX 0-10 cm.
(Emerg. Pond)

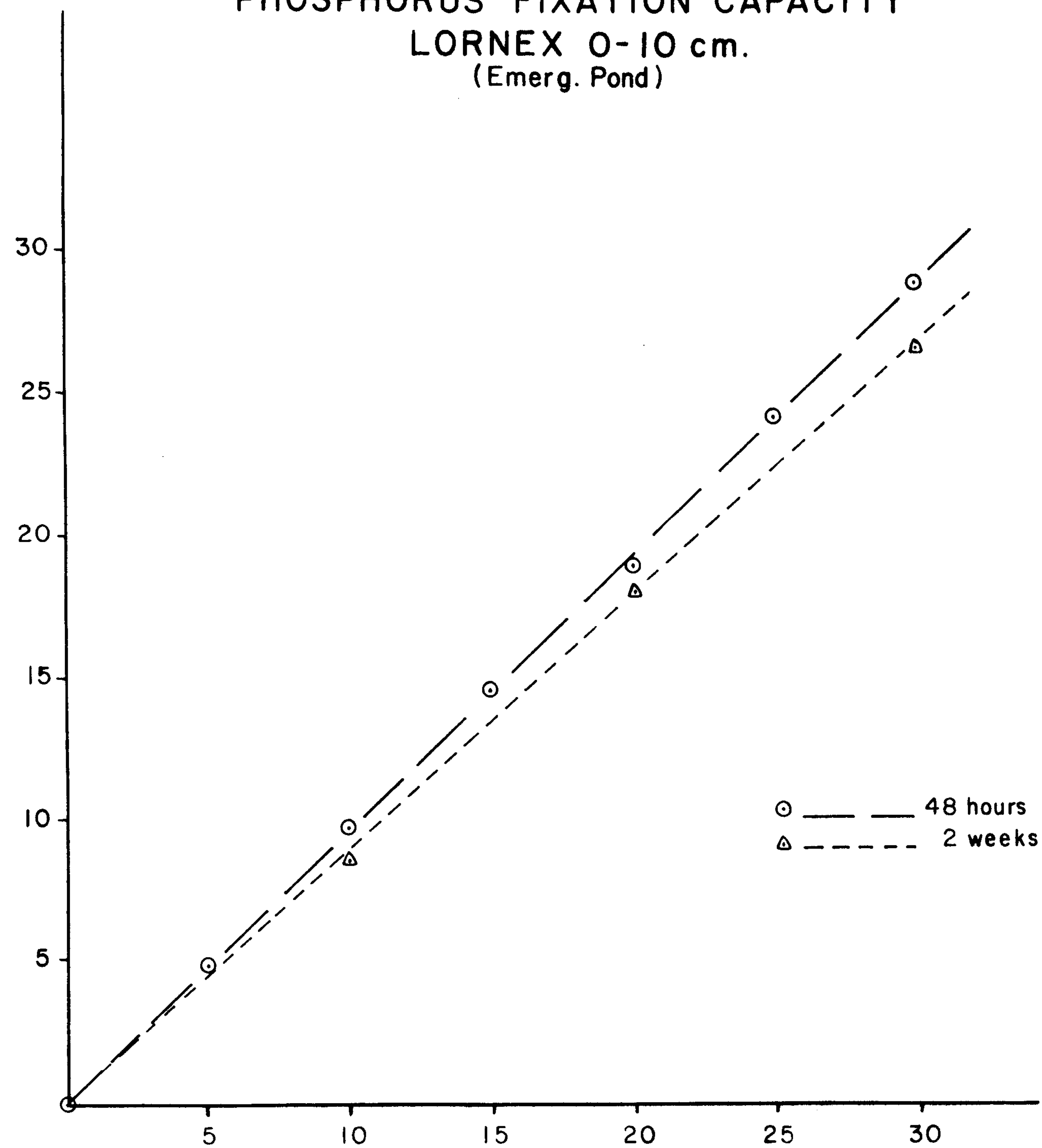


FIGURE 9:8
PHOSPHORUS FIXATION CAPACITY
LORNEX BULK
(Emerg. Pond)

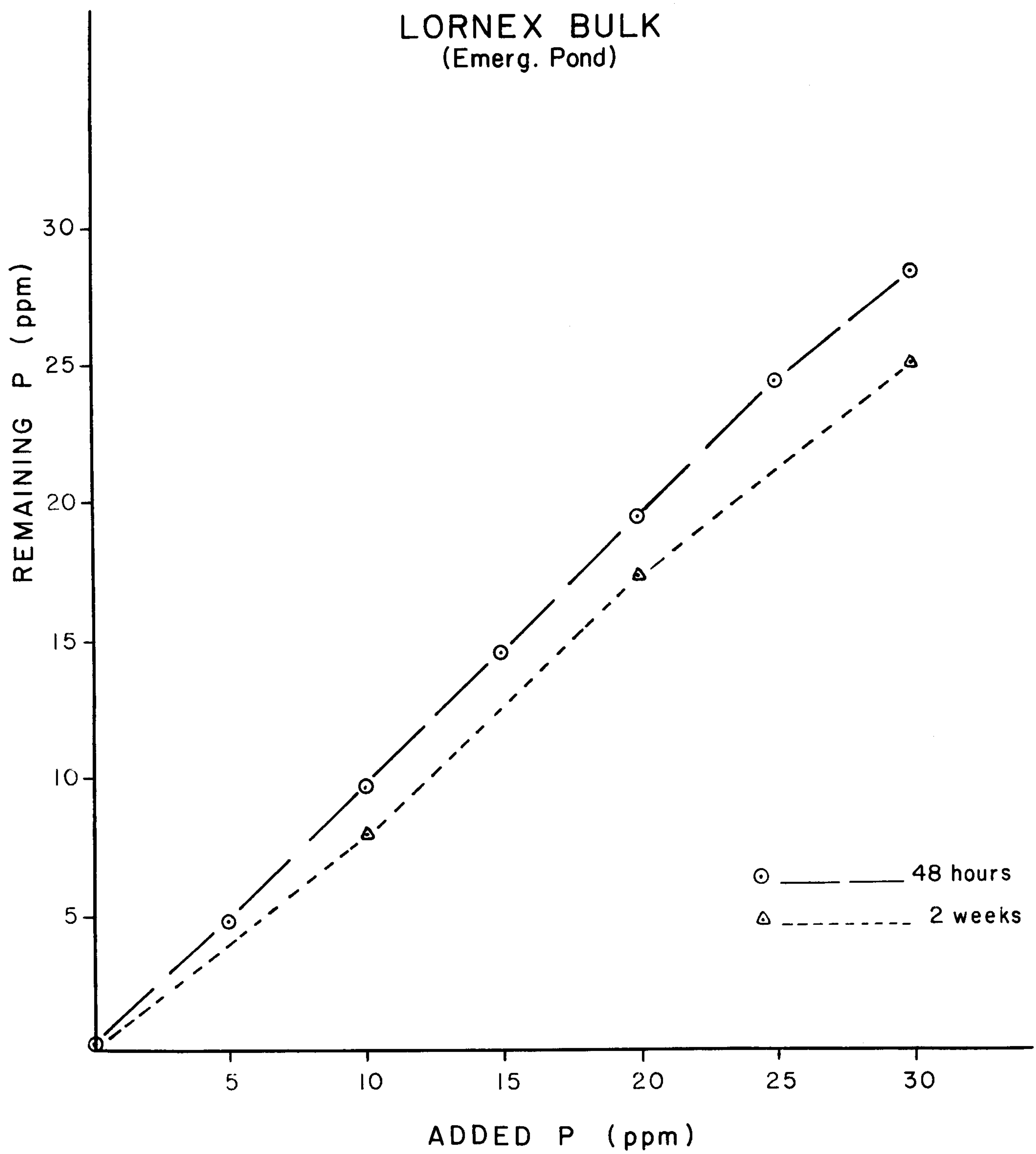


FIGURE 9:9
PHOSPHORUS FIXATION CAPACITY
LORNEX FRESH

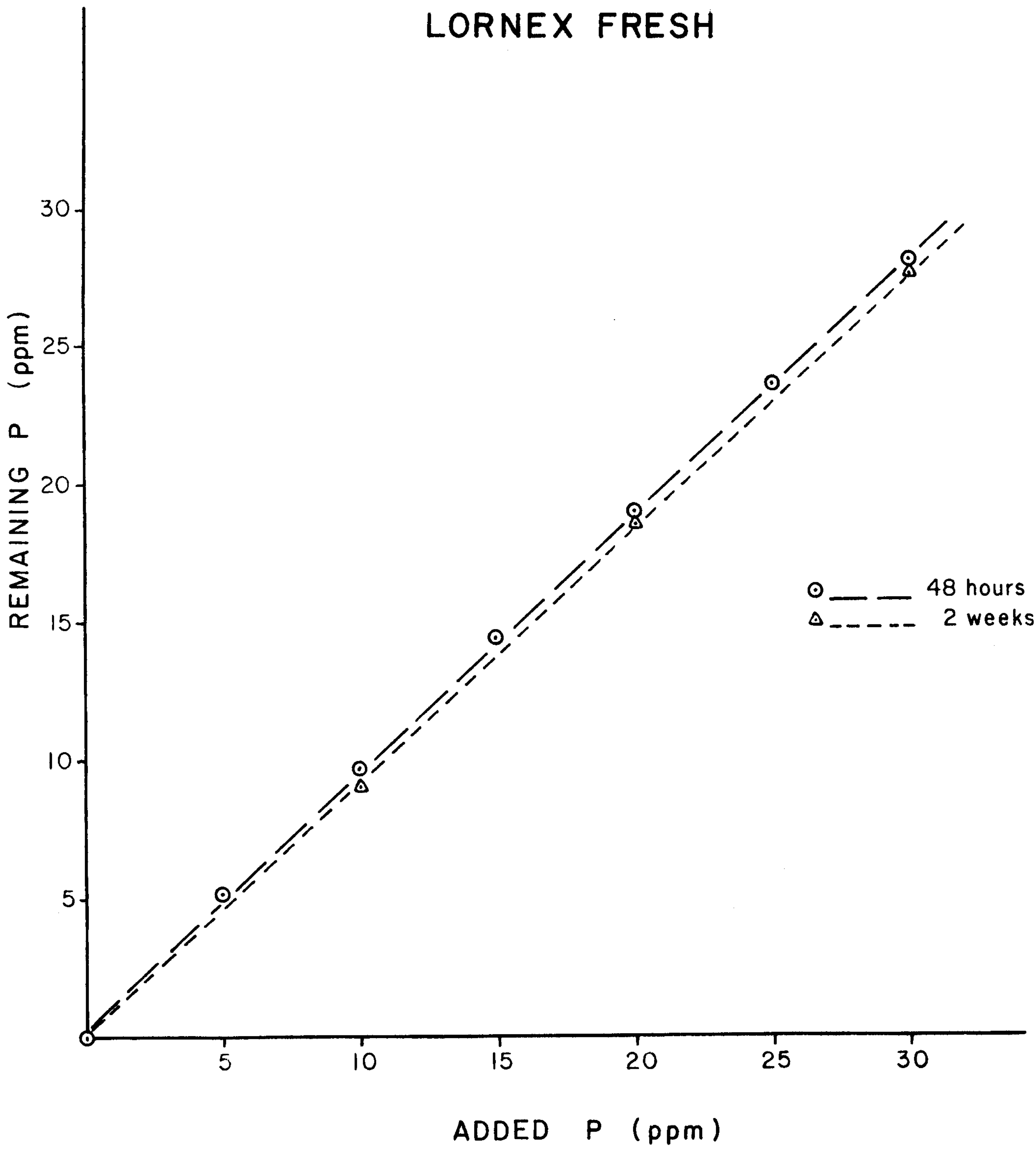


FIGURE 9:10
PHOSPHORUS FIXATION CAPACITY
SIMILKAMEEN 0-15 cm.

