AN EXAMINATION OF FACTORS AFFECTING VEGETATION ESTABLISHMENT AT THE KITSAULT MINESITE

By

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ABSTRACT

The end land use objective for most mines in British Columbia is a vegetation cover of equal productivity to that which existed prior to mining. The subject of this study was the Kitsault minesite in north coastal B.C.. The project had two components. The objective of the first was to identify plant and soil factors impeding forest development. Vigorous plant growth indicated that a number of materials and methods can be used to achieve a sustained vegetative cover on the wasterock dumps. Studies of similar natural substrates (recently exposed moraines in S.E. Alaska) showed that litter and N additions were the main driving forces for plant and soil development. The two plant species producing the highest amounts of litter and N on the wasterock dumps were Sitka alder and birdsfoot trefoil. While good plant growth was achieved on the dump benches, on the dump slopes it was impeded by the absence of soil-sized particles. The best source of such particles was the incompetent wasterock.

The objective of the second part of the study was to evaluate the long term performance of the incompetent wasterock, used as a source of fines, on slopes at the angle of repose. The higher proportion of fine particles in the incompetent wasterock appeared to result from the relatively large proportion of sericite and calcite, most of which

ended up in the < 2mm fraction. The modal composition of the incompetent wasterock coarse fragments was 90% quartz and K feldspar. The resilience of these minerals to weathering suggests that further fragmentation, beyond that observed in the first few years, will be limited, and thus the veneer of incompetent wasterock should maintain the angle of repose and maintain good drainage. With regards to nutrient availability, the incompetent wasterock appeared to be a better source of Ca, K, Mg, and P than any of the other wasterock types or the mineral layers in adjacent natural soils. Of the trace elements analysed, levels in the incompetent wasterock were no higher than in the other wasterock types.

TABLE OF CONTENTS

		Page
	Abstract	ii
	Table of Contents	iv
	List of Tables	x
	List of Figures	xvi
	Acknowledgements	xvii
I.	INTRODUCTION	1
1.	Glossary	1
2.	Overview of the Project	3
3.	Description of Study Site	6
	3.1 Location	6
	3.2 Geology	7
	3.3 Climate	8
	3.4 Topography and Drainage	8
	3.5 Vegetation	8
	3.6 Surficial Materials and Soils	10
	3.7 Mine History and Mining Method	11
	3.8 Previous Reclamation and the Present Reclamation Objective	12
II.	PLANT AND SOIL FACTORS THAT COULD LIMIT THE RATE OF RECLAMATION	14
1.	Objective	14
2.	Literature Review	15
	2.1 Properties of Wasterock	15
	2.2 Suitability of Wasterock for Use as a Soil	18
	2.3 Mine Reclamation Regulations	20

2.4 Reclamation Research 21

2.5 Reclamation Research at Kitsault 30

2.6 Soil Development on Mine Wastes 31

2.7 Natural Plant Succession 36

2.8 The Early Stages of Natural Soil Development 41

2.9 Well Developed Soils 45

3.0 Summary 48

3. Materials and Methods 51

3.1 Description of Study Sites 51

3.1.1 Soil Resources 51

3.1.2 Plant Growth 56

3.2 Foliage and Soil Sampling 56

3.3 Laboratory Analyses 64

3.3.1 Soil Samples 64

3.3.2 Plant Samples 65

3.4 Data Analysis 65

4. Results and Discussion 67

4.1 Soil Resources 67

4.1.1 Untreated Dumps 67

4.1.1.1 Physical Properties 67

4.1.1.2 Chemical Properties 77

4.1.2 Field Trials 90

4.1.1.1 Surface Conditions 90

4.1.1.2 Physical Properties 92

4.1.1.3 Chemical Properties 100

4.2 Plant Growth 109

4.2.1 Grass and Legume Growth in the Bench Trials 113

4.2.1.1 Trial 70.1: Species / Amendment 113

4.2.1.2 Trial 82.1: Species / Amendment 128

4.2.2 Woody Plant Growth in the Bench Trials 135

4.2.2.1 Trial 70.3: Conifer Species 135

4.2.2.2 Trial 77.1: Sitka Alder 137

4.2.2.3 Trial 82.1: Pine and Alder 139

4.2.3 Natural Plant Invasion 144

4.2.3.1 Natural Plant Invasion of Untreated Surfaces .. 144

4.2.3.2 Natural Plant Invasion of Trial 70.1 146

4.2.4 Evaluating the Long Term Performance of Materials and Methods Tested in the Field Trials 152

4.2.5 Slope Trials 157

4.2.5.1 Trial 75.1: Wasterock .. 158

4.2.5.2 Trial 81.1: Overburden . 159

4.2.5.3 Trial 82.1: Incompetent Wasterock 164

5. Summary 167

6. Literature Cited 175

III EVALUATING THE LONG TERM PERFORMANCE OF THE INCOMPETENT WASTEROCK, USED AS A SOURCE OF FINES, ON SLOPES AT THE ANGLE OF REPOSE. 183

1. Introduction 183

1.1 Objective 183

1.2 Literature Review 186

1.2.1 Properties of Podzolic Soils 186

1.2.2 Methods of Simulating Weathering 196

2. Characteristics of Rock Types found in the Waste 199

2.1 Objective 199

2.2 Materials and Methods 199

2.2.1 Sample Selection 199

2.2.2 Sample Analysis 199

2.2.3 Data Analysis 203

2.3 Results and Discussion 204

2.3.1 Grain Size 204

2.3.2 Total Mineralogy 204

2.3.3 Major Elements 213

2.3.4 < 2 um Mineralogy 215

2.3.5 Trace Elements 217

2.4 Summary 221

3. Characteristics of Weathered Wasterock 223

3.1 Objective 223

3.2 Materials and Methods 223

3.2.1 Sample Selection 223

3.2.2 Sample Analysis 223

3.2.3 Data Analysis 224

3.3 Results and Discussion 225

3.4.1 pH and Organic Carbon 225

3.4.2 Mineralogy and Major Elements Content of < 2mm Fraction 225

3.4.3 < 2 um Mineralogy 231

3.4.4 Particle Size 231

3.4.5 Trace Elements content of < 2mm Fraction 234

3.4.6 Extractable Elements 236

3.5 Summary 242

4. Properties of Natural Soils Adjacent to the Minesite 244

4.1 Objectives 244

4.2 Materials and Methods 244

4.2.1 Sample Selection 244

4.2.2 Site Description 245

4.2.3 Sample Analysis 245

4.3 Results and Discussion 249

4.3.1 Site and Profile Descriptions ... 249

4.3.2 Extractable Elements 254

4.3.3 Coarse Fragment and < 2 mm Mineralogy 259

4.3.4 Heavy Minerals 266

4.3.5 Particle Size 268

4.3.6 Major Element Composition 272

4.3.7 Minor Element Composition 276

4.3.8 2-20 um and < 2 um Mineralogy ... 281

4.4 Summary 284

5. Simulated Weathering 288

5.1 Introduction 288

5.2 Objective 288

5.3 Materials and Methods 289

5.3.1 Samples 289

5.3.2 Soxhlet Methods and Sample Analysis 289

5.4 Results and Discussion 291

5.4.1 Weight Loss and Calcite Dissolution 291

5.4.2 Particle Size 294

5.4.3 2-20 um and < 2 um Mineralogy ... 296

5.4.4 Major Element Composition 298

5.4.5 Trace Element Composition 306

5.5 Summary 309

6. Literature Cited 311

IV CONCLUSIONS 317

V APPENDICES 329

LIST OF TABLES

PART II

		Page
1.1	Surfaces sampled and number of samples analysed for untreated wasterock.	53
1.2	Descriptions of the wasterock dumps and the overburden sampled in this study.	54
1.3	Treatments sampled and number of samples analysed for the field trials.	57
1.4	A list of the trials testing plant growth. ..	58
1.5	The Latin names of agronomic species tested at Kitsault.	59
1.6	Seed mixes applied on the bench trials.	60
1.7	Seed mixes applied on the slope trials.	61
1.8	The rate at which fertilizer was applied in the agronomic field trials.	62
1.9	Surface conditions in 1980 on areas of untreated wasterock and overburden abandoned in 1972.	68
1.10	Soil physical properties of the untreated wasterock dumps.	69
1.11	The probability that differences exist between the physical properties of the 0-5 and the 5-10 cm depths of the untreated wasterock dumps.	69
1.12	Correlation coefficients for soil physical properties of the untreated wasterock dumps.	71
1.13	Soil texture information for different sites on the untreated wasterock dumps.	76
1.14	Soil chemical properties of the untreated wasterock dumps	78

1.15 Correlation coefficients among soil chemical and other properties of the untreated wasterock dumps 80

1.16 The probability that differences exist between the chemical properties of the 0-5 and 5-10 cm depths of the untreated wasterock dumps. 82

1.17 The pH and the calcite and organic matter contents of selected wasterock samples. 84

1.18 The surface cover on sampled areas of the field trials. 91

1.19 Soil physical properties of the field trials. 93

1.20 Correlation coefficients for soil physical properties of the field trials. 96

1.21 The probability that differences exist between the soil physical properties of the 0-5 and 5-10 depths of the field trials. 96

1.22 Soil texture information for different treatments in the field trials. 99

1.23 Soil chemical properties of the field trials. 101

1.24 The probability that differences exist between the physical properties of the 0-5 and 5-10 cm depths on the treated dumps. 102

1.25 Correlation coefficients for soil chemical properties of the field trials. 104

1.26 Average data for soil chemical properties on sections of 70F and 70P sown with different seed mixes. 107

1.27 Soil properties of the overburden. 110

1.28 Average percent cover on different treatments in Trial 70.1. 114

1.29 Average percent cover for individual agronomic species growing on Trial 70.1. 115

1.30 Coefficients of variance for different cover types in Trial 70.1 120

1.31 Coefficient of variance for different grass and legume species growing on Trial 70.1. 121

1.32 Above ground biomass and foliar chemistry data from Trial 70.1 in 1980. 123

1.33 Above ground biomass of species sampled in Trial 70.1 in September, 1981. 125

1.34 Above ground biomass of agronomic species in field trials in September, 1984. 125

1.35 Average percent cover of agronomic species growing in Trial 82.1. 133

1.36 Average heights and annual growth of conifers planted in Trial 70.3. 136

1.37 Alder growth statistics from Trial 77.1. ... 138

1.38 Average survival of alder and pine over the first three years of growth in Trial 82.1. 140

1.39 Average height, and growth of seedlings on different treatments in Trials 82.1. 140

1.40 The number and height of woody species in 1984 on untreated surfaces aboandoned in 1972. 145

1.41 The number of seedlings colonizing different treatments in Trial 70.1 in 1982. 148

1.42 The number, height, and growth of invading seedlings taller than 49 cm on different treatments in Trial 70.1. 150

1.43 Cover of agronomic species on fines-containing portions of Trial 81.1. 161

1.44 Proportion of < 2 mm particles in upper 10 cm of slope, three years after it was covered with incompetent wasterock. 165

PART III - Section 2

2.1 Analyses carried out on different fractions of the rock and wasterock. 200

2.2 The grain size distribution in different rock types 205

2.3 Proportion and size of different minerals in potassic and incompetent rock thin sections. 206

2.4 Mineralogy of hornfels, potassic and incompetent rock and wasterock. 207

2.5 Major element concentrations in the rock samples and the < 2 mm fractions of the wasterock. 214

2.6 Mineralogy of the < 2 um fraction in the wasterock and the crushed rock. 216

2.7 Trace element concentrations in the rock and the < 2 mm fraction of the wasterock. ... 218

PART III - Section 3

2.8 The pH, carbonate-C, and organic-C levels of the weathered and unweathered wasterock. 226

2.9 Mineralogy of the < 2 mm fractions of the unweathered and weathered wasterock. 227

2.10 Major element concentrations in the < 2 mm fractions of the unweathered and weathered wasterock. 228

2.11 Mineralogy of the < 2 um fractions of the unweathered and weathered wastrock. 232

2.12 Particle size distribution of the unweathered and weathered wasterock. 233

2.13 Trace element concentrations in the < 2 mm fractions of the unweathered and weathered wasterock. 235

2.14 Spearman correlation coefficients for significant correlations between levels of extractable elements in weathered and unweathered waterock. 237

2.15 Extractable element concentrations in the < 2 mm fractions of the wasterock and the crushed (< 2 mm) rock samples. 238

2.16 Spearman correlation coefficients for significant correlations between extractable element concentrations and other properties of the wasterock. 239

PART III - Section 4

2.17 Analyses carried out on samples from the natural soils. 246

2.18 Profile descriptions for the natural soils. . 251

2.19 Extractable element concentrations in the natural soils. 255

2.20 AAO extractable element concentrations in the quartz diorite soil (difference in total composition before and after AAO extraction). 255

2.21 Estimated mineralogy of the coarse fragments and < 2 mm fractions of the natural soils. 260

2.22 Estimated mineralogy of the sand and coarse silt fractions of the Ae, Bhf1, Bf, and BC3 horizons of the quartz diorite soil. 265

2.23 Heavy mineral content in selected horizons of the quartz diorite soil. 267

2.24 Proportion of individual heavy minerals in the 3.31 g/cm3, 100 to 50 um fraction of selected horizons of the quartz diorite soil. 269

2.25 Particle size distributions in the < 2 mm fractions of the natural soils. 270

2.26 Major element composition of the coarse fragments and < 2 mm fractions of the natural soils. 273

2.27 Minor element concentrations in the coarse fragments and < 2 mm fractions of the natural soils. 277

2.28 Estimated mineralogy of the < 2 um and 2-20 um fractions of the natural soils. 283

PART III - Section 5

2.29 Average weight loss and other properties of the Soxhlet residue and leachate. 292

2.30 Average particle size distribution after Soxhlet leaching. 295

2.31 Estimated mineralogy of the < 2 and 2-20 um fractions of the FI and GM samples before and after 8 weeks of Soxhlet leaching. 297

2.32 Average major element composition of the Soxhlet residues. 299

2.33 Average cumulative and proportion of initial major element weight recovered in the leachate. 300

2.34 A comparison of weight losses from the residues and weight gains in the leachate. .. 301

2.35 Average trace element composition of the Soxhlet residues. 307

2.36 Average cumulative and proportion of initial trace element weight recovered in the leachate. 308

LIST OF FIGURES

PART II

		Page
1.1	A schematic diagram of the Kitsault mine showing the location of sites examined in this study.	52
1.2	pH vs N/m^3 for the 0-5 cm depth on the untreated dumps (r=-0.79).	85
1.3	pH vs N/m^3 for the 5-10 cm depth on the untreated dumps (r=-0.83).	85
1.4	pH vs available P for the 0-5 cm depth on the untreated dumps (r=-0.79).	89
1.5	pH vs available P for the 5-10 cm depth on the untreated dumps (r=-0.90).	89
1.6	pH vs %C for the field trial treatment x depth averages.	102
1.7	Average agronomic cover for the year x seed mix combinations in Trial 82.1.	130
1.8	Average agronomic cover for the soil type x seed mix combinations in Trial 82.1.	130
1.9	Average agronomic cover for the block x soil type combinations in Trial 82.1.	131

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1. INTRODUCTION

1. Glossary

Ore: Rock that contains sufficient amounts of the economically valuable elements to warrant its extraction.

Wasterock: Rock that does not contain sufficient amounts of the economically valuable elements to warrant its extraction, but which has to be removed to allow access to the ore. The wasterock is blasted into smaller particles to allow its removal by truck and shovel.

Tailings: Material remaining after the economically valuable elements are removed from the ore.
To remove the valuable elements, in this case Mo, the blasted rock goes through several steps of crushing and Mo extraction. The resulting residue or tailings usually consists of a slurry of sand and/or silt-sized particles in water.

Overburden: At coal mines, overburden includes both bedrock and naturally unconsolidated surficial materials on top of the coal seams. At metal mines, the term overburden usually only refers to naturally unconsolidated surficial materials. The metal mine definition was used in this thesis.

Soil: The rooting medium, present or potential. Man-made media on the surface containing soil-sized particles and which can support plant growth are often called proto-soils. In this study the term soil was used for both natural and man-made rooting media.

Soil-sized: Particles less than 2 mm in diameter.

Incompetent Rock: A relatively rare intrusive rock type, identified by its lack of cohesion. Found in the center of the pit.

Potassic Rock: The most common rock type found in the waste at Kitsault, it is a cohesive intrusive rock, predominantly composed of quartz and K feldspar phenocrysts.

2. Overview of the Project

The subject of this study was the land reclamation of mine wastes at the Kitsault minesite. The project had two components. The objective in the first, "Plant and Soil Factors Limiting the Rate of Reclamation", was to identify the factors impeding plant growth. To meet this objective, plant growth and soil properties in field trials established between 1970 and 1982 were studied, natural plant invasion and the associated changes in soil properties were measured, and evaluated techniques for establishing plant growth on the coarse dump slopes were evaluated.

Conclusions were reached as to the major limitations of the soil and plant resources with regards to forest development. Transformations occurring on the wasterock dumps were compared with the changes observed in primary succession on recently deglaciated sites in S.E. Alaska, an area with similar environmental conditions, and suggestions were made as to the best manner for accelerating the natural processes. The most inhospitable environment for plant growth occurred on the boulder covered dump slopes. Methods for ameliorating the slopes were tested in field trials.

The second part of the study, an outgrowth of the slope trials, examined whether a veneer of incompetent wasterock could be used on the angle of repose slopes. The exposure of blasted rock particles to ambient levels of pressure and temperature, air and water, and organic inputs associated with plant growth is likely to result in significant changes

in their make-up. With further soil development and plant growth, factors promoting weathering will be intensified. The objective of the second part of the study was to predict what effects these changes will have on the properties of the incompetent wasterock, in order to determine how compatible it will be with the goals of reclamation: the development of a wilderness forest with protected watershed values.

The first step to understanding how the incompetent wasterock will perform was to determine its composition. Analyses were carried out to characterize the incompetent wasterock and show how it differed from the more common rock types found in the waste.

Information on pedogenesis and weathering at the minesite was gathered from two sources: wasterock on the abandoned dumps and two natural soil profiles within the proposed pit limits. The changes in the wasterock on the abandoned dumps provided information about the type of changes that will occur within ten years. The natural soil profiles showed the effects of much longer periods of pedogenesis, and the conditions under which pedogenic changes occurred. It was impossible to examine soil profiles developed from incompetent rock, since areas where the incompetent rock may have been exposed had already been mined. Although the parent materials of the natural soils and much of the weathered wasterock were not composed of incompetent rock, they had a great number of properties in

common with it. Thus information about how they altered could be used to predict certain aspects of incompetent wasterock alteration.

In order to more accurately assess the effects of weathering on properties such as particle size, weathering of the incompetent wasterock was simulated in the laboratory. The technique used was a soxhlet distillation with acetic acid.

While the data collected and the environmental effects considered are those of the Kitsault minesite, the wasterock soil properties, geology, and dump construction are similar to those of many hard rock mines in B.C. and elsewhere in the world. Many mines lack sufficient reserves of unconsolidated soil-like materials to use as surface growth media, either because much of the mine had been developed before the necessity of soil conservation was realized or because the quality and quantity of the unconsolidated soil-like material is low in steep, glaciated mountain landscapes. Thus, although the conclusions reached vis a vis identifying and using different wasterock types specifically refer to Kitsault, the methodology is generally applicable and the potential benefits of optimally placing different rock types have wider significance.

3. Description of the Study Site

3.1 Location

The Kitsault molybdenum mine is located at latitude 55° 25' north and longitude 129° 25' west, approximately 150 km northeast of Prince Rupert, British Columbia. The property has two components, the townsite and the mill-mine complex. The townsite was built at sea-level, near the head of Alice Arm. The mill-mine complex is situated 6 km south of the townsite, at an elevation of 600 to 900 m.

3.2 Geology

The Kitsault ore body is a porphyry Cu-Mo type of deposit (Eckstrand, 1984). Ore deposits of this type account for 60% of the world's copper reserves and 99% of the world's molybdenum reserves, and a large number of companies are mining these deposits both in Canada and abroad. In B.C. such mines include Endako, Lornex, Bethlehem, Brenda, Granisle, Island Copper, Similkameen, and Afton (Eckstrand, 1984).

The geology of Cu-Mo porphyry deposits has received much attention (Beane, 1982; Carter, 1974; Soregaroli & Sutherland Brown, 1976; Rose & Burt, 1979). Most of the porphyry Cu-Mo deposits found in west-central B.C. are associated with small stocks, which intrude volcanic and sedimentary rocks (Carter, 1974). These intrusive stocks generally do not exceed a kilometre in diameter, are

commonly multiple, and range in composition from quartz diorite to granite. According to Griffiths and Godwin (1983), Cu and Mo are derived from the primary granitoid melt and the Cu:Mo ratio reflects the composition of that melt. Other trace elements, Pb, Zn, Au, and Ag, occur in veins peripheral to the porphyry intrusions, and the metal content of these veins is controlled by the lithology of the wall rocks. Of the porphyry Cu-Mo deposits located in west-central B.C., Kitsault had the most granitic mineralogy . . (Carter, 1974; Soregaroli & Sutherland Brown, 1976). Of the other operating mines, the lithology of the rock at Endako was the most similar to Kitsault.

Molybdenum ore at Kitsault is associated with the series of igneous stocks which make up the Lime Creek Intrusive Complex. The host rocks through which the igneous rock intruded are interbedded argillites and graywackes of the Bowser Lake Group. These were thermally metamorphosed into hornfels. The intrusives stocks vary in composition from quartz diorite to quartz monzonite porphyry, with the latter making up most of what has been mined to date. Much of the igneous rock within the pit was hydrothermally altered. Silicic, potassic, phyllic, argillic, and propylitic alteration types have all been identified, however most of the igneous ore and wasterock is the potassic alteration type. In the potassic rock the predominant form of hydrothermal alteration was the selective replacement of plagioclase by K feldspar

(Steininger, 1985). In the field, the potassic rock was identified by the predominance of coarse grains of K feldspar and quartz. Another less common, but distinct igneous rock type was identified by its incompetent nature.

3.3 Climate

The minesite has a cool, humid maritime climate, although it is not unusual to have 3 or 4 weeks without precipitation in the summer. During winter the microclimate at the soil surface is moderated by the deep snow cover. Under a similar deep snow cover, in a slightly harsher subalpine environment in S.W. British Columbia, Brooke et al (1970) found that the surface soil temperature rarely dropped below $0^{o}C$.

3.4 Topography and Drainage

The minesite is located in rugged, mountainous terrain. Within a 10 km area, the elevation varies from sea level to 1800 m. The minesite is drained by the deeply incised channels of the Patsy and Lime Creeks. As all the soils are coarse textured, the rate of drainage largely depends on the topography.

3.5 Vegetation

Changes in species composition of the vegetative cover in the Kitsault area result from changes in elevation, and from the transition from a maritime to a more continental

climate. According to Haeussler et al. (1974), the minesite is located at the transition between the high elevation variant of the Northern Drier Maritime Subzone of the Coastal Western Hemlock Zone and the Subalpine Mountain Hemlock Zone, and close to the transition from Subalpine Mountain Hemlock to the Englemann Spruce - Subalpine Fir zones.

The distribution of vegetation and soil types is closely linked to the terrain (Gill, 1978). Where the topography is relatively flat and the drainage is poor, a sedge (Carex species)-mountain hemlock (Tsuga mertensiana (Bong.) Carr) parkland ecosystem forms. On well drained slopes there is an overmature mixed western (Tsuga heterophylla (Raf.) Sarg.) and mountain hemlock forest, with amabalis fir (Abies amabalis (Dougl.) Forbes) common in the understory. On well drained areas, the most common shrubs are various Vaccinium species and false azalea (Menziesia ferruginea Smith) (Gill, 1978).

Adjacent to the mine, a dense cover of Sitka alder (Alnus sinuata (Reg.) Rydb.), with a scattered component of black cottonwood (Populus trichocarpa Torr. and Gray) and willow species (Salix spp.) are growing on ground disturbed by mine exploration and on recently active colluvium. Where a litter layer has developed beneath the alder, Sitka spruce (Picea sitchensis (Bong.) Carr. and hemlock (Tsuga spp.) seedlings are growing vigorously. At the elevation of the minesite, willow is the most prolific species on active

alluvium, while at lower elevations (approx. 300-400 m), 50 km northeast in the Nass Valley, large stands of approximately 20 year old lodgepole pine (Pinus contorta Dougl.) grow on recently burned areas. Red alder (Alnus rubra Bong.), a very vigorous colonizer of disturbed areas at sea level (e.g., the townsite), is not found above about 200 metres elevation.

3.6 Surficial Materials and Soils

According to the B.C. terrain classification (E.L.U.C., 1976), the surface cover adjacent to the mine is largely colluvium with lesser amounts of bedrock and organic materials, and a few areas of morainal and fluvial material. In most cases the unconsolidated materials were mapped as veneers (10 cm to 1 m deep) or blankets (thicker than 1 m, but not thick enough to mask underlying minor topographic irregularities in the bedrock). Due to the cool, humid climate, plant debris decomposes very slowly, and all but the most precipitous slopes are covered by at least 10 cm of plant litter. Considerably deeper organic deposits have accumulated in waterlogged hollows and on gentle slopes.

No thorough soil surveys have been carried out in the immediate vicinity of the minesite. In a biophysical study adjacent to the mine, Gill (1978) found Orthic Humo-Ferric Podzols and Folisols on the well drained slopes. On areas with impeded drainage he found Gleysols and fibric or mesic organic soils. Regosols and Brunisols occurred on more

recently disturbed sites. Mineral soils generally had a high coarse fragment content, with textures ranging from loam to sand.

3.7 Mine History and Mining Method

The mine was initially developed by British Columbia Molybdenum Limited who operated it from 1967 to 1972. In 1972, falling molybdenum prices caused the mine to close. Subsequently it was bought by Amax of Canada Ltd., and was reopened in 1980. In 1982, falling molybdenum prices again led to the closure of the mine, and although it has not been abandoned, no mining has occurred since that date. The future viability of the mine will depend upon the molybdenum market.

The mine was an open pit truck and shovel operation. The largest terrestrial disturbances are the open pit and the wasterock dumps. Initially roads and buildings formed a significant proportion of the disturbed areas, but as mining proceeded, their size relative to the wasterock dumps decreased. For use in reclamation, AMAX stripped soil-like overburden prior to mine expansion. Soil material was not conserved by the predecessor company, BC Molybdenum.

Due to the steepness of the terrain, wasterock was stored in terraced dumps. The technique used to build a terrace was for a bulldozer to push piles of blasted rock up to and over the advancing terrace face. This resulted in a gravimetric separation of the rock, with stones and boulders

bouncing down the slope, while fines were retained in crevices at or near the top. At present, except for the bench at the top, most of the dump contains little or no fines. A foundation of boulders is important for dump stability as the large pores between boulders can conduct large volumes of water, thus preventing the build up of hydraulic pressures that could cause mass wasting.

3.8 Previous Reclamation and the Present Reclamation Objective

When requesting an extension of its mining permit in 1970, B.C. Molybdenum proposed to turn the pit into a lake and allow the waste rock dumps to revegetate naturally (Price, 1982). The company's assurance that natural revegetation would occur was based on: (1) the humid climate and lush vigorous natural vegetation, and (2) the evidence of natural reforestation that had already occurred at the old Anyox mine site. Anyox, a large smelter and underground mine abandoned in the 1920's, is located at the mouth of Alice Arm. In case natural plant invasion failed, B.C. Molybdenum agreed to set up field trials to develop artificial reclamation methods. Several trials were established. The field trials were visually monitored each year from 1970 to 1978 (Price, 1982).

When the mine re-opened in 1980 more rigorous rules for reclamation were in place. In order to get a Mining Permit AMAX had to submit an acceptable reclamation plan to the

provincial government. A mining permit was given for the re-opening of the mine on the basis that after mining, an erosion-preventing forest cover would be grown on all the disturbed areas, except the open pit. It is to be turned into a lake. The erosion-preventing end land use was justified on the basis that the pre-mining environment was an overmature forest, with no productive soils, not important wildlife habitat, and no access for recreation (AMAX, 1980). At present there is no time limit for reclamation.

II. PLANT AND SOIL FACTORS THAT COULD LIMIT THE RATE OF RECLAMATION

1. OBJECTIVE

The objective of the first part of the thesis was to identify the plant and soil factors limiting the rate of reclamation on the terraced wasterock dumps. This study focused on the terraced wasterock dumps for two reasons. First, according to the reclamation plan, when the mine is completed, dumps of this type will account for most of the area disturbed. The second reason is that observations of natural plant invasion both at this and other mines (Lavkulich et al., 1976) suggest that the large dumps will be the most difficult areas to revegetate.

Other factors, such as climate, topography, time and financial considerations, are potentially limiting. However at Kitsault, these factors are either not likely to pose problems or they will be taken into account in the selection of soil and plant materials and methods. For example, with such a heavy snow fall, avalanching could be a problem on long, steep slopes. However, the mine plans to make the dump slopes quite short (AMAX, 1980).

2. LITERATURE REVIEW

2.1 Properties of Wasterock

Porphyry Cu-Mo mines are commonly referred to as hard rock mines, because the rock mined is generally indurate and competent. As a result the wasterock from porphyry Cu-Mo mines contain a much smaller proportion of fines than wasterock derived from coal overburden. On average only 16 to 25% of particles in wasterock on terraced dump benches at porphyry Cu-Mo mines in B.C. were < 2 mm (Murray, 1977), while the associated slopes were almost devoid of fines (Lavkulich et al., 1976). Most of the soil-sized particles (60 to 71%) were sand-sized, and thus the wasterocks had a low available water retention (6 to 11%) and a low CEC (7 to 15 meq/100g). The high bulk density (1.6 to 1.8 g/cm3) of wasterock was attributed to the high coarse fragment content.

The Kitsault rock and wasterock contained more Ca, K, and S than the wasterock from other porphyry Cu-Mo mines (Steininger, 1985; AMAX, 1980). Higher Ca values may be attributed to the presence of either plagioclase or calcite. Higher total K values resulted in higher available K levels (AMAX, 1980). Higher S values in the Kitsault wasterock sample suggest that acid generation may occur. However studies of potential acid production on a wide range of different rock types from Kitsault concluded that the high

acid-consuming ability will prevent the wasterock from becoming acidic (B.C. Research, 1981).

By definition the trace element composition of an ore body is anomalous. At Kitsault, As, Cd, Cu, Mo, Pb, and Zn levels in the rock were all significantly higher than the typical composition of a granite rock (AMAX, 1980). All trace elements except Cu were higher than the upper limits allowed in Alberta agricultural soils (Ballard, 1980). In the unweathered wasterock, available levels of trace elements are not likely to be high, but will increase as weathering proceeds.

The availability of different elements depends on the original composition of the rock and its susceptibility to weathering. All the wasterock types collected from porphyry Cu-Mo mines by Murray (1977) were unweathered, and thus had high pH values ranging from 7.1 to 8.3. The range for pH with $CaCl_2$ was 6.6 to 7.5, 0.7 to 1.0 unit lower than that in water. Levels of ammonium acetate extractable Ca were high (0.1 to 1.0 %), indicating that the wasterock contained calcite. Calcite will also contribute to the high pH. The low available P levels (0 to 8 ppm) resulted from a lack of adsorbed P in unweathered materials. Available P levels should increase as weathering proceeds (Bray, 1974).

Researchers sampled foliage at the bloom stage from plants growing on mine wastes and on adjacent natural soils at mines in B.C. (Lavkulich et al., 1976). Trace elements concentrations in the foliage of red fescue grown on Endako

mine wastes were similar to the amounts found in red fescue grown on adjacent natural soils (Lavkulich et al., 1976). The concentrations of Mo (42 to 52 ppm) in both the mine wastes and adjacent natural soils were much higher than the normal range of 0.2 to 3.0 ppm found in soils (Archer & Hodgson, 1987). The Cu:Mo ratio of 0.3 to 0.4 was also very low. According to Agriculture Canada dietary guidelines (1981), ratios of less than 3:1 Cu:Mo in forage are hazardous for beef cattle. Other researchers have proposed that Cu:Mo ratios less than 2:1 indicate potentially toxic feed (Miltimore & Mason, 1971). Although Mo was only determined for foliage grown on tailings, similar results may be expected on wasterock.

In greenhouse trials, orchard grass grown on Endako wasterock showed a dramatic response to N and P fertilizer, but no response to any other nutrients (Lavkulich et al., 1976). Although timothy (Phleum pratense L.) and red fescue grown on natural soils contained substantially more K than individuals grown on mine wastes, applying K fertilizer did not increase either foliar K or the yields. Applying micronutrients (B, Cu, Fe, Mn, Mo, and Zn) and the presence of heavy metals also did not appear to affect plant growth.

2.2 Suitability of Wasterock for Use as a Soil

Poor plant growth on wasterock may be due to a combination of factors. Various authors (Bradshaw & Chadwick, 1980; Michaud, 1981; Lyle, 1986; Williams & Schuman, 1987) have listed the wasterock characteristics that limit plant growth and suggested different methods for identifying them. Sometimes deleterious properties can be predicted from the characteristics of the pre-waste bedrock. For example a coarse grained bedrock indicates that the waste will have a coarse texture (Carrol, 1970). However, differences in geology, the great diversity in environmental conditions, and the lack of research at other mines make predictions of this sort very difficult.

Several authors have devised criteria for evaluating the suitability of disturbed soil materials as a rooting medium (e.g., Schafer, 1979; U.S.D.A., 1979; Alberta Soils Advisory Committee, 1981). All are from jurisdictions where the pre-mining soil cover must be reapplied and thus the criteria are based on properties of the previous soil cover. The rating scheme most applicable to B.C. is the one created for coal mines in the Eastern Slopes Region of Alberta (A.S.A.C., 1981). The Eastern Slopes Region is forested and mountainous, similiar to most of B.C., and as the aim of mine reclamation in B.C. is usually to return the rooting medium to its previous productivity, it is appropriate to evaluate mine wastes with criteria used to evaluate the previous soil cover. According to the A.S.A.C. (1981)

criteria, the lowest rating for a property determines the overall rating of a soil. Based on most of their properties, the porphyry Cu-Mo wasterock types (Murray, 1977) would be rated as either good or fair. A few materials with loamy sand textures would be rated as poor. However all the wasterock types would earn the rating of unsuitable or poor on the basis of their high coarse fragment contents.

The negative attributes of rock fragments include a reduction in rooting volume, a decline in total water-holding capacity, a reduction in total soil nutrients, and elevated surface temperatures (Munn et al., 1987). The elevated surface temperature results from an increase in the surface rock coverage. In forestry, site quality is often strongly correlated with available soil moisture and effective rooting volume. Stoniness may also require the use of different site preparation equipment, if stones damage equipment used to prepare the surface, and may preclude otherwise suitable cultural techniques. Tree planting is also more difficult in rocky substrates.

"Positive attributes of rock fragments in soils include reduced susceptibility to erosion and compaction (Munn et al., 1987)." McCormack et al. (1984) suggested that the self-mulching properties of rock fragments on the surface may contribute to vegetative establishment on sites subject to erosion. Evaporation may also be reduced because in a rocky soil a given quantity of water will penetrate to a

greater depth, due to a reduced water storage capacity per unit volume near the surface (Birkeland, 1984).

Despite these positive attributes, the rock fragment suitability criteria required by U.S. authorities were even stricter than these for the Eastern Slopes Region of Alberta.

A less arbitrary scheme for evaluating mine wastes is to check whether they meet the minimal physical and chemical characteristics associated with the growth of the desired vegetation cover in the surrounding undisturbed environment. This approach has been used in reconstructing soils on areas disturbed by the Oil Sands Project in Alberta (Monenco Consultants Ltd., 1983). One problem with this technique is that important dynamic processes and subtle differences at the microsite level may be difficult to measure. Another problem is that the minimal soil characteristics are often poorly defined and this type of information may be time-consuming and costly to collect.

2.3 Mine Reclamation Regulations

In B.C., mine reclamation is enforced by provincial laws regulating the allocation of permits and licenses, without which mining is illegal. To obtain a Mining Permit, a mine must meet reclamation requirements stipulated in sections 7, 8 and 9 of the Mines Act. However, the Act does not enforce how the standards must be met. The philosophy is for "industry to accomplish it in the way most suited to

them (Errington, 1985)". A list of guidelines have been drawn up outlining criteria for acceptable reclamation in accordance with the Mines Act (Rogers, 1984). For productivity, the guidelines state that, "The level of land productivity to be achieved on reclaimed land shall not be less than existed prior to mining on an average property basis unless the proponent can produce adequate documentation to support the impracticality of this level. Land shall be vegetated to a self sustaining state using appropriate plant species." For soils the guidelines say "A growth medium which will satisfy land use and productivity objectives shall be placed on the surface. Where necessary, sufficient topsoil or other suitable growth medium shall be saved for use in reclamation programs (Rogers, 1984)".

2.4 Reclamation Research

A great variety of different forms of land disturbance require reclamation. In the Pacific N.W., most of the research has been carried out on land disturbed by logging (e.g., Dryness, 1973), some of which is applicable to mine land reclamation. For example, agronomic seed mixes created for use in forestry (e.g., Carr, 1980) provide a good starting place when looking for the appropriate agronomic species to use in mine land reclamation. However unlike mine wastes, which initially are sterile, land disturbed by logging and highway construction often already contains abundant propagules and is biologically active.

Other differences between land disturbed by logging and mine wasterock were illustrated by Errington's (1975) study of natural plant invasion on abandoned logging roads and coal spoils near sea level on the east side of Vancouver Island. On logging roads, all invading plant species increased their cover and frequency for the first 15 to 20 years. At this stage red alder, a relatively late arrival, became dominant and its closed canopy shaded the other species. In the early stages of plant invasion there was a good correlation between the invading plant species and the species already growing beside the road. A similar relationship was observed along the edge of coal spoils.

Compared with the logging roads, plant colonization of the coal spoils was much slower. One factor that contributed to this was the relatively large size of the coal dump, which limited the effect of surrounding vegetation both as a source of propagules and as a source of shade. Lack of shade, along with the south-facing aspect, affected the surface temperature and evapotranspiration, important considerations in an area with a large summer water deficit.

Errington's (1975) conclusion that natural plant invasion of wasterock was very slow in this environment was supported by Lavkulich et al. (1976) who found very little plant colonization on wasterock dumps at the nearby Texada metal mine. The growth of volunteer vegetation was much stronger where natural unconsolidated materials were

present. The faster plant colonization on natural overburden was attributed to a finer texture.

In Canada, the jurisdiction with the most rigorous mine reclamation requirements is Alberta. The Alberta government has carried out a thorough research program to show why and how their requirements must be met (e.g., Ziemkiewicz, 1985). Unfortunately differences in the environment, in the type of mines, and in the end land use objectives prevent one from using most of this technology on the humid, west coast of B.C.. In B.C. the government has played a less active role in reclamation research. Most of the work in B.C. has been done by individual companies or by their consultants. As a result, research results generally are published only when they can be used for public relations or in dealing with regulatory agencies. Thus the knowledge obtained often is not readily accessible.