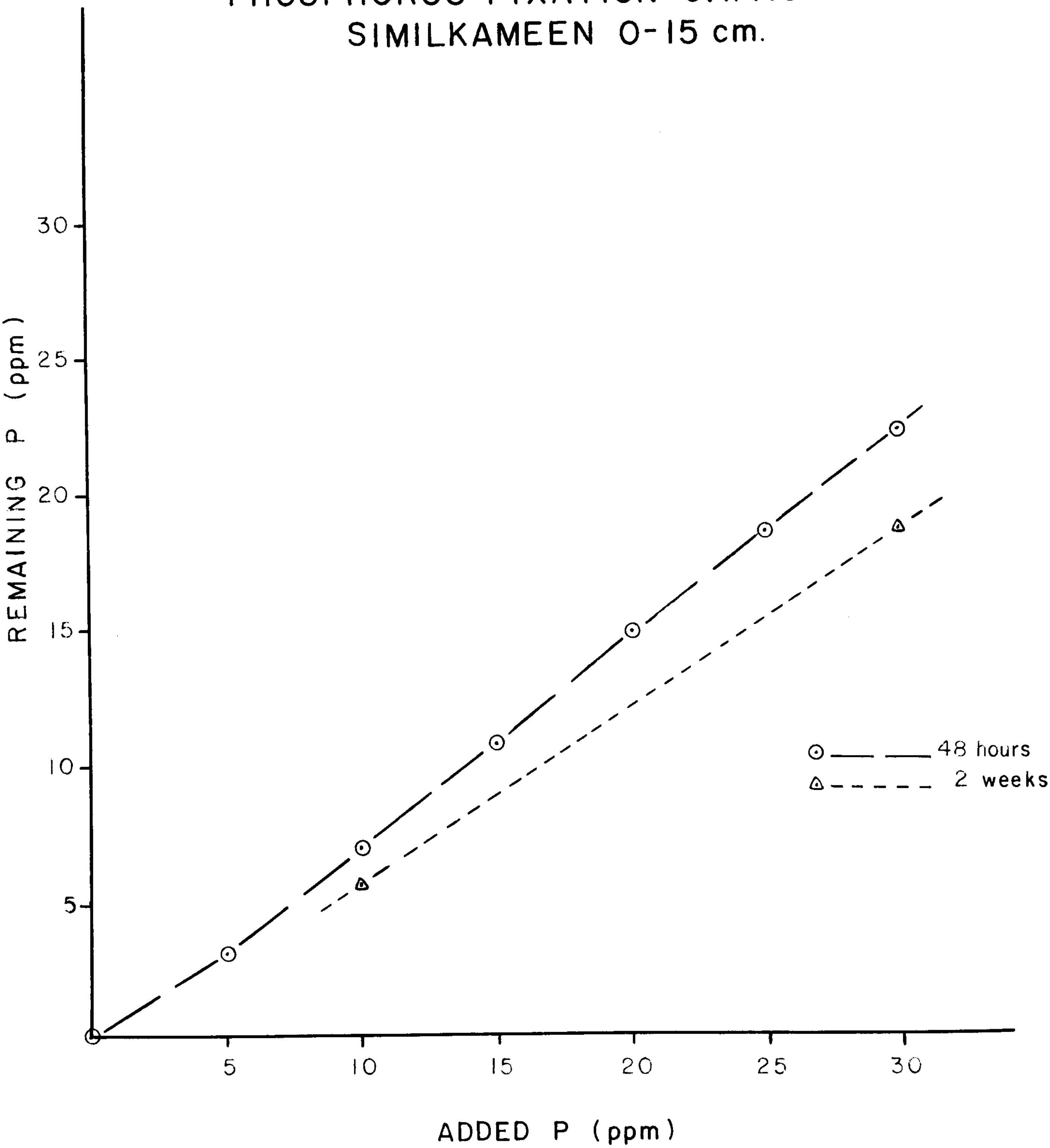


FIGURE 9:11
PHOSPHORUS FIXATION CAPACITY
SULLIVAN Fe OXIDIZED BULK

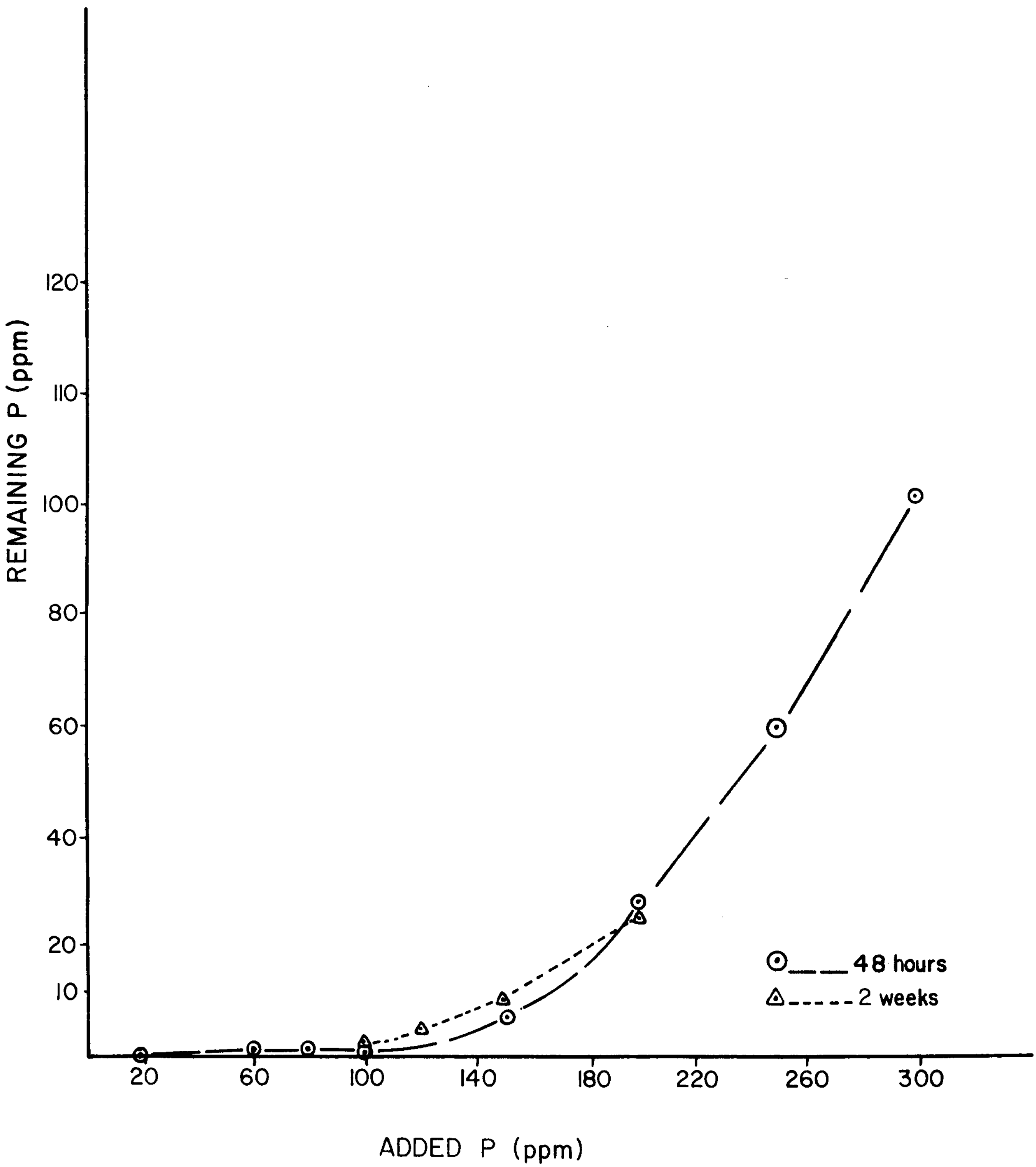


FIGURE 9:12
PHOSPHORUS FIXATION CAPACITY
SULLIVAN GYPSUM 1-5 cm.

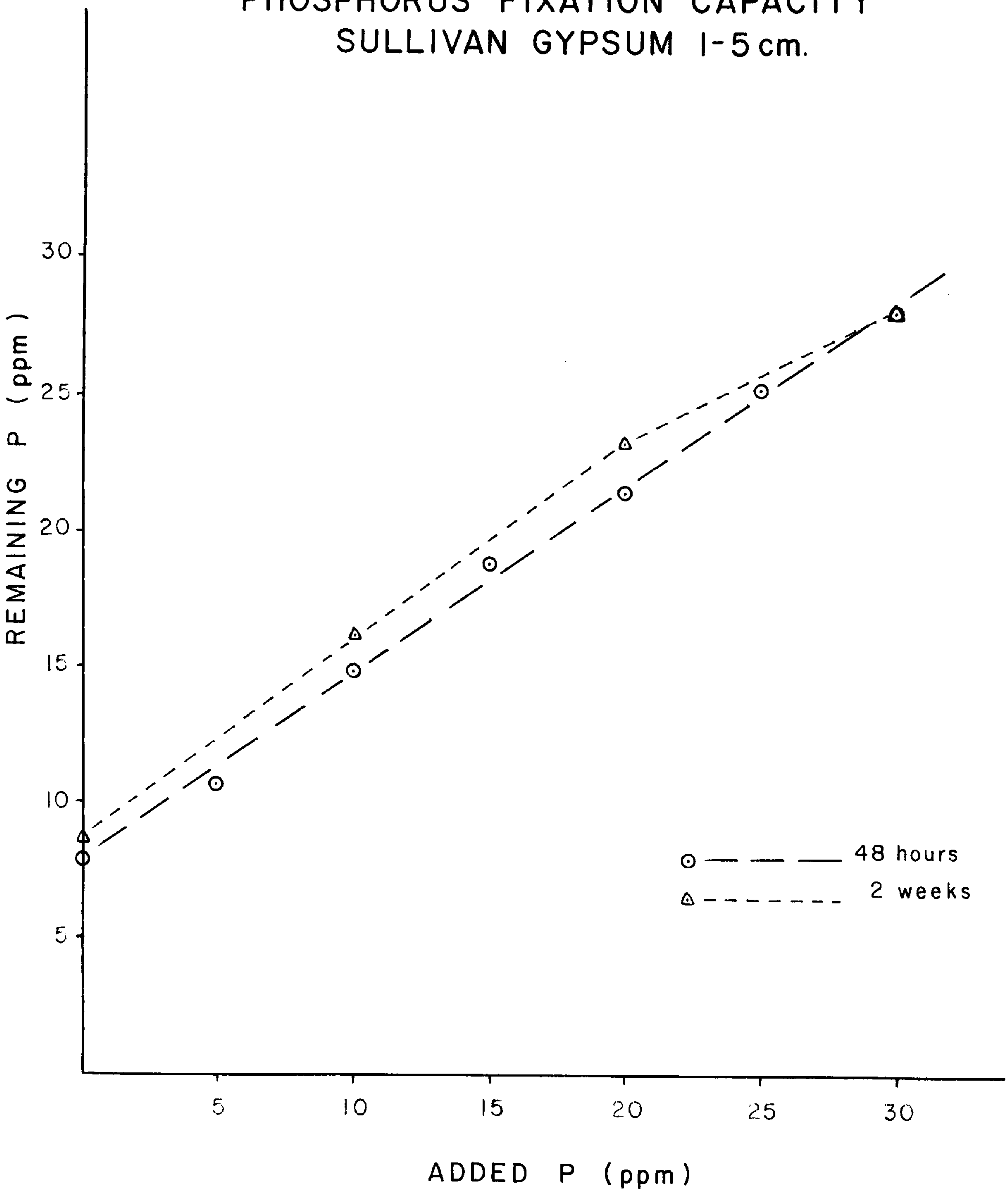


FIGURE 9:13
PHOSPHORUS FIXATION CAPACITY
SULLIVAN Si-Fe 0-1cm.

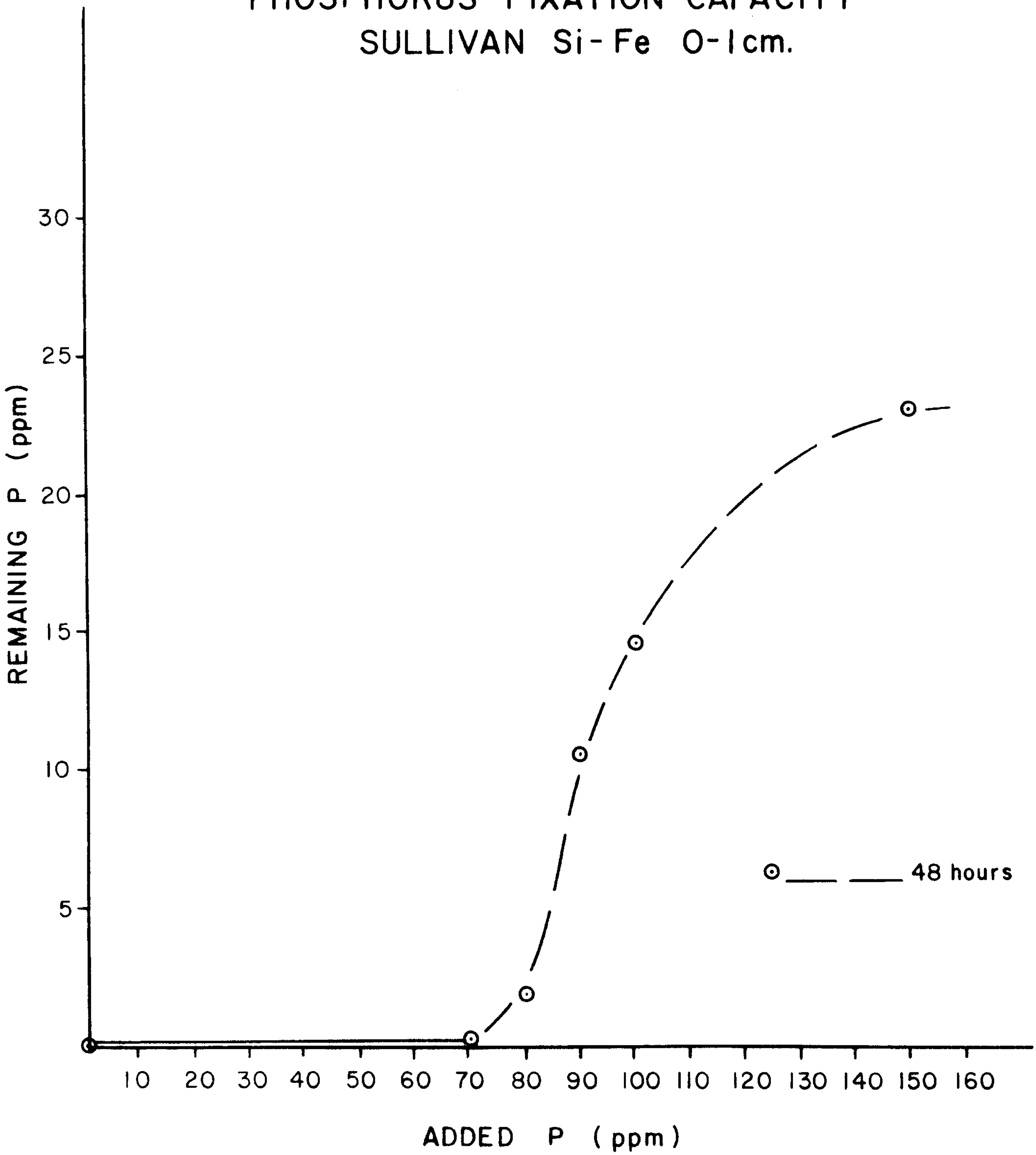


FIGURE 9:14
PHOSPHORUS FIXATION CAPACITY
SULLIVAN Si-Fe 4-6 cm.

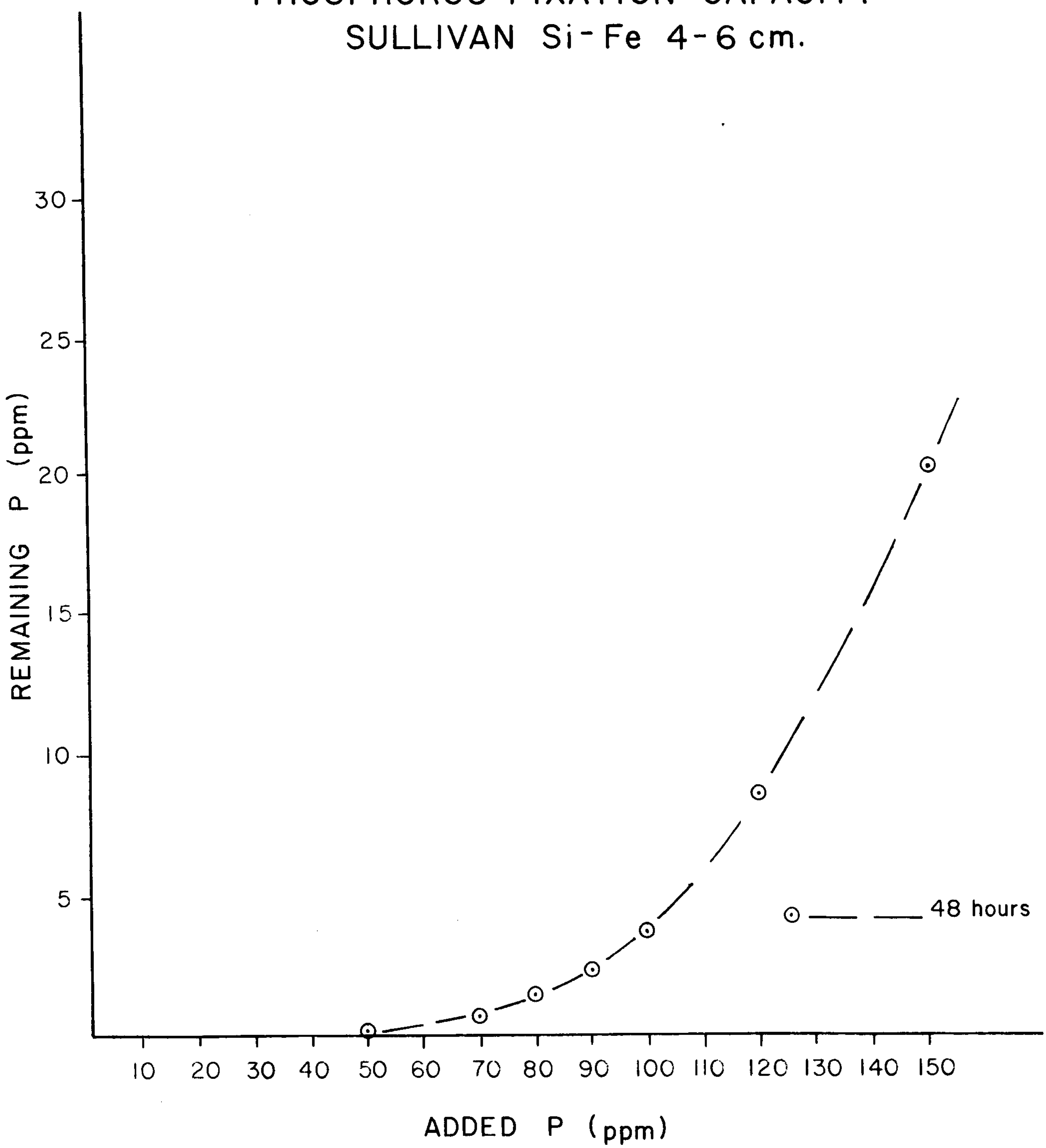


FIGURE 9:15
PHOSPHORUS FIXATION CAPACITY
SULLIVAN Si OXIDIZED BULK

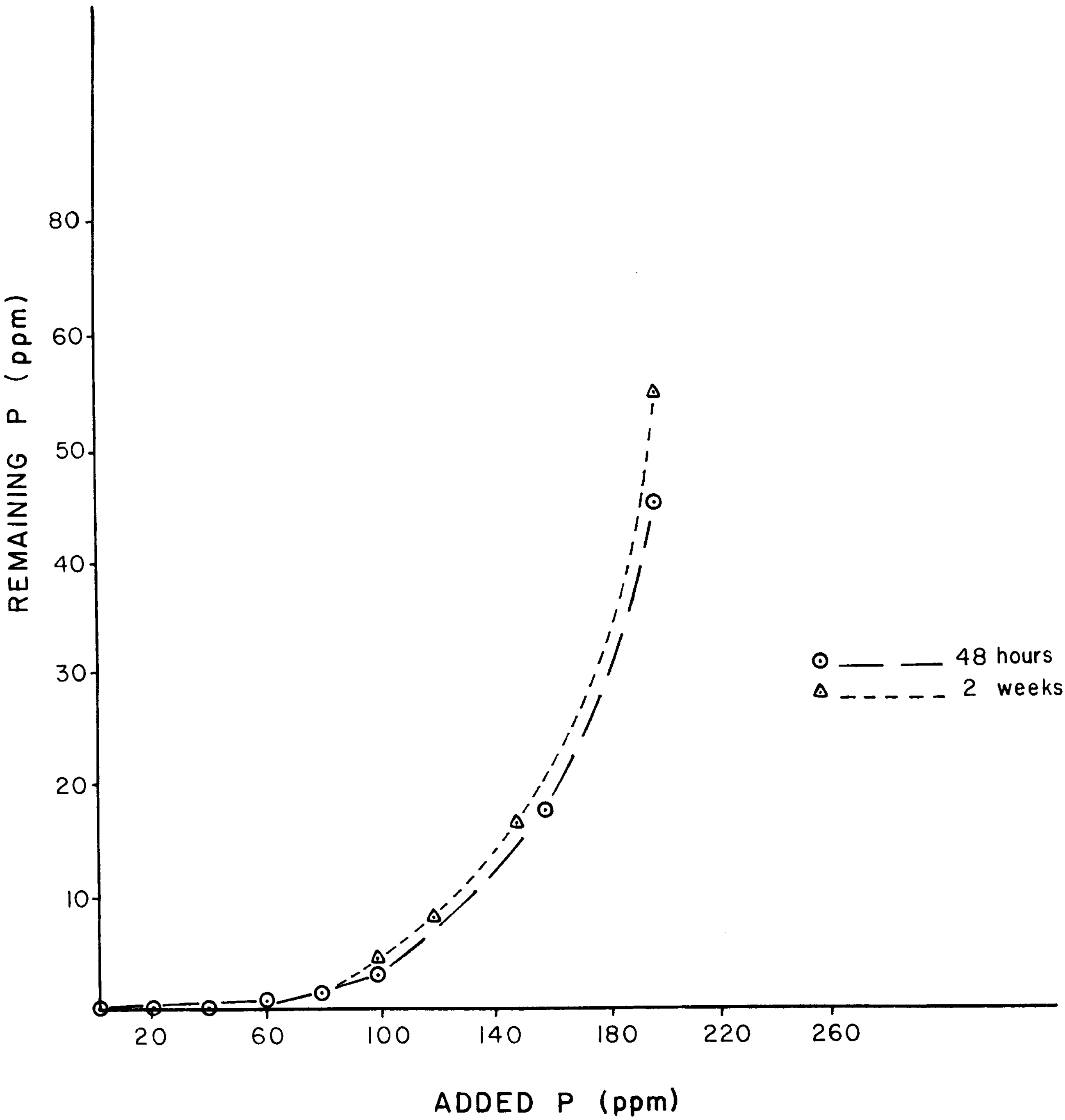
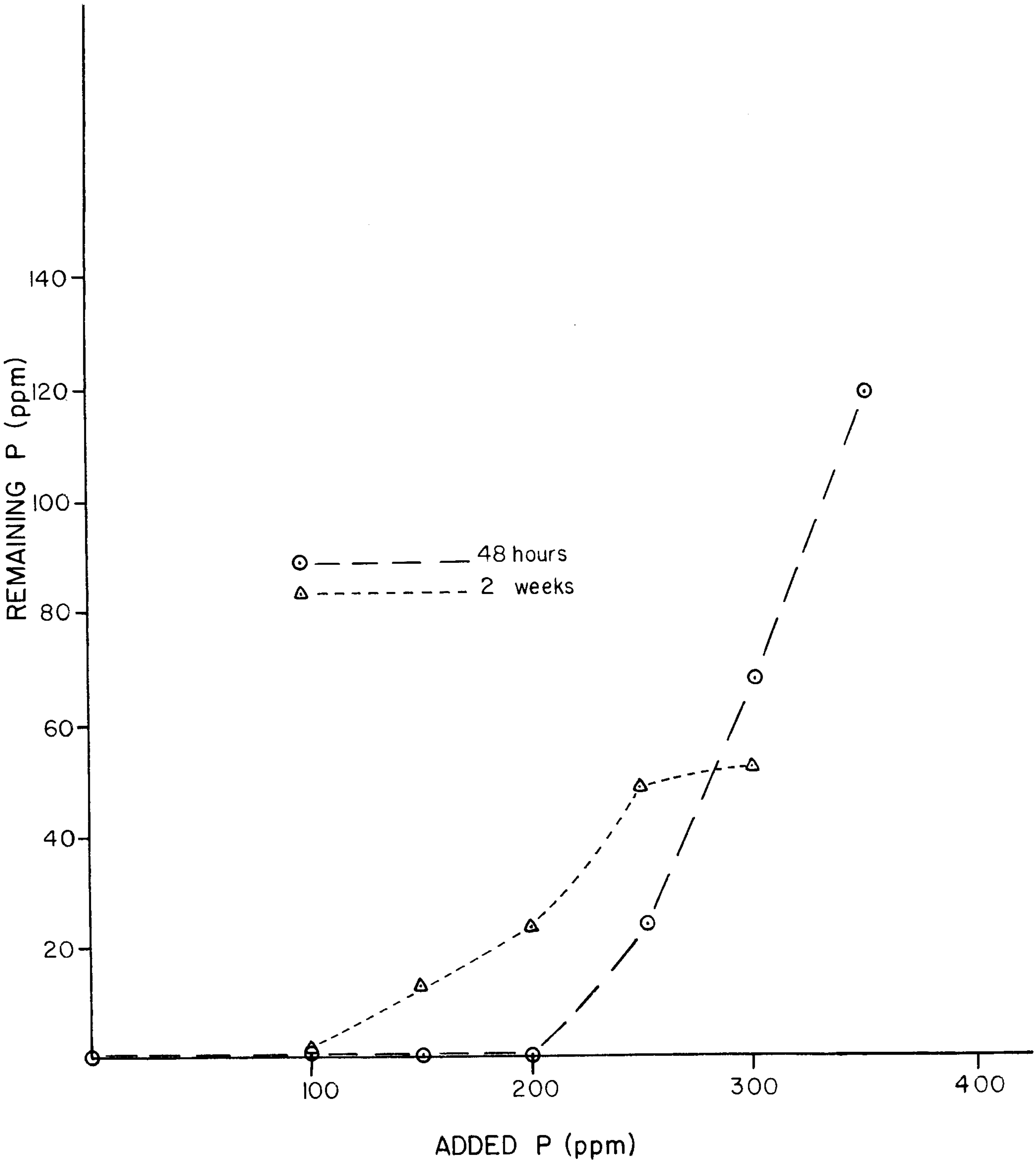


FIGURE 9:16
PHOSPHORUS FIXATION CAPACITY
SULLIVAN Si FRESH



4. Conclusion

From the preliminary results obtained from this study it appears that a single, relatively large dose of phosphorus fertilizer can be added to the mine spoil of Bethlehem, Lornex, Endako, and Kaiser to overcome phosphorus deficiencies for plant growth. In general this seems to apply to the Sullivan gypsum tailings also. Emerald and to a lesser extent Similkameen tailings appear to have a higher P fixation capacity. It appear that the P fixation potential in these tailings could be overcome, with time, by large amounts of a single applicatien of phosphorus fertilizer. To prevent possible losses of phosphorus fertilizer to deep leaching and possible contamination of groundwaters, it would probably be best to apply phosphorus fertilizers, at least initially in one heavy dose followed by light top dressing subsequently. It appears that with time, phosphorus applications could become less frequent.

Sullivan tailings are once again unique, The reaction products formed with phosphorus and the tailings materials are not understood. Practically, the pH and salt problem require solving before meaningful recommendations can be given for phosphorus fixation.

LITERATURE REVIEW

LITERATURE REVIEW

Allen, M.B. 1959. Studies with cyanidium caldarium, an anomalously pigmented chlorophyte. Arch. fur Mikrobiol. 32:270-277.

Ball, Clive W. 1954. The Emerald, Feeney, and Dodger tungsten ore bodies, Salmo, B.C. Ec. Geol. 49:625-630.

Bascomb, C.L. 1968. Distribution of pyrophosphate extractable iron and organic carbon in soils of various groups. J. Soil Sci. 19: (2) : 251-268.

Beaton, James D., George R. Burns, Jan Platou. 1968. Determination of sulphur in soils and plant material. Tech. Bull. no. 14. The Sulphur Institute, England.

Belly, R.T. and T.D. Brock. 1974. Ecology of iron-oxidizing bacteria in pyritic materials associated with coal. J. Bacteriol. 117:726-732.

Billingsley, P. and C.B. Hume. 1941. The ore deposits of Nickel Plate Mountain, Hedley, B.C. Trans. Can. Inst. Mining Met. 44:524-590.

Black, C.A. (Ed.). 1965. Methods of soil analysis. Am. Soc. Agr., Spec. Pub. 9.

Buckley, D.E. and R.C. Cranston. 1971. Atomic absorption analysis of 18 elements from a single decomposition of alumino-silicate. Chem. Geol. 7:273-284.

Canadian Soil Survey Committee. 1974. The system of soil classification for Canada. Agric. Canada.

Collens, C.H. 1964. Microbiological methods. Butterworth and Co. Ltd., London.

Connor, A.J. 1949. The frost-free season in British Columbia. Meteor. Div; Dep. Transport.

Dowling, D.B. 1915. Coal fields of British Columbia. Geol. Surv. Can., Mem. 69.

Dowling, D.B. 1909. Coal fields of Manitoba, Saskatchewan, Alberta, and eastern British Columbia. Can. Dep. Mines, Geol. Surv. Br., p. 32-33.

Drysdale, C.W. 1915. Geology and ore deposits of Rossland. Geol. Surv. Can., Mem. 77.

Fliermans, C.B. and T.D. Brock. 1973. Assay of elemental sulfur in soil. Soil Sci. 115:120-122.

Frankton, C. and W.H. Wright. 1956. Weeds of Canada. CDA Publ. no. 948.

Fyles, J. T. 1966. Lead-zinc deposits in British Columbia. p. 231-238. In Tectonic history and mineral deposits of the Western Cordillera. Can. Inst. Mining Met., Spec. vol.8.

Fyles, J.T. and C.G. Hewlett. 1959. Stratigraphy and structure of the Salmo lead-zinc area. B.C. Dep. Mines, Bull. 41.

Geological Survey of Canada. 1970. Geology and economic minerals of Canada. Dep. Energy, Mines and Res.

Hedley, M.S. and K. De P. Watson. 1945. Lode-gold deposits - Central southern British Columbia, p. 20.

Henin, S. and G. Pedro. 1965. The laboratory weathering of rocks. p. 29-39. In E. H. Hallsworth and C. V. Crawford (ed.) Experimental pedology. Proceedings of the eleventh Easter school in agricultural sciences, Univ. Nottingham, 1964.

Hitchcock, A.S. 1971. Manual of grasses of the United States, Vol. 2. 2nd ed. rev. Dover Publications, New York.

Hitchcock, C.L. and A. Cronquist. 1974. Flora of the Pacific Northwest: An illustrated manual. University of Washington Press, Seattle.

Holland, S.S. 1964. Landforms of British Columbia: A physiographic outline. B.C. Dep. Mines Petrol. Resources, Bull. 48.

Hutchinson, M., K.I. Johnstone, and D. White. 1969. Taxonomy of the genus Thiobacillus: The outcome of numerical taxonomy applied to this group as a whole. J. Gen. Microbiol. 57:397-410.

Kragina, V.J. 1965. Ecology of western North America. University of British Columbia, Dep. Botony, Vancouver.

Lavkulich, L.M. 1977. Methods manual - Pedology Laboratory. University of British Columbia, Dept. Soil Sci., Vancouver.

Lavkulich, L.M., A.A. Bomke, R.E. Hardy, C.A. Murray, J. M. Robbins, D.A. Nutchey, and C.A. Rowles. 1976. Pedological inventory of three sulfide mine areas in British Columbia. University of British Columbia, Dep. Soil Sci., Vancouver.

Lavkulich, L.M., A.A. Bomke, J.W. Morton, P.A. Dairon, R.E. Hardy, M.E. Walmsley, and C.A. Rowles. 1975. Pedological inventory of three sulfide mine areas in southwest British Columbia. University of British Columbia, Dep. Soil Sci., Vancouver.

Mathews, W.H. 1948. Lode-gold deposits - Southeastern British Columbia. B. C. Dep. Mines, Bull. 20, Part II, p. 9.

McKeague, J. A. and J.H. Day. 1966. Dithionite and oxalate extractable iron and aluminum as aids in differentiating various classes of soils. Can. J. Soil Sci. 46:13-22.

Meteorological Branch, 1975. Canadian normals, precipitation, vol. 2-SI, 1941-1970. Env. Canada.

Meteorological Branch. 1975. Canadian normals, temperature, vol. 1-SI, 1941-1970. Env. Canada.

Miltimore, J. E. and J. L. Mason. 1971. Copper to molybdenum ratio and molybdenum and copper concentrations in runimant feeds. Can. J. Anim. Sci. 51:193-200.