In B.C., most of the effort in mine reclamation has been directed at producing surface covers of agronomic grasses and legumes. A large number of mines have succeeded in this regard. Agronomic species are attractive for reclamation for a number of reasons:

- cheap seed sources of known quality are available,
- they are compatible with amendments such as fertilizer and limestone,
- ease of application and seed storage,
- they grow in a wide range of conditions,
- they grow rapidly, producing an aesthetically

pleasing erosion-controlling cover.

The adaption to a wide range of conditions is in part due to the great number of species available. Adapted species can be found for all but the harshest conditions (Watson et al., 1980). In some cases individual species are tolerant of a wide range of conditions. For example, red fescue has performed well on the west coast of Vancouver Island (Hillis & Horne, 1984), at a variety of elevations in south eastern B.C. (Fraser, 1984), on a number of substrates at Pinchi Lake near Fort St. James (Wright & Gardiner, 1980), and throughout the Yukon (Younkin & Martens, 1985).

Two different approaches for using agronomics are illustrated by the work at Westar and Fording Coal Mines, mines in similar environments in the Crows Nest Pass area of southeast B.C. At Westar Coal Ltd., the initial purpose of reclamation was to reduce surface erosion, provide organic matter for nutrient cycling and faunal activity, and provide forage for wildlife (Westar, 1983). To accomplish this, stands predominantly comprised of grass species were established and then refertilized annually with 200 kg/ha of 13-16-10. To determine when annual re-fertilization could be stopped, studies were carried out to see how long it took to develop adequate nutrient cycling (e.g., Fyles, 1984). Fyle's (1984) study of N dynamics showed that once fertilization ceased, root N: shoot N ratios increased to levels similar to native grasslands. The dependence of the grasses on new fertilizer N declined significantly 2 to 5

years after establishment. Based on these results, maintenance fertilization is continued for 5 to 8 years after the grass cover has been established (Fraser 1984).

Fraser (1984) reported that within grass stands the proportion of different species fluctuated markedly from year to year. On exposed dryer sites the dominant grass species was red fescue. At lower elevation and on moister sites there was a larger component of tall grasses such as bromegrass (Bromus inermis Leys) and orchard grass (Dactylis glomerata L.) Yields averaged 800-1500 kg/ha above ground weight on the drier sites and 1000-3000 kg/ha on the moister areas.

In contrast to Westar, at Fording Coal the short term reclamation objective is to establish legumes. Based on a number of greenhouse and field trials, Fording developed the following recipe for reclamation (Fording Coal, 1983). Separate seed mixes are used at low and high elevations. At high elevation the main species used is sainfoin (Onobrychis viciifolia Scop.), while at low elevation it is alfalfa (Medicago sativa L.). The seed mixes also include some grass species, but the seeding rate for grasses is kept down to 56 kg/ha to ensure that the legumes have room to develop. The fertilizer rate is 225 kg/ha of 11-55-0. Field trials have shown that the high P and low N fertilizer favours the growth of legumes versus the grasses. K is not required, presumably because the rock (mica in shale) is an adequate K

source. At Fording, fertilizer only needs to be applied at the time of seeding because legumes can use atmospheric N.

Although agronomic plant covers at both mines have sustained vigorous growth, it is unclear whether this will continue indefinitely. There has been no previous research with these species in this environment. It is hoped that native species will gradually replace the agronomics, but to date that has not occurred (Fraser, 1984). As a result both mines are now investigating how they may incorporate native herbaceous species into the ground cover to ensure its long term stability.

Fording and Westar have also carried out trials with woody species. At both mines, lodgepole pine (Pinus contorta var. latifolia Engelm). has grown faster than either Douglas fir (Pseudotsuga menziesii Carr.) or Engelmann spruce (Picea engelmannii Perry) (Fording, 1983; Westar, 1983). Salix and Populus species have also grown well, however all species have grown poorly when planted in dense herbaceous covers. Browse has also been a problem, especially for the deciduous species (Fording, 1983).

Of the hard rock mines in B.C. one of the most thorough reclamation programs was carried out by Cominco at Pinchi Lake. Pinchi Lake was an open pit and underground Hg mine, approximately 50 km northwest of Fort St. James. The mine ceased operation in 1975, and since then trials have been run on a variety of materials to test different grass and legume species, fertilizer rates, the elimination of

maintenance fertilizer, seeding rates, and fall versus spring seeding. The short term reclamation objective at Pinchi Lake was to establish an agronomic cover that would:

- improve infiltration and prevent erosion,
- retain and recycle nutrients added as fertilizer and weathered from rock,
- provide coverage and protection for wildlife,
- improve the site's appearance.

As a result of research work, Gardiner & Stathers (1978) concluded that a self-sustained alfalfa-dominated stand could be established. The reclamation prescription produced a 93% vegetation cover, a 79% legume cover and 6200 kg/ha of biomass. When the annual maintenance fertilization was stopped the most persistent species were alfalfa and creeping red fesue. Spring sowing resulted in a greater legume cover than if the seed mix was sown in the fall (Wright & Gardiner, 1980).

Surveys carried out at Pinchi Lake in the 1983 showed that a thick humus layer had developed beneath vegetation, which had sustained growth without maintenance fertilizer since 1975. From 1980 to 1983 the grass growth and cover deteriorated, while the cover of alfalfa and alsike clover (Trifolium hybridum L.) increased. This was attributed to a soil N deficiency. On many dumps increasing numbers of poplar (Populus spp.) and willow were appearing above the tall alfalfa. Alder and spruce were also noted on a number of dumps (Pinchi Lake, 1983).

One reason for the stronger natural invasion on the wasterock dumps at Pinchi Lake, relative to Westar and Fording, was the wetter climate. Vogel (1980), reviewing research in the eastern U.S., concluded that trees grown in combination with agronomic species seemed to be most affected by competition for moisture, and that tree survival was greatest where adequate water was available. Vogel (1980) also noted that while dense stands of legumes may initially reduce tree survival, the growth of surviving trees increased. Another common cause of seedling mortality is clipping by rodents. This is more pronounced when trees are grown in conjunction with a herbaceous cover, as grasses and legumes hide the rodents from predators (Wisch, 1985).

The closest large mines to Kitsault are the Scotty Gold and the Granduc mines. However both mines are located above the tree line and their reclamation does not include vegetation (e.g., Walker, 1985). The Tasu mine on the Queen Charlotte Islands is at a similar latitude to Kitsault. Agronomics were tested at Tasu, but natural invasion by red alder was so quick that it was decided that no artificial plant establishment was required (Westfrob, 1981). The major difference between the Tasu and Kitsault minesites is elevation, as the Tasu minesite is at sea level. Rapid red alder colonization occurs at sea level on disturbed surfaces of the Kitsault Townsite.

Like Tasu and the Kitsault Townsite, the Island Copper Mine on the west coast of Vancouver Island is also at sea level. At Island Copper, reclamation research started in 1971 and at present some dumps are in the process of being reclaimed to a forested state. According to Hillis and Horne (1984) the recipe for wasterock dump reclamation at Island Copper is as follows. Surfaces are recontoured to create gentle slopes and then capped with 30 cm of till. Next 110 kg/ha of seed and 450 kg/ha of fertilizer are applied. The seed mix includes 40% red fescue, 25% ryegrasses (Lolium species) and 25% of the legumes, alfalfa and white clover (Trifolium repens L.). The fertilizer analysis is 27-18-9 for spring planting and 13-16-10 for fall planting. Later, at some unspecified time, red alder seedlings are transplanted onto the site. Lodgepole pine seedlings were tested but their growth was much slower than the alder. Island Copper's annual reclamation reports do not say whether agronomics were required to prevent erosion or if they accelerated tree growth. Nor was any data presented to show why red alder needed to be artificially established.

Probably the most extensive mine reclamation program in the Pacific Northwest is that carried out at the coal mine near Centralia, Washington (Wisch, 1985). Present regulations force the mine to reapply the original topsoil. However there are a large number of areas that were disturbed prior to the present regulations. These areas,

which consist of subsoil, were found to be deficient in N and in soil biological activity. To rectify this, subsoil areas were initially vegetated with selected grasses, and proceeded through a multi-year sequence of tillage, sewage sludge injection, and cropping until nutrient levels reached target levels of 1,100-1,146 kg/ha of total N. This took 3 to 6 years to accomplish. Douglas fir, inoculated with essential mycorrhizae, were then planted. "Early efforts to plant trees in disced grass residues resulted in high mortality from burgeoning populations of voles, Microtus townsendii Bachman, (Wisch, 1985)". During periods of drought, competition for moisture was also felt to be a problem. On some areas, Sitka alder has been interplanted with the Douglas fir. The plan is that within 10-15 years Douglas Fir will shade out the alder. In the meantime, the Sitka alder is expected to add 5-8 kg/ha of N annually. Sitka alder was also used to block the encroachment of non-desirable species and improve the internal soil structure and surface stability.

In comparison with Kitsault, Centralia has a more benign climate (e.g., Douglas fir) and gentler landscape, and the surface to be vegetated contains more fines than wasterock (Wisch, 1985).

2.5 Reclamation Research at Kitsault

Reclamation research was started at the Kitsault minesite in 1970. Descriptions of the trials built and the

monitoring results were submitted to the Ministry of Energy Mines and Petroleum Resources in the annual reclamation report. This information is summarised in Price (1982).

2.6 Soil Development on Mine Wastes

Like the soil development on recently exposed moraines (Ugolini, 1967), the first change in the morphology of mine wastes is usually the development of a dark coloured A horizon. For example, on a mixture of sandstone and siltstone wasterock in S.W. Virginia, four years of vigorous grass growth created a 4 cm deep Ah horizon (Roberts et al., 1988b). Under the same conditions pretreatments with sawdust and sludge deepened the Ah to 7 and 14 cm respectively. In Pennsylvania minesoils (Ciolkosz et al., 1985), it took 3 to 13 years to form an Ah horizon, 6 to 20 years to form an Ah, AC sequence, and 12 to 28 years to form an Ah, Bm sequence. Soil horizons were identified by their colour, as even the Ah horizon showed weak structural development. Roberts et al. (1988b) found some soil development, including structure, beneath the A horizon, but it lacked the continuity or strength to create a cambic B horizon.

According to Smith et al. (1971), the bulk density, porosity, and coarse fragment content of iron ore slag in W. Virginia had not changed 70 to 130 years after being abandoned. The only physical change at these sites was a loss of clay from the upper 5 cm. In Pennsylvania

minesoils, it took 15 to 20 years for eluviation to create clay skins and about 100 years for a significant portion of the clay to move in an Iowa spoil comprised of loess (Hallberg et al. 1978).

In contrast, after eight years, the 0 to 5 cm layer in a reclaimed colliery spoil in N.E. England had a lower bulk density and stone content than the material below (Rimmer, 1982). In 0 to 178 year old colliery waste in S.W. England, particle breakdown was restricted to the upper 20 cm (Down, 1975). Most of the disintegration occurred quite quickly. The > 9.5 mm fraction declined from 39 to 1% within 21 years. The quantity of the 9.5-4.0 mm fraction also decreased, with a concurrent increase in the 4-2 mm and 2-1 mm fractions. No significant differences were found in the < 500 um fraction after 21 to 55 years. After recreating rock disintegration in the laboratory with alternating wet/dry and freeze/thaw cycles, Down (1975) attributed the field changes to physical weathering. Schafer et al. (1980) noted that in a coal spoil in S.E. Montana, the proportion of soft fragments decreased near the surface, while "resistant" coarse fragments had a constant volume with depth. Schafer et al. (1980) were not clear as to the identity of the soft fragments, other than to say that they disintegrated in water.

Roberts et al. (1988a) in S.W. Virginia, also observed a rapid decline in the coarse fragment content at 0-5 cm in both sandstone and siltstone wasterock. Changes in finer

fractions were limited to the siltstone, whose sand fraction decreased from 59 to 48% and silt fraction increased from 30 to 40%. Differences occurred at both 0-5 cm and 25-30 cm, the two depths sampled, and were attributed to the dissolution of carbonate cements. As a result of its finer texture, the < 2 mm water holding capacity was highest in the siltstone. On a total weight basis, the water holding capacity was highest in the sandstone, which contained less coarse fragments (65% vs 77%).

Vigorous plant growth and organic pretreatments, like sewage sludge, can dramatically increase the surface organic content of a mine waste. On sandstone and siltstone wasterock in S.E. Montana, Schafer et al. (1980) observed that 0-10 cm organic-C levels reached contents found in natural soils (e.g. 5%) after 30 years of grass growth, but at 20-50 cm would not reach natural levels for 400 years. In the study carried out by Roberts et al. (1988b), the organic content at 0-5 cm at the end of the third growing season was 2% in the wasterock control, 8.5% for the sawdust treatment, and from 4 to 7% for various amounts of sewage sludge. In 8 year old colliery wastes in N.E. England, the 0-5 cm organic content was 7% on sites supporting vigorous agronomic growth (Rimmer, 1982). Organic additions were also significant on older naturally invaded mine wastes (Down, 1975; Anderson, 1977).

On 70 to 130 year old iron ore slag in W. Virginia, the rates of N addition and the N content near the surface were

comparable to natural soils (Smith et al., 1971). Data for N in the mine wastes studied in S.W. Virginia illustrated how a high coarse fragment content may concentrate inputs in the < 2 mm fraction. Despite similar levels of N on a volumetric basis, the coarser siltstone wasterock contained higher < 2 mm N concentrations than the sandstone wasterock (Roberts et al., 1988a). In this study, at 0-5 cm N levels were 1.5 to 2 times higher than at 25-30 cm, and increased each year.

Bicarbonate extractable P levels were also significantly higher at 0-5 cm than at 25-30 cm, and increased with the organic surface treatments, sewage sludge and sawdust. Differences probably resulted from the P added in the fertilizer and organic amendments. Organic amendments might also have reduced the fixation of P by available Fe. The levels of available Fe increased dramatically from the end of the first to the end of the second growing season, and then decreased slightly by the end of the third growing season.

With the advent of weathering, one of the major chemical changes observed in mine wastes is the dissolution of soluble salts and carbonates. In arid climates, research on mine wastes has shown that soluble salts were lost from the upper 50 cm in tens of years, while carbonates will take thousands of years to remove (Anderson, 1977; Schafer et al., 1980). In humid environments, the removal of salts and carbonates should be quicker. For example, in the study

carried out by Roberts et al. (1988a and b), the loss of carbonates caused the levels of exchangeable Ca and Mg to decrease significantly in the first few years. Even with greater leaching, minesoils in the eastern U.S.A. generally contained higher levels of available cations than natural soils (Smith et al., 1971; Ciolkosz et al., 1985). This is attributed to their youth and, in some cases, larger amounts of rapidly weathering minerals in the minewastes.

Another change observed in mine wastes was a decline in pH. In the study carried out by Roberts et al. (1988a), small changes in pH were attributed to the leaching of carbonates and base cations, and to nitrification of fertilizer N. The materials in this study contained little or no sulphide minerals. In the Pennsylvania mine soils study (Ciolkosz et al., 1985), seven of the twenty four minesoils had two or more horizons at pH 4.0 or less, a factor attributed to sulphide oxidation. Natural soils in the area seldom have pH values < 4.0. In the colliery waste studied in S.W. England, the pH dropped to 3.0 in five years and rose back up to 6.7 by 178 years (Down, 1975).

Changes associated with a decreased pH include the release of K from mica forming vermiculite (Smith et al., 1971) and the redistribution of trace metals (Chase and Wainwright, 1983). In a 100 year old Cu smelter waste in Wales, the drop in pH from 4.3 to 4.0 at 10 cm paralleled a similar drop in EDTA and acetic acid extractable Cu, Zn, and extractable Pb. Deeper in the profile, there was no change

in the concentration of available Pb. However, there were large peaks of extractable Cu at 40 cm (pH 4.5) and 1.54 m (pH 6.0), and Zn at 80 cm (pH 5.6). Long term continuous leaching studies run in the laboratory indicated that pH gradients largely determined the distribution of metals (Chase and Wainwright, 1983).

Soil flora and fauna can produce beneficial changes in the properties of mine waste (Ettershank et al., 1978). Prior to exposure, mine wastes do not contain the flora and fauna found in natural soils. Biological activity of this kind may be enhanced by capping the waste with natural topsoil or by using native plant species (Biondini et al., 1985). Alternatively animal species, like grasshoppers or rodents, can act as vectors (Pender, 1980).

2.7 Natural Plant Succession

Primary plant succession and soil development can produce a fertile soil and a productive flora from barren infertile land created by natural processes such as receding glaciers (Ugolini, 1967), mudflows (Dickinson & Crocker, 1953) and lava flows (Mueller-Dombois & Ellenberg, 1974). If conditions are similar to those on wasterock dumps, studies of natural plant succession may provide useful information for reclamation. For instance, studies of natural succession could be used to show which native species are capable of growing on the wasterock dumps, how different species and amendments will contribute to plant

and soil development, and how plant and soil development will proceed.

In order for data from natural succession studies to be applicable, environmental factors such as climate, flora, fauna and rooting media should be similar. Most of the research on natural plant invasion-soil development relevant to the wasterock dumps at Kitsault has been done on recently deglaciated sites in B.C. and Alaska. Despite differences in lithology, particle size and the time of exposure, both the glacial moraines and mine waste rock are coarse textured, rocky, barren rooting media. Of the areas studied, those most similar to Kitsault are Glacier Bay (Crocker & Major, 1955; Lawrence et al., 1967; Ugolini, 1967) and the Herbert and Mendenhall Glaciers (Crocker & Dickson, 1957) in southeastern Alaska. Both areas, like Kitsault, have a Pacific coastal climate and differences in elevation (the Kitsault minesite is higher) are compensated for by differences in latitude.

At Glacier Bay, plant propagules started to arrive soon after the glaciers receded. The sequence of plant colonization on the Glacier Bay moraines has been the following (Ugolini, 1967).

Stage I	Early pioneer, largely dryas (Dryas
0-5 yrs	drummondii (Rich)) and willow spp. with

Equisetum (moist sites) and Epilobium spp. (sandy sites).

Stage II 5-15 yrs	Dryas mats up to 4 m or more in diameter.
Stage III 15-20 yrs	Dryas mats form a uniform carpet with scattered Sitka alder and black cottonwood.
Stage IV 20-25 yrs	Clumps of alder 2 m or more high form open thickets.
Stage V 25-30 yrs	Clumps of alder coalesce.
Stage VI 30-35 yrs	Scattered poplar trees emerge above alder.
Stage VII 40-70 to 95 yrs	Sitka spruce becomes dominant. Alder dies out.
Stage VIII	Spruce-hemlock (mountain and western hemlock) forest, carpeted with thick moss.

The sequence of plant colonization at the Mendenhall and Herbert glaciers was similar, except that it lacked the

growth of Dryas (Crocker & Dickson, 1957). Dryas species have only been reported growing on calcareous materials (Watson et al., 1980; Tisdale et al., 1966; Viereck, 1966; Given and Sopar, 1975) and thus presumably were unable to grow on the Mendenhall and Herbert glacial moraines. Lawrence et al. (1967) suggested that Dryas, which has a low densely matted carpet-like growth form, contributed to primary succession of Glacier Bay by:

1. rapidly stabilizing the soil surface against erosion,
2. increasing the amount of soil nitrogen through its ability to carry out N_2 fixation,
3. beginning to develop a humus layer, and
4. aiding the survival and growth of woody plants.

Viereck (1966) found Dryas contributing in the same manner to the plant succession on gravel outwash terraces of the Muldron Glacier, near Mt. McKinley, Alaska. In addition Viereck (1966) noted that wind blown silt and sand accumulated within the dryas clumps.

Of Dryas's various contributions, Lawrence et al. (1967) considered aiding the survival and growth of woody plants to be the most important "since alder is so much more efficient in providing a ground cover and enriching and building up the surface organic layer." Coalesced Dryas mats create a more favourable microclimate and increase nutrient levels through N_2 fixation and litter decomposition. The increased N level is especially

important for non-N_2 fixing Willow spp. and cottonwood. Lawrence et al. (1967) thought that dryas, by speeding up the establishment of alder, which in turn promoted the growth of spruce, speeded up plant succession. They suggested that on the Mendenhall glacial moraines it took an additional 20 to 30 years for alder thickets to create an erosion-resistant blanket equivalent to that created by dryas at Glacier Bay. In contrast, Crocker and Dickson (1957), comparing their results with those reported by Crocker and Major (1955) at Glacier Bay, found that although they were of the same order of magnitude, the absolute amount of N that accumulated over equivalent units of time was higher in the Mendenhall-Herbert sequences. This they attributed to Mendenhall-Herbert's superior climate for plant growth, and the much larger area deglaciated at Glacier Bay, resulting in a slower, more erratic plant colonization.

Why did this complex succession take place? Within 5 to 10 years of deglaciation, young spruce and hemlock were growing on the moraines (Crocker & Dickson, 1957). So why did a spruce forest not develop directly? Crocker and Dickson (1957) suggested this was partially due to inter-species competition and to the different growth rates of the plant species. A more important reason was the inability of spruce, which could not fix N, to utilize the early successional environment as fully as the more productive, early seral species. The failure of early seral species to

sustain their dominance resulted from their inability to grow in the shade of their competitors (Crocker & Dickson, 1957; Crocker & Major, 1955). However, on the Muldrow Glacier terraces, Viereck (1966) suggested that either the accumulation of fine materials within the clumps or the presence of mosses killed dryas.

2.8 The Early Stages of Natural Soil Development

The first visible sign of soil formation at Glacier Bay was the appearance of a gray brown Ah horizon beneath a patchy mix of dryas and a crust of moss, on areas deglaciated for approximately 10 years. The Ah horizon reached a maximum depth of 10 cm 41 years after deglaciation. Then, as spruce became dominant and the alder died out, the Ah horizon was gradually replaced by a B horizon which grew upwards, completely replacing the Ah horizon 85 to 150 years after deglaciation (Ugolini 1967). An Ae horizon was first observed at Glacier Bay in areas deglaciated for about 150 years, while in the Mendenhall and Herbert sequences the Ae developed after about 75 years. Two hundred and fifty years after deglaciation none of the Ae horizons had increased in size and the B horizons remained shallow (< 15cm).

At both Glacier Bay and the Mendenhall/Herbert sequences the most dramatic changes in properties of the rooting media were associated with the development and deepening of the surface organic layer. An L layer was

first noted on sites deglaciated for 11 years at Glacier Bay, and on sites deglaciated for 20 and 34 years respectively at the Mendenhall and Herbert Glaciers. At Glacier Bay the litter layer reached a maximum thickness of 20 cm on 150 year old sites on which alder and other understory plants were still contributing litter. At the Mendenhall and Herbert sites, even after alder and other shrubs had died out, the litter layer continued to accumulate, although at a reduced rate. At both Glacier Bay and the Mendenhall/Herbert sites, the development of a humified (FH) layer followed the creation of a litter layer by about 20 years. At Glacier Bay the FH layer accounted for approximately half of the depth of the litter 250 years after deglaciation. Little or no mixing of litter and mineral soil occurred at any of the study sites, although Crocker and Dickson (1957) noticed some evidence of organic matter illuviation in very sandy moraines at the Herbert Glacier.

Concurrent with changes in plant cover and the development of soil horizons, there were marked changes in soil properties. Changes were greatest in properties affected by the addition and decomposition of organic matter, and thus were most pronounced near the surface. Physical changes included decreases in bulk density and an increase in the soil moisture retention (Crocker & Dickson, 1957). At Glacier Bay, Ugolini (1967) found no changes in the sandy loam texture and no sign of clay movement. Both

the Glacier Bay and the Mendenhall/Herbert glacial moraines were very stoney. The fine earth fraction (< 2 mm) of areas sampled at the Mendenhall/Herbert varied from 45% to 94%, despite efforts to select sites with as few possible stones. At Glacier Bay the locations sampled by Ugolini (1967) contained approximately 50% fines. Variations in the percent stones will have contributed to the variability observed in both physical and chemical properties.

Summarising the changes observed in chemical properties with age: the pH decreased; the CEC increased; soil organic C increased; soil N levels increased and then levelled off; and the C/N ratio increased. The role of organic matter as a source of acidity was evident from the low pH of the litter layer relative to the mineral soil. At the Mendenhall/Herbert sites the lower pH of the FH layer, compared to the undecomposed litter, was evidence that organic acids were being produced as the litter decomposed. In both studies the litter pH declined with time. This may be attributed to decomposition and to changes in the type of litter with the development of a coniferous forest. In the mineral soil, the decline in pH was most pronounced at the surface. Changes at lower depths lagged behind. Two hundred fifty years after deglaciation, on the Herbert and Glacier Bay moraines the pH values of the L, FH, B, and C horizons were approximately 4.3, 3.7, 4.7, and 5.8 respectively.

Differences in soil pH between Glacier Bay and the Mendenhall/Herbert sites resulted from the presence of carbonates at Glacier Bay. Data from Glacier Bay shows that the decline in percent carbonate in the < 2 mm fraction was correlated with the pH decline, with the loss of calcite occurring faster than that of dolomite. In the Ah horizon most of the carbonate was lost between 5 and 24 years after deglaciation. At 15-25cm, in the C horizon, most of the carbonate was lost between 55 and 150 years after deglaciation.

Based on changes in soil C, N and C/N, the sequence of soil development can be split into 2 parts; changes attributed to alder and those occurring under a spruce forest. Immediately after deglaciation the moraines are wind-swept surfaces devoid of nitrogen. This lack of N gives N_2 fixing species a competitive advantage. Without any competition, N_2 fixing Sitka alder grew prolifically, its somewhat prostrate, shrubby growth, protecting the surface from the wind and rapidly building up a forest floor. As a result of the strong alder growth a large amount of N was added to the ecosystem, and organic residues in both the forest floor and the mineral soil had a low C/N ratio. During the period of alder growth most of the soil organic matter was in the surface litter layer. Forty-one years after deglaciation at Glacier Bay, the litter layer was 7 cm thick, contained 0.11 kg N/m2 and the FH layer had a C:N ratio of 21.

Spruce cannot fix atmospheric N_2, so after spruce replaced alder, the rate of N additions to the ecosystem was reduced. Consequently at Glacier Bay, N levels in the litter decreased to 0.08 kg N/m2 and the litter C:N ratio rose from 15 to 30 up to 45 to 60. In contrast to the litter, the mineral soil C and N contents under spruce continued to rise at much the same rate as under alder cover. As a result of organic matter additions, mineral soil CEC levels increased from 7.3 to 14.7 meq/100g and the accumulation of organic matter and iron in the mineral soil created a podzolic B horizon.

2.9 Well Developed Soils

Soil development beyond 250 years in the Glacier Bay region was observed on a series of sand and gravel covered (2 to 4 metres thick), marine terraces (Ugolini & Mann, 1979). The terraces were 400, 2-3 x 10^3, and 6-8 x10^3 years old. The younger two terraces were covered by a coniferous forest, dominated by Sitka spruce and western hemlock. From the youngest terrace to the back of the second terrace, the depth of surface litter increased from 20 to 35 cm. On the 400 year old terrace, the main horizon was a weakly developed B, containing 0.6% organically complexed Fe. On the 2-3 x 10^3 terrace, soils contained well developed Ae, Bhf, and Bf horizons. At the back of the second terrace the Bf had developed into an impervious placic-B horizon, which impeded drainage.

On the oldest terrace, impeded drainage had resulted in the accumulation of a 1 to 2 metres deep surface peat layer, capable of retaining water the whole year round. Even after reducing conditions removed the placic horizon, anaerobic conditions were maintained by the deep peat. As a result of waterlogging, the vegetative cover on the oldest terrace ranged from Alaska yellow cedar (Chamaecyparis nootkatensis D. Don Spach.) and mountain hemlock to sphagnum, sedge, and ericaceous shrubs.

The closest region to Kitsault for which a soil survey was carried out was the Hazelton area (Wittneben, 1984). The surveyed area contains a number of physiographic regions, including the Skeena mountains, which are adjacent to Kitsault and have similar topography, elevation, and vegetation to the minesite. On flat and gently sloped valley floors and depressions in the Skeena mountains, terrain which resembles that studied at Glacier Bay, the soils were classified as Mesisols and peaty Rego Humic Gleysols. On more steeply sloped areas, each parent material - vegetation zone combination had a different soil association. The Kispiox and Janze Lake soil associations, formed on the colluvium in the western and mountain hemlock zones respectively, were developed under conditions most similar to Kitsault wasterock dumps. Colluvium had a high coarse fragment content, was generally steep, well to rapidly drained, and thus analagous to a dump slope. The coarse fragment content often exceeded 50%, especially at

higher elevation. The 50% is presumably on a per volume basis. The proportion would be even higher if reported on a per weight basis. Compared to a wasterock dump the main difference in the colluvium was the depth, which was usually less than 2 metres.

Kispiox soils are gravelly sandy loams, with a 5 to 10 cm deep mor litter layer, covering up to 10 cm of Ae, and a Bf. Strongly acid solum was usually less than 50 cm thick, and relatively unweathered parent material occurred within 75 cm of the surface. Most of the soils were classified as Orthic Humo-Ferric Podzols. Luvisolic Humo-Ferric Podzols or Podzolic Gray Luvisols were found on finer textured materials. Gleyed Humo-Ferric Podzols occurred in seepage zones.

At higher elevation in the Mountain Hemlock-Subalpine Fir Zone (Janze Lake association), the main difference was the greater accumulation of illuvial organic matter creating sufficiently deep Bhf horizons to change the classification to Ferro-Humic Podzols. In both vegetation zones, morainal materials had a gravelly loam or gravelly clay loam texture, were generally finer than the colluvium, moderately pervious, and usually classified as luvisolic humo-ferric or ferro-humic podzols, depending on the elevation.

A survey of podzolic soils formed in S.E. Alaska found that rooting was largely confined to the surface organic layers and the top few centimetres of the mineral soil (Hellman & Gass 1974). In these same soils the influence of

parent material lithology on soil chemical properties was only evident in the lowest horizons. Typically the soil pH was between 3.5 and 4.5 for the litter layers and the Ae horizons and between 4.5 and 5.5 for the B horizon (Hellman and Gass 1974, Stephens 1969). Stephens (1969) in his study of S.E. Alaskan podzol mineral horizons concluded that organic matter and sesquioxides were primarily responsible for the CEC and water retention. Aluminosilicate clays either had not formed or had been leached out of the profiles.

3.0 Summary

Wasterock from other Cu-Mo porphyry mines contained 75 to 85% coarse fragments, had high trace element concentrations, and lacked N and available P. According to schemes for rating the quality of rooting media, the high coarse fragment content makes wasterock an unsuitable or poor substrate. However the coarse fragment content of wasterock was comparable to that of colluvial soils in the Kitsault region. As most of the minesite was originally covered in colluvium, a high coarse fragment content will therefore not compromise the provincial reclamation guidelines that minesites should be restored to their pre-mining productivity.

Research on different disturbed substrates on Vancouver Island, showed that the larger the area disturbed the slower was natural plant invasion, and that the composition of

species arriving reflected the composition of the adjacent vegetation. Most of the research done in B.C. has been in establishing agronomic covers. Natural plant invasion of the grass\legume covers was greatest in areas with high precipitation.

Researchers have noted changes in mine wastes with time and as a result of plant growth. Physical changes included decreases in bulk density and coarse fragment content, and clay movement. Changes in soil chemical properties included increased organic matter, N, and available P, and decreases in pH and carbonate minerals. Decreases in pH were associated with the release of K and trace elements.

The most relevant studies of natural plant and soil development to Kitsault were those carried out on recently exposed moraines in S.E. Alaska. The sequence of plant succession on non-calcareous moraines was Sitka alder, Sitka spruce, and western hemlock. If the moraines were calcareous, the first species to invade was dryas, which in turn accelerated the invasion of alder. The initial soil changes (e.g., decreased bulk density, pH, and calcite) were similar to those observed on mine wastes. The main factors controlling plant and soil development on the moraines were the additions of litter and N, most of which were added by alder. After 400 years, the soils on the moraines developed podzolic Bf horizons. Studies of mature soils, in areas with similar soil forming factors to Kitsault, found that podzols developed on all well drained parent materials. In

these soils, rooting was concentrated in the thick, acid litter layer.

3. MATERIALS AND METHODS

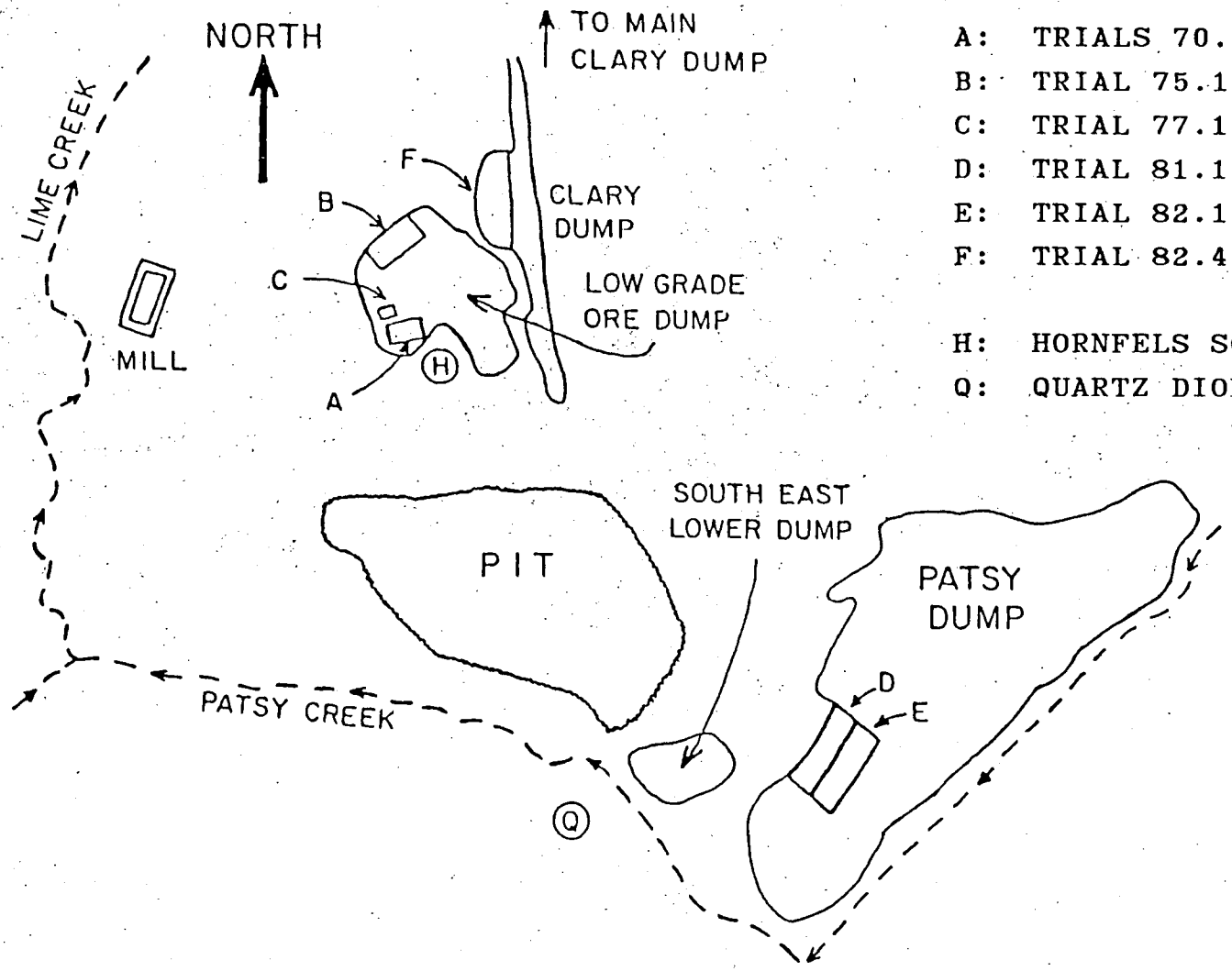
3.1 Description of Study Sites

3.1.1 Soil Resources

Most of the soil samples came from the terraced wasterock dumps. The location of the sites sampled is shown in Figure 1.1. Sample sites were chosen to show the effects of a number of factors including rock type, slopes vs benches, time since dump construction, and natural plant invasion (Tables 1.1). A general description of each of the dumps sampled is given in Table 1.2.

Much of the sampling was carried out in 1980 during the period of mine development prior to the mine re-opening. The sites selected had not been disturbed since the mine closed in 1972. The choice of sites was limited to two terraced dumps, the South East Lower (SEL) and the Low Grade Ore (LG) dumps, because much of the wasterock mined from 1965 to 1972 was spread thinly over natural slopes or had been used as road fill. Most of the sampling was carried out on the LG dump because more extensive natural plant invasion had occurred there and it was the location of several field trials. The LG contained more molybdenite but otherwise was similar to a "typical" wasterock dump.

Recently exposed wasterock on the Patsy (WR) and Clary (AR) dumps were sampled in 1982 (Table 1.2), on surfaces used for the 82.1 and 82.4 trial. Sampling was carried out soon after the dumps were built and immediately prior to



LEGEND

A: TRIALS 70.1 and 70.3
B: TRIAL 75.1
C: TRIAL 77.1
D: TRIAL 81.1
E: TRIAL 82.1
F: TRIAL 82.4

H: HORNFELS SOIL PROFILE
Q: QUARTZ DIORITE SOIL PROFILE

Figure 1.1 A schematic diagram of the Kitsault mine showing the location of sites examined in this study.

Table 1.1 Surfaces sampled and number of samples analysed for untreated wasterock.

Abbreviation Used in Text	Dump	Lithology	Topography	Cover	Date Constructed	Date Sampled	Number of Samples Analysed		
							For % < 2 mm	For other physical analyses	For Chemical Analyses
SEL.HN	South East Lower	hornfels	bench	none	pre-1973	1980	4	4	3
SEL.PO.U		potassic	bench	none	pre-1973	1980	3	3	3
SEL.PO.V				annual species	pre-1973	1980	5	5	5
LG.U.B	Low Grade Ore	potassic	bench	none or annual species	pre-1973	1980	6	6	6
LG.U.S			slope	none	pre-1973	1980	9	9	9
LG.V			bench	perennial species	pre-1973	1980	7	7	7
WR.82	Patsy	potassic	bench	none	1982	1982	28	4	4
WR.84						1984	8	-	-
AR.82	Clary	incompetent	bench	none	1982	1982	8	4	4
AR.84						1984	25	-	-

Table 1.2 Descriptions of the wasterock dumps and the overburden sampled in this study.