Miltimore, J. E., J. L. Mason, J. M. McArthur and R. B. Carson. 1964. Ruminant mineral nutrition. The effect of copper ingestions on weight of cattle pastured on groundwater soils in the British Columbia Interior. Can. J. Comp. Med. Vet. Sci. 28:108-112.

Morton, J. W. 1976. The physical limitations to vegetation establishment of some southern British Columbia mine waste materials. M. Sc. Theisis. University of British Columbia, Dep. Soil Sci., Vancouver.

Newmarch, C.B. 1953. Geology of the Crowsnest Basin. B.C. Dep. Mines, Bull. 33.

Rice, H.M.A. 1947. Geology and mineral deposits of the Princeton map-area, British Columbia. Geol. Surv. Can., Mem. 243.

Silverman, M.P., and Lundgren, D.G. 1959. Studies on the Chemoautotrophic Iron Bacterium Ferrobacillus Ferrooxidans. I. An Improved Medium and Harvesting Procedure for Securing High Cell Yields. J. Bacteriol. 77;642-647.

Singleton, Glen. 1978. PhD. Theisis. University of British Columbia; in progress.

Smittenberg, J., G.W. Harmsen, A. Quispel, D. Otzen. 1951. Rapid methods for determining different types of sulfur compounds in soil. Plant and Soil III-4:353-360.

Soil Survey Staff. 1952. Soil survey manual. Agric. Handb. no. 18, USDA. U.S. Government Printing Office, Washington, D.C.

Surveys and Mapping Branch. 1973. Soils and landform map of the Salmo area. B.C. Dep. Lands and Forests.

Tisdale, S.L., and L.N. Werner. 1975. Soil fertility and fertilizers. 3rd ed., rev. Macmillan Co., New York.

U. S. Salinity Laboratory Staff. 1954. L. A. Richards (ed.) Diagnosis and improvement of saline and alkalai soils. Agric. Handb. no. 60, USDA. U.S. Government Printing Office, Washington, D.C.

Vishniac, W., M. Santer. 1957. The thiobacilli. Bacteriol. rev. 21:195-213.

Walker, J. F. 1934. Geology and mineral deposits of the Salmo map-area. Geol. Surv. Can., Mem. 172.

Weaver, R.M., J.K. Syers, and M. L. Jackson. 1968. Determination of silica in citrate-bicarbonate-dithionite extracts of soil. SSSAP 32:497-501.

APPENDIX I

PLANT SPECIES LIST

APPENDIX I: PLANT SPECIES LIST

A. COAL CREEK

a. Tailings Pond Site

Trees	*Cornus stolonifera*	red-osier dogwood
	Picea glauca	white spruce
	**Populus tremuloides*	trembling aspen
	**Populus trichocarpa*	cottonwood
Shrubs	*Acer douglasii*	Douglas' maple
	Amelanchier alnifolia	saskatoon
Herbs	*Atemisia absinthium*	absinthium
	Capsella bursa-pastoris	Shepherd's purse
	Chenopodium album	lambsquarter
	Epilobium minutum	small-flowered willow-herb
	Equisetum hyemale	horsetail
	**Heliopsis scabra*	ox-eye daisy
	Lepidium densiflorum	peppergrass
	Linaria vulgaris	butter and eggs
	**Melilotus alba*	white sweet clover
	**Melilotus officinalis*	yellow sweet clover
	Plantago major	plantain
	**Potentilla flabellifolia*	fan-leaf cinquefoil
	Potentilla gracilis	cinquefoil
	Senecio serra	butterweed groundsel
	Sonchus arvensis	sow thistle
	Taraxacum officinale	dandelion
	Thalaspi arvense	stinkweed
	Trifolium agrarium	yellow clover
	Trifolium repens	dutch clover
Graminoids	**Agrostis alba*	redtop
	Agrostis sp.	bentgrass
	Alopecurus ssp.	foxtail
	Festuca rubra	red rescue
	**Phleum pratense*	timothy
	Poa compressa	Canada bluegrass
Mosses	*Unidentified	

* These species were found growing within 5 m of the "vegetated" pit site.

b. Dry Grassland Site

Trees

Populus trichocarpa	cottonwood

Shrubs

**Chrisothamnus nauseosus*	rabbit-brush

Herbs

Achillea millefolium	yarrow
Artemisia absinthium	absinthium
Cirsium vulgare	bull thistle
Epilobium angustifolium	fireweed
**Melilotus alba*	white sweet clover
**Melilotus officinalis*	yellow sweet clover
Phacelia hastata	silverleaf phacelia
**Silene cucubalus*	bladder campion

Graminoids

**Agrostis alba*	red fescue
**Festuca rubra*	redtop
Phleum pratense	timothy

c. Forested Site

Trees

Cornus stolonifera	red-osier dogwood
Pinus contorta var. latifolia	lodgepole pine
Populus tremuloides	trembling aspen
Populus trichocarpa	cottonwood

Shrubs

Acer douglasii	Douglas' maple
Amelanchier alnifolia	saskatoon

Herbs

Achillea millefolium	yarrow
Arabis douglasii	rockcress
Epilobium angustifolium	fireweed
Heliopsis scabra	heliopsis
Melilotus alba	white sweet clover
**Melilotus officinalis*	yellow sweet clover
Potentilla gracilis	cinquefoil
Tanaxacum officinale	common dandelion
Trifolium agrarium	yellow clover
**Trifolium repens*	dutch clover
Verbascum thapsus	common mullein
Vicia sp.	vetch

* These species were found growing within 5 m of the "vegetated" pit site.

Graminoids

Agrostis alba	redtop
**Agrostis exarata*	bentgrass
**Festuca rubra*	red fescue
**Phleum pratense*	timothy

B. EMERALD

Trees

Populus tremuloides	trembling aspen
Populus trichocarpa	cottonwood

Shrubs

Corylus cornuta	hazelnut
Salix exigua	cyote willow
Salix sp.	willow

Herbs

Circium vulgare	bull thistle
Epilobium minutum	small-flowered willow-herb
Fragaria virginiana	blueleaf strawberry
**Linaria vulgaris*	butter and eggs
Lotus corniculatus	birdsfoot-trefoil
**Medicago sativa*	alfalfa
**Melilotus alba*	white sweet clover
Melilotus officinalis	yellow sweet clover
Plantago major	plantain
**Tanaxacum officinale*	dandelion
Trifolium agrarium	yellow clover
**Trifolium repens*	dutch cldver
**Verbascum thapsus*	mullein

Graminoids

**Agrostis stolonifera*	creeping bentgrass
Agrostis sp.	bentgrass
**Festuca rubra*	red fescue
**Phleum pratense*	timothy
Secale cereale	rye

C. H.B.

Trees

**Alnus sinuata*	sitka alder
Crataegus douglasii var. douglasii	black hawthorn

* These species were found growing within 5 m of the "vegetated" pit site.

Shrubs

Salix sp.	willow

Herbs

**Equisetum arvense*	horsetail
Lotus corniculatum	birdsfoot-trefoil
Trifolium repens	dutch clover

Graminoids

**Agrostis alba*	redtop
Agrostis sp.	bentgrass
Poa trivialis	rough bluegrass

Mosses

Unidentified

D. HEDLEY

Trees

Pinus ponderosa	ponderosa pine
Populus trichocarpa	cottonwood
Pseudotsuga minziesii	Douglas fir

Shrubs

Amelanchier alnifolia	saskatoon
Chrisothamnus viscidiflorus	rabbit-brush
Salix sp.	willow

Herbs

Achillea millefolium	yarrow
**Agroseris sp.*	false-dandelion
Asperagus officinalis	wild asparagus
**Centaurea repens*	Russian knapweed
Conyza canadensis	horseweed
Grindelis squarrosa	gumweed
**Melilotus alba*	white sweet clover
Silene cucubalus	bladder campion
Solidago canadensis	goldenrod
Spergula arvensis	corn spurry

Graminoids

**Agropyron cristatum*	crested wheatgrass

* These species were found growing within 5 m of the "vegetated" pit site.

E. VELVET

Trees	*Alnus sinuata	sitka alder
	Pinus ponderosa	ponderosa pine
	**Populus tremuloides*	trembling aspen
	**Populus trichocarpa*	cottonwood
Shrubs	*Salix bebbiana*	Bebb willow
	**Salix sp.*	willow
Herbs	*Anaphalis margaritacea*	pearly-everlasting
	Antennaria anaphaloides	tall pussy-toes
	Castilleja ssp.	Indian paintbrush
	Cirsium vulgare	bull thistle
	Epilobium minutum	small-flowered willow-herb
	**Equisetum hymale*	horsetail
	Erigeron philedephicus	prickly lettuce
	Lactuca scariola	white sweet clover
	Melilotus alba	curly dock
	Rumex crispus	goldenrod
	**Solidago canadensis*	common tansy
	Tanacetum vulgare	yellow clover
	**Trifolium agrarium*	red clover
	**Trifolium pratense*	mullein
	**Verbascum thapsus*	pink fleabane
Graminoids	**Agrostis alba*	redtop
	**Carex disperma*	soft-leaved sedge
	Carex practicola	meadow sedge
	Phleum pratense	timothy
	**Poa trivialis*	rough bluegrass
Mossess	*Unidentified	

* These species were found growing within 5 m of the "vegetated" pit site.

APPENDIX II

PROFILE DESCRIPTIONS OF MINE SPOILS

"VEGETATED" AND "UNVEGETATED" PITS

PROFILE DESCRIPTION OF MINE SPOIL "VEGETATED" AND "UNVEGETATED" PITS

COAL CREEK

TAILINGS POND SITE

HORIZON	DEPTH (cm)	DESCRIPTION
Ah	0 - 3.5	Black (10YR 2/1 m), very dark grayish brown (10YR 3/2 d) fine sand; mottles around roots; granular; friable; abundant, fine roots; coarse coal fraction minimal; abrupt, wavy boundary; pH 8.1.
	3.5 - 10	Black (7.5YR 2/0 m,d) very fine sand; mottles around roots; coarse, subangular blocky structure; few, coarse roots and abundant, fine, vertical roots; no coarse coal fraction; abrupt, wavy boundary; pH 8.2.
	10 - 12.5	Black (7.5YR 2/0 m,d) medium sand; single grain; loose; few, fine roots; abrupt, wavy boundary; pH 7.9.
	12.5 - 16	Black (7.5YR 2/0 m,d) very fine sand; massive; very friable; few, fine roots; coarse coal fraction, 15%; abrupt, wavy boundary; pH 8.1.
	16 - 19	Black (7.5YR 2/0 m,d) medium sand; single grain; loose; fine, plentiful roots and few, horizontal, coarse roots; abrupt, wavy boundary; pH 7.9.
	19 - 33	Black (7.5YR 2/0 m,d) fine sand; single grain; loose; plentiful, fine, vertical roots becoming few and coarse near bottom; coarse coal fraction minimal; abrupt, wavy boundary; pH 7.5; lens becoming wide to 5 cm found from 23 to 28 cm; similar to material in 60+ cm.
lens	30 - 33	Black (7.5YR 2/0 m,d) fine sand; single grain; loose; few, fine and few, coarse roots, some growing vertically; coarse coal fraction, 5%; abrupt, wavy boundary; pH 7.4; lens fading out at pit sides.

HORIZON	DEPTH (cm)	DESCRIPTION
	33 - 60	Black (7.5YR 2/0 m,d) medium sand; single grain; loose; few, fine and few, coarse roots, following fine layers of coarse material horizontally; coarse coal fraction minimal; abrupt, wavy boundary; pH 7.5.
	60+	Black (7.5YR 2/0 m,d) medium-coarse sand; single grain; loose; few, coarse roots to 90cm; coarse coal fraction, 5% pH 7.3.

DRY GRASSLAND SITE

Ah	0 - 7	Black (7.5YR 2/0 m,d) very fine sand; granular; very friable; abundant, fine roots; coarse coal fraction, 40%; abrupt, irregular boundary; 6 to 9 cm thick; pH 7.0.
Ah_2	7 - 21	Black (7.5YR 2/0 m,d) very fine sand; massive; friable; few, fine roots; coarse coal fraction, 20%; abrupt, irregular boundary; from 12 to 19 cm thick; pH 6.2.
	21 - 27	Black (7.5YR 2/0 m,d) very fine sand; single grain; loose; few, fine, vertical roots; coarse coal fraction, 70%; abrupt, wavy boundary; from 2 to 9 cm thick; pH 7.5.
	27 - 34	Black (7.5YR 2/0 m,d) very fine sand; massive; friable; plentiful, fine roots; coarse coal fraction, 30%; abrupt, wavy boundary; from 4 to 11 cm thick; pH 7.8.
BC	34 - 60	Black (7.5YR 2/0 m,d) very fine sand; single grain; loose; few, fine roots; coarse coal fraction, 70%; abrupt, wavy boundary; pH 7.5.
C	60+	Black (7.5YR 2/0 m,d) very fine sand; single grain; loose; no roots; coarse coal fraction, 90%; pH 7.5.

FORESTED SITE

HORIZON	DEPTH (cm)	DESCRIPTION
F	2 - 0	Dark reddish brown (5YR 2/2 m) semi-decomposed organic matter; abrupt, wavy boundary; pH 7.3.
Ah	0 - 5	Black (7.5YR 2/0 m), very dark brown (10YR 2/2 d) sandy loam; granular; loose; plentiful, fine roots; coarse coal fraction minimal; abrupt, wavy boundary; pH 7.3.
Ahe	5 - 16	Black (2.5YR 2/0 m), light gray (10YR 7/2 m), salt and pepper-like; gravelly, fine sand; granular; loose; plentiful, fine and few, medium, vertical roots; few, coarse, horizontal roots at bottom of horizon; coarse coal fraction, 50%; abrupt, wavy boundary; pH 7.8.
Bm_1	16 - 25	Black (2.5YR 2/0 m,d) fine sand; single grain; loose; few, fine and few, medium roots; coarse coal fraction, 75%; abrupt, wavy boundary; pH 7.4.
Bm_2	25 - 70	Black (2.5YR 2/0 m,d) fine sand; single grain; loose; plentiful, fine, vertical roots and few, medium, horizontal roots; coarse coal fraction, 95%; gradual, irregular boundary, due to coal up to 10 cm diameter; pH 7.6.
C	70 +	Black (2.5YR 2/0 m,d) fine sand; single grain; loose; no roots; coarse coal fraction, 65%; all sizes up to >10 cm; pH 7.7.

PROFILE DESCRIPTION OF MINE SPOIL "VEGETATED" AND "UNVEGETATED" PITS

H. B.

VEGETATED SITE

HORIZON	DEPTH (cm)	DESCRIPTION
Ah	0 - 2	Grayish brown (2.5Y 5/2 m), light gray (2.5Y 7/2 d) loamy fine sand; granular; very friable; abundant, fine roots; abrupt, wavy boundary; 2 to 3 cm thick; pH 7.5.
	2 - 7	Olive gray (5Y 5/2 m), light gray (5Y 7/2 d) very fine sand; mottles in old root channels; medium-fine, subangular blocky, and granular around roots; many tiny layers of similar material; very friable; few, fine, vertical roots and few, medium horizontal roots; abrupt, wavy boundary; 2 to 6 cm thick; pH 7.7.
	7 - 10	Olive gray (5Y 5/3 m), pale olive (5Y 6/3 d) very fine sand; mottles in old root channels; single grain; very friable; few, fine and few, coarse roots; abrupt, wavy boundary; 2 to 7 cm thick; pH 7.7.
	10 - 12	Light olive gray (5Y 6/2 m) and dark gray (2.5Y 4/0 m) distinct layering of very fine sand; yellowish brown (10YR 5/8 m) mottles along root channels; massive to subangular blocky; friable; plentiful, medium, horizontal roots; abrupt, wavy boundary; 0 to 2 cm thick; pH 7.7; 0.5 cm of semidecomposed organic matter found at the base of this layer.
	12 - 29	Gray (7.5YR 5/0 m) and olive yellow (5Y 6/4 m) distinct layers of very fine sand; few, medium distinct yellowish brown (10YR 5/8 m) mottles along root channels; massive to coarse, subangular blocky; friable; few, fine, vertical roots and plentiful, medium, horizontal roots; abrupt, smooth boundary; 15 to 17 cm thick; pH 7.7.
	29 - 32	Dark gray (N 4/0 m), gray (N 6/0 d) very fine sand; few, medium, distinct yellowish brown (10YR 5/8 m) mottles; massive; plentiful, medium roots; abrupt, wavy boundary; pH 7.4.

HORIZON	DEPTH (cm)	DESCRIPTION
	32 - 49	Olive (5Y 4/4 m), blending to dark gray (2.5Y 4/0 m) fine sand; few, medium, distinct yellowish brown (10YR 5/8 m) mottles; medium, subangular blocky; friable; few, medium roots; abrupt, wavy boundary; pH 7.5.
	49 - 50	Dark gray (N 4/0 m), gray (N 6/0 d) very fine sand; few, medium, distinct yellowish brown (10YR 5/8 m) mottles; massive; nonsticky; very few, medium roots; abrupt, wavy boundary; from 0 to 1 cm thick; only occurs in one portion of the pit; pH 7.4; small layer of semidecomposed organic matter at the bottom.
	50 - 56	Olive gray (5Y 4/2 m), light olive gray (5Y 6/2 d) fine and very fine sand; few, medium, distinct yellowish brown (10YR 5/8 m) mottles; medium, subangular blocky; friable; few, medium, decaying roots; abrupt, wavy boundary; pH 6.8; a transition between the two bordering horizons.
	56 - 67	Olive (5Y 4/3 m), light olive gray (5Y 6/2 d) fine sand; with fine lenses of olive (5Y 4/3 m) dilating, very fine sand; few, medium, distinct strong brown (7.5YR 5/6 m) mottles; medium, subangular blocky; friable; few, medium, decaying roots; clear, wavy boundary; pH 6.8.
	67 - 83	Olive (5Y 4/3 m), light olive gray (5Y 6/2 d) fine sand; few, medium, distinct yellowish brown (10YR 5/8 m) mottles following decaying root channels; medium, subangular blocky; friable; few, medium, decaying, vertical roots; pH 6.8; thin, semidecomposed layer of organic matter at base.

UNVEGETATED SITE

HORIZON	DEPTH (cm)	DESCRIPTION
	0 - 23	Olive gray (5Y 4/3 d, 5Y 5/3 d) and light olive gray (5Y 6/2 d) intricate layers of very fine and fine sand, with lenses of dark gray (2.5Y 4/0 d); single grain; friable; no roots; abrupt, wavy boundary; pH 7.0.
	20 - 38	Dark gray (5Y 4/1 m), gray (5Y 6/1 d) silt; few, medium, distinct yellowish brown (10YR 5/8 m) mottles along old root channels; massive; friable; plentiful old roots; abrupt, smooth boundary; pH 6.9.
lens	23 - 41	Olive (5Y 4/3 m), light olive gray (5Y 6/2 d) coarse sand; lenses of fine gravel; single grain; very friable; abrupt, wavy boundary; only exists to half way around pit; 0 to 18 cm thick; pH 7.1.
	38 - 56	Pale olive (5Y 5/3 m), light gray (5Y 7/2 d) fine sand; massive; friable; few, medium, old roots; pH 7.1; layers of semidecomposed organic matter at 40 cm and 45 cm, and below is original soil surface.

PROFILE DESCRIPTION OF MINE SPOIL "VEGETATED" AND "UNVEGETATED" PITS

HEDLEY

VEGETATED SITE

HORIZON	DEPTH (cm)	DESCRIPTION
	0 - 9	Dark graysih brown (2.5Y 4/2 m), grayish brown (2.5Y 5/2 d) silt loam; medium granular but single grain where rootless; soft; abundant, fine roots; abrupt, smooth boundary; pH 7.6.
	9 - 19	Olive gray (5Y 4/2 m), light olive gray (5Y 6/2 d) silt; single grain; slightly hard; abundant, micro roots; abrupt, smooth boundary; pH 7.4.
	19 - 26.5	Olive (5Y 4/3 m), pale olive (5Y 6/3 d) silt; medium platy; slighty hard; abundant, micro roots; abrupt, smooth boundary; pH 7.3.
	26.5 - 35.5	Dark olive gray (5Y 3/2 m), olive gray (5Y 5/2 d) fine sandy loam; small lenses of strong brown (7.5YR 5/6 d) silt; single grain; loose; no roots; abrupt, broken boundary; pH 7.6.
	35.5 - 43	Olive (5Y 5/4, 5/6 d) and pale yellow (5Y 7/3 d) silt; massive; firm; many fine, distinct layers; abrupt, smooth boundary; pH 7.5.
	43 - 49.5	Very dark gray (5Y 3/1 m), olive gray (5Y 5/2 d) fine, sandy loam; few lenses of olive gray (5Y 5/4 m) silt; single grain; loose; abrupt, broken boundary; pH 7.7.
	49.5 - 63.5	Olive yellow (2.5Y 6/6 m), pale yellow (5Y 7/4 m) and pale olive (5Y 6/3 m) silt; massive; continuous, fine layering; firm; abrupt, broken boundary; pH 7.6.
	63.5 - 68.5	Light olive gray (5Y 4/2 m), olive (5Y 6/2 d) fine sandy loam; small lenses of strong brown (7.5YR 5/6 d) silt; massive; very friable; abrupt, broken boundary; pH 7.6.

HORIZON	DEPTH (cm)	DESCRIPTION
	68.5 - 91.5	Olive yellow (2.5Y 6/6 m), pale yellow (5Y 7/4 m) and pale olive (5Y 6/3 m) silt; small lenses of gleyed (N 6/0 m) silt; massive; firm; abundant, broken boundary; pH 7.5.
UNVEGETATED SITE		
	0 - 9	Olive gray (5Y 4/2 m), light olive gray (5Y 6/2 d) silt; very fine platy; very friable; very few, fine, dead roots; abrupt, wavy boundary; pH 7.7.
	9 - 15	Olive (5Y 4/2 m), light olive gray (5Y 6/2 d) silt; very fine platy; very friable; very few, fine, dead roots; abrupt, smooth boundary; pH 7.7.
	15 - 30	Olive gray (5Y 4/2 m), light olive gray (5Y 6/2 d) very fine sand; single grain; loose; abrupt, wavy boundary; pH 7.7.
	30 - 40	Pale yellow (5Y 7/3 m) fine sandy loam; finely vesicular; light olive gray (5Y 6/2 m) very fine sand; very few, vertical, fine to medium, dead roots; brown (10YR 5/3 m) very fine sandy loam; combined layers; medium, subangular blocky; very friable; few, fine, horizontal roots, both at surface and bottom of horizon; abrupt, smooth boundary; pH 7.7.
	40+	Olive (5Y 5/4 m) and pale yellow (5Y 6/4 m) fine sandy loam; finely layered; thin coatings of olive yellow (5Y 6/6 m); very thin platy; friable; abrupt, smooth boundary; pH 7.6.

PROFILE DESCRIPTION OF MINE SPOIL "VEGETATED" AND "UNVEGETATED" PITS

EMERALD

VEGETATED SITE

HORIZON	DEPTH (cm)	DESCRIPTION
Ah	0 - 0.5	Pale brown (10YR 6/3 d), dark brown (10YR 3/3 m) silt; granular; loose; plentiful, fine and plentiful, medium roots; clear, wavy boundary; pH 6.8.
	0.5 - 15	Dark gray (10YR 4/1 m, 6/1 d) silt; few, fine, distinct strong brown (7.5YR 5/6 m) mottles, following planes of platiness and along root channels; fine to medium platelike; granular in immediate rooting area; firm; abundant, fine roots, congested vertically and spreading horizontally along planes; abrupt, smooth boundary; pH 6.9.
	15 - 23	Dark gray (2.5Y 5/0 m) and gray (2.5 6/0 m) silt layers and brownish yellow (10YR 6/6 m and 6/8 m) loamy fine sand layers; massive and single grain; friable; plentiful, fine roots; abrupt, smooth boundary; total pH 7.1; transition layer.
	23 - 26	Yellowish brown (10YR 5/6 d), dark reddish brown (5YR 3/4 m) loamy fine sand; single grain; friable; very few, fine roots; abrupt, smooth boundary; pH 6.9.
	26 - 28	Dark gray (5Y 4/1 m), light gray (2/5Y 7/0 d) silt loam; few, fine, prominant dark reddish brown (10YR 4/4 m) horizontal mottles; massive; slightly sticky; no rooting; abrupt, smooth boundary; pH 7.3.
	28 - 34	Dark brown (10YR 3/3 m), light olive brown (2.5Y 5/4 d) changing along pit side to olive gray (5Y 5/2 m) fine sand; single grain; very friable; abrupt, smooth boundary; pH 6.7.
	34 - 42	Dark gray (5Y 4/1 m), light gray (2.5Y 7/0 d) silt loam; few, fine, prominant dark reddish brown (2.5YR 3/4 m) and dark yellowish brown (10YR 4/4 m) horizontal mottles; massive; slightly sticky; abrupt, smooth boundary; pH 7.3.

HORIZON	DEPTH (cm)	DESCRIPTION
	42 - 52	Black (5Y 2/1 m, 4/1 d) fine sand changing to olive (5Y 4/3 m) at pit side; single grain; very friable; abrupt, smooth boundary; pH 7.3.
	52+	Very dark grayish brown (2.5Y 3/2 m), dark gray (10YR 4/1 d) loamy fine sand; single grain; very friable; pH 7.2.
UNVEGETATED SITE		
	0 - 1.5	Reddish brown (5YR 4/4 d), dark reddish brown (5YR 3/3 m) fine sand; platy; friable; abrupt, wavy boundary; pH 6.0.
	1.5 - 14.5	Brown (10YR 5/3 m) fine sand; single grain; very friable; diffuse; wavy boundary; pH 7.0.
	14.5 - 38.5	Dark reddish brown (5YR 2/2 m), dark brown (10YR 4/3 d) medium sand; single grain; very friable; abrupt, wavy boundary; pH 7.6.
	38.5 - 83.5	Very dark gray (5Y 3/1 m), gray (2.5Y 5/0 d) very fine sand; single grain; friable; abrupt, wavy boundary; pH 7.7.
Cg	83.5 - 90	Very dark gray (5Y 3/1 m), gray (5Y 6/1 d) silt; massive; slightly sticky; pH 7.9.

PROFILE DESCRIPTION OF MINE SPOIL "VEGETATED" AND "UNVEGETATED" PITS

VELVET

VEGETATED SITE

HORIZON	DEPTH (cm)	DESCRIPTION
L-H	2 - 0	
Ah	0 - 2	Very dark brown (10YR 2/2 m), olive gray (5Y 2.5/2 d) fine sandy loam with some semidecomposed organic matter; granular; very friable; abundant, fine roots; abrupt, wavy boundary; pH 6.9.
	2 - 14	Black (N 2/0 m), very dark gray (N 3/0 d) fine sand; few, fine lenses of dark gray (5Y 4/1 m) and dark grayish brown (2.5Y 4/2 m) silt; medium, subangular blocky; friable; few, fine, horizontal roots; abrupt, wavy boundary; pH 7.9.
	14 - 17	Very dark gray (N 2/0 m), black (N 3/0 d) very fine sand; massive; friable; no roots; abrupt, wavy boundary; pH 7.7.
	17 - 67	Black (N 2/0 m) loamy fine sand and olive gray (5Y 4/2 m) medium sand; single grain; very friable; old, dead, medium to coarse, horizontal roots; gradual, smooth boundary, actually due to saturation below; pH 7.6.
Cg	67+	Black (N 2/0 m), black (5Y 2/2 d) loamy fine sand; single grain; non-sticky; pH 8.0.

UNVEGETATED SITE

	0 - 0.5	Black (N 2/0 m), dark gray (N 4/0 d) medium sand; granular; loose; abrupt, broken boundary; may be windblown; pH 7.8.
Surface Clay		Dark gray (5Y 4/1 m), gray (5Y 6/1 d) silt; subangular blocky; friable; discontinuous, random, vesicular pores; abrupt, broken boundary; 0 to 4 cm thick; pH 8.0.

HORIZON	DEPTH (cm)	DESCRIPTION
	0 - 27	Black (N 2/0 m,d) fine sand and dark olive gray (5Y 3/2 m) medium sand; single grain; very friable; clear, broken boundary; pH 8.2.
	27 - 33	Black (N 2/0 m), dark gray (N 4/0 d) loamy fine sand; medium, subangular blocky; friable; abrupt, broken boundary; pH 7.8.
	33 - 36	Black (5YR 2/1 m) fine sand; single grain; very friable; abrupt, broken boundary; pH 8.2.
	36 - 42	Black (N 2/0 m), dark gray (N 4/0 d) loamy fine sand; thin lens at surface of olive (5Y 5/4 m) silt; also small lenses of dark olive gray (5Y 3/2 m) medium sand; medium, subangular blocky; friable; clear, irregular boundary; convoluted at side, up to 25 cm; pH 7.8.
	42 - 49	Black (N 2/0 m) medium sand; single grain; very friable; abrupt, wavy boundary; pH 8.0.
	49 - 55	Very dark gray (N 3/0 m) medium sand; single grain; very friable; clear, broken boundary; pH 8.2.
	55+	Black (N 2/0 m) medium sand; single grain; very friable; pH 8.0.