WASTEROCK DUMPS

SEL: south east lower dump; wasterock fills bottom of valley, intersecting Patsy Creek on west side; built prior to 1972; buried in 1981,

LG: low grade ore dump; large plateau north of pit; built prior to 1972; site of field trials 70.1, 70.3, 75.1 and 77.1; untreated areas presently used to store machinery and tools,

WR: Patsy dump; series of terraces south east of pit; built from 1981 to 1982; site of field trials 81.1, 81.2, 81.3, 82.1 and 82.2,

AR: Clary dump: a series of terraces north of pit; at point sampled, a single, large terrace, the bench of which serves as a road to the Clary dump complex; built in 1982; site of field trial 82.4.

OVERBURDEN

OB.59 594 Bench: overburden tested in Trial 82.1; used and sampled immediately after it was stripped; a well drained, mixture of colluvium, till, and fractured bedrock.

OB.SH Spy Hill: overburden tested in Trial 82.1; material from the Spy Hill stockpile; stripped from a waterlogged depression in 1981.

applying trial amendments. The Patsy Dump was comprised of "potassic" rock, the most pervasive type of wasterock. When it was resampled in 1984, samples were taken from rows between the plots. As in 1982, sampling was restricted to the terrace bench. The slopes of the Patsy Dump were almost totally devoid of fines.

The 82.4 trial on the Clary Dump was located on a veneer of "incompetent" wasterock. This material had been pushed onto the slope in 1982, just prior to sampling. In 1982, unstable footing limited sampling to the upper 10% of the slope. In 1984, extensive sampling was carried out along 5 transects from crest to toe. Samples were collected every 20 metres. The 10% of the slope lacking < 2 mm material was not sampled.

The treatments sampled and the number of samples analysed for the field trials are shown in Table 1.3. All the sampling was carried out in 1980. Like the untreated slope beside it (LG.US), sampling on the slope trial 75.1 was limited to the upper 8 metres, the only portion of the slope containing < 2 mm particles.

Within designated areas on the field trials and the untreated dumps, the selection of sample sites was made randomly. Exceptions to this were the vegetated sites on the SEL dump (SEL.PO.V), which were so few that they were all sampled. The other exception was when plots had to be shifted to avoid large rocks. This happened about 20% of the time.

Overburden samples were taken from the two materials tested in the Patsy Dump trial 82.1. Descriptions of each are given in Table 1.2.

3.1.2 Vegetation

A summary of the sites where plant growth was studied is given in Table 1.4. Information on natural plant invasion was collected from Trial 70.1 and from untreated surfaces around the mine. Most of the vegetation data was collected from field trials. Trials were named according to the year in which they were established. Trials established prior to 1980 were built by Dr. J.V. Thirgood (Price, 1982). Detailed descriptions of each trial, including objectives, experimental design, materials, plot preparation, and monitoring are given in Appendix A. The location of each trial is shown in Figure 1. Latin names of agronomic species tested at Kitsault are given in Table 1.5. The components of seed mixes applied on the bench and slope trials and the rates at which fertilizer was applied in field trials are compiled in Tables 1.6,1.7, and 1.8. The reader may want to refer to information in Tables 1.4 to 1.8 when reading the results and thus should note their location.

3.2 Foliage and Soil Sampling

A 900 cm^2 quadrant (30 cm x 30 cm) was used to delineate the boundaries of each foliage sample. Before

Table 1.3 Treatments sampled and number of samples analysed for the field trials.

Abbreviation Used in Text	Trial	Topography	Surface ** Treatment	Vegetation	Seed Mix ***	Number of Samples: Soil Analyses	Number of Samples: Foliar Chemistry
70R	70.1	bench	none	grass and legume	1,5 & 6	9	6
70PF			peat ****	grass and legume	1,5 & 6	12	12
70P1			peat (+ fertilizer)	mainly grass	1	4	4
70P5				mainly legume	5	4	4
70P6				mainly grass	6	4	4
70F1			fertilizer	mainly grass	1	4	4
70F5				mainly legume	5	4	4
70F6				mainly grass	6	4	4
70AI			fertilizer	annual grass		3	-
75.1	75.1	slope	fertilizer	grass and legume	A,B,C & D	17	-
77.1	77.1	bench	none	Sitka alder	-	4*	-

* : for % < 2 mm only
** : fertilizer rate listed in Table 8
*** : seed mixes described in Tables 6 (mixes 1,5,6) and 7 (mixes A,B,C,D)
**** : Although the original trial plan stated that 70PF was fertilized while 70P was not, the high P and strong plant growth indicate that it was the 70P section which was fertilized.

Table 1.4 A list of the trials testing plant growth.

Topography	Plant Species	Trial	Treatments Tested **
Bench	Agronomic	70.1	7 seed mixes on 4 surface covers
		82.1	4 seed mixes and 5 surface covers
Bench	Woody	70.3	conifer species with treatments applied in Trial 70.1
		77.1	Sitka alder
		82.1	Sitka alder and lodgepole pine on 82.1 treatments
Bench	Natural Plant Invasion	-	none
		70.1	treatments applied in Trial 70.1
Slope	Agronomic	75.1	4 seed mixes
		81.1	1 seed mix on 4 overburden depths
		82.4	incompetent wasterock

** Treatments described in detail in Appendix A, for seed mix composition and fertilizer rate refer to Tables 6, 7 and 8

Table 1.5 The Latin names of agronomic species tested at Kitsault.

Latin Name	Common Name
Grasses	
Agrostis alba L.	red top
Alopecurus arundinaceus Poir.	creeping foxtail
Dactylis glomerata L.	orchard grass
Deschampsia caespitosa (L.) Beauv.	tufted hairgrass
Festuca ovina L.	hard fescue
Festuca rubra var. *communata* L.	chewings fescue
Festuca rubra var. *rubra* L.	red fescue
Lolium multifolium L.	annual ryegrass
Lolium perenne L.	perennial ryegrass
Phalaris arundinacea L.	reed canarygrass
Phleum pratense L.	timothy
Poa compressa L.	Canada bluegrass
Poa pratensis L.	Kentucky bluegrass
Legumes	
Astragalus cicer L.	milk vetch
Lotus corniculatus L.	birdsfoot trefoil
Medicago sativa L.	alfalfa
Onobrychis viciaefolia Scopoli	common sainfoin
Trifolium hybridum L.	alsike clover
Trifolium pratense L.	red clover
Trifolium repens L.	white clover

Table 1.6 Seed mixes applied on the bench trials.

70.1 - #1		70.1 - #5	
91.5	perennial ryegrass	61.0	sainfoin
61.0	red fescue	61.0	birdsfoot trefoil
61.0	chewings fescue	122.0	kg/ha
61.0	Kentucky bluegrass		
15.3	red top		
15.3	white clover		
305.0	kg/ha		

70.1 - #6		81.1 bench	
65.4	timothy	5.0	perennial ryegrass
43.8	perennial ryegrass	20.0	red fescue
65.4	hard fescue	10.0	white clover
21.8	red top	25.0	birdsfoot trefoil
21.8	alsike clover	5.0	red top
218.0	kg/ha	65.0	kg/ha

82.1 - AG		82.1 - L	
50.0	annual ryegrass	35.8	birdsfoot trefoil
		35.8	alsike clover
		35.8	white clover
		107.6	kg/ha

82.1 - GL		82.1 - EC	
5.0	perennial ryegrass	20.0	perennial ryegrass
5.0	orchard grass	30.0	red fescue
5.0	red top	20.0	red top
5.0	creeping foxtail	20.0	orchard grass
35.8	birdsfoot trefoil	20.0	tufted hairgrass
35.8	white clover	100.0	kg/ha
91.6	kg/ha		

Table 1.7 Seed mixes applied on the slope trials.

75.1 - A		75.1 - B	
9.3	red top	16.8	alfalfa
9.3	red fescue	16.8	birdsfoot trefoil
9.3	timothy	16.8	sainfoin
9.3	Canada bluegrass	16.8	white clover
9.3	orchard grass	16.8	alsike clover
9.3	perennial ryegrass	84	kg/ha
56	kg/ha		

75.1 - C		75.1 - D	
12.6	timothy	12.6	perennial ryegrass
12.6	Canada bluegrass	12.6	orchard grass
8.4	red top	16.8	alfalfa
16.8	birdsfoot trefoil	16.8	white clover
21.0	sainfoin	16.8	milk vetch
12.6	alsike clover	84	kg/ha
84	kg/ha		

81.1	
10.0	perennial ryegrass
40.0	red fescue
20.0	white clover
50.0	birdsfoot trefoil
10.0	red top
130	kg/ha

Table 1.8 The rate at which fertilizer was applied in the field trials.

Trial	Surface	Rate (kg/ha)	Analysis	N	P	K
				(kg/ha)		
Bench						
-70.1	WR & OB	610	13-16-10	79	43	51
-82.1	WR	417	12-39-12	50	71	42
-82.1	OB *1	208	12-39-12	25	36	21
Slope						
-75.1	WR	373	12-6-10	45	10	31
-81.1	WR	625	12-39-12	75	107	63
-81.1	OB *2	313	12-39-12	38	53	31

OB : overburden
WR : wasterock

*1 : also applied 69 kg/ha of lime
*2 : also applied 103 kg/ha of lime

sampling the percentage cover of plant species, moss, litter, fines, and rock were visually estimated. The pin interception technique was used to check the accuracy of the visual cover estimates. Visual estimates were within 10% of the pin data. Where the foliage was sampled, all above ground material within the 900 cm^2 quadrant was clipped.

A 225 cm^2 (15 cm x 15 cm) quadrant placed in the center of each sample site was used as an areal guide for digging soil samples. To measure the volume of material removed, the space created was lined with a plastic bag. The hole was then filled with marbles (1.5 cm diameter) and the volume of marbles determined in a volumetric cylinder. Marbles were used instead of water or sand because if, as often happened, the plastic was punctured by the sharp rocks, the material below was not irrevocably contaminated. The dump surface was very rough and thus the uneven surface of the marbles did not compromise the accuracy of the volumetric measurement.

On surfaces abandoned prior to 1973 (sampled in 1980), separate samples from the 0-5 and 5-10 cm depths were extracted. For surfaces dumped in 1982 (sampled in 1982 and 1984), one 0-10 cm sample was collected. In both cases litter, peat, and roots were sampled along with the mineral material. The depth of the surface organic layer was measured after sample extraction.

3.3 Laboratory Analyses

3.3.1 Soil Samples

Soil samples were oven-dried at 80°C for 24 hours and then reweighed to determine total dry weight, which was used to calculate the bulk density. Next the sample was separated into > 12.7 mm, 12.7 to 2 mm and < 2 mm fractions by sieving for 3 minutes on a roto-tap mechanical siever. Where primary particles adhered to one another, clumps were broken up using a rolling pin. The samples were then resieved by hand. This was always necessary when samples contained peat. After sieving, each fraction was weighed and the < 2 mm fractions were stored in plastic cartons. pH and available P assays were done on the < 2 mm material. For total C and N analysis, a portion of each sample was ground to < 50 um using a mortar and pestle.

Prior to particle size analysis, organic matter was removed with NaOCl, carbonates and soluble salts were removed with Na acetate, and sesquioxides were removed with citrate dithionate bicarbonate, according to the methods of Lavkulich and Wiens (1970), and Kunze (1965). Particle size was then determined by the hydrometer method (Day, 1965). pH was measured using a 1:2 mix of soil and 0.01 M $CaCl_2$ (Peech, 1965). Total C was measured on a Leco dry combustion analyser. Total N was extracted by wet (block) digestion (Bremner, 1965). Available phosphorus was extracted using the Bray P1 method (Olsen & Dean, 1965). N

and P extracts were analyzed colorimetrically with a Technicon Auto-Analyser II.

3.3.2 Plant Samples

Immediately after sampling, foliage samples were oven dried at 80°C for 24 hours, and then reweighed to determine the dry weight. Total C was measured on a Leco dry combustion analyser. Total N, P, K, Ca, and Mg were determined using Parkinson and Allen's (1975) wet oxidation method. Extract K, Ca, and Mg were measured by flame atomic absorption spectroscopy. N and P were measured colorimetrically with a Technicon Auto-Analyser II.

3.4 Data Analysis

3.4.1 Soil Resources

Descriptive statistics (mean, standard deviation, coefficient of variance, minimum and maximum) were calculated for each group, sample site x depth combination. The Mann Whitney U test was used to determine whether differences among groups were significant. The Wilcoxon matched-pairs signed-ranks test was used to determine whether differences between depths were significant. Both the Mann Whitney and the Wilcoxon tests are non-parametric techniques. These tests were used because the data did not meet some of the requirements (e.g., homogeneous variance, normal distribution) required for parametric techniques (e.g., T. test). Correlations between variables were run

separately on the samples from the field trials and on the samples from the untreated dumps.

In some cases, groups which were not significantly different were lumped together prior to interpretation. For example, unvegetated sites, sites colonized by annual species, and sites inhabited by perennial species were sampled on the LG dump. Subsequent soil analysis showed no difference in the physical and chemical properties between the unvegetated plots and plots colonized by annual plant species, so these two groups were combined into one, LG.U.B. The two other cases in which groups were combined were on the field trials. In Trials 70.1 and 75.1, there were no significant differences in the soil properties in areas sown with different seed mixes. So within each surface treatment, plots from areas sown with different seed mixes were combined into one group.

4. RESULTS AND DISCUSSION

4.1 Soil Resources

4.1.1 Untreated Wasterock

4.1.1.1 Physical Properties

Surface conditions for the samples collected on the abandoned wasterock dumps are shown in Appendix A. Area x depth means and standard deviations are shown in Table 1.9. The thin depth of litter indicates that the plant growth has not been very vigorous. Of the different measurements of surface cover, moss was the most strongly correlated with the depth of litter (r=0.76). Adding either the vascular plant or the litter cover to the moss cover reduced the correlation coefficient. It was not clear whether moss growth was stimulated by previous organic additions from vascular plants or if the moss itself was the primary source of the surface organic layer. Probably both scenerios occurred.

Soil physical data for individual samples for each group of samples collected from the untreated dumps are tabulated in Appendix B. Area x depth means and standard deviations for % < 2 mm, wt. < 2 mm/m^3 and bulk density are listed in Table 1.10. The untreated areas showed considerable variation in their average % < 2mm, wt. < 2 mm/m^3, and bulk densities. Many of the differences among

Table 1.9 Surface conditions in 1980 on areas of untreated wasterock and overburden abandoned in 1972.

Site	% Moss	% Vascular Plant	% Moss + Litter
SEL.HN	0 (0) a	0 (0) a	1 (1) ab
SEL.PO.U	0 (0) a	0 (0) a	0 (0) a
LG.U.S	5 (6) b	0 (0) a	6 (6) bc
LG.U.B	5 (2) b	3 (3) b	8 (5) c
SEL.PO.V	23 (41) bc	9 (4) c	31 (56) bcd
LG.V	35 (30) c	26 (28) c	40 (34) d
70.OB	83 (13) d	47 (14) d	116 (9) e

	% Moss + Vascular Plant	Litter (cm)
SEL.HN	0 (0) a	0.0 (0.0) a
SEL.PO.U	0 (0) a	0.0 (0.0) a
LG.U.S	5 (6) b	0.2 (0.3) ab
LG.U.B	8 (3) bc	0.2 (0.4) ab
SEL.PO.V	32 (44) c	0.7 (0.7) ab
LG.V	61 (34) d	0.8 (0.8) b
70.OB	130 (23) e	6.6 (4.5) c

% : % cover 0 (0) : mean (std dev) cm : depth

means followed by the same letter were not significantly different at p = 0.5

Table 1.10 Soil physical properties of the untreated wasterock dumps.

Site	Depth	%<2mm		<2mm/m3 (kg/m3)		Bulk Density (1000 kg/m3)	
SEL.HN	0-5cm	11 (4)	a	198 (83)	ab	1.87 (.23)	bc
SEL.HN	5-10cm	12 (4)	a	266 (63)	bc	2.21 (.23)	a
LG.U.B	5-10cm	19 (5)	b	327 (58)	cd	1.76 (.29)	ecd
WR.84	0-10cm	19 (5)	b				
LG.U.B	0-5cm	21 (6)	bc	379 (124)	def	1.81 (.24)	bcd
LG.U.S	0-5cm	23 (8)	bcd	415 (149)	defg	1.80 (.17)	bcd
WR.82	0-10cm	24 (9)	cde	452 (194)	efg	2.08 (.44)	ab
SEL.PO	0-5cm	25 (7)	cde	423 (112)	efg	1.76 (.32)	ecd
SEL.PO	5-10cm	25 (10)	cde	483 (173)	fgh	1.95 (.28)	abc
LG.U.S	5-10cm	26 (6)	cde	456 (102)	efg	1.75 (.31)	cd
AR.84	0-10cm	32 (13)	ef				
AR.82	0-10cm	35 (10)	f	644 (191)	h	1.82 (.12)	bc
LG.V	5-10cm	36 (9)	f	533 (153)	gh	1.55 (.48)	ed
LG.V	0-5cm	37 (11)	f	541 (133)	gh	1.52 (.30)	ed

0 (0) : mean (standard deviation)
means followed by the same letter were not significantly different at p = 0.5

Table 1.11 The probability that differences exist between the physical properties of the 0-5 and the 5-10 cm depths of the untreated wasterock dumps.

Site	% <2mm	<2mm/m3	Bulk Density	
SEL.HN	0.23	0.07	0.07	
SEL.PO	0.47	0.20	0.03	*
LG.U.S	0.34	0.30	0.38	
LG.U.B	0.22	0.07	0.26	
LG.V	0.43	0.43	0.20	

* : significant at the 0.05 level of probability

areas were statistically significant. Like other Cu-Mo porphyry mines in B.C., in comparison with agricultural soils, the % < 2 mm of the wasterock was very low and the bulk density was very high. The range in % < 2 mm and bulk density for the potassic wasterock was similar to wasterock of similar lithology at the Endako, Lornex and Bethlehem mines, while the proportion of soil sized particles in the finer grained hornfels wasterock paralleled similar low values for fine grained volcanic rock at the Similkameen mine (Murray 1977).

According to the Wilcoxon Test, the only significant difference between the 0-5 cm and the 5-10 cm soil physical data was for SEL.PO bulk density (Table 1.11). However, it cannot be inferred that sample sites were physically homogeneous. The highest correlation coefficient between physical properties at different depths was only 0.58 (Table 1.12). This was for the % < 2mm. Each individual site was a heterogeneous mix of coarse and fine fragments, the physical properties of which depended in part on whether large stones were intercepted.

Comparing the average data for the untreated areas, the following relationship between % < 2 mm and rock type was apparent.

hornfels < potassic < incompetent

10-13% 19-26% 31-36%

With only a few exceptions, differences between areas comprised of different rock types were significant. The

Table 1.12 Correlation coefficients for soil physical properties of the untreated wasterock dumps.

	Bulk Density	% <2mm	
for all depths			
Bulk Density	X		- among 0-5, 5-10 and 0-10 cm
%<2mm	-.47	X	samples from unweathered
<2mm/m3	-.07	.89*	and abandoned sites
0-5 cm vs 0-5 cm			
Bulk Density	X		- among 0-5 cm samples
%<2mm	-.57*	X	from abandoned sites
<2mm/m3	.18	.88*	
5-10 cm vs 5-10 cm			
Bulk Density	X		- among 5-10 cm samples
%<2mm	-.61*	X	from abandoned sites
<2mm/m3	-.15	.86*	

0-5 cm vs 5-10 cm				
Bulk Density	.36	-.34	-.15	- between 0-5 cm and 5-10 cm
%<2mm	-.44	.58*	.43	samples from abandoned
<2mm/m3	-.31	.53*	.51*	sites

	Bulk Density		%<2mm		<2mm/m3		
	0-5	5-10	0-5	5-10	0-5	5-10	
% Moss	-.57*	-.19	.51*	.24	.21	.10	
% Vascular Plant	-.15	-.02	.16	.19	.14	.18	* : > 0.5
% Moss + Litter	-.53*	-.13	.46	.25	.21	.15	
% Moss+Vas.Pl.	-.51*	-.15	.46	.28	.22	.16	
Litter (cm)	-.59*	-.43	.52*	.45	.22	.21	

conclusion that fine grained hornfels rock (SEL.HN) produces the smallest % < 2 mm was supported by the data from the Spy Hill overburden (OB.SH), which was formed from hornfels rock, and which also had a very low % < 2 mm.

Incompetent (AR) and potassic (WR) wasterock surfaces created in 1982 were sampled to compare the characteristics of these two rock types. In both 1982 and 1984, samples of the incompetent wasterock contained the highest proportion of fines. From 1982 to 1984, the % < 2 mm of both the incompetent and potassic wasterock declined. A loss of finer particles from the surface can result from surface movement as a dump settles.

Potassic rock was the most common rock type in the waste and most of the areas sampled were comprised of potassic rock. Differences in the physical characteristics of potassic surfaces (Sel.PO and LG.U) may be attributed to local variations in material handling and to lithological differences. The term potassic describes rock predominantly comprised of coarse grains of K feldspar and quartz. Within this general definition, there can be considerable variation in mineralogy and grain size. These characteristics influence rock competency, which in turn can affect the physical properties of the wasterock.

Bench sites on the LG dump supporting strong perennial plant growth (LG.V) contained the highest % < 2 mm. Possible reasons for the higher % < 2 mm include some form of small scale particle size segregation or degradation

during dump construction or intense weathering resulting from plant growth. Although both depths of LG.V had a low pH values (Table 1.14), given the limited time period since the material was dumped, it is unlikely that plant growth (e.g., root growth and organic acid production) was the primary cause of the difference in physical properties. Perhaps the best explanation for the high % < 2 mm in LG.V is that perennial plants invaded areas of the LG dump containing pockets of incompetent rock. While the incompetent rock is pervasive in only a small portion of the pit, pockets of it were more widely disseminated. During the last phase of mining (1980 to 1983), pockets of incompetent material were found in ore with similar Mo concentration to the rock stored in the LG dump. The presence of incompetent material would explain why LG.V had similar < 2 mm contents to the incompetent dump slope (AR.82 and AR.84).

The range in average bulk densities was considerably less than that for % < 2 mm, and according to the Mann Whitney U test, the bulk densities of 8 of the 12 area x depth combinations were not significantly different (Table 1.10). However, the strongest correlations between soil physical properties and different cover measurements were for the 0-5 cm bulk density with the moss cover (r=-0.57) and the thickness of the litter layer (r=-0.59)(Table 1.12). The 0-5 cm % < 2 mm also had its strongest correlations with these two surface measures.

Soil properties with the greatest effects on bulk density were organic matter and % < 2 mm. For example, LG.V, which had the largest % < 2 mm and % organic matter, had the lowest bulk density. SEL.HN, which had the lowest % < 2 mm and contained very little organic matter, had the highest bulk density. Expansion by root growth and the loss of soluble components (e.g., calcite) might also have contributed to the low bulk density at LG.V sites, many of which were in hollows.

As expected from its higher % < 2 mm, the incompetent wasterock (AR.82) had a lower bulk density than the unweathered potassic wasterock (WR.82). As a dump settles, the surface bulk density should increase. However, the two recently dumped materials (WR and AR) had higher bulk densities than materials with a much lower proportion of fines. This could be a result of measurement errors. Bulk density determination requires measurement of the volume of material extracted, and this necessitates an estimation of the original surface height. Stoney dumps have a very uneven microtopography making this very difficult. As the unweathered potassic site was ripped prior to sampling, its surface was very rough and its bulk density had a relatively high standard deviation. Problems encountered in measuring sample volume were compounded on the incompetent site by the steepness of the slope and the unstable conditions just after dumping.

Perhaps the most notable feature with regards to soil texture was how similar all the groups were (Table 1.13). All sites contained very little clay and at least 50% sand, and were classified as sandy loams based on their average sand, silt and clay contents. A few individual samples were loamy sands.

The only distinct textural difference among groups was that the hornfels wasterock (SEL.HN) contained more silt and clay, and less sand than the other materials. The finer soil texture of the hornfels wasterock can be attributed to the finer grain size of the rock. No textural differences were evident between the unweathered incompetent (AR) and potassic (WR) wasterocks or between other groups that differed in % < 2 mm.

Table 1.13 Soil texture information for different sites on the untreated wasterock dumps.

Site	0-5 cm or 0-10 cm #	Sand %	Silt %	Clay %	Texture	5-10 cm #	Sand %	Silt %	Clay %	Texture
Average										
WR.82	4	66	29	5	sl.					
AR.82	4	65	31	5	sl.					
SEL.HN	3	57	37	6	sl.	3	53	36	12	sl.
SEL.PO	6	68	23	9	sl.	6	68	22	10	sl.
LG.U.B	2	70	18	12	sl.	2	65	27	9	sl.
LG.U.S	2	73	21	6	sl.	2	73	18	9	sl.
LG.V	5	70	24	6	sl.	5	67	24	9	sl.
Standard Deviation										
WR.82		2	2	1						
AR.82		6	7	1						
SEL.HN		4	5	2			1	6	5	
SEL.PO		3	4	3			6	5	4	
LG.U.B		6	9	9			1		1	
LG.U.S		9	6	3			6	1	4	
LG.V		4	4	4			2	5	4	

: number of samples s.l. : sandy loam

4.1.1.2 Chemical Properties

Results from the four chemical analyses (pH, C, N and available P) carried out on the < 2 mm fraction of wasterock soil are reported on a weight per weight (%, ppm) and weight/volume basis. Data for individual samples can be found in Appendix B. The pH data was not converted into H^+ ion activity prior to calculating the descriptive statistics. Thus the pH averages reported are geometric means. All other means are arithmetic.

Despite the problems encountered in measuring the volume of each sample, the variability was not increased when the data was transformed into the per m^3 basis. The advantage of data reported on a weight/volume basis is that it accounts for the large proportion of stones. This is particularly important for comparing soil inputs since a large stone volume may increase the concentration of the added material in the < 2 mm fraction.

Differences in years of exposure (e.g., WR.82 vs LG.PO.U), rock type (e.g., AR.82 vs WR.82, SEL.PO.U vs SEL.HN, and SEL vs LG), vegetation (e.g., SEL.PO.U vs SEL.PO.V), and sampling depth (0-5 vs 5-10 cm) resulted in significant differences between groups, as well as a wide range of average values (Table 1.14). The range in values is approximately 10x for %C, 25x for %N, 200x for ppm available P, and 4000x for H ion activity. The range in values is similar when the data is reported on a weight/m^3

Table 1.14 Soil chemical properties of the untreated wasterock dumps.

Site	Depth	pH*		%C		C/m3 (kg/m3)	
WR.82	0-10cm	7.6 (0.1)	a	1.1 (0.1)	fg	6.2 (1.6)	g
AR.82	0-10cm	7.6 (0.2)	a	1.4 (0.7)	fg	7.8 (1.9)	g
SEL.PO.U	5-10cm	7.7 (0.2)	a	0.5 (0.2)	bcd	2.4 (1.0)	cde
SEL.PO.U	0-5cm	7.5 (0.2)	a	0.5 (0.2)	cd	2.4 (1.1)	cde
SEL.HN	0-5cm	7.3 (0.0)	b	0.8 (0.1)	ef	1.3 (0.3)	abc
LG.U.B	5-10cm	7.1 (0.4)	bc	0.5 (0.2)	cd	1.7 (0.7)	cd
SEL.HN	5-10cm	7.1 (0.2)	bce	0.9 (0.1)	ef	2.3 (0.3)	cde
SEL.PO.V	5-10cm	7.0 (0.1)	cd	0.4 (0.2)	abc	2.2 (1.5)	abcdef
LG.U.B	0-5cm	6.5 (0.6)	def	0.5 (0.4)	cd	1.6 (0.6)	cdf
SEL.PO.V	0-5cm	6.4 (0.6)	e	0.7 (0.6)	def	2.7 (2.3)	cde
LG.U.S	5-10cm	6.4 (1.2)	cdef	0.2 (0.1)	a	0.9 (0.4)	a
LG.U.S	0-5cm	6.2 (1.2)	cdef	0.2 (0.1)	ab	1.0 (0.6)	ab
LG.V	5-10cm	4.1 (0.5)	g	0.7 (0.2)	cde	3.6 (0.7)	ef
LG.V	0-5cm	4.1 (0.3)	g	1.2 (0.7)	fg	6.5 (3.4)	g

Site	Depth	%N		N/m3 (kg/m3)		available P (ppm)	
WR.82	0-10cm					0.4 (0.1)	abc
AR.82	0-10cm					0.5 (0.4)	abc
SEL.PO.U	5-10cm	0.004 (0.003)	a	0.02 (0.00)	a	0.2 (0.0)	a
SEL.PO.U	0-5cm	0.008 (0.003)	abc	0.03 (0.01)	ab	0.4 (0.0)	b
SEL.HN	0-5cm	0.013 (0.002)	bc	0.02 (0.01)	a	1.0 (0.4)	cd
LG.U.B	5-10cm	0.012 (0.006)	bc	0.04 (0.02)	ab	3.0 (2.7)	def
SEL.HN	5-10cm	0.011 (0.004)	abc	0.03 (0.02)	ab	1.1 (0.1)	d
SEL.PO.V	5-10cm	0.007 (0.003)	ab	0.03 (0.01)	ab	1.5 (0.9)	d
LG.U.B	0-5cm	0.020 (0.007)	de	0.07 (0.02)	c	2.2 (2.0)	bcde
SEL.PO.V	0-5cm	0.022 (0.018)	cdef	0.09 (0.07)	cd	3.0 (1.7)	efg
LG.U.S	5-10cm	0.006 (0.004)	ab	0.03 (0.03)	ab	6.5 (7.9)	dfghi
LG.U.S	0-5cm	0.011 (0.008)	abcd	0.05 (0.04)	bc	6.2 (7.6)	defgh
LG.V	5-10cm	0.023 (0.010)	ef	0.11 (0.03)	d	19.2 (8.1)	jk
LG.V	0-5cm	0.038 (0.012)	f	0.20 (0.08)	e	12.4 (6.2)	hijk

Site	Depth	available P/m3 (g/m3)		C/N		xC/xN	N /available P	
WR.82	0-10cm	0.2 (0.1)	a					
AR.82	0-10cm	0.2 (0.1)	ab					
SEL.PO.U	5-10cm	0.1 (0.1)	ab	144 (72)	a	115	206 (142)	ab
SEL.PO.U	0-5cm	0.2 (0.0)	a	76 (35)	abcd	67	192 (77)	ab
SEL.HN	0-5cm	0.2 (0.0)	a	67 (11)	bc	65	147 (50)	abc
LG.U.B	5-10cm	1.1 (1.1)	bc	48 (20)	cdef	42	116 (161)	abce
SEL.HN	5-10cm	0.3 (0.1)	abc	101 (41)	abd	83	103 (48)	abcd
SEL.PO.V	5-10cm	0.7 (0.3)	bc	76 (43)	abcde	64	62 (35)	abcde
LG.U.B	0-5cm	1.0 (1.0)	abc	24 (11)	g	25	463 (949)	a
SEL.PO.V	0-5cm	1.2 (0.8)	c	37 (16)	defg	32	67 (20)	bcde
LG.U.S	5-10cm	3.5 (4.5)	cde	64 (61)	abcdef	31	21 (14)	fg
LG.U.S	0-5cm	2.9 (4.5)	cd	29 (18)	fg	20	36 (22)	ef
LG.V	5-10cm	9.2 (2.2)	g	33 (4)	efg	29	13 (4)	g
LG.V	0-5cm	7.0 (4.2)	efg	31 (9)	efg	32	44 (30)	def

* : geometric mean xC/xN : mean %C / mean %N 0 (0) : mean (standard deviation)
means followed by the same letter were not significantly different at p = 0.5

basis. Although some of the differences were quite large, it is important to remember that only the top 0-10 cm was sampled. Even within the thin layer sampled, in many cases, marked changes only occurred in the upper 5 cm.

On newly exposed glacial moraines in this environment, Ugolini (1967) concluded that most pedogenic changes resulted from the addition of plant residues. Plant growth and the addition of plant residues also appeared to be the driving force for many of the changes observed on the newly exposed wasterock dumps. There were a number of strong correlations between organic cover types and soil chemical properties (Table 1.15), two of the strongest of which were for moss cover with the 0-5 cm %C (r=0.86) and %N (r=0.82) levels. This can be explained both by the contributions of moss to the soil organic matter and that moss growth reflected the amount of litter added in the past. Poor correlations between the 0-5 cm C and N levels and the vascular plant cover was probably because many of the vascular plants were annual species that had not yet contributed litter.

Correlations between the different cover types and the 5-10 cm C and N levels were generally weaker than those for the 0-5 cm C and N data. The exception to this was for the vascular plant cover. Correlation coefficients between the 5-10 cm %N and N/m^3 and the vascular plant cover were 0.63 and 0.64 respectively, and were the strongest correlations with the chemical properties of this depth.

Table 1.15 Correlation coefficients among soil chemical and other properties of the untreated wasterock dumps.

		Bulk Density	% <2mm	<2mm /m3	Moss	Vas.Pl.	S.O.C.	Moss+ Vas.Pl.	Litter Depth
					(percent cover)				
pH	ALL	0.38	-0.49	-0.29					
	0-5	0.41	-0.65	-0.53	-0.46	-0.47	-0.43	-0.58	-0.46
	5-10	0.37	-0.59	-0.40	-0.48	-0.46	-0.42	-0.59	-0.45
%C	ALL	-0.29	0.18	-0.07					
	0-5	-0.61	0.45	0.08	0.86	0.23	0.81	0.75	0.69
	5-10	0.09	-0.15	-0.18	0.25	0.42	0.22	0.39	0.05
C/m3	ALL	-0.41	0.60	0.39					
	0-5	-0.62	0.75	0.45	0.82	0.24	0.78	0.73	0.70
	5-10	-0.13	0.45	0.45	0.47	0.55	0.43	0.60	0.37
%N	ALL	-0.37	0.36	0.15					
	0-5	-0.51	0.53	0.29	0.82	0.31	0.85	0.77	0.63
	5-10	-0.15	0.10	0.00	0.31	0.63	0.27	0.54	0.01
N/m3	ALL	-0.39	0.61	0.46					
	0-5	-0.47	0.76	0.60	0.70	0.27	0.73	0.65	0.57
	5-10	-0.26	0.47	0.39	0.44	0.64	0.41	0.63	0.21
avail.P	ALL	-0.32	0.42	0.28					
	0-5	-0.31	0.55	0.52	0.33	0.54	0.32	0.52	0.17
	5-10	-0.35	0.43	0.24	0.54	0.41	0.43	0.61	0.48
avail.P	ALL	-0.26	0.55	0.47					
/m3	0-5	-0.28	0.64	0.64	0.28	0.41	0.28	0.42	0.15
	5-10	-0.27	0.53	0.42	0.42	0.43	0.37	0.53	0.35
C/N	ALL	0.13	-0.07	-0.02					
	0-5	-0.04	-0.12	-0.20	-0.07	-0.13	-0.10	-0.12	-0.03
	5-10	0.12	-0.04	0.04	-0.19	-0.23	-0.17	-0.25	-0.17
N/avail.P	ALL	0.00	-0.13	-0.14					
	0-5	0.00	-0.11	-0.12	-0.08	-0.07	-0.06	-0.10	-0.14
	5-10	0.09	-0.34	-0.33	-0.12	-0.21	-0.11	-0.19	-0.24

	5-10 cm pH	%C	C/m3	%N	N/m3	avail.P	avail.P /m3	C/N	N / avail.P
0-5 cm									
Bulk Density	0.50	-0.21	-0.30	-0.16	-0.27	-0.53	-0.43	0.05	0.04
%<2mm	-0.66	-0.10	0.33	0.19	0.43	0.72	0.69	-0.09	-0.26
<2mm/m3	-0.47	-0.18	0.24	0.13	0.35	0.50	0.56	-0.06	-0.26

	0-5 cm pH	%C	C/m3	%N	N/m3	avail.P	avail.P /m3	C/N	N / avail.P
5-10 cm									
Bulk Density	0.39	0.20	-0.04	-0.03	-0.45	-0.17	-0.13	0.16	-0.09
%<2mm	-0.61	0.10	0.39	0.30	0.45	0.40	0.38	-0.08	-0.13
<2mm/m3	-0.44	0.16	0.42	0.29	0.43	0.36	0.36	-0.02	-0.17

ALL : 0-5, 5-10, and 0-10 cm samples
0-5 : 0-5 cm samples from sites abandoned in 1972
5-10 : 5-10 cm samples from sites abandoned in 1972

S.O.C. : moss + peat + litter
Vas.Pl. : Vascular Plants

Prior to atmospheric inputs, the only N in the wasterock consisted of traces of ammonium nitrate left after blasting. Most N additions occurred at the surface (e.g., precipitation, moss and algae growth, and litter accumulation). As a result, for all the sites, except SEL.HN, the 0-5 cm N levels were significantly greater than the levels at 5-10 cm (Table 1.16).

As expected, the two unvegetated sites (SEL.PO.U and SEL.HN) contained the least N. Nitrogen levels were significantly higher on three of the four vegetated areas (LG.U.B, SEL.PO.V, and LG.V). On the two sites where the plant growth was weak (LG.U.B, and SEL.PO.V), the increase in N was limited to the 0-5 cm layer. This was not the case for LG.V, for which the average 5-10 cm N/m3 content was significantly higher than the average N/m3 content of all other area x depth combinations except SEL.PO.V at 0-5 cm.

Although N was almost entirely organic, carbon occurred in two fractions: organic-C and mineral or carbonate-C. In the two recently-built dumps (AR.82 and WR.82), where there was no opportunity for organic inputs, one can assume that all the C was in mineral form. Assuming that all the C was calcite, the calcite content of the < 2 mm fraction of the unweathered potassic (WR.82) and incompetent (AR.82) wasterock were 11% and 14% respectively. These levels were much higher than those reported in the geological survey of the site (Steininger 1985), in which calcite was said to be a trace mineral. One possible explanation for the high < 2

Table 1.16 The probability that differences exist between the chemical properties of the 0-5 and 5-10 cm depths of the untreated wasterock dumps.

	Treatment					
Analysis	75.1	70.R	70F	70P	70PF	70AI
pH	.00*	.00*	.00*	.00*	.00*	.14
%C	.00*	.41	.00*	.00*	.00*	.06
C/m3	.00*	.07	.00*	.00*	.00*	.06
%N	.00*	.04*	.00*	.00*	.00*	.06
N/m3	.00*	.19	.00*	.00*	.00*	.06
avail.P	.00*	.00*	.06	.00*	.01*	.06
avail.P/m3	.00*	.00*	.29	.02*	.03*	.06
C/N	.00*	.00*	.08	.21	.38	.29
N/avail.P	.01*	.30	.21	.00*	.03*	.14

* : significant at 0.05 level of probability

mm calcite levels found in this study was that all the calcite present in the original rock ended up in the < 2 mm fraction of the wasterock. If this was the case, the calcite content of the original rock would have been only 2.6% in WR.82 and 4.4% in AR.82.