APPENDIX III

WATER RETENTION CURVES

OF SELECTED MINE SPOILS

FIGURE III:1 COAL CREEK
WATER RETENTION CURVES OF SELECTED MINE SPOILS

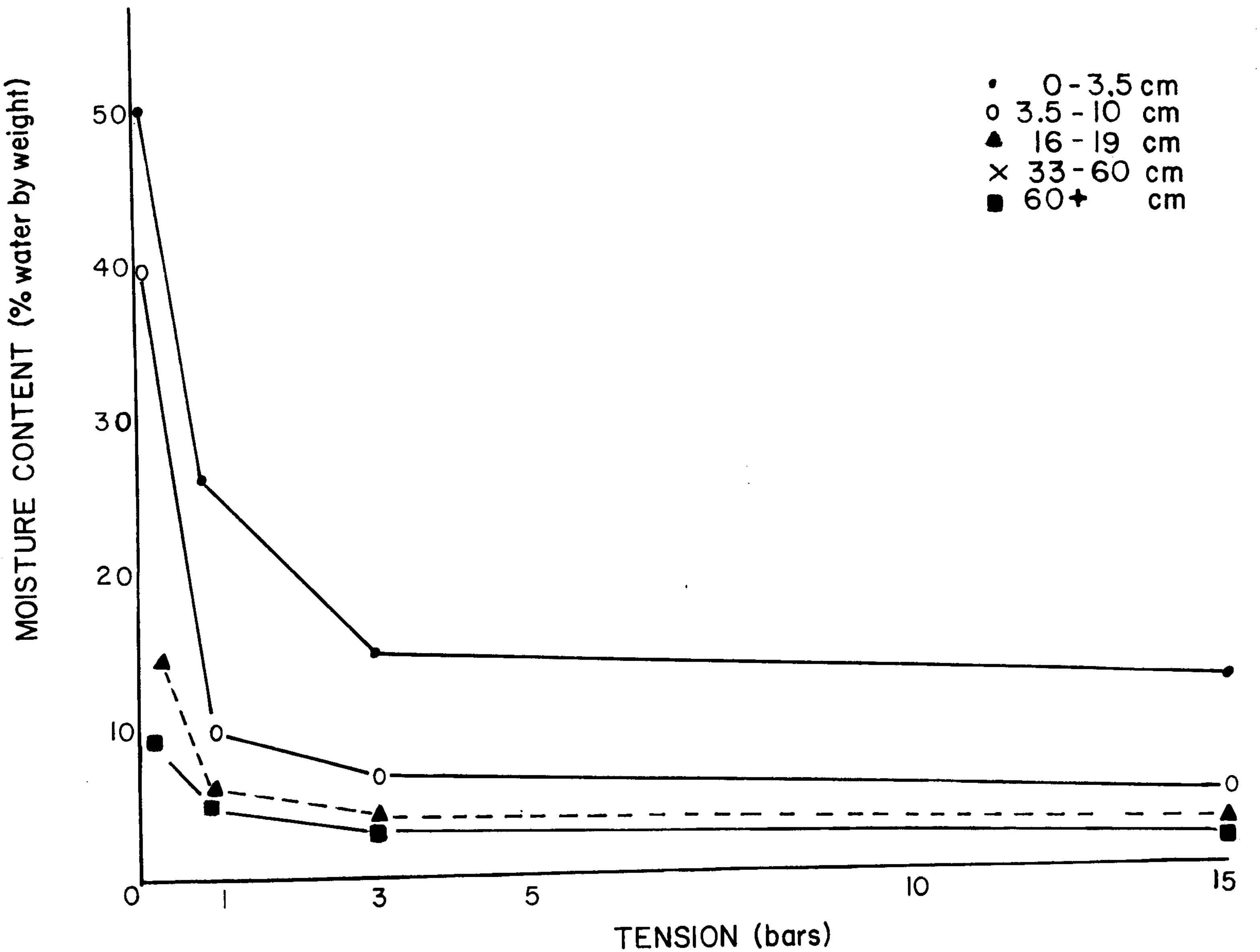


FIGURE III:2 EMERALD
WATER RETENTION CURVES OF SELECTED MINE SPOILS

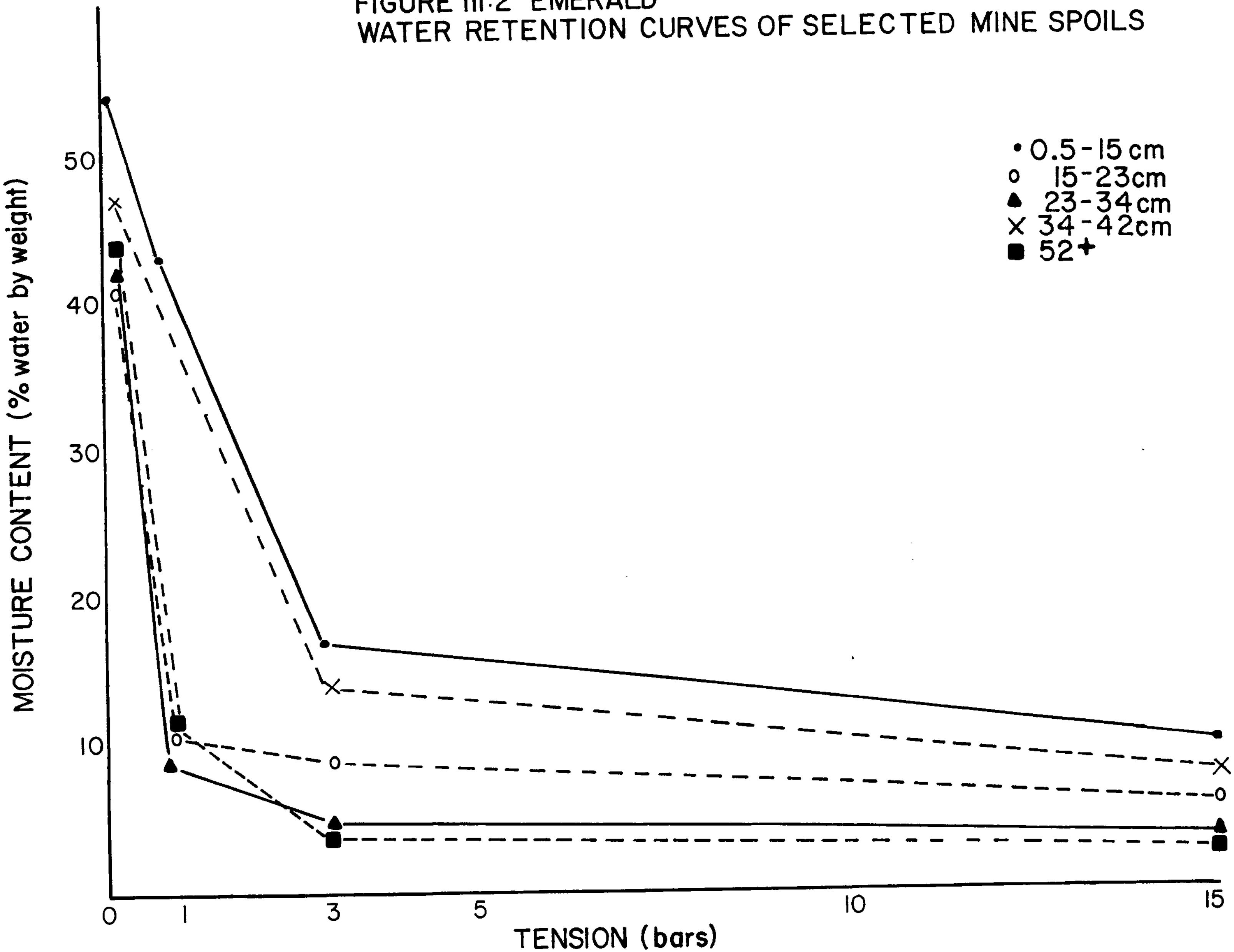


FIGURE III:3 H.B.

WATER RETENTION CURVES OF SELECTED MINE SPOILS

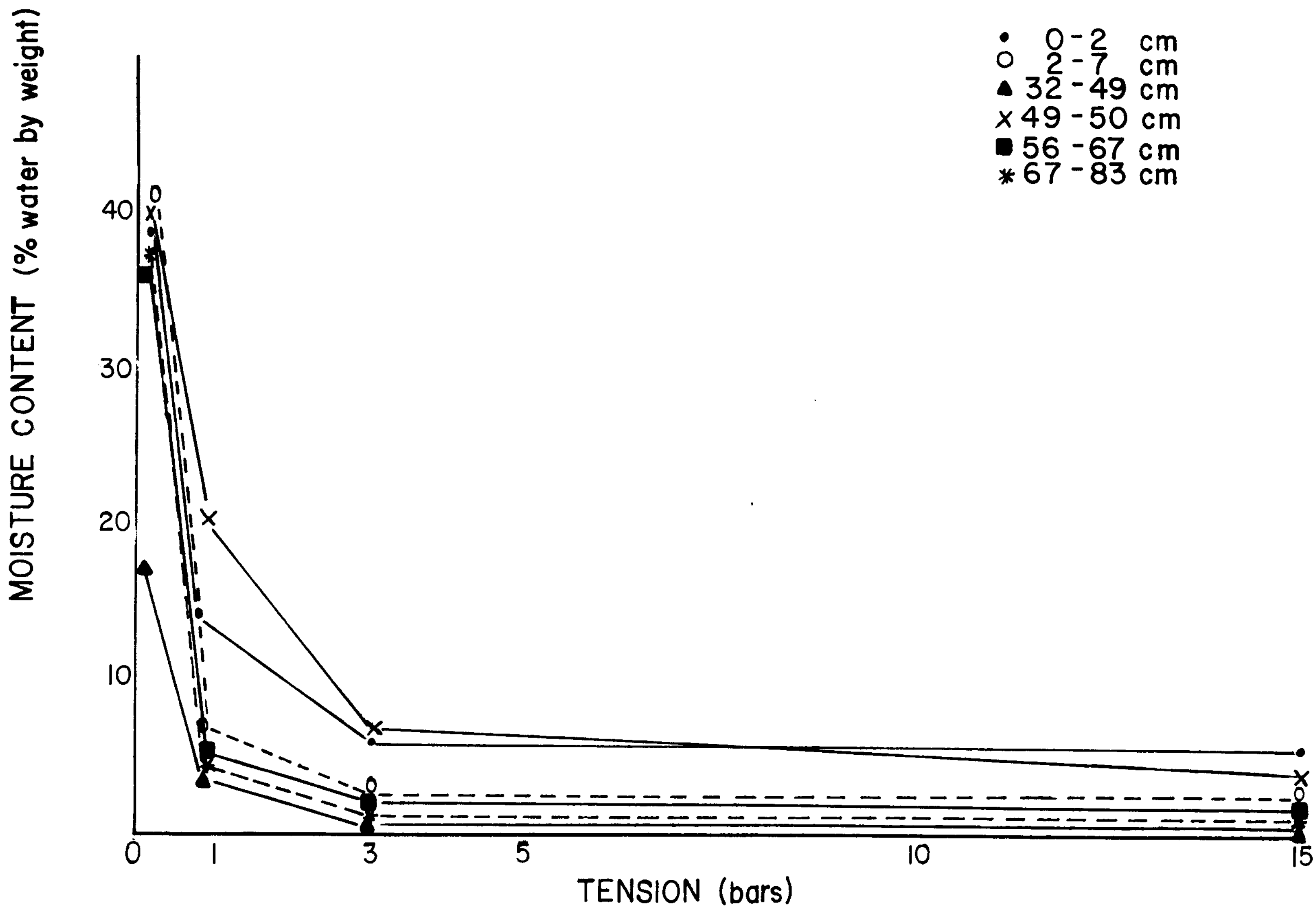


FIGURE III:4 HEDLEY
WATER RETENTION CURVES OF SELECTED MINE SPOILS

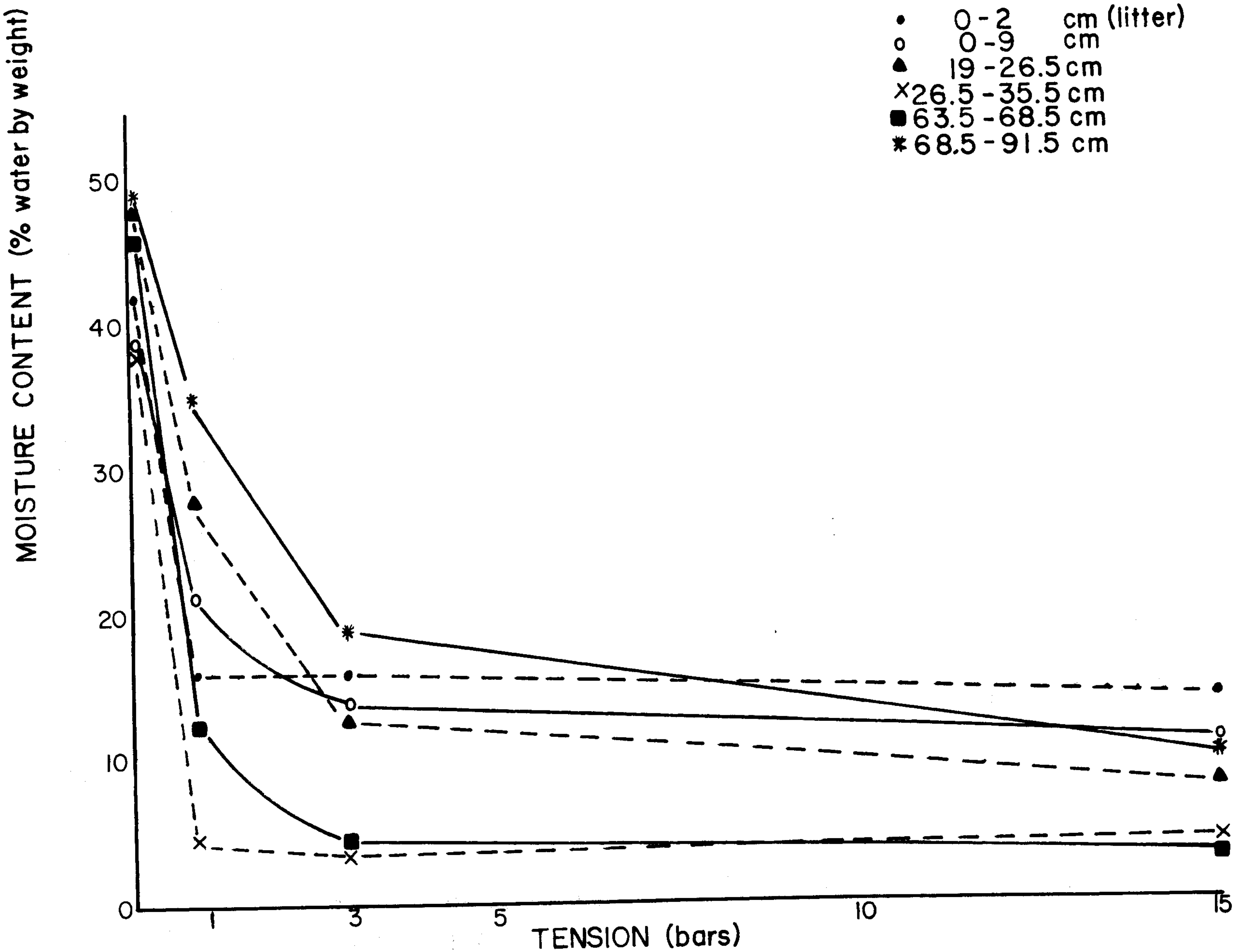
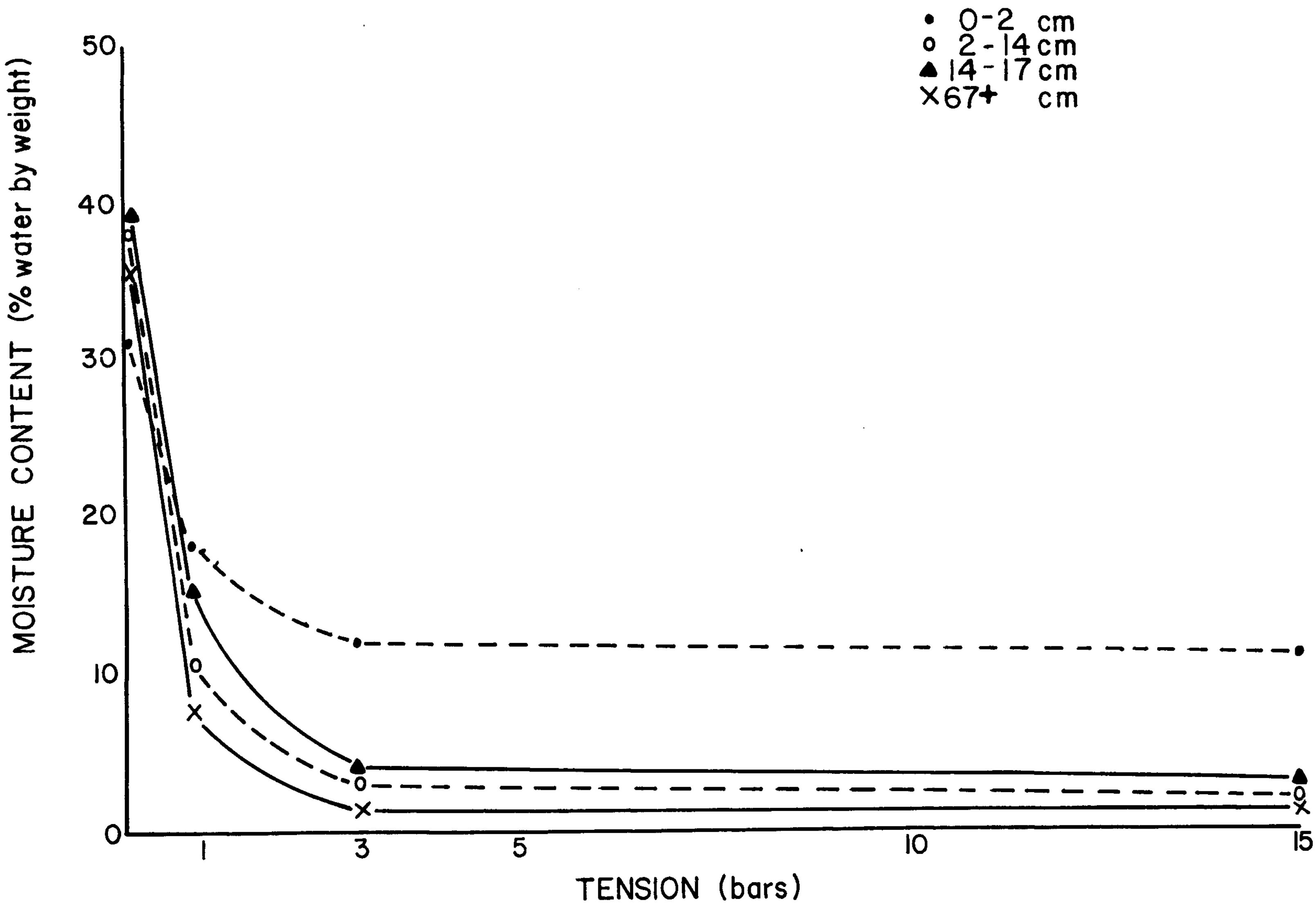


FIGURE III:5 VELVET
WATER RETENTION CURVES OF SELECTED MINE SPOILS



APPENDIX IV

PHOTOGRAPHS OF MINE SITES

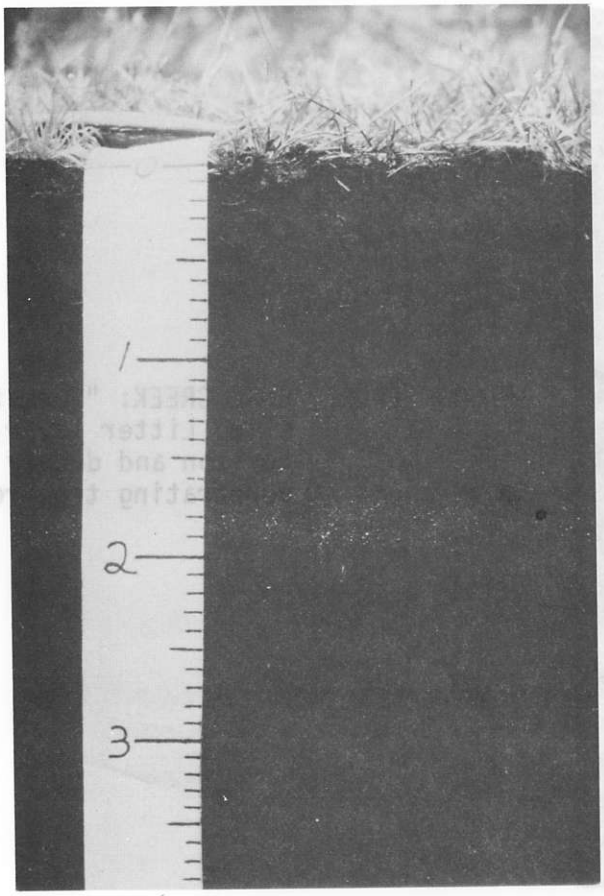


FIGURE IV:1: COAL CREEK: "tailings pond" site. Formation of Ah horizon.

FIGURE IV:2: COAL CREEK: "dry grassland" site. Well drained due to a significant coarse fraction.

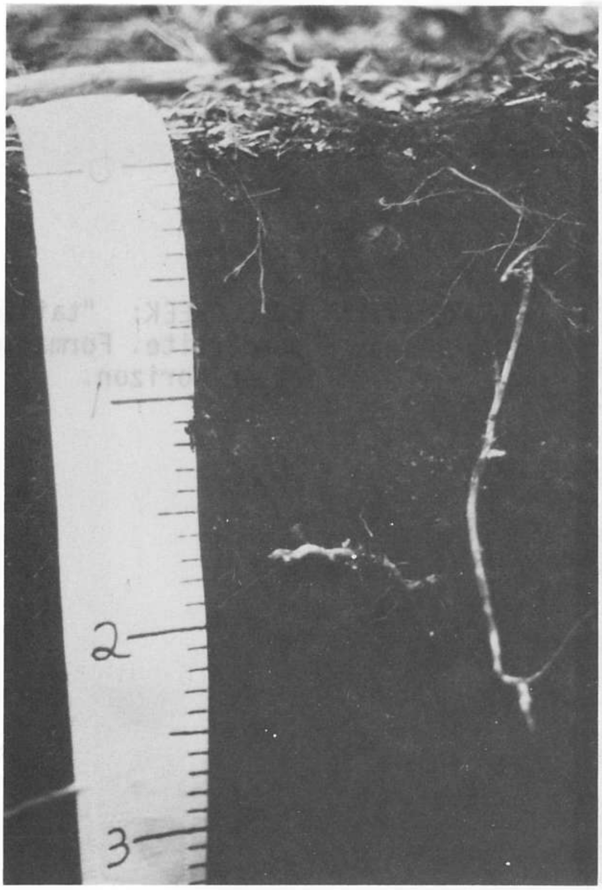


FIGURE IV:3: COAL CREEK: "forested" site. Litter layer, Ah horizon and deeply penetrating tree roots.

FIGURE IV:4: COAL CREEK: "forested" site. Inactive spoil area for approximately 20 years.

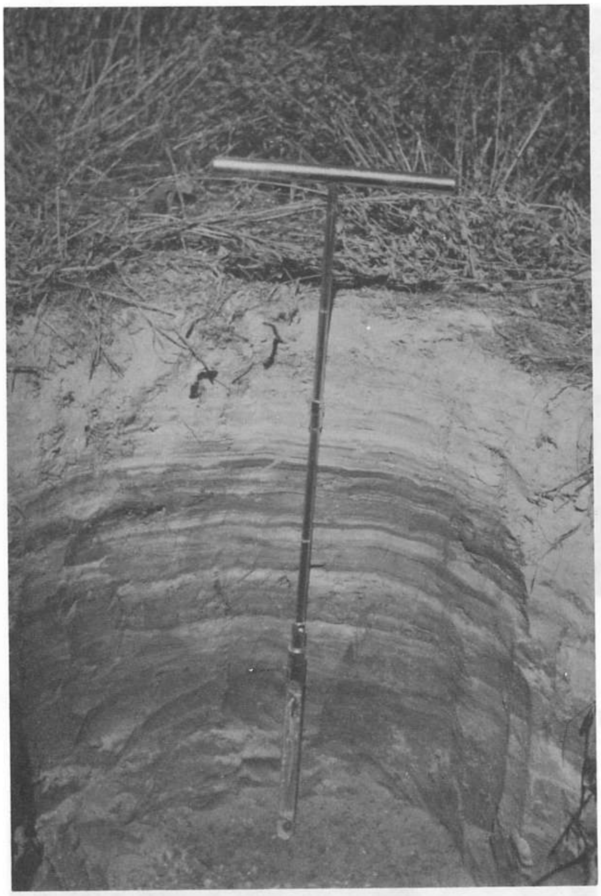


FIGURE IV:5: EMERALD: "vegetated" site. Vegetation is restricted to certain areas of the pond and is predominantly alfalfa.

FIGURE IV:6: EMERALD: "vegetated" site. Root development assists in breaking up massive material as part of soil development. Roots following planes of platiness horizontally.

FIGURE IV:7: EMERALD: tailings pond. Inactive since 1972 and seeded and fertilized in 1973.

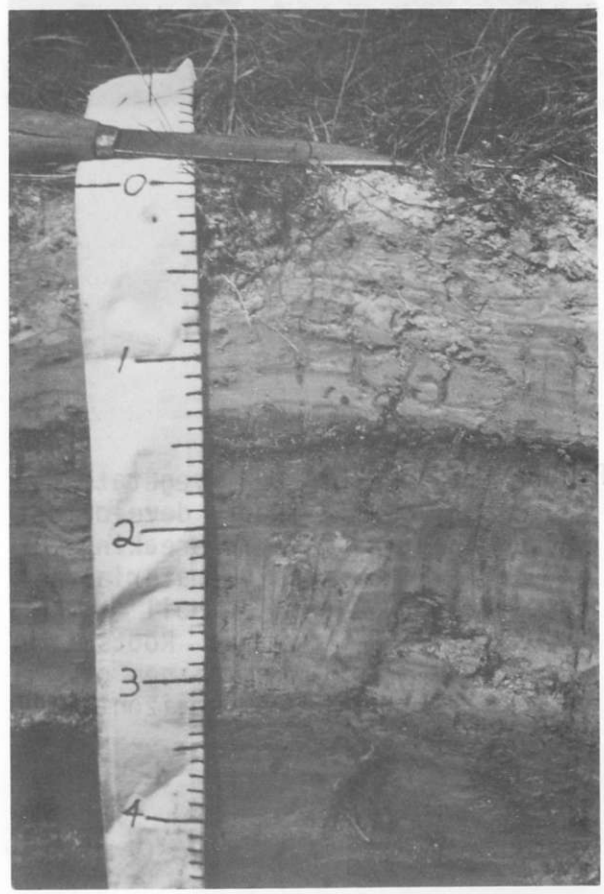


FIGURE IV:8: H.B.: "vegetated" site. Prominant mottling along root channels. Layer of organic matter at 15 cm indicates that this was once the surface.

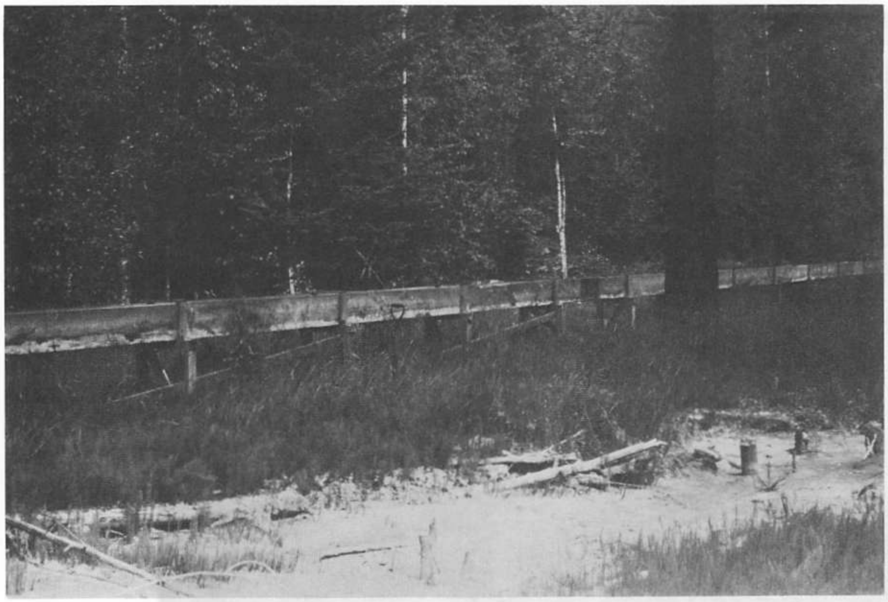


FIGURE IV:9: H.B.: horsetail is dominant vegetation invading spillage area.

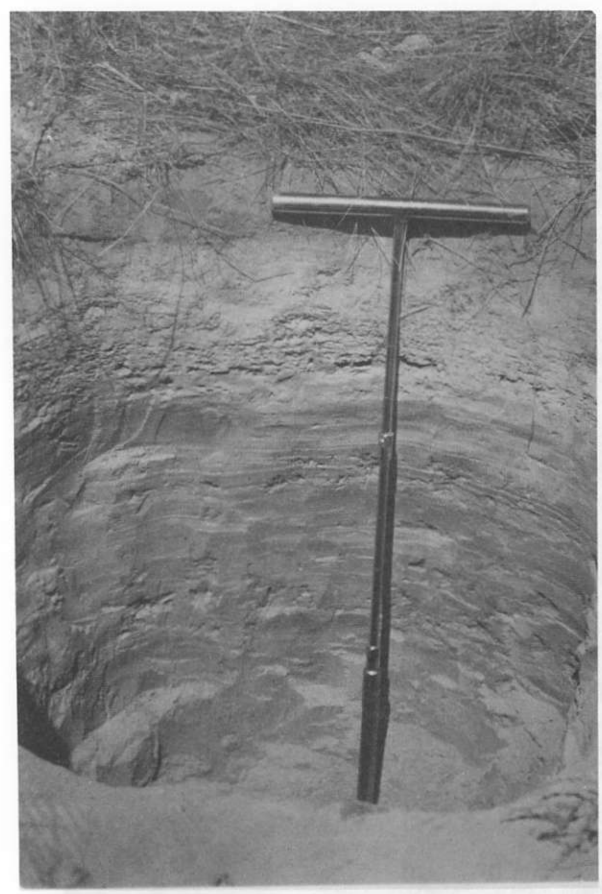


FIGURE IV:10: HEDLEY: "vegetated" pit. Vegetation mainly grasses. Ah underlain by platy horizon and then by extremely compacted layers.

FIGURE IV:11: HEDLEY: tailings pond. Variation in vegetation growth likely due to particle size differences and changes in moisture-holding capacity.

FIGURE IV:12: VELVET: "vegetated" site. Ah horizon is shallow but densely rooted. Grass species predominate.