Dumps exposed since 1972 contained both mineral and organic forms of C. The calcite and organic matter content of a number of sites are listed in Table 1.17. Calcite was only a significant proportion of the total C in samples whose pH was above 6.8. The decline in calcite as the pH increased suggest that the two properties were related. For all the samples in Table 1.17, the correlation coefficient between calcite and pH was -0.67 . Excluding the unweathered and the hornfels sites increased the r value to -0.75 . The traces of calcite in low pH samples were probably small crystals occluded, and thus protected, within large sand grains.

The other trend shown in Table 1.17 is the decrease in pH as organic matter content increased. The correlation between pH and the organic matter had a coefficient of -0.80 . Although none of them were very strong, the negative correlations between pH and the various organic cover types also suggest that plant growth and litter were a major source of acidity. The strong correlations between N/m3 and pH confirm this (Figures 1.2 and 1.3).

Table 1.17 The pH and the calcite and organic matter contents of selected wasterock samples.

Site	Depth	pH	%calcite -C	%organic -C
Untreated				
WR.82	0-10cm	7.69	1.17	0.00
WR.82	0-10cm	7.61	1.04	0.00
WR.82	0-10cm	7.65	1.17	0.00
WR.82	0-10cm	7.55	1.03	0.00
AR.82	0-10cm	7.71	1.25	0.00
AR.82	0-10cm	7.65	0.89	0.00
AR.82	0-10cm	7.38	0.93	0.00
AR.82	0-10cm	7.64	2.41	0.00
SEL.PO.U	0-5cm	7.60	0.62	0.12
LG.U.S	0-5cm	7.50	0.24	0.02
SEL.HN	0-5cm	7.31	0.70	0.20
SEL.PO.U	0-5cm	7.30	0.32	0.00
SEL.HN	0-5cm	7.24	0.64	0.12
SEL.HN	0-5cm	7.15	0.26	0.43
LG.U.B	0-5cm	6.90	0.04	0.45
SEL.PO.V	0-5cm	6.80	0.17	0.33
SEL.PO.V	0-5cm	5.30	0.02	0.27
LG.V	0-5cm	4.10	0.00	1.04
LG.V	0-5cm	3.70	0.00	2.78
Treated				
70P5	5-10cm	5.30	0.07	0.66
70P5	5-10cm	4.80	0.02	1.13
70P5	5-10cm	4.00	0.00	0.93
70P5	5-10cm	3.90	0.05	8.71

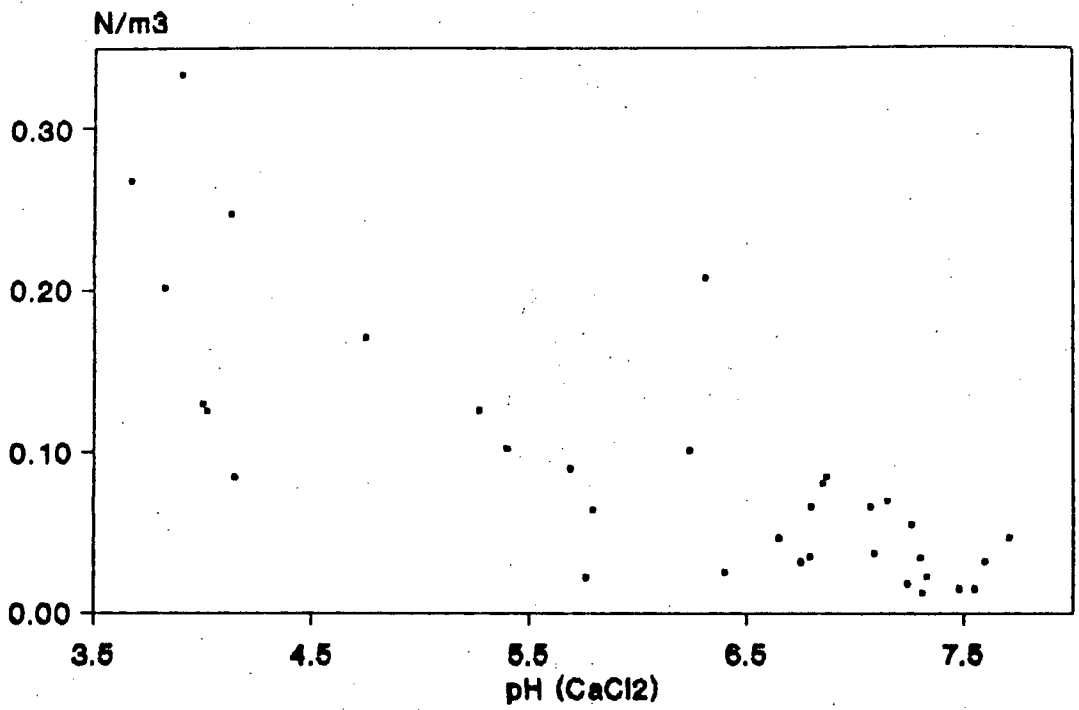


Figure 1.2 pH vs N/m3 for the 0-5 cm depth on the untreated dumps (r= -0.79).

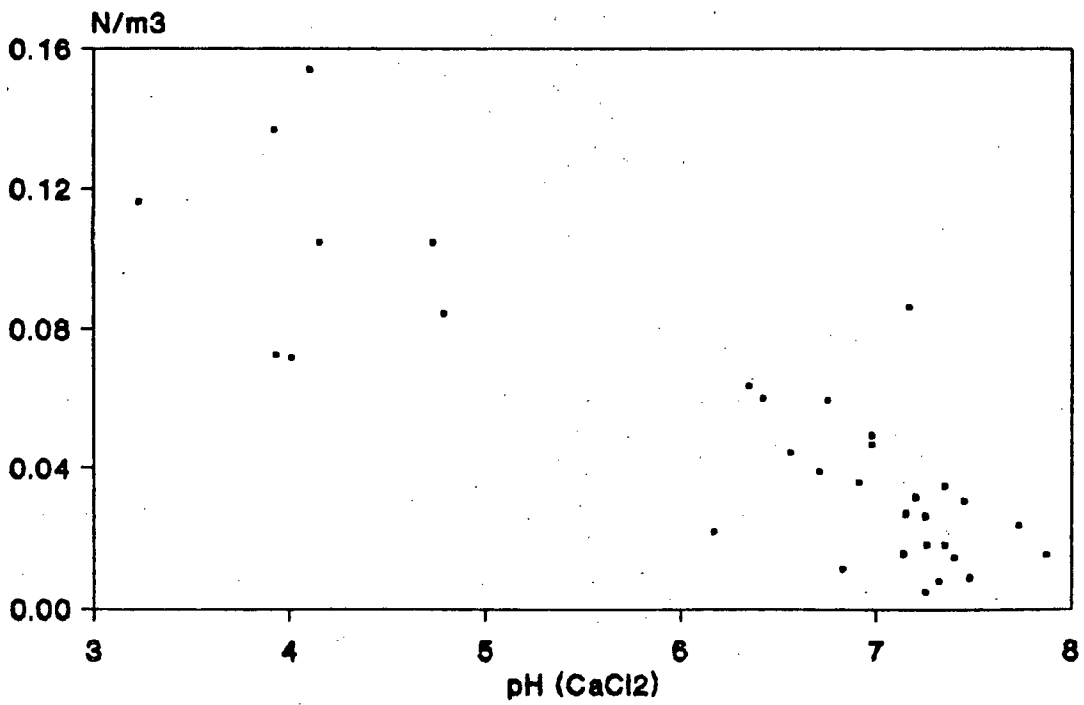


Figure 1.3 pH vs N/m3 for the 5-10 cm depth on the untreated dumps (r= -0.83).

According to their average pH, the area x depth combinations from the untreated dumps can be separated as follows:

pH	7.7-7.5	7.3-7.0	6.5-6.2	4.2-4.0
area x depth	-WR.82 (0-10 cm) -AR.82 (0-10 cm) -SEL.PO.U (0-10 cm)	-SEL.HN (0-10 cm) -LG.U.B (5-10 cm) -SEL.PO.V (5-10 cm)	-LG.U.B (0-5 cm) -SEL.PO.V (0-5 cm) -TOP.SU (0-10 cm)	-LG.V (0-10 cm)

With the exception of a few groups in the pH ranges 7.3-7.0 and 6.5-6.2, area x depth combinations in different ranges varied significantly.

As expected, the unweathered, recently dumped materials (AR.82 and WR.82) were in the highest pH range. Immediately after the bedrock is blasted apart, the pH of the wasterock soil will be similar to the abrasion pH of the rock. Despite at least 8 years exposure and leaching, the average pH values at both depths on the unvegetated potassic SEL sites (SEL.PO.U) were also between 7.5 and 7.7. The most likely cause of the stable pH at SEL.PO.U was calcite dissolution. SEL.PO.U had a significantly lower %C and less than half the C/m^3 of the recently exposed potassic material (WR.82).

Like SEL.PO.U, both depths of the unvegetated hornfels SEL site (SEL.HN) had pH values higher than 7. The high %C and C:N ratio suggested that the wasterock still contained high levels of calcite.

The two other area x depth combinations whose average pH fell in the range of 7.3 to 7.0 were the 5-10 cm samples

from SEL.PO.V and LG.U.B. At both sites the plant growth was weak and significant differences in chemical properties from the unweathered samples were restricted to the 0-5 cm layer. Assuming a C:N ratio for organic matter of between 20 and 30, most of the C in the 0-5 cm layer of SEL.PO.V and LG.U.B was organic, while at 5-10 cm, the high pH and high C:N ratio indicated that a significant proportion of the C was calcite. The surfaces of these sites were near the threshold point where calcite reserves were exhausted and small organic acid additions and leaching dramatically decrease the pH.

Both depths of LG.V had average H ion activities 100 times larger than those of any other untreated area x depth combination. The low pH indicates that neither depth contained calcite, and thus all the C present in the top 10 cm of LG.V was organic. Organic inputs should be expected as LG.V had the highest plant cover (60%). In this cool, humid environment, the microbial decomposition of plant residues results in the formation of organic acids, which are responsible for low pH values in natural soils.

The other possible cause for low pH values at LG.V was sulphide oxidation. If, as suggested, LG.V sites contained incompetent wasterock, rock of this type is highly fractured and thus permits quick access of water, oxygen, and microorganisms to any sulphide grains that are present. However, the sulphide content (largely pyrite) of the

Kitsault wasterock is relatively small (Steininger 1985) and acidification by this process will be limited.

According to the correlation coefficients, the property most strongly related to pH was available P (Figures 1.4 and 5). Notably, both pH and available P are measures of available rather than total element content, and sites whose pH was most variable also had highly variable available P levels (e.g., LG.U.S). The increase in available P as the pH decreased can be explained by the effect of pH on apatite stability. Apatite was the only common primary P mineral found in the wasterock (Steininger, 1985) and apatite solubility increases exponentially as the pH drops (Lindsay & Moreno, 1960).

In the SEL samples, levels of available P were higher at 0-5 than at 5-10 cm. On the LG dump, available P levels at 5-10 cm were greater than at 0-5 cm. The LG dump data was the opposite of what might be expected from the pH values, and suggest that either P released at 0-5 cm was being fixed into unextractable forms, or P released at the surface was lost through leaching.

The other notable feature about the available P levels on the LG dump was the relatively high amounts of available P at LG.U.S. One explanation is that the pH data only provides a measure of the present weathering intensity. The duration of lower pH conditions is also important, and the low 5-10 cm pH suggests that a decline in pH occurred earlier on LG.U.S than on LG.U.B or SEL.PO.V.

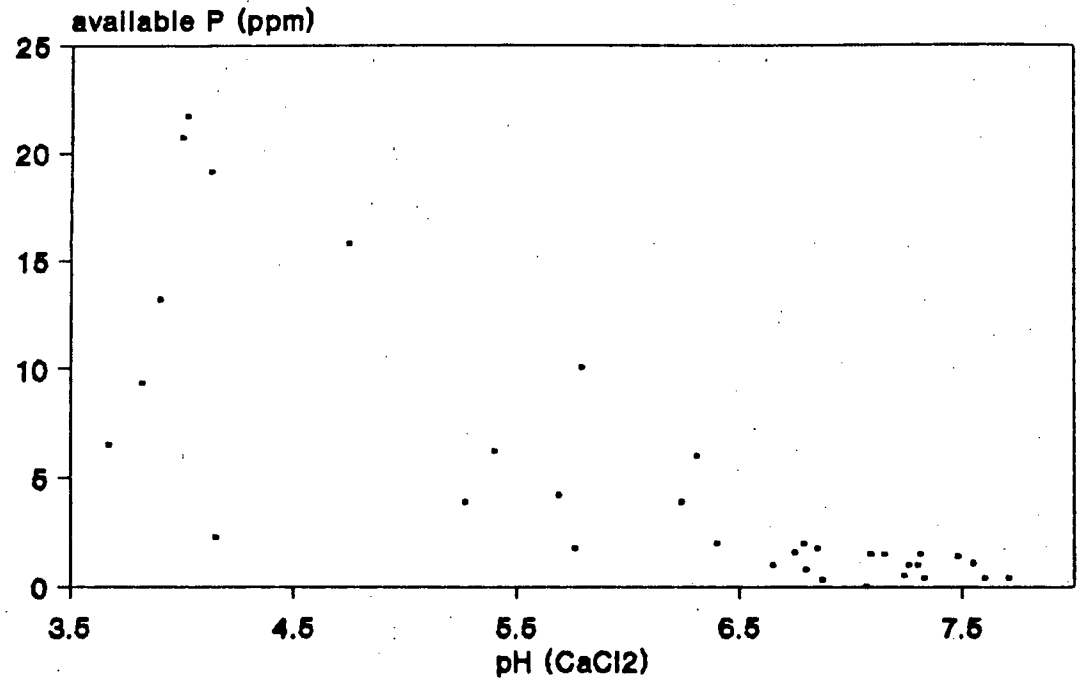


Figure 1.4 pH vs available P for the 0-5 cm depth on the untreated dumps (r=-0.79).

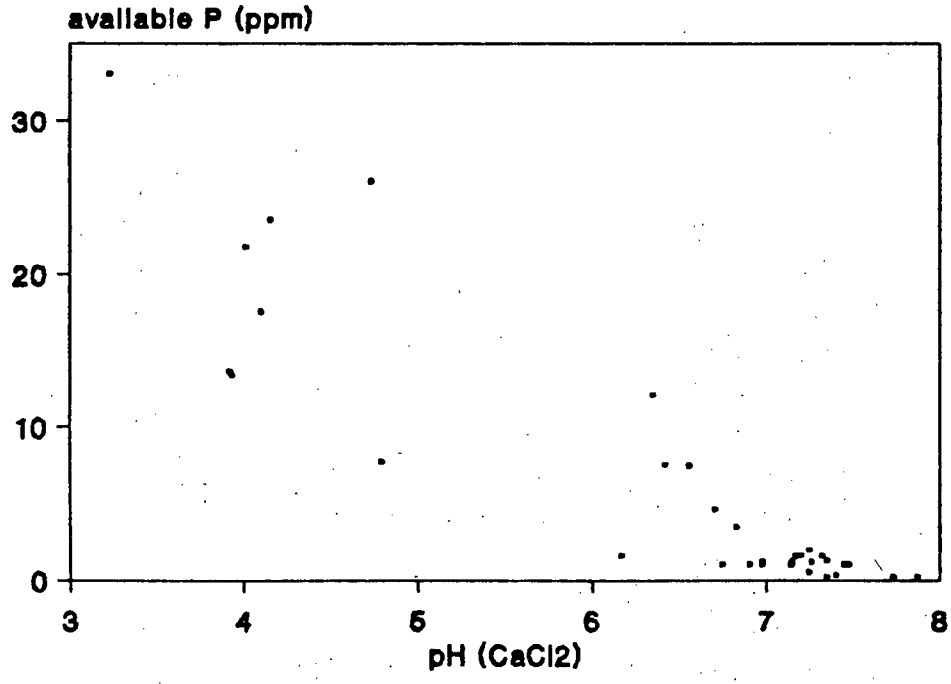


Figure 1.5 pH vs available P for the 5-10 cm depth on the untreated dumps (r=-0.90).

4.1.2 Field Trials

4.1.2.1 Surface Cover

Treatments applied to the field trials are described in Appendix A, and a complete report of the resulting plant growth is presented in Section 4.2. Soil samples were taken from the trials in 1980. According to their vascular plant cover, the ranking of the different treatments in 1980 was 70AI (fertilized) < 70R (control) < 75.1 (fertilized slope) < 70PF (peat) < 70F (fertilizer) < 70P (peat)(Table 1.18). With the exception of 70AI, vascular plant growth on the sites sampled was almost entirely perennial agronomics. Treatment 70AI was spring rye (Secale cereale L.) and barley (Hordeum vulgare L.) sown on fertilized wasterock. In 1980, it was the treatment in Trial 70.1 with the most vigorous invasion of native species (e.g., willow and cottonwood).

The relative ranking of different treatments according to moss cover was similar to that for vascular plants (Table 1.18). Like on the untreated dumps, the moss cover on the field trials was generally greater than that of the vascular plants.

One result of stronger plant growth on the field trials than on the untreated dumps was the formation of thicker surface litter layers. Field trials, like the untreated sites, showed no noticeable incorporation of surface litter. The thickness of the surface organic layers reflected both previous plant growth and peat application. The sharp

Table 1.18 The surface cover on sampled areas of the field trials.

Treatment	Moss 80	Moss 81	Moss 83	Litter 83	Lichen 83	Wort 83	Inv. 83	Grass 80	Grass 81	Grass 83	Legume 80	Legume 81	Legume 83	Litter Depth (cm)
					(Percent Cover)									
70R1	6	6	12	5	1	tr	tr	3	2	tr	tr	0	0	0.2
70R5	19	6	22	1	1	0	1	5	tr	1	4	3	2	0.3
70R6	30	15	27	4	1	tr	1	6	1	1	1	1	1	0.3
70F1	69	63	58	16	tr	tr	tr	36	14	2	5	4	2	1.4
70F5	78	72	80	3	0	1	0	29	17	11	34	36	39	2.3
70F6	72	63	62	5	0	0	tr	21	9	4	11	12	8	2.1
70P1	91	72	84	9	0	tr	1	55	34	11	12	11	6	4.3
70P5	95	89	95	tr	0	0	1	37	26	12	38	47	48	5.3
70P6	92	91	92	3	0	tr	tr	21	7	6	15	13	12	3.8
70PF1	80	70	64	19	0	tr	1	39	17	8	5	2	1	2.9
70PF5	63	32	41	16	tr	0	1	13	5	2	9	7	7	3.3
70PF6	65	37	45	18	tr	0	1	14	4	2	7	2	3	2.5
70AI*	18	nm	nm	38	0	0	46	3	nm	nm	3	nm	nm	1.7
75.1*	31	nm	nm	1	0	0	0	4	nm	nm	4	nm	nm	0.8

nm : not measured
Inv : naturally invading vascular plants
* : all data measured in 1980

Litter : litter + peat
Wort : liverwort
tr : trace

boundary between the surface organic matter and the wasterock indicated that little or no faunal mixing had occurred. Organic matter added to the surface remained there in a LFH-like layer. Judging from the thickness of the surface organic layers, organic matter additions from plant growth on 70F had been at least as large as the amount of organic matter applied by the peat treatment plus poor plant growth on 70PF. Treatment 70P had both strong plant growth and a peat amendment, and as a result, the average thickness of its organic layer (4.5 cm) was only slightly less than the combined total for 70PF and 70F (4.8 cm).

4.1.2.2 Physical Properties

Soil physical data for individual samples are tabulated in Appendix B.

Like other soil properties, the physical properties showed no statistically significant response to the type of seed mix sown. There were however many significant differences as a result of surface treatments (Table 1.19). The field trials, like the untreated dumps, produced a weak negative correlation between bulk density and % < 2 mm, and a stronger positive correlation between % < 2 mm and weight < 2 mm/m^3 (Table 1.20). Compared to findings from the untreated dumps, the range in average values was smaller for % < 2 mm and wt. of < 2 mm/m^3 and larger for bulk density. The narrow range in < 2 mm content was probably because all

Table 1.19 Soil physical properties of the field trials.

Treatment	Depth	%<2mm		<2mm/m3 (kg/m3)		Bulk Density (kg/m3)	
70Al	0-5cm	7 (3)	a	157 (71)	ab	2169 (98)	a
70P	5-10cm	12 (4)	a	252 (82)	bc	2059 (532)	ab
70PF	5-10cm	14 (7)	a	261 (85)	bcd	2096 (594)	ab
70PF	0-5cm	14 (8)	a	232 (139)	abc	1693 (409)	c
70Al	5-10cm	14 (2)	ab	276 (53)	abcde	1914 (105)	b
70R	0-5cm	15 (4)	ab	294 (91)	cde	2013 (342)	ab
70F	0-5cm	16 (7)	abc	212 (81)	ab	1449 (358)	d
70F	5-10cm	17 (6)	abc	300 (103)	cde	1860 (293)	b
70R	5-10cm	18 (8)	bcd	353 (124)	de	2113 (546)	a
75.1	5-10cm	21 (5)	d	385 (96)	e	1868 (212)	b
75.1	0-5cm	21 (12)	d	321 (168)	cde	1551 (268)	c
70P	0-5cm	22 (11)	d	200 (90)	a	1011 (354)	e
77.84	0-10cm	20 (4)	cd				

0 (0) : mean (standard deviation)
means followed by the same letter were not significantly different at p = 0.5

the treatments sampled were on the same dump, and thus comprised of similar material.

Although, like Trials 75.1 and 77.1, Trial 70.1 was comprised of potassic rock, several of the treatment x depth combinations (e.g., 0-5 cm 70R, 70F and 70PF) from it had % < 2 mm contents which were more like the untreated hornfels wasterock (SEL.HN). The low % < 2 mm on Trial 70.1 was probably caused by the manner in which the trial was built. Unlike other trials, the 70.1 site was levelled by a grader before amendments were applied. As it levels the surface, a grader shakes and moves the material, in a process similar to sieving. With stoney material like wasterock that lacks cohesion, grading shakes loose smaller particles which fall into spaces that open below. Stones that are too large to fit into crevasses are left stranded at the surface. Grading may also compact the surface.

The result was a very low 0-5 cm % < 2mm, the most extreme example of which was 70AI. After grading, the particle size distribution of most of Trial 70.1 was probably like the present condition of the unfertilized wasterock (70R) plots. Subsequently, organic matter, added either as a peat amendment or through root and herbaceous growth, modified the physical properties of the surface. As it lacked a peat amendment and had little plant growth, the effect of these processes on 70R were minimal.

As was found on the untreated sites, the soil physical property most strongly correlated with the organic cover

types was bulk density. Bulk density correlated most strongly with cover types including moss (Table 1.20). On all the treatments, except 70R, the 0-5 cm bulk density was significantly lower than at 5-10 cm (Table 1.21). The only significant difference with depth in % < 2 mm at 0-5 cm was on 70P, the treatment with the largest difference between its 0-5 cm and 5-10 cm organic-C contents.

Perhaps the greatest effect of organic matter addition on particle size was in raising the surface. In this manner, surficial organic additions diluted the amount of wasterock in the 0-5 cm layer, dropping a portion of the original fines-deficient surface material into the 5-10 cm depth.

As a result of both continuously strong plant growth and the original peat amendment, the thickness of the LFH-like layer was greatest on the 70P plots. On average, 4.4 cm of the upper 0-5 cm of 70P was peat and litter, putting most of the original high density upper 5 cm of wasterock soil in the 5-10 cm layer. At 5-10 cm, 70P had one of the highest bulk densities and the smallest < 2 mm contents. Conversely, in the highly organic surface, 70P had the lowest bulk density and the highest % < 2 mm, and the 0-5 cm bulk density was significantly lower than that of all the treatments.

As expected from their shallower surface organic layers, the 0-5 cm depths on the 70F and 70PF treatments contained significantly less % < 2 mm and had higher bulk

Table 1.20 Correlation coefficients for soil physical properties of the field trials.

	Bulk Density			%<2mm			<2mm/m3	
Depth	ALL	0-5	5-10	ALL	0-5	5-10	0-5	5-10
Bulk Density	X	X	X					
%<2mm	-.44	-.43	-.51	X	X	X		
<2mm/m3	.19	.19	-.03	.74	.76	.84	X	X
% Moss		-.64	-.08		.32	-.12	-.07	-.15
% Vascular Plant		-.39	-.18		.06	.01	-.13	-.06
% Grass		-.28	-.21		.12	-.09	-.03	-.18
% Legume		-.26	-.05		.00	.06	-.12	.05
% Moss + Peat + Litter		-.58	-.01		.31	-.16	-.02	-.18
% Moss + Vascular Plant		-.64	-.14		.26	-.08	-.11	-.14
Litter (cm)		-.36	.33		.22	-.44	-.04	-.33

Table 1.21 The probability that differences exist between the soil physical properties of the 0-5 and 5-10 cm depths of the field trials.

Treatment	%<2mm	<2mm/m3	Bulk Density
75.1	0.08	0.36	0.00 *
70R	0.16	0.19	0.19
70F	0.24	0.00 *	0.00 *
70P	0.00 *	0.04 *	0.00 *
70PF	0.27	0.17	0.01 *

* : significant at the 0.05 level of probability

densities than the 70P plots. Comparing the two, the only significant difference in their physical properties was that 70F had a lower 0-5 cm bulk density. Thus 10 years of strong plant growth after the fertilizer treatment (70F) had created slightly better physical characteristics than the initial peat amendment with poor plant growth (70PF).

The fines-containing portion at the top of slope Trial 75.1 had a relatively high < 2 mm content and low bulk density, presumably because it was not compacted by trucks or reworked by the grader.

Although a lack of fines and a high bulk density are not desirable characteristics, the most vigorous natural plant invasion occurred on 70AI, the site with the lowest % < 2 mm and highest bulk density. This suggests that if the dump benches are fertilized and sown with agronomics, competition for space is a greater limitation to plant invasion than the physical conditions. A high coarse fragment content resists compaction by trucks, results in good drainage, and thus is somewhat desirable. However, the finer fraction is also necessary and the lack of fines on all but the upper part of the slopes was an obvious impediment to growth.

The high bulk density on Trial 70.1 could have been prevented by ripping the surface, rather than grading it flat. Having a rougher surface would also create a more varied microclimate, increasing the retention of airborne

seed and hence natural plant invasion (Lavkulich et al., 1976).

The surface of the trials, like the untreated dumps, contained very little clay and at least 50% of the < 2 mm fraction was sand-sized (Table 1.21). Based on average sand, silt, and clay contents, the < 2 mm fractions of all the treatments were classified as sandy loams. A few individual samples in different groups were loamy sands and several 0-5 cm samples from 70P were loams. Compared to the other groups, the 0-5 cm layer of 70P contained less sand and more silt and clay. One explanation for this was that the low pH and high organic content caused more intense particle breakdown than in any other treatment x depth combination. Another possible reason was that the low proportion of sand in 70P was an artifact of the pre-treatment used prior to the textural analysis. Adding more bleach in order to oxidise the higher organic matter content of these samples might have caused more particle degradation. Alternatively, the silt and clay fractions of 70P could contain unoxidized organic matter. Other than 70P, the samples from the field trials all had the same texture as the untreated dump samples.

Table 1.22 Soil texture information for different treatments in the field trials.

	0-5cm				5-10cm			
Treatment	Sand	Silt	Clay	Texture	Sand	Silt	Clay	Texture
				Averages				
75.1	69	21	10	s.l.	66	22	11	s.l.
70R	70	22	7	s.l.	62	26	12	s.l.
70F	72	20	8	s.l.	68	24	8	s.l.
70P	53	35	12	s.l.	66	26	8	s.l.
70PF	62	27	11	s.l.	65	26	9	s.l.
70Al	69	22	10	s.l.	72	21	8	s.l.
				Standard Deviation				
75.1	9.5	7.0	5.3		4.0	8.6	4.9	
70R	8.1	8.7	3.5		8.0	5.2	4.7	
70F	5.0	4.5	4.2		6.6	4.7	3.8	
70P	8.3	9.7	2.0		6.3	5.2	3.3	
70PF	4.3	2.1	3.2		2.9	3.5	2.9	
70Al	0.7	2.1	2.8		3.5	7.8	4.2	

s.l. : sandy loam

4.1.2.3 Chemical Properties

The soil chemical properties of individual samples can be found in Appendix B.

Unlike the untreated areas, all the field trial treatments had had at least some plant growth on them. One result of the stronger plant growth was the addition of more C and N. Like the untreated sites, the 0-5 cm depths contained more C/m^3 and N/m^3 than the 5-10 cm layer (Table 1.23 and 1.24). The exception was the unfertilized wasterock (70R), which as a result of poor plant growth, no peat amendment, and the presence of calcite, contained more C at 5-10 cm. The drop in pH at the surface of 70R can be attributed to a loss of calcite.

The other treated area with low C and N levels was the unfertilized slope (75.1). Visual observations made prior to 1980 (Price, 1982) and measurements of plant growth made in this study indicate that the primary cause of the low C and N levels on 75.1 was poor plant growth. Although 75.1 was fertilized, the poor growth could be due to a lack of N. Average 0-5 cm and 5-10 cm N levels for 75.1 were lower than that those of 70R.

While 70F and 70PF differed significantly in pH and available P, they contained comparable amounts of C and N. Eleven years of relatively strong plant growth on fertilized wasterock (70F) produced only slightly less C/m^3 than poor plant growth plus the peat amendment on 70PF. Average N/m3

Table 1.23 Soil chemical properties of the field trials.

Site	Depth	pH	%C	C/m3 (kg/m3)
70R	5-10cm	7.1 (0.5) a	0.7 (0.2) bc	2.3 (0.8) bd
75.1	5-10cm	6.5 (0.8) b	0.3 (0.2) a	1.1 (0.6) a
70F	5-10cm	5.9 (1.1) bc	0.8 (0.4) c	2.3 (1.3) b
75.1	0-5cm	5.8 (0.9) cd	0.6 (0.3) b	1.9 (1.2) bcd
70R	0-5cm	5.6 (1.1) cde	0.7 (0.4) b	1.9 (1.2) bd
70AI	5-10cm	5.4 (1.0) bcde	0.3 (0.1) a	0.8 (0.2) a
70PF	5-10cm	5.4 (1.1) d	0.9 (1.1) bc	2.0 (1.7) ad
70P	5-10cm	4.9 (1.1) ef	2.0 (2.4) d	5.4 (7.0) c
70AI	0-5cm	4.7 (0.3) ef	1.2 (0.7) bcd	1.7 (0.7) abc
70F	0-5cm	4.3 (0.6) f	5.1 (3.3) e	10.0 (6.4) f
70PF	0-5cm	4.2 (0.7) g	6.2 (2.9) e	13.7 (12.3) f
70P	0-5cm	4.1 (0.6) h	12.5 (3.1) f	24.6 (12.5) g

Site	Depth	%N	N /m3 (kg/m3)	avail.P (ppm)
70R	5-10cm	0.020 (0.006) bc	0.07 (0.01) cd	1 (1) a
75.1	5-10cm	0.007 (0.002) a	0.03 (0.01) a	9 (9) bcd
70F	5-10cm	0.039 (0.018) e	0.12 (0.08) d	17 (16) deg
75.1	0-5cm	0.031 (0.018) de	0.11 (0.12) d	23 (18) efg
70R	0-5cm	0.031 (0.017) cde	0.08 (0.04) cd	3 (2) a
70AI	5-10cm	0.015 (0.006) b	0.04 (0.01) ab	5 (5) abce
70PF	5-10cm	0.030 (0.025) bcd	0.07 (0.05) bcd	7 (10) ab
70P	5-10cm	0.067 (0.058) e	0.17 (0.17) d	15 (10) efg
70AI	0-5cm	0.065 (0.048) bcde	0.08 (0.03) bc	26 (22) gh
70F	0-5cm	0.167 (0.08) f	0.33 (0.19) e	31 (17) i
70PF	0-5cm	0.211 (0.099) f	0.39 (0.17) e	14 (9) e
70P	0-5cm	0.369 (0.213) g	0.61 (0.24) f	29 (6) h

Site	Depth	avail.P /m3 (g/m3)	C/N	xC/xN	N /avail.P
70R	5-10cm	0.3 (0.3) a	34 (8) a	34	250 (151) a
75.1	5-10cm	3.4 (3.2) c	46 (25) a	45	14 (10) g
70F	5-10cm	5.1 (5.1) cd	21 (8) cd	21	44 (32) de
75.1	0-5cm	6.5 (4.1) d	21 (9) c	20	20 (17) fg
70R	0-5cm	1.0 (0.8) b	21 (6) cd	22	177 (185) abc
70AI	5-10cm	1.2 (1.0) ab	22 (4) b	20	67 (49) abde
70PF	5-10cm	1.8 (2.7) b	36 (25) abc	30	89 (79) be
70P	5-10cm	3.9 (3.3) c	31 (16) ab	29	56 (48) de
70AI	0-5cm	2.8 (1.2) cd	23 (5) b	19	28 (6) ef
70F	0-5cm	5.8 (3.0) d	30 (14) abd	30	82 (97) cd
70PF	0-5cm	2.6 (1.4) c	31 (11) ab	29	185 (147) ab
70P	0-5cm	5.8 (2.9) d	37 (17) ab	34	135 (84) b

7 (9) : average (standard deviation)
means followed by the same letter were not significantly different at p = 0.5

Table 1.24 The probability that differences exist between the physical properties of the 0-5 and 5-10 cm depths on the treated dumps.

	75.1	70R	70F	70P	70PF	70AI
pH	.00*	.00*	.00*	.00*	.00*	.14
%C	.00*	.41	.00*	.00*	.00*	.06
C/m3	.00*	.07	.00*	.00*	.00*	.06
%N	.00*	.04*	.00*	.00*	.00*	.06
N/m3	.00*	.19	.00*	.00*	.00*	.06
avail.P	.00*	.00*	.06	.00*	.01*	.06
avail.P /m3	.00*	.00*	.29	.02*	.03*	.06
C/N	.00*	.00*	.08	.21	.38	.29
N /avail.P	.01*	.30	.21	.00*	.03*	.14

* : significant at 0.05 level of probability

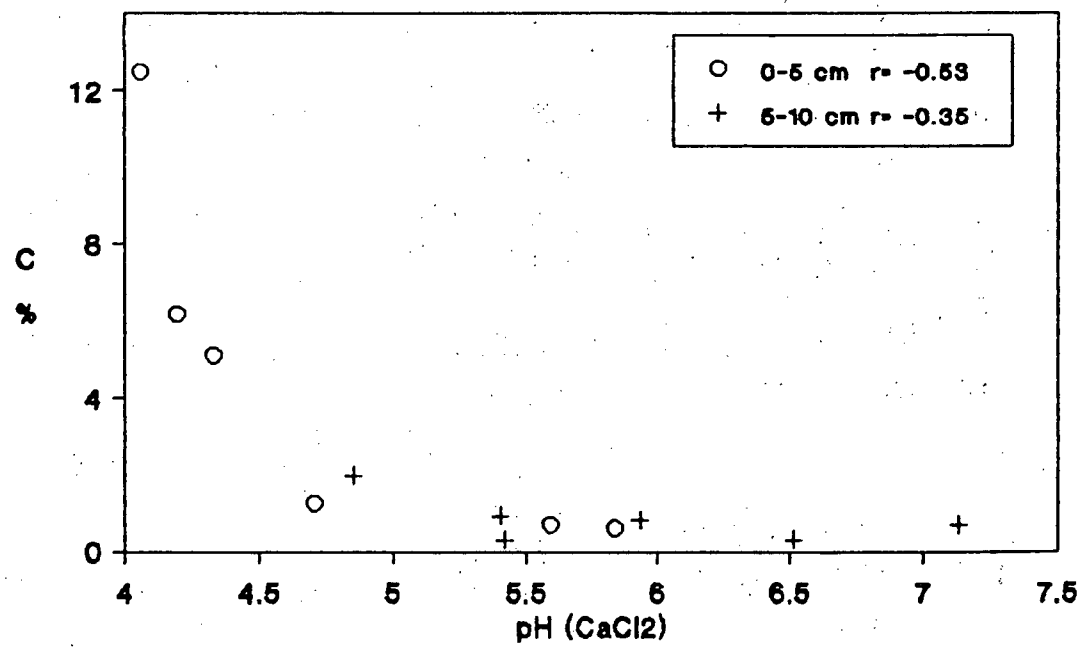


Figure 1.6 pH vs %C for the field trial treatment x depth averages.

levels were slightly higher on 70F, presumably as a result of the strong legume growth on 70F5.

As one would expect from the thicker surface organic layer, at both 0-5 and 5-10 cm, 70P had higher C and N levels than any of the other treatments. Amounts of C and N in 70P were approximately equal to the sum of these for 70F and 70PF.

In the field trials, soil C and N were largely present in the organic form. The stronger correlations between C and N at 0-5 cm than at 5-10 cm (Table 1.25) were due to a greater spread in values at 0-5 cm and the absence of calcite. The source of organic matter affected the C:N ratio. Average C:N ratios were significantly higher on the peat-amended treatments (70P and 70PF) than on treatments on which the main source of organic matter was plant growth (e.g., 70F).

Through the formation of organic acids, organic matter additions can lower the pH. The 0-5 cm layer, the zone of maximum organic additions, was the most acidic for all the treatments. All of the treatments with strong plant growth or on which peat was applied had $CaCl_2$ pH values lower than 5.

The relationship between organic matter and pH is illustrated by the plot of average C versus pH (Figure 1.6), which shows a curvilinear relationship. At high pH there are relatively large drops in pH with only small increases in C. The large pH drops suggest that in this pH range the

Table 1.25 Correlation coefficients for soil chemical properties of the field trials.

		pH	%C	C/m3	%N	N/m3	avail.P	avail.P /m3	C/N
pH	ALL	X							
	0-5	X							
	5-10	X							
%C	ALL	-0.53	X						
	0-5	-0.53	X						
	5-10	-0.35	X						
C/m3	ALL	-0.47	0.85	X					
	0-5	-0.47	0.80	X					
	5-10	-0.27	0.94	X					
%N	ALL	-0.46	0.86	0.54	X				
	0-5	-0.40	0.82	0.43	X				
	5-10	-0.43	0.83	0.78	X				
N/m3	ALL	-0.48	0.83	0.80	0.82	X			
	0-5	-0.42	0.79	0.76	0.77	X			
	5-10	-0.34	0.77	0.85	0.91	X			
avail.P	ALL	-0.29	0.44	0.32	0.36	0.33	X		
(ppm)	0-5	-0.10	0.36	0.20	0.27	0.20	X		
	5-10	-0.26	0.28	0.30	0.29	0.31	X		
avail.P	ALL	-0.15	0.22	0.32	0.08	0.27	0.81	X	
/m3	0-5	0.00	0.15	0.29	-0.05	0.19	0.72	X	
	5-10	-0.12	0.22	0.31	0.20	0.33	0.93	X	
C/N	ALL	0.04	0.24	0.34	-0.03	0.06	0.02	0.05	X
	0-5	-0.26	0.58	0.73	0.13	0.37	0.22	0.24	X
	5-10	0.15	0.10	0.11	-0.22	-0.21	-0.08	-0.04	X
N /	ALL	0.05	0.27	0.16	0.35	0.27	-0.29	-0.40	-0.08
avail.P	0-5	0.07	0.25	0.12	0.37	0.25	-0.38	-0.49	0.05
	5-10	0.24	0.09	0.04	0.15	0.10	-0.38	-0.39	-0.17

ALL : 0-5, 5-10, and 0-10 cm samples

wasterock soil had very little pH buffering capability, other processes such as leaching and oxidation contributed to the acidity, and that the total C and N levels were not good measures of the acidifying action of organic matter. For example, the levels of %C at 5-10 cm do not necessarily indicate the rate at which organic acids have leached through this layer. Nor do they indicate the strength of the acids or for how long leaching has been occurring. Organic acid additions to the 5-10 cm layer of the peat amended sites will have started earlier than on the fertilized wasterock (70F). This may explain why at 5-10 cm, 70PF had a significantly lower pH but contained less C than 70F. The importance of the surface conditions in controlling the 5-10 cm pH was illustrated by the strong correlation between the 0-5 cm and the 5-10 cm pH values ($r=0.74$).

Below about pH 4.8, the rate of pH decrease relative to the increase in C becomes steadily smaller. This suggests some form of pH buffering. Buffering may result from elements released by weathering, such as Fe and Al, or because the pH approached the isoelectric pH of organic acid functional groups. A decrease in pH will accelerate mineral weathering, releasing elements like Al which play an important role in regulating soil pH.

On the field trials, there were no strong correlations with available P, indicating that several factors played a role in P availability. For example, by increasing the

release and availability of Fe and Al, acidic conditions, which accelerate apatite weathering, may also have accelerated P fixation.

The presence of residual fertilizer may explain why levels of available P/m^3 in 70P, 70F, and 75.1 were significantly higher than those of 70PF and 70R. Notably, the differences in available P levels between 70P and 70PF were similar to differences in their C and N contents. This observation suggests that there was a correlation between the available P and the organic matter content on the peat amended plots, and that the P released by the Bray extractant was mainly from the organic fraction. Although not very strong, the highest correlation coefficients between available P and other soil chemical properties were for available P with 0-5 cm C and C/m3.

Like the physical properties, soil chemical properties showed no statistically significant response to the type of seed mix used. This was to be expected in Trial 75.1 and on treatments 70R and 70PF, where none of the seed mixes produced strong growth. The growth of agronomic species was much stronger on 70F and 70P, and here large differences in plant growth resulted in some large differences in average soil values on sections sown with different seed mixes (Table 1.26). In 1980, the highest plant growth was on plots sown with seed mix 5. This resulted in the thickest surface organic layer and highest concentrations of C and N. Nitrogen was especially high, as a result of the growth of

Table 1.26 Average data for soil chemical properties on sections of 70F and 70P sown with different seed mixes.

Treat	Depth	pH	%C	C/m3 (kg/m3)	%N	N/m3 (kg/m3)	avail.P (ppm)	avail.P/m3 (g/m3)	C/N	N / avail.P
70F1	5-10cm	6.1	0.8	2.4	0.03	0.09	27	8.4	24	18
70F6	5-10cm	5.9	0.9	1.5	0.04	0.08	11	1.5	20	62
70F5	5-10cm	5.8	0.8	3.0	0.05	0.18	14	5.4	19	53
70P6	5-10cm	5.2	1.1	3.0	0.03	0.09	8	2.3	41	60
70P1	5-10cm	4.9	1.9	6.2	0.06	0.17	21	5.8	32	25
70F5	0-5cm	4.7	7.0	13.7	0.19	0.39	44	8.3	36	48
70P5	5-10cm	4.5	2.9	6.8	0.11	0.26	16	3.5	22	83
70F1	0-5cm	4.2	4.5	10.0	0.14	0.31	18	4.0	30	142
70P6	0-5cm	4.1	10.6	19.6	0.30	0.51	27	5.0	41	127
70F6	0-5cm	4.1	3.7	6.4	0.17	0.28	31	5.0	24	56
70P5	0-5cm	4.1	14.5	23.5	0.52	0.63	29	4.8	27	184
70P1	0-5cm	4.0	12.3	30.8	0.28	0.67	30	7.4	44	94

birdsfoot trefoil (Lotus corniculatus L.). The failure of these differences to be statistically significant was due to the great variability in the soil data, which was a result of the great variability in plant growth within each treatment (see Section 4.2).

4.1.3 Overburden

Observations of plant invasion around the minesite suggest that the overburden was a more hospitable medium for plant growth than the wasterock. Similarly on the Trial 70.1, plant growth was more abundant and vigorous where an organic rich overburden had slumped onto the dump (70.OB).

The proportion and weight per m^3 of particles < 2 mm in diameter in the overburden were similar to those found in the hornfels and potassic wasterocks (Table 1.27). However, OB.59 and both depths of 70.OB had lower average bulk densities than any of the wasterock area x depth combinations. The lower bulk densities of the overburden can be attributed in part to their high (very high for 70.OB) organic matter content. Another reason was that trucks and bulldozers, ran over the dump, compacting the wasterock. While the overburden was spread by a backhoe. A backhoe was used for the field trials. However, if overburden is to be applied on a larger scale, a bulldozer probably would be used to spread it, and this should increase its bulk density.

Of the different overburden types, OB.SH had the highest bulk density. OB.SH had a high stone content relative to OB.59, and a low organic matter content compared with 70.OB. Mineral particles in OB.SH were derived from hornfels rock, explaining its low % < 2mm. Compared to both the wasterock and the other overburden types, the % < 2mm and bulk density of 70.OB were highly variable. This was

Table 1.27 Soil properties of the overburden.

Site	Depth	% < 2mm	<2mm/m3 (kg/m3)	Bulk Density (1000 kg/m3)
OB.SH	0-10cm	15 (4) a	294 (126) bcd	1.75 (.45) cde
70.OB	5-10cm	20 (13) abcde	174 (75) abc	1.23 (.58) ef
70.OB	0-5cm	30 (17) abcdef	147 (51) a	0.74 (.51) f
OB.59	0-10cm	30 (7) def	373 (102) de	1.38 (.33) f

Site	Depth	pH*	%C	C/m3 (kg/m3)
OB.SH	0-10cm	6.5 (0.3) f	2.3 (0.7) fg	6.21 (3.2) eg
OB.59	0-10cm	4.3 (0.3) fg	1.9 (0.7) fg	7.80 (3.5) g
70.OB	5-10cm	4.8 (1.6) f	12.4 (12.6) h	16.25 (12.1) gh
70.OB	0-5cm	3.8 (0.5) g	18.1 (11.8) h	23.51 (10.7) gh

Site	Depth	%N	N/m3 (kg/m3)	available P (ppm)
OB.SH	0-10cm	0.110 (0.010) g	0.36 (0.11) ef	6.3 (0.3) fi
OB.59	0-10cm	0.090 (0.030) g	0.30 (0.09) ef	8.2 (0.8) h
70.OB	5-10cm	0.239 (0.193) gh	0.29 (0.19) ef	38.1 (29.6) kl
70.OB	0-5cm	0.381 (0.225) h	0.50 (0.20) f	33.1 (7.5) l

Site	Depth	available P/m3 (g/m3)	C/N	xC/xN	N /available P
OB.SH	0-10cm	1.6 (0.7) c	20 (5) g	20	109 (44) abc
OB.59	0-10cm	3.1 (0.4) e	21 (15) g	21	181 (26) abc
70.OB	5-10cm	4.9 (2.4) f	43 (11) cdef	52	102 (83) abcdef
70.OB	0-5cm	4.7 (1.6) f	46 (3) cdef	47	110 (47) abc

* : geometric mean xC/xN : mean %C / mean %N
means followed by the same letter were not significantly different at p = 0.5

probably due to the wide variation in the thickness of its surface organic layer.

Carbon and nitrogen levels of OB.SH and OB.59 were higher than those of 70R and less than those of 70F. Levels of C, N, and available P in 70.OB were similar to those of 70P. OB.59 and 70.OB were acidic, having pH values similar to those found in natural soils in the area. The high pH of OB.SH suggested the inclusion of unweathered, unleached rock.

The high organic content and an active biota were the most likely reasons for the vigorous natural plant invasion observed on the overburden. Higher concentrations of N in the overburden accelerate the growth of plant species unable to fix N. An active biota (e.g., mycorrhiza) may make important contributions to P availability. On the recently exposed sterile wasterock, P will be a limitation for germinating seedlings unable to release P from apatite. In some cases, accelerated plant colonization resulted from plant propagules already present in the overburden. Some of the plant growth on 70.OB (e.g., vaccinium) probably resulted from this. However, many of the early colonizers (e.g., willow) were not present in the surrounding forest and arrived from offsite.

Off the wasterock dumps, subsurface seepage contributes to the strong growth of plants established on the overburden, and colonization often followed seepage lines. In general, the disturbed overburden was very shallow,

allowing plants to intercept drainage that collected and flowed along the bedrock/soil interface. However, when overburden is spread as a veneer on the surface of a well-drained dump, this will not occur.

4.2 Plant Growth

4.2.1 Grass and Legume Growth on the Bench Trials

4.2.1.1 Trial 70.1: Species/Amendment

Trial 70.1 tested four surface treatments and seven seed mixes. The seed mixes and fertilizer rates are listed in Tables 1.6 and 1.8. The four surface treatments were a control (70R), fertilizer (70F), and two treatments receiving peat (70P and 70PF). No record was kept of the amount of peat applied.

Percent cover, biomass, and foliar chemistry were measured on the resulting growth.

The vegetative cover was measured in 1980, 1981, and 1983, the 11th, 12th and 14th growing seasons. The raw data is presented in Appendix C. The average moss, native vascular plant, grass, and legume covers for the monitoring period are listed in Table 1.28. The grass plus legume cover for each treatment combination in 1971, 1972, and 1976 (from Price, 1982) are also included. The average cover of individual vascular plants whose cover was greater than 0.5% is given in Table 1.29.

The poorest substrate for agronomic growth was the unfertilized wasterock (70R). Clumps of grass found on 70R were small, chlorotic, and had few flowers. The only notable change in the vegetation on this treatmentmost was the invasion of native species. In 1983, the cover of native

Table 1.28 Average percent cover on different treatments in Trial 70.1

	% Grass + Legume						% Grass			% Legume			%Inv	% Moss	
Treatment	71	72	76	80	81	83	80	81	83	80	81	83	83	81	83
70R1	12	6	1	3	2	1	3	2	tr	tr	0	0	tr	6	12
70R2	11	6	1	3	tr	1	3	tr	tr	0	tr	tr	1	2	11
70R3	2	2	1	4	tr	1	4	tr	tr	0	0	0	1	2	13
70R4	9	7	2	5	1	1	4	0	tr	1	1	tr	tr	9	20
70R5	6	5	3	8	3	4	5	tr	1	4	3	2	1	6	22
70R6	12	19	3	7	2	3	6	1	1	1	1	1	1	15	27
70F1	72	77	48	40	19	4	36	14	2	5	4	2	tr	63	58
70F2	66	52	25	33	12	3	31	10	2	2	2	1	1	53	40
70F3	60	87	45	45	27	9	35	19	6	10	8	3	tr	64	66
70F4	42	66	18	24	9	9	18	4	4	6	4	3	1	59	47
70F5	24	65	58	63	53	50	29	17	11	34	36	39	0	72	80
70F6	64	83	34	32	20	12	21	9	4	11	12	8	tr	63	62
70P1	76	95	72	66	39	18	55	34	11	12	11	6	1	72	84
70P5	27	98	79	74	74	61	37	26	12	38	47	48	1	89	95
70P6	68	98	52	36	20	18	21	7	6	15	13	12	tr	91	92
70PF1	34	51	55	44	20	10	39	17	8	5	2	1	1	70	64
70PF5	5	18	25	22	13	10	13	5	2	9	7	7	1	32	41
70PF6	13	18	17	21	14	5	14	4	2	7	2	3	1	37	45

tr : 0.5-0.9%
71, 72, & 76 : from Price (1982) Inv : naturally invading vascular plants

Table 1.29 Average percent cover for individual agronomic species growing on Trial 70.1.

Treatment	Birdsfoot Trefoil 81	83	Alsike Clover 81	83	White Clover 81	83	Sainfoin 81	83
70F1			1	tr	4	2		
70F2					1	1		
70F3			5	2	2	1		
70F4	1	2	2	1	tr	tr		
70F5	35	37	1	1			1	1
70F6	8	5	3	2				
70P1	7	4	2	tr	3	2		
70P5	46	48					1	1
70P6	8	9	5	1				
70PF1			1	tr	1	1		
70PF5	6	7						
70PF6	3	1	2	1				

Treatment	Red Top 81	83	Red Fescue 81	83	Orchard Grass 81	83	Timothy 81	83	Reed Canary Grass 81	83
70F1			14	2						
70F2			10	1						
70F3	3	1	16	4						
70F4	tr	1			2	1			2	1
70F5	3	1	3	2	4	2	2	1	6	5
70F6	6	3	1	1			1	1		
70P1			34	11						
70P5	3	2	19	10	3	0	1	1		
70P6	2	2	4	3			1	tr		
70PF1			17	8						
70PF5	1	tr	5	2						
70PF6	2	1	2	1						

tr : 0.5-0.9%

vascular plants exceeded 1% on a number of the 70R treatment combinations.

While stronger than on 70R, agronomic growth on the 70PF peat treatment was significantly lower than that on 70P and 70F. In contrast to treatments 70F and 70P, 70PF did not produce either vigorous grass growth or sustained birdsfoot trefoil growth. The relatively large cover on 70PF1 probably resulted from its proximity to the 70P treated plots.

According to the original trial plan, the surface treatment on the 70PF plots was peat plus fertilizer. While the close contact between seed and fertilizer or excess acidity from acidification might account for the poor growth on fertilized peat, these theories do not account for the vigorous and abundant growth on the "supposedly" unfertilized peat (70P). Peat from the same source was used as a surface treatment in Trial 81.1 (Section 4.2.4.2). The poor agronomic cover on 70PF was similar to the unfertilized peat in Trial 81.1, and the vigorous growth on the fertilized peat in Trial 81.1 was more like the 70P treatment. This suggests that the 70P, rather than the PF, treatment was fertilized. The theory that plants growing on peat require fertilizer is supported by data from other studies. For instance, Maas (1972) stated that for organic soils on Vancouver Island, "although the level of total nitrogen in an organic soil may be ten times as high as in a mineral soil, its ability to release available N is quite low. At the same time the initial levels of available P and exchangeable K are also low." In Maas' (1972)

study the growth of agronomic species was very poor on unfertilized peat soils. Low available P levels and a high C:N ratio in soil samples collected from the 70PF plots suggested that a fertilizer application would improve growth. The low levels of available P in 70PF indicate that P fertilizer had not been applied.

For all the fertilized wasterock and the peat treatments, except 70F2, the agronomic cover increased from the 2nd to the 3rd growing season. The increase was most dramatic on plots sown with seed mix 5.

From the 3rd to the 7th growing season, the cover on all the treatments declined. The decline was greatest on the grass-dominated seed mixes (1,2,3,4,and 6), and may be, at least partially, attributed to a drop in the cover of vigorous short lived species like perennial ryegrass. Exhausted fertility may also have played a role. On the fertilized wasterock, the drop in surface pH as a surface litter layer developed may also have reduced grass growth.

From the 7th to the 11th growing season (1980), the agronomic cover remained fairly stable. During the monitoring period of this study (the 11th, 12th,and 13th growing seasons) there was a decline in the cover on all the seed mixes dominated by grasses (Table 1.31). The decline was particularly strong on fescue-dominated seed mix 1. Again infertility and a drop in pH were likely the cause. Infertility was suggested by the observation that the best grass growth occurred beside or within birdsfoot trefoil

clumps. On 70F5 and 70P5, the decrease in grass cover was partially compensated for by an increase in the cover of birdsfoot trefoil. During the monitoring period birdsfoot trefoil was the only agronomic species which increased its cover.

Throughout the monitoring period, the largest agronomic covers were on treatments 70F5 and 70P5. In 1983, the cover on these treatments were, respectively, 50% and 61%. The next highest covers, on 70P1 and 70P6, were only 18%. The vigorous growth on 70F5 and 70P5 was a result of sustained strong birdsfoot trefoil growth. On either treatment, birdsfoot trefoil accounted for over 75% of the cover and, given its large bushy growth form, an even larger proportion of the aerial biomass. In 1983, presumably as a result of the addded N, 70F5 and 70P5 also had the highest grass cover. Grasses were not included in seed mix 5.

Although less widespread, vigorous grass growth and litter production were also associated with the growth of a number of other legume species. After birdsfoot trefoil, the two commonest legumes were white and alsike clover. The most vigorous growth of white clover was on plots sown with seed mix 1, where it was scattered amongst the fescue swards. Alsike clover was a component of seed mixes 3 and 6.

The most common grasses were red fescue and red top. Red fescue was the dominant species on plots sown with seed mixes 1,2, and 3, while red top was the most common species on plots sown with seed mix 6. Unlike the other species which grew

singularly or in clumps, red fescue produced a dense matted turf-like growth. The only other abundant grasses during the monitoring period of this study, were orchard grass, reed canary grass, and timothy. These species have higher fertility requirements than red top and red fescue (Watson et al., 1980), and were growing well only amongst the birdsfoot trefoil clumps. Even there, strong growth was infrequent.

On all the surface treatment x seed mix combinations, plant cover was highly variable (Table 1.30). Variability was greatest for individual species (Table 1.31). This was especially true for legumes like alsike clover, that grew in scattered clumps and had, in many cases, coefficients of variance over 200%. The distribution of grass species tended to be less variable.

For all treatment combinations, the cover of moss was greater than that of vascular plants (Table 1.28). From highest to lowest, the ranking of surface treatments with regard to moss cover was 70P > 70F = 70PF > 70R. On 70P, differences in moss cover between seed mixes were much smaller than differences in agronomic growth. Smaller moss cover on 70P1, compared to 70P5 and 70P6, may be attributed to the competition for space between moss and the mat-like clumps of red fescue. Despite the strong vascular plant growth, competition for space did not appear to be a problem on 70F5 and 70P5. Most of the birdsfoot trefoil foliage was quite high and the moss was able to grow underneath it.

Table 1.30 Coefficients of variance for different cover types in Trial 70.1

	%Grass+Legume			% Grass			% Legume			% Moss		%Inv
Treatment	80	81	83	80	81	83	80	81	83	81	83	83
70R1	107	172	144	105	172					65	54	
70R2	103		122	103						112	72	152
70R3	98		85	98						78	76	87
70R4	94	336	114	83			305	336		72	72	
70R5	122	189	125	100		126	173	214	174	81	62	128
70R6	53	117	94	50	95	95	151	195	218	48	45	110
70F1	39	64	77	33	53	47	130	116	135	42	48	
70F2	36	43	61	36	39	95	127	146	158	54	61	137
70F3	33	80	74	37	94	103	93	81	97	34	30	
70F4	49	80	54	54	74	76	99	134	75	42	48	158
70F5	33	75	62	38	90	81	45	70	60	34	15	
70F6	37	87	68	30	79	95	100	109	71	55	46	
70P1	37	56	55	35	59	77	80	65	72	27	13	270
70P5	24	49	37	26	51	57	31	54	43	14	1	200
70P6	50	60	58	57	78	72	54	60	66	6	4	
70PF1	59	95	101	61	107	124	107	110	112	23	31	112
70PF5	67	97	108	58	98	134	100	118	119	70	63	129
70PF6	68	77	60	78	68	67	99	191	86	33	58	123

Inv : naturally invading vascular plants

Table 1.31 Coefficient of variance for different grass and legume species growing on Trial 70.1.

Treatment	Birdsfoot Trefoil 81	83	Alsike Clover 81	83	White Clover 81	83	Sainfoin 81	83
70F1			200		106	122		
70F2					146	137		
70F3			83	86	186	235		
70F4	115	95	247	178				
70F5	73	61	387	361			291	292
70F6	140	83	167	167				
70P1	50	76	198		123	134		
70P5	54	43					265	325
70P6	52	71	146	115				
70PF1			159		123	125		
70PF5	132	120						
70PF6	190	146	45	89				

Treatment	Red Top 81	83	Red Fescue 81	83	Orchard Grass 81	83	Timothy 81	83	Reed Canary Grass 81	83
70F1			56	51						
70F2			36	87						
70F3	76	84	113	135						
70F4		120			112	94			141	134
70F5	104	96	160	165	159	124	188	120	90	90
70F6	80	79	100	150			183	214		
70P1			59	77						
70P5	101	68	72	69	141	109	217	183		
70P6	66	61	101	122						
70PF1			108	128						
70PF5	146		114	141						
70PF6	65	60	116	106						

Rhacomitrium canescens (Hedw.) Brid. was the dominant colonizer on the stoney cover of 70R. Where some fines or litter accumulated or where the surface was gravelly rather than stoney, the most common moss species was Polytrichum juniperum Hedw. Where a dense organic layer had built up, polytrichum clumps were often mixed with those of other species (e.g., Drepanocladus aduncus and Aulacomnium palustre (Hedw.) Schwaegr.).

Lichen growth was only found on areas (e.g., 70R) lacking a surface organic layer. Similar to the increase in cover of moss from 1981 to 1983 on the unfertilized wasterock, increases were also noted for the lichen.

By the 15th season (1983), the cover of native species invading the trial site had reached 1% on more than half the surface treatment x seed mix combinations (Table 1.28). Invading species included a mix of early successional species, like willow, cottonwood, and fireweed, and species found in the surrounding forest, such as hemlock, vaccinium, Sitka spruce, and bunchberry (Cornus canadensis L.). The growth of woody native species is discussed in Section 4.2.2.1.

The above ground biomass was sampled in 1980, 1981, and 1984. Raw data for biomass weight is given in Appendix C. In 1980, foliage was sampled at the locations as the soils. The above ground biomass, surface cover, and some measures of foliar chemistry are included in Table 1.32. For 70F and 70P, unlike the soils data, there were significant differences in the foliar biomass produced by different seed mixes.

Table 1.32 Above ground biomass and foliar chemistry data from Trial 70.1 in 1980.

Treatment	Biomass (g/m2)		% Legume		% Grass	
R	7 (5)	a	0 (0)	a	1 (1)	a
PF	27 (25)	b	1 (1)	a	8 (9)	bc
F16	33 (18)	b	5 (5)	a	9 (10)	bc
P16	53 (40)	b	1 (2)	a	20 (27)	c
P5	213 (100)	c	38 (24)	b	7 (7)	ab
F5	390 (386)	c	51 (39)	b	2 (2)	a

Treatment	%N		%P		%K	
R	1.06 (0.50)	bc	0.096 (.043)	b	0.54 (0.24)	b
PF	0.72 (0.20)	a	0.086 (.026)	a	0.47 (0.17)	a
F16	1.37 (0.59)	c	0.111 (.016)	bc	0.83 (0.27)	bc
P16	0.93 (0.31)	b	0.112 (.024)	c	0.78 (0.34)	bc
P5	2.07 (0.40)	c	0.132 (.025)	c	1.17 (0.10)	c
F5	2.02 (0.18)	c	0.095 (.026)	ab	1.08 (0.33)	c

7 (9) : average (standard deviation)
means followed by the same letter were not significantly different at p = 0.5

Differences were between the legume-dominated seed mix 5 and the grass-dominated seed mixes 1 and 6. As a result, for 70F and 70P, biomass data from seed mix 5 was treated separately, while data for seed mixes 1 and 6 were combined. On 70R and 70PF there were no significant differences in among seed mixes, so the data from different seed mixes were combined.

As expected from its small plant cover, 70R had a significantly lower foliar biomass weight than all the other treatments. Next lowest were 70PF, 70F16, and 70P16, none of which were significantly different, although the average biomass on 70PF was almost half that on 70P16. Biomass weights from 70F5 and 70P5 were significantly higher than all the other treatments. The biomass samples taken of individual samples in 1981 confirmed that the strong plant growth from seed mix 5 was a result of vigorous birdsfoot trefoil growth (Table 1.33). Fifteen seasons after the trial was established, birdsfoot trefoil still produced yields of 3000 to 4000 kg biomass/ha, yields as large as the best growth on recently fertilized treatments in other trials (Table 1.34).

Like the plant cover data, the biomass production within treatments was highly variable (Table 1.34). Almost all the treatments had coefficients of variation greater than 50%. Many were more than 100%. The most variable growth was on 70F5. Although the average biomass on 70F5 was much larger than on P5, due to the high variability on 70F5, the two treatments were not significantly different.

Table 1.33 Above ground biomass of species sampled in Trial 70.1 in September, 1981.

Species	Above Ground Biomass (g/m2) 70R	70F	70P	70PF
Red Fescue	43	74	117	141
Alsike Clover	73	229	90	98
Birdsfoot Trefoil	13	257	397	98

Table 1.34 Above ground biomass of agronomic species in trials in September, 1984.

Trial	Treatment	#	Above Ground Biomass (g/m2) Mean	Std Dev	Species
70.1	70F5	4	389	263	birdsfoot trefoil
	70P5	4	374	64	birdsfoot trefoil
81.1	Peat+Fert.	12	383	169	grass + legume
82.1	WR	8	308	106	mainly grass
	OBSH.10	8	195	66	mainly grass
	OBSH.30	8	98	49	mainly grass
	OB59.10	8	223	49	mainly grass
	OB59.30	8	211	19	mainly grass
82.1	EG	10	214	126	grass
	GL	10	226	50	grass
	L	10	182	88	grass + legume

: number of samples
P : peat
F or WR: fertilized wasterock
OB : overburden
SH : Spy Hill
594 : 594 bench
5 : seed mix #5

10 : 10 cm deep
30 : 30 cm deep
EG : erosion controlling grasses
GL : grass + legume
L : legumes

The ranking of treatments in terms of biomass production compared more closely with the agronomic plant cover in 1983 than that in 1980. This was because many of the species with large covers in 1980 were thrifty grasses with short, thin leaves, and thus little biomass. This was illustrated by the relatively small biomass of vigorous red fescue growth in 1981 (Table 1.33). Compared to the grasses, the legumes had much larger stems and leaves and grew much higher. In 1980, the thrifty grasses contributed a lot of cover but not much biomass. In 1983, they did not contribute much cover either.

As expected, the predominantly legume samples from 70F5 and 70P5 contained substantially more N than the other treatments. The correlation coefficient for N and legume cover was r=0.67. Of the grass-dominated treatments, the peat-treated areas (70PF and 70P16) had lower average foliar N concentrations than either of the wasterock treatments (70R and 70F16). A lack of available soil N on the peat could have resulted from microbial immobilization, as these soils had high C:N ratios.

There were no strong correlations for measures of foliar composition with soil properties. Of the different soil assays, foliar N was most strongly correlated with the 5-10cm %N levels (r=0.44).

Some differences in foliar P (e.g., 70P5 and 70P16 > 70R and 70PF) may be ascribed to differences in availability of soil P, as the strongest correlation between plant P and the

soil chemical properties was with the 5-10 cm available P. However again the correlation was not very strong (r = 0.4).

The ranking of treatment means for %K generally followed that of foliar biomass. With the high precipitation, it was unlikely that residual fertilizer K remained. Thus K uptake likely depended upon the ability of plants to exploit K present in the wasterock.

Converting foliar chemistry data into a weight per area basis did not necessarily result in more statistically significant differences among treatments, because there was also much more within group variability when the data was expressed in this form. For example, for 70F5, the coefficients of variance for %N and N/m^2 were 9% and 99% respectively. Notably the coefficient of variance for N/m_2 on 70F5 was the same as that for foliar biomass.

4.2.1.2 Trial 82.1: Species/Amendment

The objective of this trial was to test the effectiveness of different overburden treatments, seed mixes, and tree species, components in the proposed sequence of amendments for developing a forest on the wasterock dumps. The surface treatments were a wasterock control (WR), and 10 and 30 cm depths of two overburden types (OB.SH and OB.59). The seed mixes contained erosion-controlling grasses (EC), grasses and legumes (GL), legumes (L), and annual ryegrass (AG). The components of the seed mixes and the rates at which the seed and fertilizer were applied are listed in Tables 1.6 and 1.8. These amendments were applied in 1982. Alder and pine seedlings were planted in 1983. Their growth is discussed in Section 4.2.2.3. The trial design included four blocks, each containing five plots. Each surface treatment was applied to one plot in each block. Each seed mix was applied to one split plot in each plot, and five of each seedling species were planted on one split-split plot in each split plot. The raw data collected from Trial 82.1 is presented in Appendix C.

Results of the analysis of variance done for cover are shown in Appendix C. In the analysis of variance, five x second order interactions were significant. These were block x soil, block x year, soil x herb, soil x date, and herb x

date. Treatment means[1] for these, along with the results of Duncans Multiple Range Test, are listed in the Appendix C.

For seed mix x date effects, the greatest source of variation was the rapid decline in the annual grass cover (Figure 1.7). Annual grass had the largest cover in the first year, and the smallest in subsequent years. For the other seed mixes, the size of the cover for all 3 years was EC > GL >> L. For all three perennial seed mixes, the cover was highest in 1983 and lowest in 1982.

The ranking of soil types according to cover was WR $\geq$ OB59.10cm > OB59.30cm and OBSH.10cm > OBSH.30cm (Figure 1.8).

None of the block effects were significantly different for the wasterock (Figure 1.9). However, the cover on the overburden treatments varied significantly. Variable growth on the same overburden treatment can be attributed to differences in the original unconsolidated material. No effort was made to mix the overburden prior to applying it. Differences may also result from any stratification (e.g., gravimetric separation by particle size) during the loading and unloading of the overburden onto and out of the trucks.

At the end of the first growing season, the most vigorous species was annual ryegrass. At the end of the second growing season, the most vigorous species were perennial ryegrass, red

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[1] In order to meet the homogeneous variance requirement for analysis of variance, both the percent cover and the biomass data were transformed into the logarithmic form. Thus the treatment means listed are geometric rather than arithmetic averages.

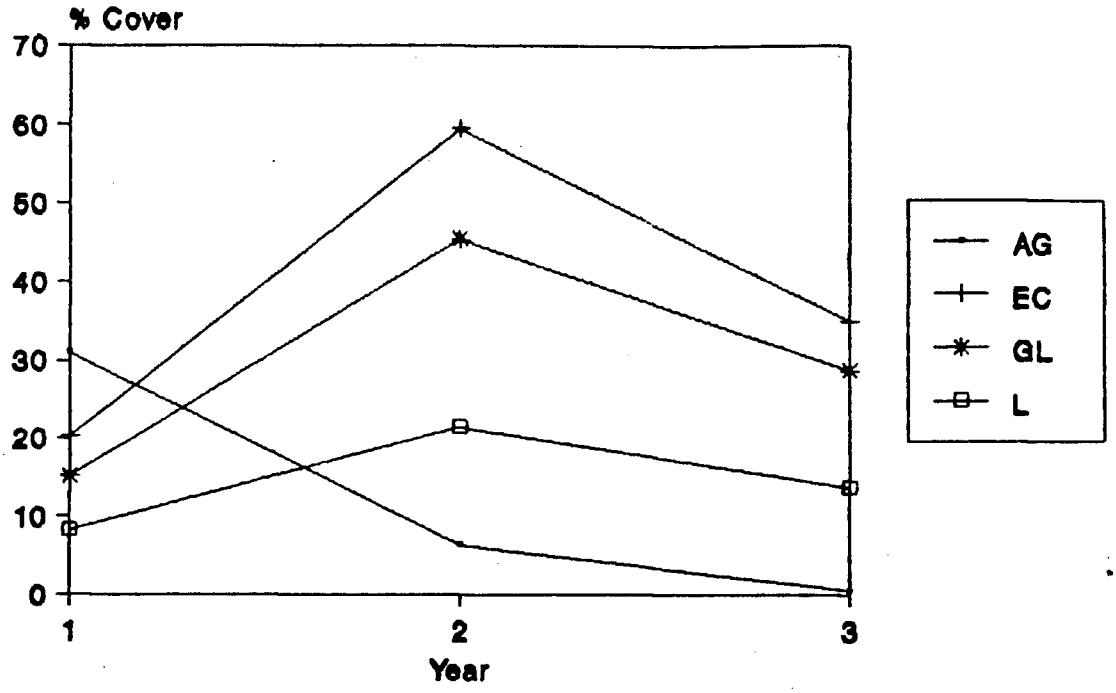

Figure 1.7 Average agronomic cover for the year x seed mix combinations in Trial 82.1.

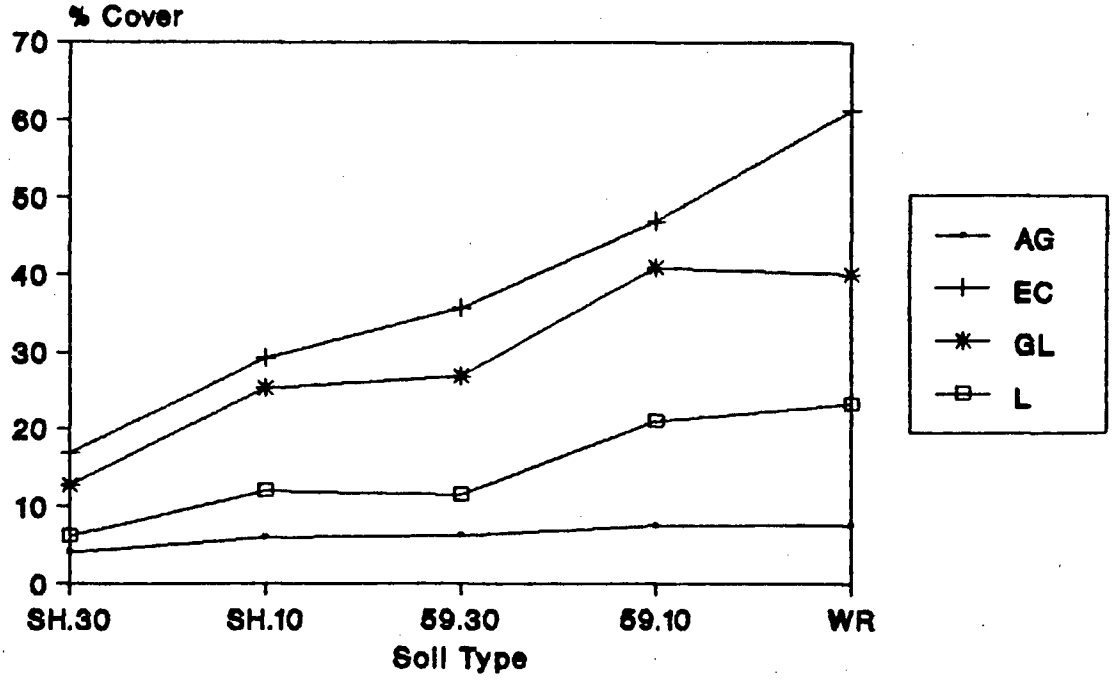

Figure 1.8 Average agronomic cover for the soil type x seed mix combinations in Trial 82.1.

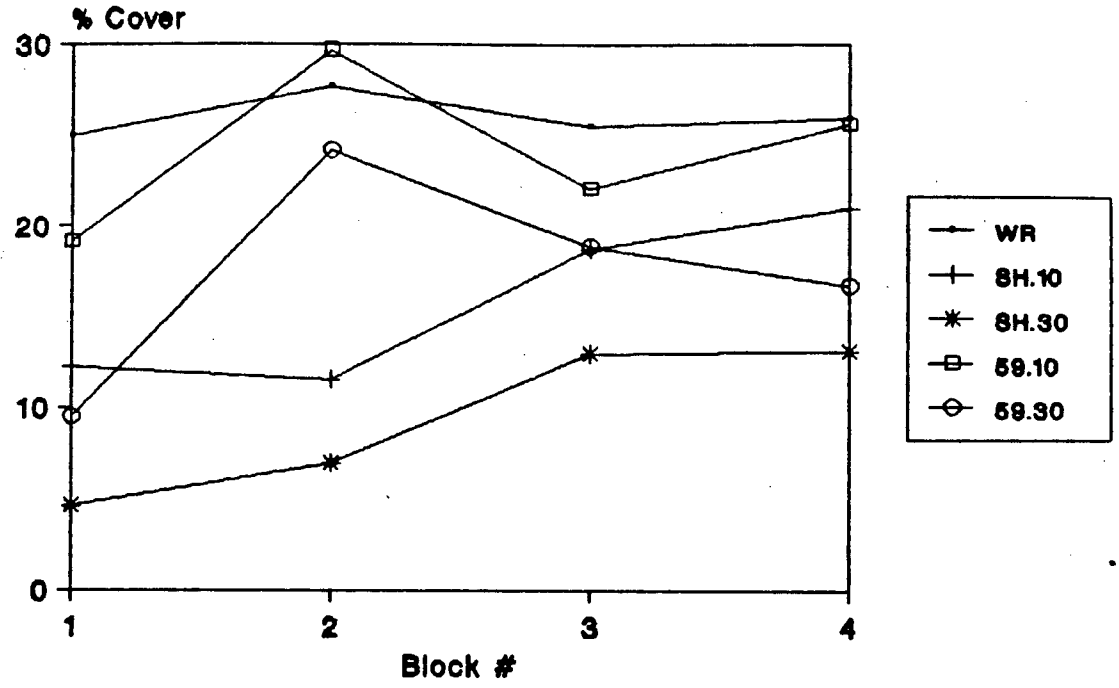

Figure 1.9 Average agronomic cover for the block x soil type combinations in Trial 82.1.

fescue, red top, and orchard grass (Table 1.35). In the third season the cover of perennial ryegrass declined dramatically, while that of red fescue increased. The decline in ryegrass cover can be attributed to its short lifespan. Changes in the cover of other grasses were probably a function of the competition for resources and space. The good ground cover and abundance of litter produced by the grasses on the EC and GL treatments suggest that both these seed mixes could be used for erosion control. Notably, the cover that resulted from the 20 kg/ha of grass seed applied as part of the GL seed mix almost equalled that grown from the 100 kg/ha applied on the EC plots.

While its performance in terms of erosion control was promising, the GL seed mix failed to produce a good cover of legumes. Little or no legume growth occurred on any of the plots. This was surprising because in the GL seed mix, the amount of grass seed was lower, while that of legumes (birdsfoot trefoil and white clover) was higher than the seed mix, which produced a good cover of legumes in Trial 81.1. This can be attributed to the poor growth of birdsfoot trefoil (Table 1.35). Results from demonstation plots set up adjacent to the trial indicate that the poor birdsfoot trefoil growth resulted from the poor viability of the seed.

On the plots sown entirely with legumes, initially the dominant species was alsike clover. However the alsike clover cover declined precipitously in the third year, and timothy,

Table 1.35 Average percent cover of agronomic species in Trial 82.1.