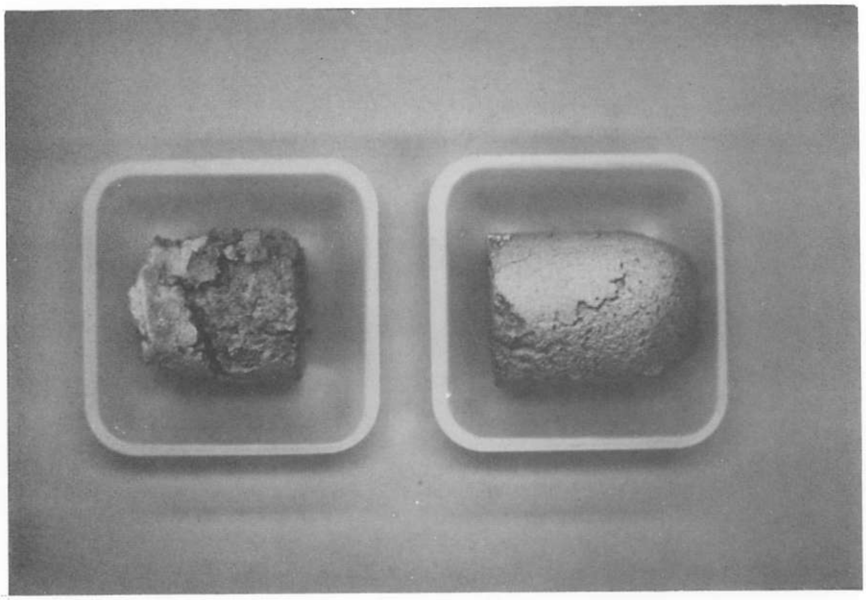


FIGURE IV:15: LORNEX: Soxhlet weathered mine tailings. Accululation product after 3 weeks weathering. Thimble contents devided into a top and bottom portion.

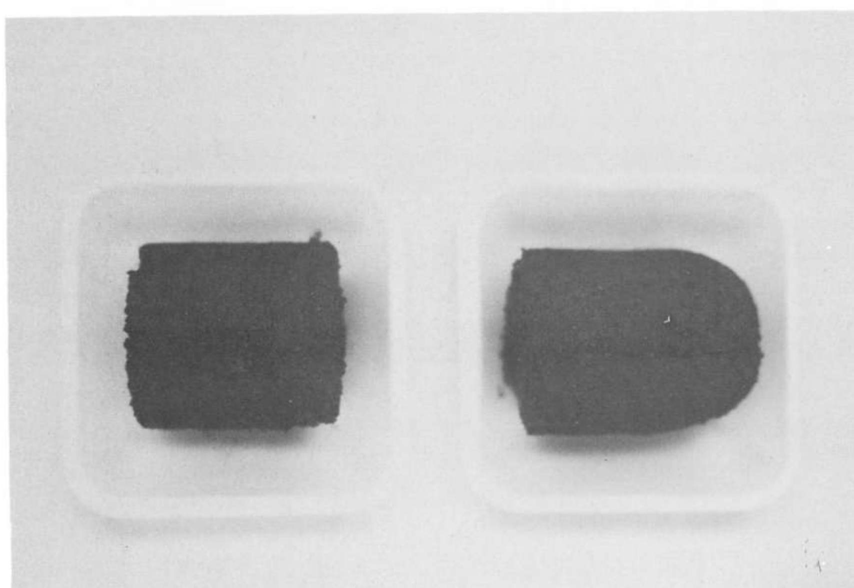


FIGURE IV:16: SULLIVAN Fe: Soxhlet weathered mine tailings. Reddish color change occurring as top portion is increasingly weathered.

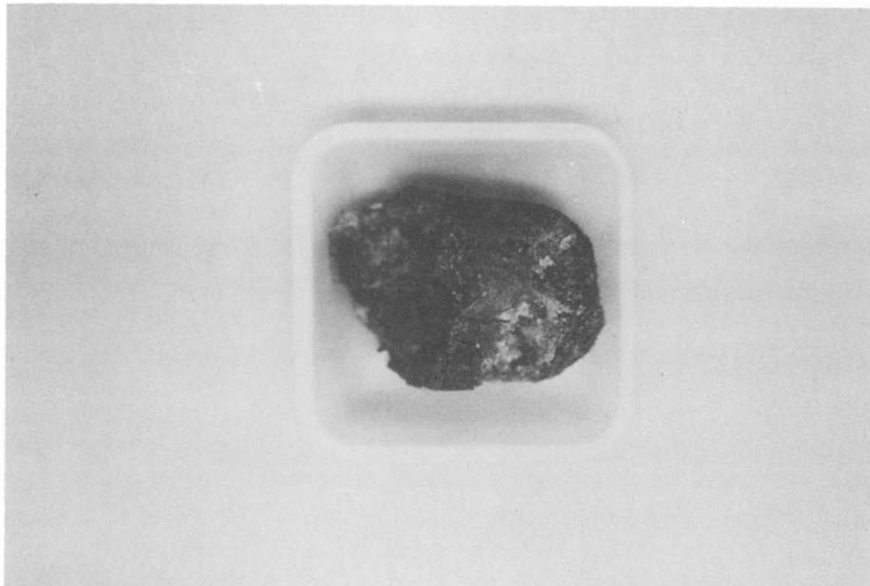


FIGURE IV:17: SULLIVAN GYPSUM: Soxhlet weathered mine tailings. Volume of accumulation product is extremely reduced due to high solubility of gypsum.

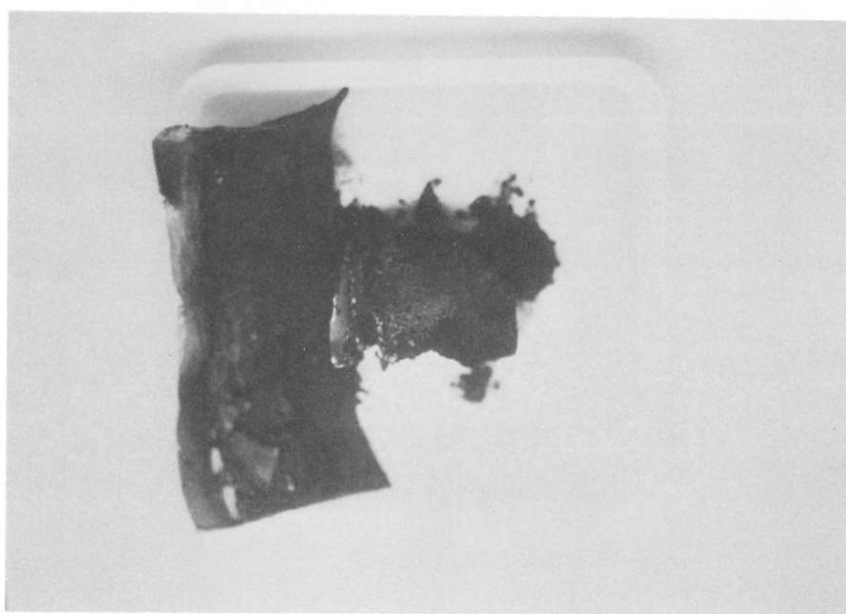


FIGURE IV:18: SULLIVAN Si FRESH: Soxhlet weathered mine tailings. Surface becomes metallic and vesicular in appearance and fuses with filter paper

APPENDIX V

MAPS OF MINE SPOILS INDICATING

SAMPLE SITES

FIGURE V:1: COAL CREEK SCALE 1:8450

A-TAILINGS POND B-DRY GRASSLAND C-FORESTED SITES

FIGURE V:2: EMERALD SCALE 1:6500

FIGURE V:3: H.B. SCALE 1:6670

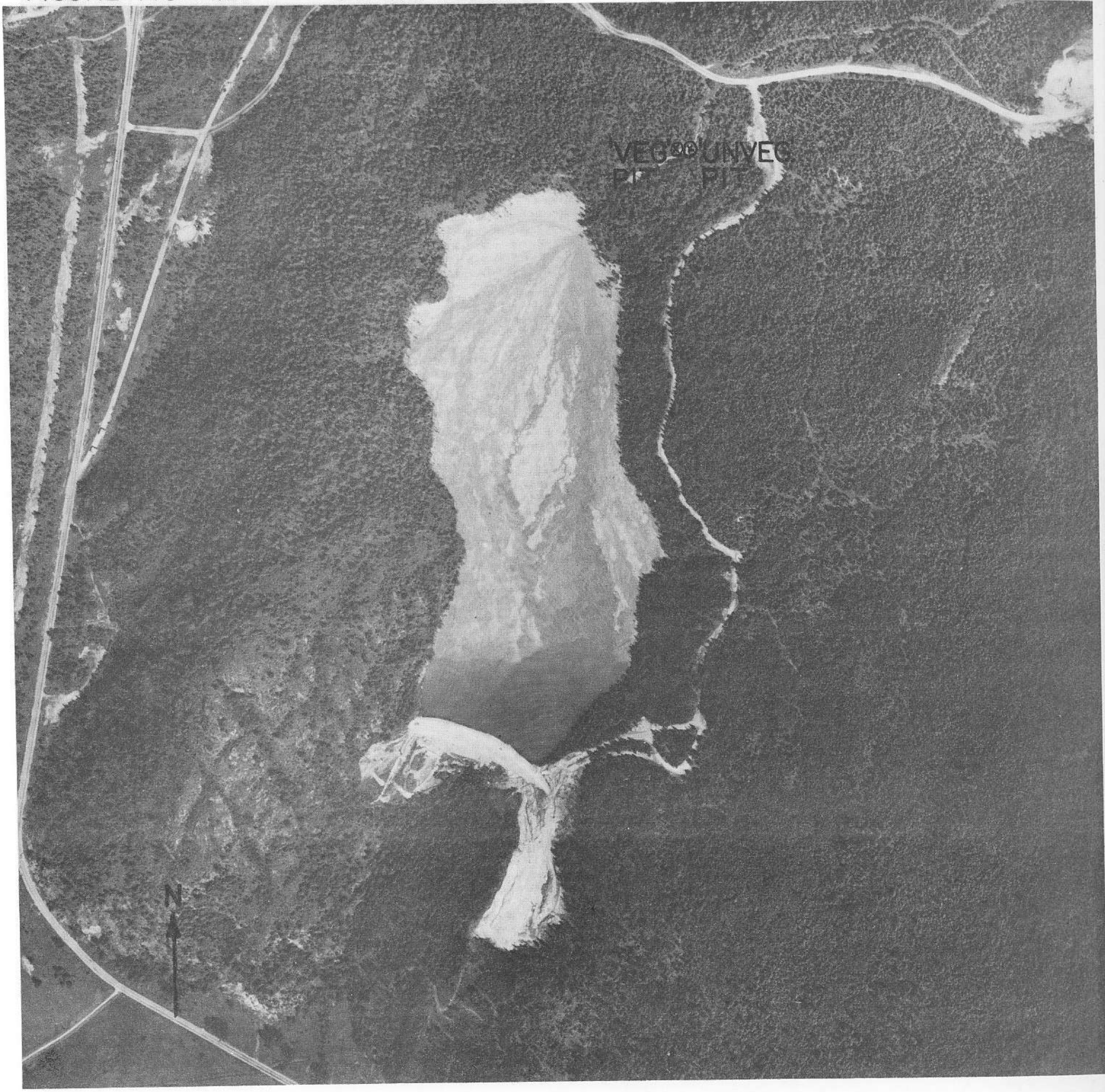
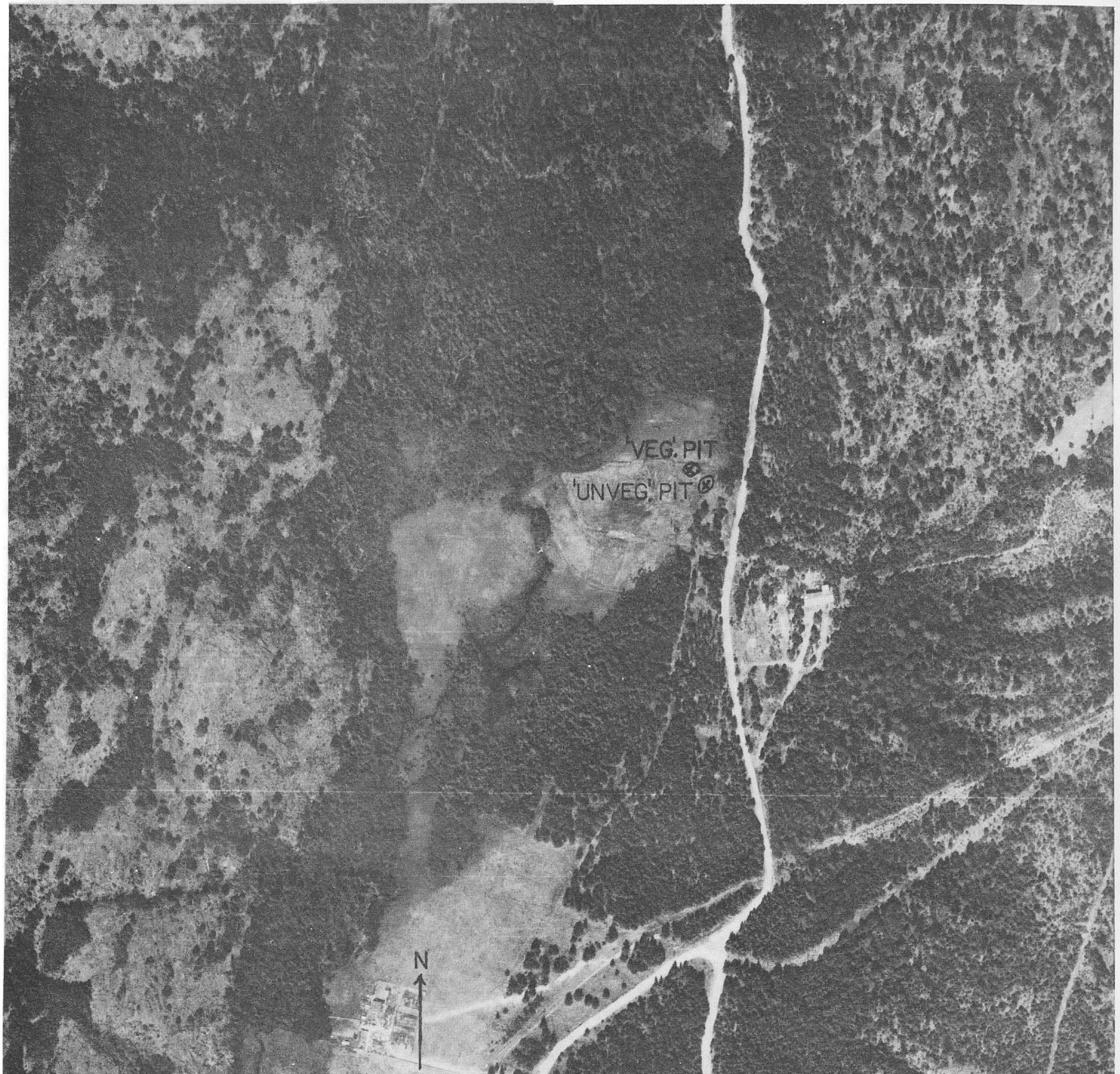


FIGURE V:4: HEDLEY SCALE 1:6100

FIGURE V:5: VELVET SCALE 1:4400



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