Seed Mix - Species	WR		OBSH 10 cm		OBSH 30 cm		OB59 10 cm		OB59 30 cm	
	82	83	82	83	82	83	82	83	82	83
Annual Grass										
-Annual Ryegrass	46	8	33	7	23	6	36	8	28	7
	83	84	83	84	83	84	83	84	83	84
Erosion Control										
-Perennial Ryegrass	35	2	34	2	18	3	33	1	23	2
-Red Top	28	16	7	7	4	4	25	15	22	12
-Orchard Grass	18	28	3	5	3	5	8	10	12	8
-Red Fescue	20	33	15	14	10	8	21	20	26	23
Grass + Legume										
-Perennial Ryegrass	29	1	21	1	14	4	25	0	14	1
-Red Top	25	15	10	5	3	5	32	19	21	19
-Orchard Grass	16	16	13	19	6	6	17	14	13	10
-Creeping Foxtail	2	10	1	6	1	0	2	7	2	10
Legume										
-Timothy	4	11	3	6	2	4	5	7	4	6
-Alsike Clover	34	5	15	6	9	8	26	13	22	11
-Birdsfoot Trefoil	1	1	1	1	0	0	1	0	1	0

82 : at the end of the first growing season
83 : at the end of the second growing season
84 : at the end of the third growing season

which was a contaminant, became the most vigorous species. Again there was little or no birdsfoot trefoil growth.

Biomass was sampled on Trial 82.1 in 1984. Results of the analysis of variance are given in Appendix C. The ranking of average biomass weights for the main effects were the same as for percent cover (Table 1.34). However unlike cover, for biomass significant differences were found in soil x block x seed mix effect. The great variability in the biomass data was a result of estimating biomass from small subsamples. All the cover types contained a high proportion of coarse fragments and the number of samples and the size of the area sampled (900 cm^2) were too small to average out the local effects of surface stones on plant growth, effects which were averaged out in the cover measurements. The number of biomass samples was not increased to avoid the destructive effects of this form of sampling on subsequent plant and soil development.

4.2.2 Woody Plant Growth in Bench Trials

4.2.2.1 Trial 70.1: Conifer Species

Four conifer species were tested; amabalis fir, western hemlock, Sitka spruce, and lodgepole pine. The surface treatments, seed mixes, and fertilizer applied were those of Trial 70.1. No record was kept of the number of seedlings planted, so it was not possible to measure their % survival. Mean height and growth-per-year for each species x treatment combination after 10 (1980), 12 (1982) and 15 (1985) years of growth are shown in Table 1.36.

Of the four species, amabalis fir (Abies amabalis (Dougl.) Forbes) performed poorest. On the rows between the unfertilized (70R) and the fertilized wasterock (70F) plots, it barely survived and as a result of dieback, its average height actually decreased. Amabalis fir's best growth was on the peat (70PF) and the annual grass (70AG) plots, where it averaged 1.0 and 1.5 cm of height growth per year.

Although they grew faster than the fir, the Sitka spruce (Picea sitchensis (Bong.) Carr.) and western hemlock (Tsuga heterophylla (Raf.) Sarg.) also grew slowly. Hemlock and spruce seedlings planted on the inter-plot rows of treatments 70F5 and 70P5 grew 5 to 7 cm per year. This was the best inter-plot growth of either species, and was due, in part, to the contribution of N from neighbouring birdsfoot trefoil. The best growth of Sitka spruce was by seedlings planted on 70P5 plots. Averaging 102 cm, these individuals were markedly

Table 1.36 Average heights and annual growth of conifers planted in Trial 70.3.

Species	Treat	Plot	#	Mean Height (cm) 10 yr	12 yr	15 yr	Growth (cm/yr)
Amabalis Fir	R	P	4	13	13	15	0.2
		I	16	12	12	12	-0.1
	F-5	I	7	17	17	16	-0.3
	F5	I	2	22	19	19	-0.7
	PF	I	9	22	24	27	1.0
	AG1	I	2	34	36	42	1.5
Western Hemlock	R	P	3	27	33	41	2.9
		I	13	30	35	35	1.0
	F-5	I	6	26	29	49	4.7
	F5	I	2	29	40	63	6.7
	PF	P	2	23	30	38	3.0
		I	9	25	27	34	1.8
	AG1	I	11	27	33	41	2.8
Sitka Spruce	R	P	2	13	16	20	1.5
		I	16	30	30	32	0.4
	F-5	I	8	29	29	33	0.7
	F5	I	2	30	44	55	5.0
	P5	P	9	69	85	102	6.6
		I	5	49	62	74	4.9
	P16	P	1	62	59	91	5.8
	AG1	P	1	44	47	54	2.0
Lodgepole Pine	R	I	6	34	34	40	1.6
	F-5	I	1	65	81	112	9.4
	F5	I	1	30	51	82	10.4
	PF	I	10	58	76	95	7.4
	AG1	I	9	80	91	104	4.8
	AG2	I	15	78	86	99	4.2

Plot P : plot Plot I : interplot 5 : seed mix #5
: number of seedling measured -5 : all seed mixes except #5
16 : seed mixes 1 and 6

taller than any of the spruce seedlings planted between the plots. They also looked healthier, with thick, dark green foliage and longer needles.

On the unfertilized wasterock, the height of lodgepole pine (Pinus contorta var. contorta Dougl.) was similar to that of western hemlock. On all the other treatments, lodgepole pine was much taller than the other conifers. On 70PF, 70AG1, and 70AG2, the pine foliage had good colour and there was strong leader growth. However where the pine were growing fastest, a large number had broken branches and pronounced cork-screwing of their stems, signs of snow damage.

4.2.2.2 Trial 77.1: Sitka Alder

This Trial was established on the terrace bench adjacent to Trial 70.1. The Sitka alder seedlings were transplanted from a disturbed area near the mill. Unlike the conifers planted in Trial 70.1, the alder were not fertilized. The individual alder heights, and in some cases, widths measured after 3 (1980), 4 (1981), 5 (1982), 6 (1983), 7 (1984), 8 (1985) and 10 (1987) years of growth are listed in Appendix C. The data from 1987 was collected by AMAX. The mean height, standard deviation, average growth rate, and number in different height categories are shown in Table 1.37.

From 1980 to 1987, the average height of the alder seedlings increased from 42 cm to 158 cm, an increase of 16.6 cm per year. Height measurements were made on the tallest shoot. Most seedlings had five or six large shoots, many of

Table 1.37 Alder growth statistics from Trial 77.1.

Year	Height (cm)		Growth (cm/yr)	Number of Seedlings					
	Mean	Std Dev		0-51 cm	51-75 cm	76-100 cm	101-125 cm	126-200 cm	>201 cm
3	42	15		20	4	1			
4	56	27	14	14	7	2	1	1	
5	68	31	12	8	9	5	1	2	
6	90	39	22	3	7	6	6	3	
7	110	46	20	1	6	3	5	8	2
8	118	48	8	1	6	3	4	9	2
10	158	59	20			4	5	11	5

which were not just growing up but also spreading out. As a result, the width of each shrub was growing at much the same rate as the height. By the 7th year growing season, the canopies of the shrubs, which were planted at a 4 ft. row spacing, started to coalesce. Many individuals produced seed, and litter had accumulated beneath the prostrate lower branches.

4.2.2.3 Trial 82.1: Sitka Alder and Lodgepole Pine

The surface amendments, seed mixes, and fertilizer applied in this trial are described briefly in Section 4.2.1.2 and in more depth in Appendix A. In 1983, a year after the seed and fertilizer were applied, five one year-old lodgepole pine and Sitka alder seedlings were planted on each block x soil type x seed mix combination in Trial 82.1. The average rate of survival for each species in each year is shown in Table 1.38. In 1985, 59% of the alder and 27% of the pine survived.

The results from the analysis of variance carried out on the seedling survival data from 1985 are shown in Appendix C. According to the analysis of variance, soil x block, soil x tree species and seed mix effects were all significant. In 1985, alder survival was greater than pine survival on all the soil types and seed mixes (Table 1.39). Seedling mortality was attributed to 3 causes: soil cover, competition with agronomic plants, and damage by the long tailed vole (Microtus longicaudus (Merriam)). For alder, there was a significant

Table 1.38 Average survival of alder and pine over the first three years of growth in Trial 82.1.

Year	Species	% Survival Mean	Std Dev
1	alder	77 c	31
2	alder	59 b	37
3	alder	59 b	36
1	pine	62 b	31
2	pine	27 a	32
3	pine	27 a	31

means followed by the same letter were not significantly different at p = .05

Table 1.39 Average, height, and growth of seedlings on different treatments in Trial 82.1.

	Sitka Alder				Lodgepole Pine			
	% Survival	Height 84 (cm)	Height 87 (cm)	Growth (cm/yr)	% Survival	Height 84 (cm)	Height 87 (cm)	Growth (cm/yr)
Soil Type								
WR	34	22	83	20	4	17	14	-1
OB59.10	51	18	94	25	34	26	38	4
OB59.30	63	20	100	26	30	27	41	4
OBSH.10	75	29	112	28	29	23	26	1
OBSH.30	88	38	143	35	23	25	37	4
Seed Mix								
AG	83	33	129	32	36	22	30	3
L	63	29	108	26	19	22	30	2
GL	53	19	92	24	20	29	42	4
EC	49	20	99	27	20	27	33	2

correlation between survival in 1985 and the herbaceous cover in 1983 (r=-.67), suggesting that problems resulting from the herbaceous cover masked any differences due to soil properties. The correlation between pine survival and 1983 herbaceous cover was much weaker (r=-.30). Pine survival was lowest on the two Spy Hill overburden treatments.

Competition with vigorous agronomic plant growth was a problem where the tall, dense grass growth buried the seedlings (e.g., seed mixes EC and GL on surface treatments WR). Planting the seedlings in the second growing season put the seedlings at a disadvantage by combining the period when grass growth was most vigorous with the time when the seedlings were most vulnerable.

While direct competition caused some seedling mortality, the greatest effect of the herbaceous growth was its role as a habitat for voles. In 1982, there were no signs of voles. However, in late August-early September 1983 the signs of vole activity were everywhere. The most obvious signs were the voles themselves. There were also a number of nests, lots of clipped grass and faeces, and a large number of clipped or girdled seedlings. Vole-inflicted damage was most extensive and severe on the treatments with the largest cover. However there was an edge effect, as the grass cover on the EC and GL subplots also influenced the amount of vole activity on the neighbouring AG and L treatments.

In the seedlings first growing season (1983), the voles preferred to eat the alder. Over the seedlings first winter

(1983-1984), almost all the alder and a large proportion of the pine were attacked. Although more alder were attacked, more pine were killed. This was because the pine did not resprout after its the main stem was cut, while even where all the above-ground alder growth was eaten over the winter, it produced basal shoots and leaves the next spring.

In 1984, undamaged seedlings rose above the grass cover. However, shoots on damaged seedlings were much lower, and could be buried by dense foliage and litter. In 1984, signs of vole activity had decreased. Although the grass was clipped in a few areas, there was no new seedling damage. One reason for the decreased vole activity was the increased activity of predators. In the fall of 1984, a large hawk was observed on numerous occasions catching voles at the site. In 1985, there were no new signs of vole activity.

Average height and growth data for 1984 to 1987[4] for each soil type and seed mix combination shows the great difference between pine and alder growth (Table 1.39). 1984 was used as the initial year for calculating growth to avoid the changes in height resulting from vole damage. Over the study period pine grew very slowly. The maximum average growth of pine was 4 cm per year. By comparison, alder averaged from 20 to 35 cm height growth per year and by the end of its fifth growing season averaged over a meter tall. Comparing different treatments, the alder growth was greatest where its survival was highest. On these treatments (e.g., OBSH.30), most of the alder only had one stem, while growth of damaged alder was

usually split among a number of shoots. In both cases, growth exceeded that of all other species.

4.2.3 Natural Plant Invasion

4.2.3.1 Natural Plant Invasion of Untreated Surfaces

Table 1.1 shows the number and height of native species growing on surfaces disturbed prior to 1973. Two kinds of surfaces were examined: disturbed natural surfaces and wasterock. The sites sampled on the overburden were randomly chosen. On the wasterock, only the sites with the strongest plant growth were examined. As a result, sampling of the wasterock was restricted to the benches. There was no growth on the slopes except for the thin fines-containing strip at the top.

On the overburden and wasterock the most numerous invaders were the annual forbs fireweed (Epilobium angustifolium L.) and redweed (Epilobium ulatifolium L.) respectively. The dominant understory species in the surrounding forest, vaccinium and false azalea, were also quite common, although neither was growing very vigorously.

Plant invasion was substantially greater on the overburden than on the wasterock (Table 1.40). Even more striking than the differences in the number of seedlings established were the differences in seedling height. The average number of seedlings per 100 m2 taller than 69 cm was 31 on the overburden and less than 2 on the wasterock. This indicates that the woody species invaded sooner and have grown faster on the overburden. On all the surfaces, cottonwood and

Table 1.40 The number and height of woody species in 1984 on untreated surfaces abandoned in 1972.

Number of Seedlings per 100 m2

Species	Overburden A 10-69cm	Overburden A >70 cm	Overburden B 10-69cm	Overburden B >70 cm	Overburden C 10-69cm	Overburden C >70 cm	Overburden D 10-69cm	Overburden D >70 cm	Overburden E 10-69cm	Overburden E >70 cm
Cottonwood	7	5	12	14	2	15	2	3		25
Willow spp.	7	10	32	16	7	22	6	5	15	25
Sitka Alder	1	1				1	2			12
Hemlock spp.	1				11	1			12	
Sitka Spruce						1				
Total	16	17	44	30	20	40	10	8	27	62

Species	Wasterock Bench A 10-69cm	Wasterock Bench A >70 cm	Wasterock Bench B 10-69cm	Wasterock Bench B >70 cm	Wasterock Bench C 10-69cm	Wasterock Bench C >70 cm	Wasterock Bench D 10-69cm	Wasterock Bench D >70 cm	Wasterock Bench E 10-69cm	Wasterock Bench E >70 cm	Wasterock Bench F 10-69cm	Wasterock Bench F >70 cm
Cottonwood	17		26	2	17		6		6		3	
Willow spp.	11	2	19		10		4	3	2	1	2	1
Sitka Alder												
Hemlock spp.	17				3		4		5			
Sitka Spruce					3		1				2	
Total	45	2	45	2	33	0	15	3	13	1	7	1

willow were the most vigorous tree species. The surrounding forest provided large amounts of hemlock seed and thus hemlock seedlings were also common, but they were not growing very vigorously. The only hemlock taller than 69 cm was growing beside a large Sitka alder.

Sitka alder was the dominant species on naturally disturbed areas adjacent to the mine site and on disturbed overburden near the mill. On the wasterock dumps and disturbed overburden around the pit, Sitka alder was relatively scarce. However where it was established it was growing vigorously. Of the 17 Sitka alder found on the overburden sites, 14 were higher than 70 cm high. Due to its dense bushy growth, the above-ground biomass and litter accumulation beneath the Sitka alder were greater than that for any other species. In addition to having denser growth, the alder foliage also was less chlorotic and had less insect damage.

4.2.3.2 Woody Plant Invasion of Trial 70.1

The height of each woody plant that invaded the 70.1 field trial was measured in the trial's 11th (1980), 13th (1982) and 16th (1985) season of growth. This data is shown in Appendix C. Hemlock, vaccinium, willow, or cottonwood accounted for almost all the woody plants that invaded the trial site, but there were also a few alder and spruce seedlings and a number of small false azalea. On all the treatments the rate of plant invasion was higher on the inter-

plot rows than on the plots (Table 1.41). This was especially true on the treatments with strong agronomic plant growth, and suggests that competition for space affected the rate of invasion that can occur.

Hemlock was the most common species on the surface treatments where there was little or no agronomic plant growth, while vaccinium was most common species on the treatments (70F, 70P and 70PF) with a surface litter or peat layer. The prolific invasion of hemlock and vaccinium resulted from their dominance in the surrounding forest, where they are the most common overstory and understory species respectively. The trial site bordered the forest on one side. On more isolated sections of wasterock, the rate of hemlock and vaccinium invasion would be reduced.

While natural colonization produced a good stock of hemlock, this was not the case for other species. In plant succession on glacial moraines in S.E. Alaska (Ugolini, 1967), Sitka spruce was the first conifer to grow vigorously. The forest adjacent to the Kitsault mine was over-mature, with little spruce, and very few spruce seedlings were found on the wasterock dumps. Thus it does not appear as if natural invasion can be relied upon to introduce spruce at Kitsault. The same conclusion applies to Sitka alder. Where alder was established it grew strongly, but only a few individuals were present.

The invasion of cottonwood and willow was greatest on fertilized wasterock originally sown with annual grass. The

Table 1.41 The number of seedlings colonizing different treatments in Trial 70.1 in 1982.

		Number/100 m2				Number/100 m2	
Species	Treatment	Plot	Inter-Row	Species	Treatment	Plot	Inter-Row
Hemlock Species	R	57	68	Cottonwood	R	6	9
	F16	11	12		F16	1	6
	F5	0	13		F5	0	6
	P16	0	14		P16	1	4
	P5	0	19		P5	3	6
	PF	47	86		PF	2	4
	AG1	47	55		AG1	23	21
	AG2	44	62		AG2	18	10
Vaccinium Species	R	10	14	Willow Species	R	8	8
	F16	17	92		F16	0	7
	F5	6	57		F5	0	0
	P16	19	163		P16	0	4
	P5	2	32		P5	0	0
	PF	33	57		PF	1	8
	AG1	11	13		AG1	11	10
	AG2	7	4		AG2	10	0

strong colonization on these areas can be ascribed to a lack of herbaceous competition for space and the residual fertilizer and organic matter. Conversely the poor colonization of willow and cottonwood on the 70PF treatment, where competition for space was also never intense, suggested that the highly acidic surface organic layer inhibited their germination.

While there were more hemlock and vaccinium, the cottonwood and willow grew much faster. There were no vaccinium and only one hemlock taller than 49 cm (Table 1.42). Even on the peat treatments, hemlock and vaccinium were unable to utilise the early successional environment as fully as the cottonwood and willow.

Growing rates were calculated for individuals taller than 49 cm to illustrate the growth rate of established seedlings (Table 1.42). The data shows that on a wide range of treatments, willow and cottonwood growth exceeded 10 cm/year. In a number of cases, their growth equalled or exceeded the growth of Sitka alder in Trial 77.1 (16.6 cm/year). However, cottonwood has only one stem, so compared to an alder of similar height, its biomass and cover was far less. Willow, like alder, produces a number of prostrate stems, and litter had accumulated beneath a few of the large willows. The amount of litter was less than that produced by alder of the same height because the willows produced less leaves.

Compared to the conifers planted on the same site, the cottonwood and willow were growing faster and in many cases

Table 1.42 The number, height, and growth of invading seedlings taller than 49 cm on different treatments in Trial 70.1.

Species	Treatment		Number	Height (cm)			Growth (cm/yr)
				1980	1982	1985	80-85
Hemlock	P5	Plot	1	10		55	9
Cottonwood	R	Plot	6	22	49	69	10
	F5	Plot	1			59	
	PF	Plot	3	17	62	90	15
	AG1	Plot	28	45	72	98	11
	AG2	Plot	16	56	71	98	8
	R	Inter-Row	2	26	40	59	7
	F16	Inter-Row	3	40	75	126	17
	F5	Inter-Row	1	20	39	98	16
	P5	Inter-Row	1	10		83	15
	AG1	Inter-Row	5	66	118	169	21
Willow	R	Plot	7	21	48	76	11
	PF	Plot	1	35	111	118	17
	AG1	Plot	7	70	105	121	10
	AG2	Plot	6	64	107	129	13
	R	Inter-Row	5	26	47	68	8
	F16	Inter-Row	2	53	88	134	16
	P16	Inter-Row	1	30	60	64	7
	PF	Inter-Row	3	40	58	77	7
	AG1	Inter-Row	3	40	77	141	20

were larger. A number of cottonwood and willow on treatment AG1 exceeded 2 m tall. Unlike the lodgepole pine, the willow and cottonwood showed no signs of snow damage.

4.2.4 Evaluating the Long Term Performance of Materials and Methods Tested in the Field Trials

Vigorous plant growth in field trials indicated that a number of materials and methods can be used to achieve a sustained vegetative cover on the terrace benches. The main questions remaining are 1. what is the optimal combination of components and 2. at what stage of plant and soil development can the site be abandoned? The reclamation objective at Kitsault is an erosion-controlling forest cover. Decisions about the appropriateness of the reclamation methods for meeting the overall reclamation objective and about the stage of plant and soil development at which the site can be abandoned remain unanswered at most B.C. mines. Where long term plant and soil development is required, field trials can only illustrate the preliminary stages, and hence their usefulness in answering these questions will be limited.

There is little long term evidence to draw upon from the mining industry. Large open pit mines are a relatively new development (1960s) and the reclamation of these mines is an even more recent (1970s). In addition mine wastes are unique substrates, and thus to a certain degree each reclamation project is breaking new ground. This is especially true in B.C., where small geographical differences can result in large environmental changes.

Most mines have been able to sustain agronomic plant growth on their mine wastes. However each new year of growth

is a record for that environment. Reclamation proceeds under the assumptions that any strong erosion-controlling plant growth ameliorates the rooting media, and that either suitable native species will eventually replace grass/legume cover or that the grass/legume growth will continue indefinitely to meet the reclamation objective. Little or no evidence is given to substantiate these assumptions.

The technique used in this study to answer questions about the appropriateness of reclamation methods, and for deciding under what conditions the site can be abandoned, was to look for a natural analogue of the processes of plant and soil development. The analogous situation selected was the forest development ocurring on moraines exposed by retreating glaciers in S.E. Alaska (Ugolini, 1967; Crocker & Major, 1955). Despite the geographical differences, the moraines and wasterock dumps are located in areas with similar climates, the available floras are almost identical and both have a coarse, barren rooting media. As a result the main pedogenic changes (the increase in N and surface litter and the decrease in pH and bulk density) on the dumps were similar to those observed during the early stages of plant succession on the moraines. The initial stages of plant succession (the establishment of a mix of pioneer and serally more advanced species, and the vigorous growth of cottonwood, willow and alder) on disturbed natural surfaces and in Trial 70.1 were also very similar to the initial stages of plant succession on the moraines.

On the moraines, the main driving forces for soil and plant development were the increases in soil N and the addition of surface litter, most of which resulted from the vigorous growth of Sitka alder. The importance of N for plant growth on the wasterock dumps was indicated by the dominance of birdsfoot trefoil in Trial 70.1, despite the initial application of N fertilizer and 15 years of organic inputs. The role of litter deposition in soil development was indicated, even at this early stage, by the strong relationship between pedogenic changes and plant growth and by the concentration of these changes at the surface.

Sitka alder was the most productive species in the field trials. In Trial 82.1, the average height growth of alder reached 35 cm per year and, unlike other woody species, its lateral growth was almost as great as the vertical.

If natural succession was relied upon, there would be a problem in getting alder established. Even on the moraines, it took 15 to 20 years for native invasion to stock the site. Natural alder colonization appeared to be even slower on the wasterock dumps. One reason for this is that dump construction is an abrupt event, while moraine exposure was a progressive process, occurring adjacent to previously exposed sites well stocked with seed-bearing alder. This suggests that forest development would be significantly accelerated if the alder were introduced. The trials indicate that this can be done using seedlings propagated from seed collected in the area or by transplanting alder from other disturbed sites.

In contrast to alder, the lighter-seeded willow and cottonwood rapidly colonized both the moraines and the wasterock. Although less efficient at litter production than alder, their presence is important for species diversity. Notably in Trial 70.1, the willow and cottonwood invasion and growth were markedly higher after a pretreatment of annual grass and fertilizer.

The later stages of forest development on the moraines were dominated by Sitka spruce and Hemlock species. On the moraines, within 5 to 10 years of deglaciation, a large number of spruce and hemlock seedlings were established. On the moraines, the coniferous seedlings did not start growing vigorously until there were dramatic increases in soil-N and litter. Observations from untreated areas on the abandoned dumps and in Trial 70.1, indicate that there will be a similar good stocking of hemlock seedlings, but there were very few spruce. The moraines are at sea level, where spruce is common, while the wasterock dumps, at 900 m, are surrounded by an over-mature forest containing very little spruce. On the moraines, spruce was able to utilize the site productivity much earlier than the hemlock. Thus if accelerating the coniferous stage of forest development is important, spruce should be introduced.

The only common species found in the plant successions on the moraines, not found on the dumps, was dryas. The absence of dryas is attributed to the absence of limestone. According to Lawrence et al, (1967) the main contribution of dryas was

to aid in the establishment and stimulate the early growth of woody plants. These functions can be replaced by adding fertilizer and planting seedlings.

Using the natural plant succession to select the most appropriate reclamation techniques does not limit the choice to native species or to plants for that matter. Some fertility problems can be resolved by using plant species adapted to infertile conditions. However, especially when plants are introduced, an application of fertilizer should increase growth. An application of fertilizer was required, to initiate the growth of agronomic species. A number of agronomic species performed well in the field trials, and there are a number of situations in which they may contribute. One way already suggested was to use a fertilized annual grass treatment to accelerate cottonwood and willow invasion. Another situation where agronomic species play a role would be for erosion control. However as Trial 82.1 illustrated, vigorous grass growth created a habitat for voles, which may retard the growth of woody species. If a dense grass cover is required for erosion control, seedlings should not be planted in the second year.

Of the agronomic species tested at Kitsault, by far the most productive species, with regards to N additions and litter production, was birdsfoot trefoil. Its slow initial growth and coated seed will make it less of a problem in terms of vole damage. The slow initial growth of trefoil will also reduce the competition with introduced seedlings. While the

additions of N by birdsfoot trefoil accelerated the growth of non-N-fixing species, its prolific growth also retarded plant invasion.

In the morainal succession, the stage of plant and soil development when N and litter additions were greatest and the process of forest development seemed assured was when the clumps of alder started to coalesce. At this time, the surface was no longer windswept, and hence all the litter production was conserved. It was also the time when litter and N levels were high enough to stimulate the growth of coniferous species. Thus this appears to be the earliest stage of plant and soil succession at which the goals of forest development and erosion control are assured and the site can be abandoned. The exact conditions at abandonment, with regards to species diversity and the presence of conifers (e.g., stocking and species composition), will depend on the speed with which forest development is required.

4.2.5 Slope Trials

In the provincial reclamation guidelines, the suggested method of reclaiming terraced dump slopes is to regrade slopes to a shallower angle. To meet this requirement, the Kitsault dumps have been designed so that two slopes and one bench can be regraded into one long slope. The advantages of regrading are that: 1) it reduces the likelihood of mass wasting and 2) by moving finer particles from the bench onto the slopes, one

creates a better media to support plant growth. The disadvantages of this procedure are the difficulty and inherent costs of moving large amounts of material.

While it is suggested that slopes be regraded, mines also have the option to leave slopes at their angle of repose. However in order to do this, mines must first show that this does not compromise the reclamation objective. The great difficulty and cost of regrading dumps makes reclaiming without regrading a very attractive proposition. However to date no mining companies have proven that this is possible.

4.2.5.1 Trial 75.1: Wasterock Trial

The first trial established on the slopes, Trial 75.1 was located on the north facing side of the low grade ore dump. The slope was 61 m long, approximately 36^{o}, and composed of potassic wasterock. Plots were 6 m wide and ran from the crest to the bottom of the slope. The only amendments were seed and fertilizer.The composition of the four seed mixes and the fertilizer rate are listed in Tables 1.7 and 1.8. Monitoring was carried out at the end of the sixth growing season, just prior to the removal of this section of the dump.

Although seed and fertilizer were broadcast over the entire slope length, plants growth was restricted to the upper 10 m, the only portion of the slope containing fines. Even within this limited area, plant growth was patchy, never exceeding a 2% cover.

4.2.5.2 81.1 Slope: Overburden Trial

The lack of plant growth in Trial 75.1 indicated that the main limitation to reclamation on the angle of repose slopes was the absence of fines. If these slopes are to be reclaimed, they must first be covered with a layer of soil-sized particles.

The obvious source of soil-sized materials was the overburden (unconsolidated soils and subsurface materials) that covered the minesite before the mine was built. The objective of this trial was to test the use of stockpiled overburden as a source of fines on angle of repose slopes. The trial site chosen was a recently built dump, whose slope was 30 m long and stood at 36^{o}. Again the wasterock was composed of potassic rock. Overburden was applied by pushing it over the slope crest, where it was spread by gravity. The overburden used was peat, which, although it contained many logs and roots, was relatively stone free compared to the other stockpiled overburden. Three rates, 0.6, 1.2, and, 2.4 x 10^3 m^3/ha, of the peaty overburden were applied. Half the overburden and the two wasterock plots were fertilized when the trial was established. The unfertilized plots were fertilized the following spring.

With all three overburden treatments, the peat slid approximately the same distance (10-15 m) down the slope. Tripling the amount applied thickened the depth of the overburden cap without increasing the portion of the slope covered. The failure of the peat to cover more of the slope

indicates that it had higher angle of repose than the wasterock. The high angle of repose appeared to be caused by the cohesive and fibrous nature of the peat. After the trial was constructed, both the dump face and overburden settled. This also made the overburden cap more stable. Subsequent root growth will have also contributed to the strength of the overburden veneer by binding particles together and anchoring the overburden to the wasterock below. In the four years that the trial was monitored, there were no signs of either surface erosion or mass wasting. Erosion and mass wasting could have covered a larger area of the slope with fines and thus at least initially, might be desirable.

Although fertilizer and seed were applied over the whole slope length, plant growth was limited to the upper fines-containing section of the plots. The cover estimates given in Table 1.43 refer only to the vegetated portions of the plots. On the plots without an overburden amendment, the fines-containing section was only 2 to 3 m long. Even where agronomic species established themselves on the wasterock, their cover (e.g., 16% at the end of the 4th season) was much lower than on the overburden. The only vigorous agronomic growth on the wasterock occurred on a tongue of fines created where boulders of incompetent rock had crumbled into smaller particles.

On plots with an overburden treatment, plant grew more vigorously and on a larger proportion of the slope, but growth was restricted to the portion of the slope covered with

Table 1.43 Cover of agronomic species on fines-containing portions of Trial 81.1.

Treatment	Year	Percent Cover		
		Total	Grass	Legume
Fertilized Wasterock	81	9	6	3
	83	23	19	4
	84	16	6	10
Fertilized Overburden (0.6 m3/ha)	81	40	35	5
	83	77	75	2
	84	52	50	2
Fertilized Overburden (1.2 m3/ha)	81	70	60	10
	83	52	40	12
	84	96	90	6
Fertilized Overburden (2.4 m3/ha)	81	50	35	15
	83	52	40	12
	84	106	70	36
Overburden ** (0.6 m3/ha)	81	10	4	6
	83	55	50	5
	84	41	26	15
Overburden ** (1.2 m3/ha)	81	20	10	10
	83	55	50	5
	84	52	42	10
Overburden ** (2.4 m3/ha)	81	15	6	9
	83	41	21	20
	84	77	32	45

** : fertilized in second year

overburden. The lower half to two thirds of these plots were covered with boulders and thus remained barren.

At the end of the first growing season, the cover on the fertilized overburden ranged from 40 to 70%, considerably greater than the 10 to 20% cover on the unfertilized overburden. The lack of erosion on the unfertilized overburden plots indicated that, at least over the first winter, a strong erosion-controlling plant cover was unneccessary.

Four years later the agronomic plant growth on the patches of overburden was comparable to the best growth in other trials (383 g/m^2 mean aerial biomass - Table 1.34). The cover remained greater on the fertilized overburden, but had increased for all the treatments. Notably for both the fertilized and unfertilized treatments, the highest overburden rate had the largest cover and the largest cover of legumes. Most of the legume cover resulted from the growth of birdsfoot trefoil. Subsequently, birdsfoot trefoil has become the dominant species on all the plots.

The conclusion derived from this trial was that peaty overburden would only be a good source of fines if some way was found to spread it out. The other problem with using peat was that there was not enough to cover all the slopes. While any overburden encountered during the most recent mine expansion were conserved, overburden from areas developed earlier have been buried. Another restriction on the quantity of overburden was that its depth was generally thin. Most of

the area over which the mine has recently expanded was previously covered by a thin layer of colluvium. In waterlogged depressions, deeper organic deposits were found but these were not very extensive.

The other problem with using overburden as an amendment is its quality. Most of the colluvium contained the same proportion of coarse fragments as the wasterock, and the rugged microrelief made it impossible for the machine operaters to seperate the surface organic layer from the rocky mineral material. The poor quality of the overburden was illustrated by the data from Trial 82.1. The average % < 2 mm in the two overburden types were 15 and 28%, compared to 30% for the wasterock. And the two overburden types were picked because they contained more finer particles than most of the material stockpiled. As the overburden had already been exposed to ambient conditions, their coarse fragments should be relatively resistant to weathering. The poor quality of the overburden was reflected in Trial 82.1, where the growth of agronomic species was as good or better on the wasterock.

In summary the available overburden resources on the minesite are limited and much of it is poor quality. Therefore other sources of fines should be considered. Bringing soils from other areas is undesirable, as it would be both prohibitively expensive and it would increase the area of land disturbed.

4.2.5.3 Trial 82.4 : Incompetent Wasterock Trial

An alternative to using "natural soil" is to use the wasterock itself. As has already been suggested, for the most part the wasterock is too rocky to be suitable. That was the original problem. However, like most porphyry deposits, the Lime Creek intrusive contains a mosaic of different rock types. In Trial 81.1 a portion of the wasterock quickly crumbled into smaller particles. Following up on this observation, the region in the pit containing the incompetent rock was located and a dump slope was set aside for a trial. The test slope, ranging fom 75m to over 120 m at the north end, was the longest slope on the site. When reclaimed the slope will be broken up into shorter lengths. For experimental purposes it posed a rigorous test. The incompetent wasterock was applied in the usual fashion by a bulldozer pushing it over crest. In all, 15,000 tonnes were applied to two 20 m wide plots.

In the first year only the upper 25% of the veneer of incompetent wasterock contained soil-sized material. When first dumped the fines-containing material at the top of the slope stood at a higher angle of repose than the rest of the slope. Over the first winter (1984-1985), slumping redistributed material, lowering the angle at the top, and covering more of the lower sections with fines. While there was no further surface movement, rock breakdown continued to increase the proportion of fines. Results from samples taken along transect lines show that by the third season (1984) 80

Table 1.44 Proportion of < 2 mm particles in upper 10 cm of slope, three years after it was covered with incompetent wasterock.

Percent < 2 mm

North Plot (130 m long)

Distance **	20m	40m	60m	80m	100m	120m
Transect A	44	27	39	43	13	0
Transect B	32	33	38	28	31	37

South Plot (85 m long)

Distance **	10m	20m	35m	45m	55m	65m	75m
Transect C	44	38	66	44	21	24	0
Transect D	57	28	28	26	29	23	0
Transect E	17	42	24	21	16	0	0

** distance from the crest

to 90% of the slope surface contained a high enough proportion of < 2 mm particles (> 15%) to support plant growth (Table 1.44). By comparison only 5% of the surrounding slopes contained detectable fines. The results of Trial 82.4 suggest that the incompetent wasterock was a good source of fines. Selective placement of incompetent wasterock on the slopes is an attractive proposition, as it would be placed on the dumps anyway, and its lack of cohesion suggests that it would not make a good foundation.

Results from Trial 82.4 indicated capping the slopes with incompetent wasterock would be a good method for adding fines. However, as for the work done on the benches, the usefulness of the field trials as a basis for evaluating the long term performance of materials is limited by their short duration. Unlike the bench situation described earlier, where information was obtained from an analogous natural situation, there are no good natural analogues to a veneer of incompetent wasterock on an angle of repose slope.

5. SUMMARY

Approximately 12 years after the surfaces were disturbed, plant invasion on natural substrates has been quite vigorous. Pioneer species included vigorously growing cottonwood, willow, and Sitka alder. In contrast, natural plant invasion on untreated sections of the wasterock dumps was poor on the bench portions and almost non-existent on the slope sections.

According to various schemes for rating the suitability of disturbed soil materials as rooting media (Schafer, 1979; USDA, 1979; Alberta Soils Advisory Committee, 1981), the limiting characteristic of the bench surfaces is the high proportion of coarse fragments. The average proportion by weight of < 2 mm-sized particles on different bench sites never exceeded 40%, and most were less than 25%. However, the surface materials (mainly colluvium) on the minesite prior to mining contained a similar proportion of fines.

The main differences were that the naturally unconsolidated materials contained more organic matter, N, and available P. In its original state, the wasterock was infertile, lacking both N and available P. To some extent, these fertility problems can be resolved by adding fertilizer and by using plant species adapted to infertile conditions. When fertilized, agronomic growth on the wasterock was stronger than that achieved on fertilized overburden. Part of the reason for this appears to be the

greater supply of readily-weathered minerals in the wasterock. As they weather, minerals like calcite supply nutrients and buffer the pH. The acidic pH indicates that most of the base rich components had already been leached from the overburden. One reason for the relatively poor growth on the overburden was that it lacked the "active ingredient" of natural soils, the surface litter layer.

The objectives for using grasses and legumes were to produce an erosion-controlling cover and for site amelioration. A number of grasses showed they could provide the quickly developing, dense rooted ground cover required for erosion control. The fastest growing species was annual ryegrass which, when sown on fertilized wasterock, produced a cover of 46% in 4 months. Although it did not regrow the following season, its litter and dead roots provided some residual surface protection, without competing with the woody species. The seedling survival in Trial 82.1 and the willow and cottonwood invasion in Trial 70.3 were greatest on the fertilized annual grass plots

A number of other grasses provided erosion control for longer periods. Of these, perennial ryegrass was the most vigorous for the first 2 years (e.g. Trial 82.1). However it was relatively short lived and could not be counted on as a cover for more than 2 or 3 years. Orchard grass, timothy, and red top provided a cover for longer periods. However refertilization would be required to sustain their growth

beyond 5 years. Orchard grass and timothy, with relatively big leaves, produce large amounts of litter.

After the decline of perennial ryegrass, red fescue was the most vigorous and abundant grass species. Without refertilizing one may expect red fescue to sustain a good cover for at least 10 years. In Trial 81.1, the strong birdsfoot trefoil growth in plots with a large fescue cover suggest that fescue can be used for erosion control without sacrificing sustained litter production.

For sustained litter production and N addition, the best agronomic species was the legume birdsfoot trefoil. In Trial 70.1, birdsfoot trefoil was still producing 300 to 400 g/m2 dry aerial biomass 15 years after the trial was established. A number of other legumes also grew well in field trials (e.g. alsike clover in Trial 82.1), but their biomass was always much smaller and they were productive for a shorter period. The best grass growth in Trial 70.1 occurred next to the clumps of legumes. This suggests that a lack of N limited grass growth and that the legumes improved soil fertility. Further evidence that sustained legume growth ameliorates the soil was provided by Trial 70.3, where the best growth of Sitka spruce and western hemlock occurred beside the birdsfoot trefoil. Birdsfoot trefoil should also stimulate the growth on non-N2 fixing deciduous species such as cottonwood and willow.

One disadvantage in using birdsfoot trefoil was growth impeded the invasion of pioneer species, like cottonwood and

willow. The other possible disadvantage was that its initially slow growth makes it unsuitable for erosion control and susceptible to competition from quickly growing grasses. However the slow start also means that initially birdsfoot trefoil will not compete with tree seedlings and will not create a cover for voles.

Of the conifer species tested in 1970, lodgepole pine grew the fastest. However all the conifers grew slower than the deciduous invaders willow and cottonwood. The rapid rate at which cottonwood and willow invaded Trial 70.3 indicated that natural plant invasion can be relied upon for establishment. Data from Trial 70.3 also suggested that natural plant invasion will adequately stock the dumps with hemlock seedlings.

The most productive species growing in the field trials was Sitka alder. This concurs with observations made of natural plant growth on disturbed sites in this environment. In Trial 82.1, alder survival and growth was substantially greater than that of lodgepole pine. Its average height growth on many treatments exceeded 30 cm per year. Unlike most woody species, alder also spread out laterally, trapping litter beneath its recumbent growth form.

In both the field trials and on untreated sections of the dump, plant growth dramatically increased the organic matter content of the surface soil. Litter falling on the surface was not mixed in with the wasterock and thus it accumulated in a mor-like covering. After 10 years of

strong agronomic plant growth on fertilized wasterock, the litter layer was 2 to 3 cm thick, and levels of N (0.19%) and available P (44 ppm) at 0-5 cm on plots sown with birdsfoot trefoil were significantly higher than the levels found in stockpiled overburden. The pedogenic changes associated with the addition of organic matter (e.g., decreased bulk density and pH) were also concentrated at the surface. Although some of the differences were quite large, it is important to remember that only the top 0-10 cm was sampled. In many cases, marked pedogenic changes only occurred in the upper 5 cm.

One of the first transformations on the wasterock dumps was the loss of calcite. While some of the loss may be due solely to precipitation and leaching, the loss of calcite was greatest on sites with plant growth. Once calcite was lost, the surface pH rapidly declined. After 10 years, of strong plant growth on the fertilized wasterock, the 0-5 cm pH declined to 4.3. The acidic pH may have contributed to the reduced vigor of a number of agronomic species in the field trials. However the low pH did not appear to have had an adverse effect on the growth of birdsfoot trefoil or invading native trees. Adjacent to the minesite, natural soils are covered with very acid litter layers and have low pH values throughout their solum, so the native vegetation is compatible with the acidic conditions. On untreated sites the decline in surface pH was strongly positively

correlated with "available" (Bray P1) phosphorus levels. Lowering the pH appeared to accelerate apatite weathering.

One problem that could result from low pH conditions is increasing metal solubilities. However there were no visual symptoms of metal toxicity or element imbalances in vegetation growing on either the wasterock dumps or on natural soils developed from ore containing rock. Time constraints prevented a study of trace element accumulation in the biota.

The wasterock was comprised of a number of different rock types and this affected its particle size. Average proportions of < 2 mm particles were 10 to 13% for the hornfels, 19 to 26% for potassic, and 31 to 36% for the incompetent wasterock. On the dump benches, natural plant invasion was greatest on sites with the highest proportion of < 2 mm particles (LG.V). However the vigorous growth of both agronomic and woody plant species in field trials indicated that, if fertilized and plants were artifically introduced, 15% to 25% was an adequate < 2 mm content.

The greatest limitation to plant growth on the mine wastes was a lack of soil-sized particles on the surface of terrace slopes. A foundation of boulders is crucial for dump stability, but was an impossible medium for plants to root in. To revegetate dump slopes, the B.C. Mines Inspection Branch advocates regrading the slopes to a gentler angle, and in the process covering the slopes with fines from the bench. Regrading will involve moving large

amounts of material, resulting in large machinery costs. This makes it prohibitively expensive for most B.C. mines, including Kitsault.

If one is to establish vegetation on the slopes, the alternative to regrading is to apply a veneer of soil-sized particles. One source of fines is the overburden or topsoil that covered these areas prior to mining. When the mine re-opened in 1980 unconsolidated deposits of soil-like peat, till, and colluvium were stripped and saved for use in reclamation. However using the natural soil has many limitations. One problem is the quantity available as deposits of overburden were generally shallow. The other problem was that most of the overburden contained the same proportion of coarse fragments as the wasterock. The poor quality of the overburden was illustrated in Trial 82.1 by the better growth of agronomics on the wasterock. The high coarse fragment content and the resistance of these fragments to weathering meant that the overburden would not be a good source of fines.

The alternative to using natural materials was to use the wasterock itself. Observations from Trial 81.1 suggested that once exposed a portion of the wasterock quickly disintegrated. Following up on this observation, a veneer of incompetent wasterock was tested on a slope (Trial 82.4). After three years, 85% of the slope surface contained a high enough proportion of < 2 mm particles (> 15%) to support plant growth. By comparison only 5% of the

surrounding slopes contained detectable fines. The results of Trial 82.4 suggest that the incompetent wasterock was a good source of fines. Selective placement of wasterock on the slopes is an attractive proposition, as one would be using materials that would be placed on the dumps anyway.

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III. PREDICTING THE LONG TERM PERFORMANCE OF THE INCOMPETENT WASTEROCK, USED AS A SOURCE OF FINES, ON ANGLE OF REPOSE SLOPES

1. INTRODUCTION

1.1 Objective

While vigorous plant growth was achieved on the terrace benches, this was not the case on the dump slopes. On the dump slope surfaces, the absence of soil-sized particles prevented plant growth. Field trials showed that in the short term the best way to rectify this was to cover the slopes with a veneer of incompetent wasterock. However, the limited duration of field trials restricts their ability as tools for predicting whether the veneer of incompetent wasterock is compatible with the long term reclamation objectives.

The objective of the second part of the study was to evaluate the long term performance of a veneer of incompetent wasterock on angle of repose slopes. Characteristics of the incompetent wasterock that will affect its performance are:

- the proportion of soil-sized particles
- the proportion of silt and clay, and
- the availability of trace elements and nutrients.

While soil-sized material is necessary for moisture and nutrient retention, properties required for plant growth, a

large proportion of coarse fragments must be present in order to maintain the slopes angle of repose and for drainage. The amount of silt and clay will also affect moisture and nutrient retention, as well physical properties such as infiltration capacity. Insufficient infiltration will lead to surface runoff, which in addition to reducing water quality may remove the plant cover and erode the fertile upper layers of the soil.

In order to predict the long term performance of the incompetent wasterock, information was collected from unweathered materials, from weathered materials in the rock dumps and in natural soils, and from a simulation of weathering in the laboratory. The first step to understanding how the incompetent wasterock will perform was to determine its initial composition. Analyses were carried out on samples of exposed bedrock in the pit (pitrock) and recently dumped wasterock to characterize the incompetent wasterock and to show how it differed from the more common rock types found in the waste.

Information on pedogenesis and weathering at the minesite were gathered from two sources: wasterock on the abandoned dumps and two natural soil profiles within the proposed pit limits. The changes in the wasterock showed the type of changes that will occur within ten years. The natural soil profiles showed the effects of much longer periods of pedogenesis, and the conditions under which pedogenic changes occurred. It was impossible to examine

soil profiles developed from incompetent rock, since areas where the incompetent rock may have been exposed had already been mined. Although the natural soils and much of the weathered wasterock were not composed of incompetent rock, they had a great number of properties in common with it. Thus information about how they altered could be used to predict certain aspects of incompetent wasterock alteration.

In order to more accurately assess the effects of weathering on properties such as particle size, weathering of the incompetent wasterock was simulated in the laboratory. The technique used was a Soxhlet distillation with acetic acid. The advantage of simulated weathering over the field studies was that it permitted the direct study of different fractions of the incompetent wasterock. The laboratory study simulated approximately 100 years of weathering.

1.2 Literature Review

1.2.3 Properties of Podzolic Soils

Studies of soil development and soil surveys carried out in the area showed that podzols form on well drained parent materials. An understanding of properties of podzols is important as pedogenesis on the dump slopes should eventually create podzolic soils.

Podzolic soils are characterized by horizons enriched in amorphous organic-sesquioxide complexes. In the Canadian System of Soil Classification there are three Great Groups within the Podzolic order. The two found in the Kitsault region are the Ferro-Humic and Humo-Ferric podzols (Wittneben, 1984). The diagnostic podzolic B horizon contain at least 0.6 % pyrophosphate Fe + Al, and is at least 10 cm thick. In the Ferro-Humic great group the diagnostic horizon contains more than 5% organic-C. In the Humo-Ferric great group the C content is 0.5 to 5%.

West coast podzols typically have thick mor surface layers and relatively high B horizon carbon contents. In podzols from different moisture subzones in the Coastal Western Hemlock zone, the average thickness of the surface litter layer ranged from 11 to 20 cm (Carter et al., 1985). Compared to podzols in Central Canada, Lewis (1976) concluded that in podzols from Vancouver Island, have less redistribution of organic matter and sesquioxides within the solum, and thus weaker horizonation.

Parent material properties influence podzol morphology. In soils developed from basaltic parent materials, albic (Ae) horizons occur from 0 to 27% of the time, compared to 25 to 83 % granitic parent materials (Carter et al., 1985). For both rock types, the lowest proportion of Ae horizons were found on the drier sites. Greater weathering, more tree throw, and more mafic parent materials were suggested as possible reasons for the small size or lack of Ae horizons. The occurrence of greater weathering was explained by the fact that the soils do not freeze in the winter. On Vancouver Island, the strongest Ae and weakest B horizons were found in podzols developed on dry sites from high Si, low Fe granitic parent materials (Lewis, 1976). High contents of Fe (> 5%) and clay impede the formation of mobile organic-sesquioxide complexes, and thus eluviation (Duchaufour and Souchier, 1978).

A number of researchers have noted that the horizons in west coast podzols often are not parallel to the surface, and that maximum illuviation does not always occur at the top of the illuvial layer (Martin & Lowe, 1989; Sanborn, 1987). Preferred drainage pathways, heterogeneous root growth, and frequent tree throw are suggested causes for the oblique, irregular horizons. Compacted layers of till, for example, which lead to zones of intense root growth and seepage flow, result in the zone of maximum C and sesquioxide accumulation near the bottom of the solum.

Surface organic matter, illuvial organic matter and sesquioxides have strong effects on the chemical properties of podzolic soils, and thus have been the focus of much research. Three forms of extractable Fe and Al analysis are commonly carried out on podzolic soils (McKeague & Day, 1966; Parfitt and Henmi, 1982; Farmer et al., 1980; Adams & Kassim, 1984).

(1) Pyrophosphate (pyr) or EDTA extract organically complexed Fe and Al,

(2) Oxalate (AAO) extracts both organically complexed and amorphous Fe and Al,

(3) Citrate bicarbonate dithionite extracts free oxide and hydroxide forms of Fe, but is not selective for a particular Al fraction.

The relative proportion of each fraction varies. However, the proportion of organically-complexed Fe and Al is generally highest near the surface.

For the weathering required to release Fe and Al from primary minerals and for organic eluviation to occur, the soil must have a low pH. Thus in conditions conducive to podzol formation, but where parent materials contain calcite or large amounts of clay, the loss of these components precedes the development of podzolic horizons. Carter et al. (1985) studied podzol development in the Western Hemlock climatic zone. In podzols developed in this area, the average pH of the litter was from 3.2 to 4.1. The average pH of the podzolic B horizons ranged from 4.1 to 4.5. For these same soils, B horizon AAO-Fe (0.6 to 2.4%) and -Al (1.2 to 2.4%) levels were higher than those of pyr-Fe (0.2

to 1.8%) and -Al (0.6 to 1.5%). Low pH values and high concentrations of illuvial C, Al, and Fe were also found in podzols in S.E. Alaska (Heilman & Gass, 1974; Stephens, 1969) and in other studies carried out in British Columbia (Martin & Lowe, 1989; Sanborn, 1987). In Carter et al's (1985) study the highest concentration of B horizon carbon (9.6%) and oxalate -Fe (2.1%) and -Al (4.4%) were found in podzols developed under the wettest climate.

In addition to the climactic influences, Lewis (1976) also found that till composition differences were reflected in B horizon characteristics. For example, for all three extractions, the levels of Fe near the surface were highest in the podzols developed in the limestone till. This was thought to result from the weathering of less resistant Fe-containing carbonate minerals. Of the soils studied by Lewis (1976), inherited differences were most pronounced in the drier subzones and in younger soils where weathering was less intense.

Most research on podzolic soils has focused on the manner in which sesquioxide-enriched layers form. The traditional theory of podzol genesis is that sesquioxides, released by the weathering of primary minerals, are transported as complexes with soluble organic matter (McKeague et al., 1983). The sesquioxide-organic complex precipitates when the ratio of Al and Fe to organic matter becomes too high, or if absorbed by other complexes or by Al or Fe hydroxides. The site of deposition depends upon many

factors including the amount of available Al and Fe. In soils with high contents of easily-weathered minerals, deposition may occur at or near the surface.

An alternative hypothesis for podzol genesis suggests that Al and Fe move as hydrous oxide sols without organic matter (Anderson et al, 1982). According to this hypothesis, organic matter arrives later and precipitates on the inorganic components. Given the great variety in form and composition, it is unlikely that only one mechanism operates in a particular horizon, let alone throughout the whole solum.

Results from different studies of west coast podzols showed no consistent pattern of textural changes with depth or among horizons, and no evidence of clay translocation (Stephens, 1969; Sanborn, 1987). This concurs with a survey of French podzols carried out by Legros and Pedro (1985), who concluded that grain size distribution changes in podzolic soils were small and irregular and result from fragmentation, dissolution, and particle movement. They attributed the lack of change in podzolic soils to the dominance of dissolution.

Dissolution decreases the size of each particle, and can cause a negative enrichment in coarse particles, because finer particles are more rapidly eliminated. However, computer simulations carried out by Legros and Pedro (1985) showed that 87.5% of the mass is lost in reducing spherical particles from 2 to 1 mm in diameter. Fragmentation of

sand-sized particles created a greater proportion of silt, with a slower but progressive enrichment in clay. However, coarse sand fragmentation, unless very pronounced, also had very little effect on the particle size distribution.

Dissolution results from weathering. In podzols, most of the changes in the mineralogy of the sand and silt-sized fractions attributable to weathering are found in the A horizon. In New England podzols, April et al. (1986), found that hornblende and pyroxenes were completely removed from the A horizon, while there was little mineralogical change in the sand and silt fractions of the underlying material.

McKeague et al. (1983), attributed the greater weathering in the Ae horizon to the lack of protective sesquioxide coatings. According to McKeague et al. (1983), ferromagnesian minerals are generally depleted and quartz is enriched in the Ae horizon. The quartz:feldspar ratio increases in only some soils. The rating of sand and silt-sized minerals according to their weatherability in podzols was amphiboles > trioctahedral chlorite > biotite > muscovite and feldspar > quartz (McKeague et al., 1983). Silt-sized phyllosilicates, like clay, often weather to mixed layer minerals (e.g., chlorite-vermiculite).

Data on the weathering of heavy minerals was reviewed by Mitchell (1975). Differences in the relative stabilities of heavy minerals in subterranean strata and in subaerial environments were attributed to differences in the conditions under which the changes occurred. Studies of the

weathering of heavy minerals in the fine sand fractions in podzolic soils, summarized by Batement and Catt (1985), showed that the stability of heavy minerals was rutile > zircon > sphene > epidote > hornblende (Mg) > hornblende (Fe) > apatite. Even in intensely weathered podzols, there was no depletion in the sphene content.

Relatively few studies of podzols have looked at the sand and silt fractions. Even fewer have looked at the composition of the coarse fragments. In an acid soil developed by in situ weathering from a granodiorite parent material, Kato (1964) noted marked differences in the composition of fresh rock fragments compared to weathered particles. In the lowest unconsolidated layer, the 4-2 mm and the sand fractions were enriched in biotite and depleted in quartz, relative to the fresh rock. However, the proportion of quartz increased moving up through the C layers. The 4-2 mm and 2-0.2 mm fractions of the A, B, and upper C horizons were enriched in quartz relative to the fresh rock, while the 4-2 mm fraction in these same horizons contained lower amounts of biotite. At the same time as the proportion of quartz increased, the 4-2 mm feldspar concentration declined. Feldspar was depleted relative to the fresh rock in all the < 2 mm fractions.

In subalpine areas in France, Robert et al. (1980) found a lack of ferromagnesium and plagioclase minerals in the gravel fractions of podzols compared to fresh rock. In New Zealand podzols, Farmer et al., (1984) found that parent

sand and gravel were little weathered below the cemented Bh. In the eluviated A, stones were completely weathered to sand-sized quartz and resistant feldspar. Stones projecting through the Bh horizon were only strongly weathered on their upper surfaces.

Compared to other Canadian soils, the processes of clay mineral alteration are most intense in podzols (Kodama, 1979). As a result, there are often large mineralogical differences between the < 2 um fractions from different podzol horizons, and the resulting mineralogy profiles are unlike those of any other Canadian soil order.

For the most part, changes in clay mineralogy result from the alteration of existing phyllosilicates. Allen and Fanning (1983) characterized the changes occurring in podzols as: trioctahedral chlorite to vermiculite and pedogenic chlorite to smectite. According to McKeague et al., (1983), the clay fractions of podzol C horizons generally contain quartz and feldspar, along with some combination of mica, chlorite, and kaolinite. In podzolic B horizons sesquioxide-organic coatings protect minerals from weathering and lead to interlayering. The resulting clay minerals include either chloritized vermiculite and transformation products of mica, or primary chlorite without Al interlayering. Weathering occurs through the removal of K from mica and the OH sheet from chlorite, combined with the oxidation of Fe and possibly the removal of other octahedral cations (Jackson, 1965).

According to McKeague et al. (1983), the smectite found in the A horizons of podzols is the Al-rich beidellite form. Jackson (1965) thought that smectite formed in A horizons from the chelation of Al and Fe by organic colloids and from the reduction of Fe.

Untransformed chlorite and biotite are generally absent in podzolic A horizons. On average the clay fractions of A horizons in U.S. podzols contain equal proportions of mica, vermiculite, and kaolinite (Folkoff and Meetemeyer, 1985). McKeague et al. (1983) concluded that podzolic A horizons are dominated by smectite or vermiculite, conclusions supported by research carried out in New England (April et al, 1986), Quebec (De Kimpe et al., 1984), Japan (Mizota, 1982), and Yugoslavia (Gjems, 1970). In the podzols studied by Rutherford and Kemp (1983) in Ontario, the dominant A horizon clay mineral was an interstratified vermiculite or smectite with chlorite.

Reviewing the clay mineralogy of Canadian soils, Kodama (1979) found the presence of chloritized smectites or vermiculites in the surface horizons of only B.C. and Alberta podzols. Kodama (1979) found chlorite more susceptible to weathering than mica, and considered the presence of inherited chlorite in the surface horizons to be a sign of less advanced soil genesis. Of the different chlorite types, their susceptibility to weathering was Fe > Mg > Al. The low resistance of the Fe chlorite results from its susceptibility to oxidation.

Clay-sized chlorite minerals in Canadian podzols decomposed into non-crystalline substances or altered into interstratified vermiculite-chlorite and smectite-chlorite, while clay-sized mica minerals altered to partially or fully expansible clay minerals (Kodama, 1979). In a Scottish podzol, <2 um chlorite lost through weathering was replenished through additions from the silt fraction (Bain and Dulhie 1984). In this soil, the greatest decline in chlorite content occurred in the silt fraction. In many podzolic B horizons, chloritic minerals are formed by the precipitation of Al and Fe hydroxides between expansible silicate layers (e.g., De Kimpe et al., 1984).

In podzols developed on a variety of parent materials in Japan (Mizota, 1982), the dominant clay minerals in the A and upper B horizons were vermiculite and smectite without Al interlayers. Vermiculite-chlorite integrated with well developed interlayers were found in the lower B and C horizons.

Gjems (1970) found an increase in kaolinite, and a decrease in illite and chlorite, moving upwards in a podzol profile in Yugoslavia. The dominant minerals in the A, B, and C horizons were respectively smectite, Al-interlayered minerals, and illite.

In recent years, in part as a result of interest in the hydrous oxide sol theory of podzol genesis (Anderson et al., 1982), there has been increased interest in clay-sized minerals formed from sesquioxides (Farmer et al., 1980;

Childs et al., 1983; Adams & Kassim, 1984). For example, imogolite has been found in cemented horizons of some British Columbia soils (McKeague & Kodama, 1981) and in brunisols in eastern Ontario (Wang & Kodama, 1986). Allen and Fanning (1983) suggested that amorphous Fe in podzols recrystallizes as ferrihydrite, which in turn alters to goethite. According to Schwertmann and Fischer (1973), ferrihydrite is the main Fe oxide in podzolic B horizons.

1.2.3. Methods of Simulating Weathering

Weathering involves a complex combination of processes (Birkeland, 1984). Consequently predictions as to how a certain material will weather are usually based on field observations made on similar materials in similar environments. However if the conditions desired do not already exist, researchers must then attempt to simulate weathering artificially. The easiest and most reproducible method for replicating weathering is to insert the material into the weathering environment (Hatton et al., 1987; Paterson et al., 1987). The drawback to this approach is the time required. Weathering is a relatively slow process.

In order to replicate weathering changes more quickly, one must attempt to simulate weathering by accelerating the processes involved. The main drawback in accelerating the weathering reactions is that it is difficult to maintain the natural balance between processes. This is especially true when the processes are catalysed by biological activity, as

is the case when pyrite is oxidized. A variety of methods for simulating weathering are used to predict whether pyritic mine wastes will become acid generating. These include batch tests (Bruynesteyn & Nackel, 1984), humidity cells (Sobek et al., 1978), column tests (Patterson, 1987), and Soxhlet distillation processes (Sullivan & Sobek, 1982).

Soxhlet extractors have been used by various investigators to mimic geochemical weathering reactions, with different extracting conditions producing different types and rates of change. For example, Henin and Pedro (1965) found that acetic acid caused the rapid removal of Fe, Al and basic cations, in a process similar to that observed in podzolic soils. An alternative approach for recreating the effects of podzolization was reported by Berthelin and Belgy (1979), who found that perfusing nutrient solution for 22 weeks through a column of rock fragments transformed biotite and illite-vermiculite into vermiculite, mineral transformations shown to occur during podzolization in the field.

While a number of researchers have duplicated transformations observed in soil and in mine wastes, very little work has been done in matching chronosequences observed in the field with the sequence of changes observed in the laboratory. For the coastal B.C. environment, the only reseach of this type was done by Singleton and Lavkulich (1989), who used acetic acid and soxhlet extractors to duplicate some of the changes observed in a

Vancouver Island chronosequence. In their study "the equivalent of 13 years of calcium-bound phosphate removal from the surface 10 cm of the soil was achieved by one week of leaching in the Soxhlets." Soxhlet leaching also duplicated the removal of Ca, Na, K, Al and Si. However it did not remove Fe and Mg as effectively as natural leaching under podzolic field conditions.

2. CHARACTERISTICS OF ROCK TYPES FOUND IN THE WASTE

2.1 Objective

The objective was to characterise the "incompetent" wasterock, and to show how it differed from the main rock types found in the waste.

2.2 Materials and Methods

2.2.1 Sample Selection

Characterising all the variation within and among rock types was beyond the scope of this study, so sampling was restricted to three rock types. The two other (other than the incompetent rock) rock types examined were the hornfels and the potassically-altered intrusive, chosen because they were the most common rock types in the waste. With the aid of one of the mine geologists, five samples of each rock type were collected from exposed faces in the pit (rock). The unweathered wasterock samples were collected from recently built dumps.

2.2.2 Sample Analysis

Prior to analysis, the wasterock samples were separated into three different size fractions (> 12.7 mm, 12.7-2.0 mm, and < 2.0 mm). The various fractions examined and the analyses carried out are summarised in Table 2.1. Subsamples analysed for total mineralogy, total elemental composition, and carbonate-C were first ground to < 50 um on

Table 2.1 Analyses carried out on different fractions of the rock and wasterock.

Section	Thin	Particle Size	XRD		XRF		%C
			powder	oriented	major	trace	
Rock Samples							
Rock Fragments	X		X		X	X	X
< 2 um particles				X			
Wasterock Samples							
Stone Fraction			X				
Gravel Fraction			X				
< 2 mm fraction		X	X		X	X	X
< 2 um fraction				X			

a Ni steel ring grinder. For the > 12.7 mm wasterock fraction and the rock samples, prior to grinding, the subsample was put through a plate crusher.

Grain size distribution and associated mineralogy were determined with a petrographic microscope on thin sections cut from each rock sample. Three hundred points were examined on each section. To distinguish K feldspar from plagioclase and quartz, a second section was etched with HF and stained with sodium cobaltinitrite.

Total mineralogy was estimated from the peak intensities generated from an X-ray diffraction scan (XRD) of a subsample pressed into a pellet. Islam and Lotse (1986) reviewed the use of constants to correct for differences between the relative XRD intensity and the weight proportion of the mineral. Constants used in this study were similar to the ones they used. The factor (x2) used to correct the intensities of the groundmass minerals, sericite and kaolinite, was determined empirically from the two samples almost entirely comprised of sericite and calcite. Multiplying the sericite peak intensity by 2 gave a similar sericite:calcite ratio to that determined by carbonate-C and by thin section analysis. The ratio of the 0.499 nm to 1.00 nm peak in sericite was determined on samples in which sericite was the only mica mineral.

The correction factor for quartz was chosen to ensure that the quartz:feldspar ratios of the powder mounts were similar to those observed in the thin sections. The greater

intensity of quartz can be attributed to the better crystallinity and the absence of hydrothermally induced flaws.

The relative proportion of each mineral was estimated as follows.

Quartz: intensity of the 0.334 nm peak minus intensity of the 1.00 nm peak (mica), all divided by 2,

K Feldspar: intensity of 0.324 nm peak,

Plagioclase: intensity of 0.318 nm peak,

Sericite: intensity of 0.499 nm peak divided by 0.4, multiplied by 2,

Biotite: intensity of 1.00 nm peak, minus intensity of 0.499 nm peak divided by 0.4,

Chlorite: intensity of 1.4 nm peak,

Kaolinite: intensity of 0.71 nm peak , multiplied by 2, (the sharp kaolinite peak was easily separated from the broad 002 chlorite peak),

Hornblende: intensity of 0.84 nm peak,

The < 2 um fractions of the wasterock were separated by centrifuging a subsample of the < 2 mm fraction (Kittrick and Hope, 1963). For the rock samples, a < 2 mm fraction was created by crushing each sample until all particles passed through a 2 mm sieve. The minerals present in the < 2 um fraction were identified from the peaks generated from XRD scans of oriented samples, after pretreatments with Mg, Mg-glycerol, K, K-300c, K-550c (Kodama et al., 1977). The relative proportion of each mineral was calculated from its contribution to the peaks generated after Mg saturation. The correction factors applied to account the relative

strengths of reflectance were 0.5 for quartz and feldspar and 2 for smectite (Islam and Lotse, 1986).

For both the total and < 2 um fractions, XRD scans were made on an automated Philips PW 1710 Powder Diffractometer using CuKα X-radiation and a Ni filter.

Total elemental composition was measured with an automated Philips PW 1400 X-ray fluorescence spectrometer (XRF), using fused glass discs for major elements and pressed powder discs for trace element analysis. The suite of trace elements was determined by the capabilities of XRF, and included a number of nutrients and elements that may contribute to toxicities. Carbonate-C was measured by acid titration. All chemical data was reported on an oven dry weight basis. Unless noted otherwise analyses of the wasterock were carried out on the < 2 mm fraction.

2.2.3 Data Analysis

As the data did not meet the requirements of homogeneus variances and normal distribution, non-parametric statistical techniques were used to compare groups. Unrelated samples were compared with the Mann-Whitney U test. Data from the same samples were compared with the Wilcoxon matched-pairs signed-ranks test. The degree of correlation among different properties of the igneous rock samples were indicated by the Spearman rank correlation coefficient. For all tests 0.05 was used as the level of probability at which differences were considered significant.

2.3 Results and Discussion

2.3.1 Grain Size

The potassic and incompetent rock were both porphyries, containing large crystals or phenocrysts, along with finer grains or groundmass. In the potassic rock most of the grains were phenocrysts. On average 88% of the grains in the potassic rock were in the 2000 to 100 um range (Table 2.2 and 2.3).

The grain size distribution was more variable in the incompetent rock samples. Based on their grain size, the incompetent rock samples were split into two groups; groundmass and porphyry. In the two groundmass samples 70% of the grains were smaller than 50 um, and no grains were larger than 500 um. In the three porphyry samples, the proportion of grains 2000-500 um ranged from 27 to 72% and the proportion of grains less than 50 um ranged from 1 to 31%.

Unlike the igneous rock types, the hornfels were equigranular. Most of the grains in the hornfels rock were coarse silt-sized, and no grains were larger than 500 um.

2.3.2 Total Mineralogy

In order of abundance, the three most common minerals in the hornfels rock were quartz, plagioclase, and biotite (Table 2.4). Most of the hornfels rock samples also contained some chlorite and K feldspar. Compared to the two igneous rock types, the hornfels rock contained higher

Table 2.2 The grain size distribution in different rock types.

Rock Type		# of samples	2000-500um %	500-100um %	100-50um %	< 50um %
Hornfels	Mean	4	0	9	17	75
	Minimum			0	10	56
	Maximum			20	24	83
Potassic	Mean	5	62	26	5	7
	Minimum		52	17	1	1
	Maximum		72	33	6	11
Incompetent Porphyry	Mean	3	49	26	10	15
	Minimum		27	10	4	1
	Maximum		72	35	18	31
Incompetent Groundmass	Mean	2	0	15	11	74
	Minimum			13	10	70
	Maximum			18	12	77

Table 2.3 Proportion and size of different minerals in potassic and incompetent rock thin sections.

Rock	Mineral		Total %	2000-500um %	500-100um %	100-50um %	<50um %
Potassic	Quartz	Meam	44	31	10	2	0
		Minimum	36	24	5	0	0
		Maximum	54	37	20	5	0
	K feldspar	Meam	42	25	15	2	0
		Minimum	39	14	6	0	0
		Maximum	48	33	27	7	0
	Felsic Phyllosilicate	Meam	8	0	0	0	8
		Minimum	4	0	0	0	4
		Maximum	11	0	0	0	11
	Isotropic	Meam	2	0	0	1	0
		Minimum	0	0	0	0	0
		Maximum	4	0	1	4	1
	Calcite	Meam	1	0	0	1	1
		Minimum	0	0	0	0	0
		Maximum	2	0	0	2	2
	Plagioclase	Meam	3	2	1	0	0
		Minimum	0	0	0	0	0
		Maximum	10	8	3	0	0
Incompetent Porphyry	Quartz	Meam	48	27	16	2	3
		Minimum	30	11	3	0	0
		Maximum	64	47	29	3	8
	K feldspar	Meam	36	27	4	5	0
		Minimum	0	0	0	0	0
		Maximum	60	43	7	11	0
	Biotite	Meam	2	1	1	1	0
		Minimum	0	0	0	0	0
		Maximum	6	2	2	2	0
	Calcite	Meam	4	0	0	2	2
		Minimum	1	0	0	0	0
		Maximum	12	0	1	6	6
	Isotropic	Meam	2	0	0	0	1
		Minimum	0	0	0	0	0
		Maximum	3	1	0	1	3
	Felsic Phyllosilicate	Meam	7	0	0	0	7
		Minimum	0	0	0	0	0
		Maximum	21	0	0	0	21
Incompetent Groundmass	Felsic Phyllosilicate	Meam	74	0	2	5	66
		Minimum	69	0	2	5	62
		Maximum	78	0	2	5	71
	Calcite	Meam	27	0	13	6	8
		Minimum	22	0	11	5	6
		Maximum	31	0	16	7	9

Table 2.4 Mineralogy of hornfels, potassic, and incompetent rock and wasterock.

Rock Type	Sample	Fraction	# of samples		Quartz	Kfeldspar	Plagioclase	Chlorite	Biotite	Sericite	Kaolinite	Calcite
					(estimated proportion in %)							
Hornfels	rock	-	5	Mean	57	9	20	6	8	1	1	0
				Minimum	42	0	12	0	0	0	0	0
				Maximum	75	27	29	9	23	3	4	0
	wasterock	<2mm	3	Mean	44	11	8	4	11	10	6	5
				Minimum	34	11	6	0	0	7	5	4
				Maximum	58	12	10	7	18	14	7	6
Potassic	rock	-	5	Mean	50	34	4	0	3	5	2	3
				Minimum	39	25	0	0	2	0	0	2
				Maximum	62	45	11	1	3	8	6	3
	wasterock	composite	4	Mean	52	28	4	1	2	6	3	3
				Minimum	46	26	2	0	1	5	2	3
				Maximum	57	34	9	2	5	8	4	3
		>12.7mm	4	Mean	57	30	5	1	2	3	1	2
				Minimum	47	27	2	0	0	2	0	2
				Maximum	64	37	11	2	5	5	2	2
		12.7-2mm	4	Mean	60	27	3	1	2	3	2	2
				Minimum	54	24	2	0	0	2	1	1
				Maximum	64	32	7	1	3	5	2	3
		< 2 mm	4	Mean	32	28	4	1	4	15	7	6
				Minimum	27	22	2	0	3	13	6	5
				Maximum	36	32	7	2	6	18	11	7
Incompetent Porphyry	rock	-	3	Mean	52	16	4	1	9	12	1	4
				Minimum	32	2	0	0	0	0	0	2
				Maximum	68	31	7	3	24	23	1	5
Incompetent Groundmass	rock	-	2	Mean	0	0	0	0	0	74	0	26
				Minimum	0	0	0	0	0	69	0	22
				Maximum	0	0	0	0	0	78	0	30
Incompetent Wasterock	wasterock	composite	4	Mean	37	22	1	0	1	25	2	10
				Minimum	6	3	1	0	0	9	0	3
				Maximum	55	38	3	0	1	60	4	26
		> 12.7 mm	4	Mean	45	27	1	0	0	15	1	11
				Minimum	9	7	1	0	0	3	0	2
				Maximum	73	59	2	0	1	49	2	35
		12.7-2 mm	4	Mean	47	22	1	0	0	15	2	10
				Minimum	9	3	1	0	0	5	1	1
				Maximum	65	32	2	0	0	42	2	30
		< 2 mm	4	Mean	31	19	2	0	1	35	3	9
				Minimum	0	0	0	0	0	11	0	4
				Maximum	47	33	4	0	3	86	9	15

amounts of plagioclase and less K feldspar, sericite, and calcite.

Compared to the rock samples, the < 2 mm fraction of the hornfels wasterock contained less plagioclase and quartz and more sericite, kaolinite, and calcite. The best explanation for these differences was that the < 2 mm fraction contained larger concentrations of the easily weathered and weaker minerals (e.g., sericite and calcite), minerals that probably caused this fraction of the rock to disintegrate.

Mineralogically the incompetent and potassic rock were quite similar. In both, the phenocrysts were mainly quartz and K feldspar, while calcite and felsic phyllosilicate minerals were the most common constituents of the groundmass (Table 2.3). Two felsic phyllosilicates, sericite and kaolinite, were identified in the XRD analysis (Table 2.4). Of the two, sericite was the most common.

As one would expect from the large proportion of phenocrysts, the most common minerals in the potassic rock were quartz and K feldspar. Groundmass components accounted for < 16% of the potassic rocks composition. The only mineralogical difference between the potassic rock and wasterock was that the wasterock was less variable, a factor that may be attributed to the mixing that occurs during blasting, removal, and dumping. Among the three size fractions in the potassic wasterock, only the mineralogy of the < 2 mm fraction was significantly different. Compared

to the coarser fractions, the < 2 mm fraction contained more chlorite, biotite, sericite, kaolinite, and calcite, and less quartz.

Like their grain size distribution, the mineralogy of the porphyry and groundmass incompetent rock samples were quite different. For example, quartz and K feldspar, the most common minerals in the porphyry samples, were absent in the groundmass samples. The two groundmass samples contained only sericite and calcite.

While the largest source of variation in the incompetent rock resulted from differences between the groundmass and the porphyry samples, the three porphyry samples were themselves very variable. One porphyry sample contained large amounts of potassium feldspar and biotite, but little or no sericite, while the other two contained relatively large amounts of sericite and quartz contents, but very little biotite and potassium feldspar.

Combining the data from the five incompetent rock samples, one gets a picture of a very heterogeneous material. Because the composition of the incompetent samples was so variable, the only significant difference from the potassic rock was a higher calcite content. However, if the biotite-rich sample was excluded, the incompetent rock also had more sericite, more grains < 50 um, and less K feldspar than the potassic rock.

The mineralogy of the incompetent wasterock, while not quite as variable as the incompetent rock samples, was much

more variable than the potassic wasterock. For example, the range in < 2 mm sericite content, which was 7 to 18% in the potassic wasterock, was 11 to 86% in the incompetent wasterock. Although the great variation in the incompetent wasterock obscured differences among different size fractions in unrelated samples, compared to the coarse fractions from the same samples, the < 2 mm fractions contained the more sericite, kaolinite, and biotite. Compared to the potassic wasterock, the incompetent wasterock contained significantly more sericite and calcite, and less quartz plus feldspar, biotite and chlorite.

The lower levels of mafic phyllosilicates in the incompetent wasterock indicate that the incompetent rock was mainly formed by argillic and propylitic hydrothermal alteration, processes in which plagioclase, biotite, and chlorite were replaced by sericite and calcite (Steininger, 1985). In potassic hydrothermal alteration, all the minerals except quartz may be replaced by K feldspar, with small biotite grains added to the more intensely potassic rock. The lack of biotite in the incompetent wasterock indicates that the incompetent rock sample with a high biotite content was an anomaly, and may more properly be described as an extremely potassic rock.

The larger amounts of calcite and sericite in the incompetent wasterock, and the concentration of these minerals in the < 2 mm fraction, suggest that calcite and sericite were responsible for the incompetent rocks rapid

degradation. Soluble in rainwater, calcite should dissolve quite quickly in a high precipitation environment like Kitsault. As calcite dissolves, pores will be created, which weaken the support around phenocrysts, and allow weathering agents to penetrate into the rocks. According to mineral stability schemes (e.g., Goldich, 1938), sericite, which is a fine grained muscovite, should be relatively resistant to weathering. However, crystals formed by hydrothermal alteration may contain more flaws than the crystals studied by Goldich (1938), in which case sericite weathering may proceed faster than predicted.

While chemical weathering on the dumps may contribute to the breakdown of incompetent wasterock, a considerable amount of breakdown occurs prior to and during its removal from the pit. For example fragments of incompetent rock in the pit could be scratched with a finger nail, crumbled when dropped, and had to be impregnated with resin in order to make thin sections. The lower strength apparently results from a lack of cohesion among sericite grains. The same lack of strength was noted in the high-biotite rock sample, indicating that low cohesion was a property of phyllosilicates created by hydrothermal alteration.

Similar to the weathering processes previously described for the incompetent rock, weathering of the potassic rock should start with the groundmass. However, in the potassic rock the amount of exposed groundmass is relatively small. After this is lost, the surface is

entirely covered with quartz and K feldspar phenocrysts. Cohesive and resistant, these crystals will resist further degradation.

In the hornfels rock, hydrothermal alteration was restricted to thin veins and narrow alteration halos. The greater cohesiveness of hornfels fragments than the igneous rock fragments appears to be due to the tight interlocking of small grains and the presence of large amounts of quartz. Various researchers have observed that fine-grained rocks weather more slowly than coarse-grained rocks (Carrol, 1970). One reason for this is that the intergranular surface area increases with a decrease in surface grain size; hence more energy is required to disaggregate the grains in finer rock (Birkeland, 1974). The cohesive interlocking structure of minerals in the hornfels rock will be a barrier to water and other weathering agents. This restricts mineral breakdown to exposed grains on the surface. Further weathering will also be arrested by the high quantity of quartz, a mineral that is very resistant to weathering (Goldich 1938). Petrographic studies show that plagioclase and biotite crystals in the hornfels were surrounded by quartz. Should one of these more easily weathered minerals be removed, the resulting cavity will likely be lined with quartz, preventing further penetration of weathering agents. As the grains are small, the loss of a few biotite or plagioclase grains from the surface will not significantly reduce the overall strength of the rock.

2.3.3 Major Elements

Differences in mineralogy have resulted in a large number of differences in element composition (Table 2.5). For example, the higher Na and Fe, and lower K contents in the hornfels samples can be attributed to differences in plagioclase, mafic minerals, and K feldspar.

In the potassic and hornfels samples, the higher Al, C, and Ca levels in the < 2 mm fractions, compared to the rock, resulted from the higher concentrations of sericite and calcite. The highest concentrations of Al, C, and Ca were in the groundmass rock samples. The two groundmass rock samples also contained more Mg, P, S, and Ti than any of the other igneous fractions. The most likely forms of Mg and P, dolomite and apatite, (Steininger 1985), weather rapidly in acid soils and thus should be a good source of these nutrients.

Although pyrite was not identified in the XRD analysis, it was the only common sulphide mineral (Steininger, 1985) and thus its concentration could be estimated from levels of S. Assuming that all the S was pyrite, average pyrite concentrations ranged from 0.9% in the hornfels rock to 5.7% in the incompetent groundmass. The ratio of Fe:S in the groundmass was 0.84, the same as that of pyrite, indicating that all the Fe in these occurred in this form. Assuming that all the C was calcite, and that calcite dissolution occurs concurrently with pyrite oxidation, the amount of

Table 2.5 Major element concentrations in the rock samples and the < 2 mm fractions of the wasterock.

Sample	# of samples		%Al	%C	%Ca	%Fe	%K	%Mg	%Na	%P	%S	%Si	%Ti	Pyrite %	Calcite %	Calcite /Pyrite
Hornfels	5	mean	6.5	0.2	0.7	3.8	2.2	1.5	1.9	0.09	0.5	33.7	0.4	0.9	1.5	1.7
rock		min	5.5	0.0	0.1	1.8	0.8	0.3	1.2	0.05	0.0	31.0	0.2	0.1	0.0	0.0
		max	7.9	0.8	2.1	5.7	4.9	2.3	2.6	0.17	1.5	36.3	0.5	2.9	6.4	2.2
Hornfels	3	mean	8.0	0.8	2.4	4.6	3.4	0.9	0.9	0.14	2.8	29.0	0.5	5.2	6.5	1.3
wasterock		min	7.7	0.7	1.3	3.9	3.3	0.7	0.7	0.12	2.4	27.8	0.4	4.6	5.8	1.3
< 2 mm		max	8.4	0.9	3.0	4.9	3.5	1.1	1.1	0.16	3.2	31.2	0.5	5.9	7.5	1.3
Potassic	5	mean	5.8	0.6	1.2	1.9	5.6	0.3	0.6	0.08	1.3	34.3	0.2	2.5	5.2	2.1
rock		min	5.1	0.4	0.8	0.8	4.8	0.2	0.3	0.07	0.4	30.6	0.2	0.7	3.7	5.5
		max	6.6	1.0	1.3	3.6	6.7	0.4	1.0	0.09	3.1	35.5	0.3	5.8	8.5	1.5
Potassic	4	mean	6.9	1.1	2.4	2.4	4.7	0.7	0.5	0.14	1.8	31.3	0.3	3.4	9.2	2.7
wasterock		min	6.6	1.0	2.0	1.9	4.3	0.6	0.4	0.12	1.7	30.8	0.3	3.1	8.6	2.7
< 2 mm		max	7.1	1.2	2.9	3.1	5.2	0.9	0.8	0.16	2.2	32.7	0.3	4.1	9.8	2.4
Incompetent	3	mean	5.9	0.7	1.7	1.6	3.8	0.6	0.5	0.10	0.8	34.9	0.3	1.5	5.4	3.5
Porphyry		min	5.0	0.3	1.1	1.2	2.2	0.3	0.1	0.08	0.3	32.9	0.2	0.6	2.5	4.4
rock		max	7.1	0.8	2.1	2.1	5.4	1.2	0.8	0.12	1.3	37.0	0.4	2.5	6.9	2.8
Incompetent	2	mean	12.2	3.5	9.9	2.6	6.2	1.5	0.0	0.27	3.1	15.8	0.5	5.7	29.0	5.1
Groundmass		min	11.4	3.2	8.2	2.5	5.8	1.3	0.0	0.25	3.0	14.8	0.4	5.6	26.9	4.8
rock		max	13.0	3.7	11.5	2.7	6.5	1.7	0.0	0.30	3.1	16.7	0.6	5.9	31.1	5.3
Incompetent	4	mean	9.1	1.4	3.5	1.7	5.4	0.8	0.2	0.15	1.6	28.2	0.4	3.0	11.4	3.8
wasterock		min	7.1	0.9	2.0	1.1	4.6	0.5	0.1	0.11	0.9	18.3	0.3	1.8	7.4	4.2
< 2 mm		max	13.6	2.4	5.6	3.1	6.7	1.4	0.4	0.28	3.5	32.8	0.6	6.5	20.1	3.1

calcite was sufficient to neutralise all the acidity pyrite can produce in all but the < 2 mm hornfels samples. The small excess pyrite acidity in the hornfels wasterock can be neutralised by mixing it with other wasterock of other rock types. Notably, the incompetent sample types had the highest average calcite:pyrite ratios.

2.3.4 < 2 um Mineralogy

The < 2 um fraction of all three wasterock types were almost entirely composed of phyllosilicates (Table 2.6). Smectite was the most common mineral in the hornfels wasterock, followed in order by kaolinite, sericite, and chlorite. The relative abundance of < 2 um minerals was quite similar in the potassic wasterock. The only difference was that in the potassic samples the concentrations smectite and kaolinite overlapped.

In the incompetent wasterock, sericite and smectite were the most common < 2 um minerals. Compared to the hornfels and potassic wasterock, the incompetent wasterock contained more sericite, less kaolinite (5-25%), and the concentrations of sericite and smectite were more variable. The incompetent wasterock also differed from the two cohesive rock types by containing no chlorite.

Compared to the < 2 um fractions from the wasterock, the < 2 um fractions created by grinding the rock samples had a much higher proportion of quartz and feldspar. Another difference resulting from grinding was the increased

Table 2.6 Mineralogy of the < 2 um fractions in the wasterock and the crushed rock.

Sample	# of samples		% Wt < 2 um	Quartz	K feldspar	Plagioclase	Chlorite	Sericite	Kaolinite	Smectite
			(estimated proportion in %)							
Hornfels Wasterock	4	Mean	4.9				5	10	38	47
		Minimum	4.4				5	5	35	45
		Maximum	5.2				5	15	40	50
Potassic Wasterock	4	Mean	4.2		2		8	13	36	43
		Minimum	3.4		0		5	10	30	35
		Maximum	4.9		5		10	20	50	55
Incompetent Wasterock	4	Mean	3.1		3			44	18	38
		Minimum	2.2		0			10	5	5
		Maximum	4.3		5			90	25	60
Hornfels Rock	4	Mean	0.8	20		8	33	15	23	
		Minimum	0.3	10		5	25	10	20	
		Maximum	1.2	30		10	40	20	25	
Potassic Rock	4	Mean	2.0	9	8	2	9	18	27	27
		Minimum	0.2	0	0	0	0	5	0	0
		Maximum	6.6	30	20	5	25	40	80	65
Incompetent Rock	4	Mean	2.0	10	2			59	5	28
		Minimum	0.5	10	0			0	0	0
		Maximum	3.8	10	5			95	15	95

variability. For example, the < 2 um smectite content of the ground potassic rock ranged from 3 to 63%, compared to 35 to 55% < 2 um smectite in the wasterock.

The composition of the < 2 um fraction created from the incompetent rock, like that found in the wasterock, contained no chlorite and the proportion of kaolinite did not exceed 30%. The groundmass rock samples, which had the highest sericite content, had the highest < 2 um sericite contents. The highest smectite content (94%) was in the < 2 um fraction created from the incompetent rock sample high in biotite, suggesting a relationship between biotite phenocrysts and < 2 um smectite.

By definition smectite expands when hydrated, a property which can reduce the strength of the coarse fragments. For expansion to occur, the smectite must have access to water. Water entry will be limited in the densely packed hornfels fragments. However the large number of fractures allowing water entry and resulting in smectite expansion, may be one reason why the intensely hydrothermally altered rocks were less cohesive.

2.3.5 Trace Elements

Of the trace elements measured, Co, Mo, Pb, Se, and Zn were found in higher concentrations than the levels commonly found in rocks and soils (Table 2.7). The concentrations of Mo were up to three orders of magnitude higher than the levels commonly found in soils. As a result, the foliage

Table 2.7 Trace element concentrations in the rock and the < 2 mm fractions of the wasterock.

Sample	# of samples		Co	Cr	Cu	Mn	Mo	Nb	Ni	Pb	Ru	Se	Sr	V	Y	Zn	Zr
Hornfels	5	Mean	40	247	37	588	28	2	78	19	90	1	211	113	23	96	122
rock		Minimum	23	17	8	216	0	0	1	5	34	0	136	39	13	49	106
		Maximum	56	463	75	1255	113	7	149	34	175	1	264	218	30	211	142
Hornfels	3	Mean	21	54	152	1928	1941	7	19	184	155	5	172	158	35	329	150
wasterock		Minimum	15	29	130	1417	1197	6	12	90	147	5	144	138	29	224	134
< 2 mm		Maximum	28	102	185	2230	2317	7	34	241	165	6	196	182	39	416	160
Potassic	5	Mean	167	18	36	536	166	5	0	90	174	1	320	60	8	453	86
rock		Minimum	124	6	9	243	19	4	0	9	144	0	245	44	7	32	74
		Maximum	234	46	85	879	287	6	1	185	239	2	417	86	9	1436	99
Potassic	4	Mean	59	26	63	773	350	8	5	209	157	4	330	116	12	394	106
wasterock		Minimum	52	16	36	669	207	7	2	145	143	3	307	112	10	280	99
< 2 mm		Maximum	63	41	97	864	553	8	10	309	166	4	358	124	17	703	110
Incompetent	3	Mean	118	14	17	391	459	5	0	115	111	3	258	65	8	162	89
Porphyry		Minimum	64	8	9	334	268	4	0	8	95	2	105	35	7	55	79
rock		Maximum	158	18	26	468	759	5	0	296	127	3	406	101	8	371	99
Incompetent	2	Mean	21	3	14	832	66	10	0	70	248	11	774	50	11	267	182
Groundmass		Minimum	20	0	13	703	52	8	0	45	235	10	741	36	11	130	154
rock		Maximum	21	5	15	961	81	11	0	95	260	13	807	65	11	405	210
Incompetent	4	Mean	70	7	39	452	346	11	0	92	173	5	633	95	11	132	138
wasterock		Minimum	13	6	24	300	245	7	0	35	132	3	381	80	8	82	91
< 2 mm		Maximum	107	9	53	665	492	19	0	155	264	7	912	123	17	195	235
Granite		range	1-15	2-90	4-30		1-6		2-20	6-30				9-90		5-140	
*1		mean	5	20	15		1.4		8	18		0.0		60		40	
Shale/		range	5-25	30-	18-				20-	16-50				30-		18-	
Clay *1				590	120				250					200		180	
		mean	20	120	50		2.5		68	20		0.0		130		90	
Soil *1		range	<2-	5-	<10-	200-	1-5		10-	<20-				20-			
			80	3000	100	5000			800	80				250			

*1 data from Adriano 1986

note: all trace element concentrations in ppm

grown on the wasterock dumps will probably have a high Mo:Cu ratio.

The availability of the trace elements will depend in part on their form and distribution. According to Steininger (1985) the main mineral forms of Mo, Pb, and Zn were molybdenite (MoS_2), galena (PbS), and sphalerite (ZnS). No specific Co or Se minerals were mentioned in the Kitsault geology reports, however according to Rose et al. (1979), Co is commonly a trace component of mafic minerals, while Se, a chalcophile, is a component of many of the sulphide minerals.

Correlations indicate some associations of the trace elements with minerals. Significant correlations for S with Pb (r=0.70) and Zn (r=0.67) indicate that these metals were associated with pyrite. Molybdenum (r=0.67) and cobalt (r=0.82) were both correlated with quartz. Selenium was positively correlated with calcite (r=0.66) and sericite (r=0.66) and negatively correlated with K feldspar (r=-0.72).

The great variation in the concentrations of many trace elements resulted because they primarily occurred in veins and along fracture coatings, structures with a rather random distribution. According to Steininger (1985), 80 to 90% of the molybdenite was individual grains, < 50 um in diameter, disseminated in quartz veinlets. The veins identified by Steininger (1985) included barren quartz, quartz-molybdenite, quartz-polymetallic, and carbonate.

Despite the variation within each group, there were a large number of significant differences among different rock types and among the rock and the wasterock samples. For example, the hornfels rock had the lowest levels of Mo. This sharply contrasted with the < 2 mm fraction of hornfels wasterock whose Cu, Mn, and Mo levels were more than double those the igneous samples. These differences suggest that the degree of mineralization varied greatly in the hornfels rock.

The trace element concentrations of the igneous rock samples resembled that of the major elements, in that composition of the incompetent porphyry and the potassic rock samples were similar, and the incompetent groundmass samples was distinctly different. Compared to the porphyry samples, the incompetent groundmass samples was higher in Mn, Nb, Ru, Se, Sr, Y, and Zr, and lower in Co, Cr, and Mo. Compared to the the potassic wasterock, the incompetent wasterock was higher in Sr and lower in Cr, Mn, Pb, and Zn.

2.4 Summary

The incompetent rock was comprised of a heterogeneous mix of phenocrysts and groundmass. Quartz and K feldspar dominated the phenocrysts. Sericite and calcite dominated the groundmass. The phenocryst grains were largely 2000 to 100 um in diameter while the groundmass grains were predominantly silt sized.

In contrast to the incompetent rock, the hornfels was entirely fine grained. Mineralogically the hornfels differed from the incompetent rock by containing higher amounts of plagioclase and lower amounts of K feldspar, sericite and calcite. The tight interlocking of the grains, which limited the extent of hydrothermal alteration (Steininger, 1985), makes the hornfels coarse fragments very cohesive.

The cohesive potassic rock had the same range in grain size and contained the same minerals as the incompetent wasterock. The main difference was that the incompetent rock contained a larger proportion of sericite and calcite. These two minerals appeared to be responsible for the lack of cohesiveness of the incompetent wasterock.

For all three rock types, the < 2 mm fractions of the wasterock were enriched in biotite, kaolinite, sericite, and calcite. Higher concentrations of sericites and calicite in the < 2 mm fractions were responsible for the higher concentrations of Al, C, and Ca. While pyrite was not

detected in the XRD scans, estimates made from the levels of S gave average values of up to 5.7 %.

Despite some high average pyrite concentrations, the amount of calcite in the waterock was more than sufficiewnt to neutralize any potential acidity. Of the three rock types, the incompetent wasterock had the greatest excess of calcite.

The most common < 2 um minerals in the wasterock were smectite, kaolinite, and sericite. Smectite expands when hydrated and this can be a source of instability in rocks. In most rocks, the dense packing of grains will prevent the entry of water and thus smectite expansion will not be a problem. However, the intensely altered rock is highly fractured and porous. This permits water greater access to the smectite and thus smectite expansion might contribute to the observed instability.

Of the trace elements measured in the hornfels, potassic, and incompetent rock samples, Co, Mo, Pb, Se, and Zn were all present in higher concentrations than the levels commonly found in soils. Compared to the concentrations of these elements in the other rock types, the incompetent samples contained similar amounts of Co, Mo, and Se, and lower amounts of Pb and Zn.

3. CHARACTERISTICS OF WEATHERED WASTEROCK

3.1 Objective

The objective was to show how the < 2 mm fraction of the wasterock had changed as a result of 10 years of weathering and pedogenesis.

3.2 Materials and Methods

3.2.1 Sample Selection

Twelve samples were selected to show the range in conditions on the abandoned dumps. As most of the weathered samples were potassic wasterock, most of the samples chosen were of this type (PO). The exceptions were two naturally vegetated samples, which, judging from their high fines content, contained incompetent wasterock (INC .LG). Four of the potassic samples were from beneath the peat x birdsfoot trefoil treatment in Trial 70.1 (PO.LGP5). The other samples were from the 0-5 cm depth on untreated sections of the Low Grade Ore (LG) and South East Lower (SEL) dump. Unweathered (UW) incompetent and potassic wasterock samples were included as controls.

3.2.2 Sample Analyses

With the exception of the < 2 um mineralogy, all analyses were carried out on the < 2 mm fraction. Major and

trace elements, total mineralogy, clay mineralogy, and carbonate-C were measured in the same manner as in Section 2. Cations from different fractions were extracted with acid ammonium oxalate (McKeague and Day, 1966), EDTA (Farmer et al., 1980), and ammonium acetate (Anderson, 1975). Levels of Si, Al, Fe, Ca, Mg, Na, and K in the leachate were determined by flame atomic absorption spectroscopy. The pH and available P assays were carried out in the same manner as in the first part of the thesis. Organic-C was calculated by subtracting carbonate-C from total-C.

Prior to particle size analysis, organic matter was removed with NaOCl, carbonates and soluble salts were removed with Na acetate, and sesquioxides were removed with citrate dithionate bicarbonate, according to the methods of Lavkulich and Wiens (1970) and Kunze (1965). The sizes of the various sand fractions were determined by sieving. The sizes of the silt and clay fractions were determined by the hydrometer method (Day, 1965). The < 2 um fraction was then seperated according to the method of Kittrick and Hope (1963).

3.2.3 Data Analysis

Statistical techniques were the same as those used in the previous section. Unrelated samples were compared with the Mann-Whitney U test. Data from the same samples were compared with the Wilcoxon matched-pairs signed-ranks test.

The degree of correlation between different properties of the potassic and argillic wasterock were indicated by the Spearman rank correlation coefficient. For all tests, 0.05 was used as the level of probability at which differences were considered significant.

3.3 Results and Discussion

3.3.1 pH and Organic-C

Of the various properties measured, decreases in pH and increases in organic-C were most indicative of pedogenic development (Table 2.8). Organic matter was the source of organic acids, which in turn was the main source of acidity. As a result, pH and organic-C were strongly correlated (r= -0.92). Samples whose pH was > 7 contained very little organic-C.

3.3.2 Mineralogy and Major Element Content of the < 2 mm Fraction

There were a number of strong correlations among pH and minerals (e.g. calcite r=0.95, quartz r=-0.75) and major elements (Ca r=0.95, Si r=-0.84) found in the wasterock (Table 2.16). Of the differences found between the unweathered and the low pH samples, the most dramatic change in mineralogy was a loss of calcite (Table 2.9). This was accompanied by a similar decrease in Ca (Table 2.10).

Table 2.8 The pH, carbonate-C, and organic-C levels of the weathered and unweathered wasterock.

Sample	pH	carbonate-C %	organic-C %
INC.UW	7.7	1.1	0.0
INC.UW	7.7	0.8	0.0
INC.UW	7.6	1.8	0.0
INC.UW	7.4	0.8	0.0
PO.UW	7.7	0.9	0.0
PO.UW	7.7	0.7	0.0
PO.UW	7.6	0.7	0.0
PO.UW	7.6	0.6	0.0
PO.SEL	7.6	0.6	0.1
PO.LG	7.5	0.2	0.0
PO.SEL	7.3	0.3	0.0
PO.LG	6.9	0.0	0.4
PO.SEL	6.8	0.2	0.2
PO.LGP5	5.3	0.1	0.7
PO.SEL	5.3	0.0	0.3
PO.LGP5	4.8	0.0	1.1
INC.LG	4.1	0.0	1.0
PO.LGP5	4.0	0.0	0.9
PO.LGP5	3.9	0.1	8.8
INC.LG	3.7	0.0	2.8

Table 2.9 Mineralogy of the < 2 mm fractions of the unweathered and weathered wasterock.

Sample	pH	Quartz	K feldspar	Plagioclase	Chlorite	Biotite	Sericite	Kaolinite	Calcite	Vermiculite
		(estimated proportion in %)								
INC.UW	7.7	21	18	0	0	3	34	9	9	0
INC.UW	7.7	32	28	0	0	2	17	7	7	0
INC.UW	7.6	0	0	0	0	0	86	0	14	0
INC.UW	7.4	36	23	4	0	1	31	2	6	0
PO.UW	7.7	27	31	2	0	3	14	11	7	0
PO.UW	7.7	36	22	7	2	6	16	6	6	0
PO.UW	7.6	31	32	2	2	5	13	6	6	0
PO.UW	7.6	35	25	4	1	3	18	6	5	0
PO.SEL	7.6	24	27	4	12	6	10	11	6	0
PO.LG	7.5	36	24	5	2	4	11	14	3	0
PO.SEL	7.3	27	30	2	12	6	10	8	5	0
PO.LG	6.9	44	21	10	6	4	13	0	2	0
PO.SEL	6.8	29	30	2	13	10	7	7	2	0
PO.SEL	5.3	37	27	6	6	4	11	7	3	0
PO.LGP5	5.3	35	33	6	2	3	11	9	0	0
PO.LGP5	4.8	54	19	5	0	4	10	8	0	0
INC.LG	4.1	37	44	2	3	2	7	4	0	2
PO.LGP5	4.0	55	22	5	0	5	7	6	0	0
PO.LGP5	3.9	39	21	8	5	4	14	12	0	3
INC.LG	3.7	40	32	4	0	1	8	12	0	3

Table 2.10 Major element concentrations in the < 2 mm fractions of the unweathered and weathered wasterock.

Sample	pH	%Al	%C	%Ca	%Fe	%K	%Mg	%Na	%P	%S	%Si	%Ti
INC.UW	7.7	8.4	1.3	3.5	1.2	5.5	0.6	0.2	0.1	1.1	29.6	0.3
INC.UW	7.7	7.1	0.9	2.9	1.3	5.0	0.5	0.2	0.1	0.9	32.0	0.3
INC.UW	7.6	13.6	2.4	5.6	3.1	6.7	1.4	0.1	0.3	3.5	18.3	0.6
INC.UW	7.4	7.1	0.9	2.0	1.1	4.6	0.6	0.4	0.1	1.0	32.8	0.3
PO.UW	7.7	6.8	1.2	2.9	2.1	5.2	0.7	0.4	0.1	1.7	30.9	0.3
PO.UW	7.7	6.8	1.2	2.3	3.1	4.3	0.8	0.8	0.1	2.2	30.8	0.3
PO.UW	7.6	7.1	1.0	2.5	2.4	4.9	0.9	0.4	0.2	1.7	30.9	0.3
PO.UW	7.6	6.6	1.0	2.0	1.9	4.5	0.6	0.4	0.1	1.7	32.7	0.3
PO.SEL	7.6	7.8	0.7	2.5	1.6	5.9	0.7	0.3	0.2	0.9	31.1	0.3
PO.LG	7.5	7.4	0.3	1.2	2.1	4.9	0.6	0.6	0.2	0.8	33.0	0.4
PO.SEL	7.3	7.3	0.3	1.5	1.5	5.4	0.7	0.6	0.1	0.7	33.0	0.3
PO.LG	6.9	7.5	0.5	0.8	3.2	3.2	1.1	1.3	0.1	0.6	33.2	0.4
PO.SEL	6.8	7.3	0.3	1.0	1.4	5.6	0.7	0.6	0.1	0.5	33.6	0.3
PO.LGP5	5.3	7.2	0.7	0.7	2.6	5.0	0.6	0.7	0.2	1.1	33.3	0.4
PO.SEL	5.3	7.3	0.3	0.6	1.7	5.6	0.7	0.8	0.1	0.7	33.7	0.3
PO.LGP5	4.8	7.4	1.2	0.6	2.5	5.1	0.7	0.8	0.2	0.8	33.2	0.4
INC.LG	4.1	8.0	1.0	0.5	2.0	5.7	0.8	0.9	0.2	0.1	33.1	0.4
PO.LGP5	4.0	6.6	0.9	0.4	2.0	5.1	0.6	0.8	0.1	0.7	34.6	0.4
PO.LGP5	3.9	8.0	8.9	0.6	3.1	4.3	0.8	1.0	0.2	0.6	32.5	0.5
INC.LG	3.7	7.7	2.8	0.4	1.5	5.8	0.5	0.5	0.2	0.1	34.1	0.4

Soluble in slightly acid solutions, calcite weathered rapidly in recently exposed glacial moraines in south east Alaska (Ugolini, 1967). Calcium ions released from calcite are rapidly leached from a porous, well drained, substrate, like the wasterock. Any Ca remaining in the low pH samples is probably a component of plagioclase.

The carbonate anions released from calcite were also susceptable to leaching. However, the effect of carbonate-C los ses on the total-C concentrations was masked by the concurrent increase in organic-C. As a result the samples with an intermediate pH, which contained little of either C type, had the lowest total-C levels.

Sulphate anions created by the oxidation of sulphide minerals tend to remain in solution and are readily leached. As a result, one can assume that all the S in the wasterock occurred in sulphide minerals. The significant correlation between pH and S ($r=0.77$) indicates that a significant portion of the pyrite has weathered. While differences in S content might result from lithological factors, the low pH samples were almost all from the LG dump, and thus initially would be expected to contain more S than wasterock from other sources.

Of the samples examined, the lowest S concentrations were in the acidic samples of incompetent wasterock. Evidence from the rock samples suggest that S in the incompetent rock is concentrated in the groundmass, while a larger proportion of the S in the potassic rock occurs in

quartz veins. The greater accessibility of air and water into the groundmass, leading to accelerated S oxidation, would result in faster and more complete pyrite oxidation

While some mineralogical differences resulted from weathering, others changes appeared to be a result of lithological differences. For example, while the higher levels of amorphous Al in the low pH samples (Table 2.15), indicate the weathering of aluminosilicates. Amorphous Al levels were not high enough to account for the 3 to 4% decrease in sericite content noted in the more acidic samples.

The variable nature of the rock will obscure any small changes. For example, the loss of calcite should increase the proportion of more resistant components by negative enrichment, and this might explain the negative correlations for quartz and plagioclase with pH. However given the great variation in quartz and plagioclase contents, and the relatively small calcite concentrations in the unweathered samples, it was unlikely that negative enrichment was the sole reason for the differences observed. The high quartz and plagioclase contents in the LG samples with relatively high pH values suggest a lithological explanation.

After 10 years of exposure, the only evidence in the < 2 mm fraction of mineral alteration or authigenesis was an 1.15 nm peak in the two INC.LG and one PO.LGP5 samples. The low pH values and high organic matter contents of these samples suggest that this peak was created by pedogenesis.

Possible modes of formation include the removal of Mg hydroxy interlayers from chlorite or the conversion of sericite into vermiculite. Both processes would be stimulated by the onset of acidic conditions.

3.3.3 < 2 um Mineralogy

Variation in the mineralogy of the < 2 um fraction appears to have resulted from lithological difference rather than weathering as none of the < 2 um minerals were correlated with pH (Table 2.11). Nor were there any signs of mineral alteration or authigenesis. The 1.15 nm peak found in the < 2 mm fraction of some of the most intensely weathered samples did not appear in the XRD scans of the < 2 um samples. This suggests that either the 1.15 nm peak resulted from the formation of a mineral already present in the < 2 um fraction, or the pretreatments altered it back to its original form (e.g., removal of Al hydroxy interlayers), or it only occurred in particles larger than < 2 um. For example, the 1.15 nm peak may have been produced by the formation of vermiculite or smectite in large sheathes of sericite.

3.3.4 Particle Size

The only strong correlation between pH and a particle size fraction was with sand (r=-0.76). Possible mechanisms by which pedogenesis might increase the proportion of sand

Table 2.11 Mineralogy of the < 2 um fractions of the unweathered and weathered wasterock.

Sample	pH	< 2um	Quartz	K feldspar	Chlorite	Sericite	Kaolinite	Smectite
			(estimated proportion in %)					
INC.UW	7.7	2.6		tr		15	25	60
INC.UW	7.7	3.4	tr			10	25	60
INC.UW	7.6	4.3				90	5	5
INC.UW	7.4	2.2		5		60	15	25
PO.UW	7.7	3.5		tr	5	10	50	35
PO.UW	7.7	4.9		5	10	10	35	40
PO.UW	7.6	3.4			5	10	30	55
PO.UW	7.6	4.9		tr	10	20	30	40
PO.SEL	7.6	1.8			5	tr	30	65
PO.LG	7.5	2.7		tr	5	5	50	40
PO.SEL	7.3	3.7				tr	15	80
PO.LG	6.9	2.6		tr	5	10	35	45
PO.SEL	6.8	2.4				tr	10	90
PO.LGP5	5.3	3.6			5	10	50	40
PO.SEL	5.3	2.5			5	tr	20	75
PO.LGP5	4.8	4.6			5	10	50	40
INC.LG	4.1	3.5		tr	5	5	35	55
PO.LGP5	4.0	3.2		tr	tr	10	55	30
PO.LGP5	3.9	4.1			5	10	45	40
INC.LG	3.7	2.0			tr	5	70	25

Table 2.12 Particle size distribution of the unweathered and weathered wasterock.

Sample	pH	% <2mm	Sa	Si	Cl	VCSa	CSa	MSa	FSa	VFSa	CSi	MFSi
			(percent of < 2 mm fraction)									
INC.UW	7.7	38	65	27	8	13	14	14	14	10	8	19
INC.UW	7.7	28	66	22	12	20	14	12	12	9	8	15
INC.UW	7.6	52	77	17	6	19	18	17	14	9	7	10
INC.UW	7.4	23	58	31	11	8	12	13	14	11	10	21
PO.UW	7.7	19	64	19	18	18	12	11	12	10	7	11
PO.UW	7.7	31	65	21	14	18	15	13	12	10	7	14
PO.UW	7.6	27	66	24	10	16	13	12	12	9	8	16
PO.UW	7.6	31	70	22	8	21	16	12	12	8	8	15
PO.SEL	7.6	28	66	23	10	18	15	12	12	9	7	17
PO.LG	7.5	18	72	20	8	23	17	16	11	8	7	13
PO.SEL	7.3	34	69	17	14	19	16	13	12	8	6	11
PO.LG	6.9	21	74	19	7	27	20	13	9	5	7	11
PO.SEL	6.8	25	72	24	4	21	17	13	12	8	6	18
PO.LGP5	5.3	9	70	21	9	18	14	13	13	11	9	12
PO.SEL	5.3	29	72	18	10	20	17	14	13	9	6	12
PO.LGP5	4.8	10	70	21	9	17	14	13	14	12	9	12
INC.LG	4.1	39	74	18	8	19	18	15	13	9	7	11
PO.LGP5	4.0	29	76	17	7	23	17	13	12	10	7	9
PO.LGP5	3.9	18	62	25	14	14	14	12	12	9	8	16
INC.LG	3.7	44	75	19	6	20	18	15	13	9	6	12

Sa: 2000-50um VCSa: 2000-1000um FSa: 250-100um
Si: 50-2um CSa: 1000-500um VFSa: 100-50um
Cl: < 2um MSa: 500-250um CSi: 50-20um MFSi: 20-2um

include the loss of calcite from the silt fraction and the release of phenocryst size grains from the coarse fragments.

However, the differences in sand content may also have resulted lithological differences, as most of the acidic samples were from the LG dump (Table 2.12). The higher quartz and plagioclase and lower sericite levels in the LG samples supports this assumption, and if only samples from the LG dump are included, the correlation between pH and sand is no longer significant.

3.3.5 Trace Element Content of the < 2 mm Fraction

In general, trace element concentrations in the abandoned dumps were not significantly different from those of the unweathered wasterock (Table 2.13). Of the trace elements (Co, Mo, Pb, Se, and Zn) that exceeded the levels commonly found in soils, only Co decreased in the more acidic samples. Given the stability of other more mobile trace elements, it is unlikely that the decrease in Co resulted from weathering.

The largest difference in trace element concentrations between the unweathered and the low pH samples was in Mo. Molybdenum was also the only trace element strongly correlated with pH, a factor largely due to the high Mo concentrations in the LG dump samples. Wasterock in the LG dump was initially selected for its high Mo content. High Mo concentrations in the PO.SEL samples can be attributed to the higher cut-off grade for waste in the earlier mining.

Table 2.13 Trace element concentrations in the < 2 mm fractions of the unweathered and weathered wasterock.

Sample	pH	Co	Cr	Cu	Mn	Mo	Pb	Se	Sr	Zn	Zr
INC.UW	7.7	52	7	39	480	299	116	6	912	127	123
INC.UW	7.7	107	6	53	364	349	155	5	649	195	102
INC.UW	7.6	13	9	24	665	245	63	7	589	127	235
INC.UW	7.4	107	6	41	300	492	35	3	381	82	91
PO.UW	7.7	61	19	36	758	285	235	4	331	280	99
PO.UW	7.7	52	29	97	864	553	145	3	307	302	108
PO.UW	7.6	63	41	67	669	354	148	4	358	292	108
PO.UW	7.6	62	16	53	802	207	309	4	323	703	110
PO.SEL	7.6	15	24	51	536	760	47	5	319	157	105
PO.SEL	7.3	6	29	88	498	528	83	4	286	129	93
PO.SEL	6.8	9	28	978	489	369	397	4	322	103	99
PO.SEL	5.3	6	16	296	436	642	69	4	359	85	109
PO.LG	7.5	17	69	94	805	963	83	3	289	171	147
PO.LG	6.9	19	106	77	1198	714	107	4	209	154	129
PO.LGP5	5.3	14	32	174	1158	1113	219	5	301	465	111
PO.LGP5	4.8	18	28	157	990	1161	181	8	283	442	113
PO.LGP5	4.0	12	20	92	604	1086	126	5	274	249	101
PO.LGP5	3.9	13	81	112	885	1236	173	20	256	219	146
INC.LG	4.1	84	26	35	852	709	150	6	341	143	126
INC.LG	3.7	62	23	39	1205	807	131	11	295	166	115

note: all trace element concentrations in ppm

3.3.6 Extractable Elements

Three extractants were used to characterize the availability of major cations. Acid ammonium oxalate extracts amorphous Si, Fe, and Al, along with organic complexes (McKeague & Day, 1966), EDTA is selective for cations bound in organic complexes (Anderson et al., 1982), and ammonium acetate (pH 7) extracts exchangeable cations and cations bound in easily soluble compounds (Anderson, 1975). The relative effectiveness of the extractants was acid ammonium oxalate (AAO) > Na-EDTA >= ammonium acetate (Ac).

Of the large number of extractant x element combinations, pH was significantly correlated with measures of extractable Fe, Al, Ca, and Mg (Table 2.14). Of these the correlation with EDTA-Ca was the strongest (r=0.91). The correlation for Ac-Ca with pH was also significant (r=0.72). AAO was not used as an extractant for available Ca because Ca oxalate is insoluble. The high levels of Ca extracted from the unweathered wasterock indicate that EDTA and Ac extracted Ca directly from calcite (Table 2.15). Wasterock samples from the abandoned dumps, with similar amounts of calcite had much lower EDTA-Ca levels. This difference could not be explained by the calcite content and did not occur with Ac-Ca.

Unlike the forms of extractable Ca, none of the forms of extractable Mg were significantly correlated with the Mg minerals or with total-Mg (Table 2.16). The strongest

Table 2.14 Spearman correlation coefficients for significant correlations between levels of extractable elements in the unweathered and weathered wasterock

	pH	avail.P	Sand	Fe AAO	Fe EDTA	Al AAO	Al EDTA	Si AAO	Si EDTA	Ca EDTA	Ca Ac	Mg AAO	Mg EDTA	Mg Ac	Na AAO	Na Ac	K AAO	K EDTA	K Ac
pH	X																		
available P	-0.89	X																	
Sand	-0.76	0.61	X																
Fe-AAO	-0.59			X															
Fe-EDTA					X														
Al-AAO	-0.77	0.71	0.55	0.84		X													
Al-EDTA	-0.77	0.71	0.62	0.77	0.46	0.83	X												
Si-AAO				0.66		0.77		X											
Si-EDTA									X										
Ca-EDTA	0.91	-0.82	-0.67	-0.49		-0.71	-0.66			X									
Ca-Ac	0.72	-0.80	-0.56	-0.75		-0.70	-0.78			0.64	X								
Mg-AAO	0.78	-0.59	-0.63			-0.58	-0.46			0.82	0.45	X							
Mg-EDTA	0.64	-0.48	-0.46		0.48				0.54	0.68		0.90	X						
Mg-Ac			-0.48									0.54	0.73	X					
Na-AAO					0.48		0.48		0.45						X				
Na-Ac																X			
K-AAO															0.45		X		
K-EDTA															0.60		0.79	X	
K-Ac																	0.69	0.82	X
organic-C	-0.92	0.87	0.63	0.61		0.84	0.72			-0.95	-0.69	-0.80	-0.68						

Table 2.15 Extractable element concentrations in the < 2 mm fractions of the wasterock and the crushed (< 2mm) rock samples.

Sample	pH	%Fe AAO	%Fe EDTA	%Al AAO	%Al EDTA	%Si AAO	%Si EDTA	%Ca EDTA	%Ca AAc	%Mg AAO	%Mg EDTA	%Mg AAc	%Na AAO	%Na AAc	%K AAO	%K EDTA	%K AAc	av.P ppm
WASTEROCK																		
INC.UW	7.7	0.13	0.07	0.013	0.001	0.016	0.001	0.37	0.32	0.064	0.010	0.012	0.002	0.001	0.012	0.006	0.010	0.3
INC.UW	7.7	0.25	0.01	0.018	0.001	0.020	0.002	0.37	0.35	0.040	0.009	0.015	0.002	0.001	0.009	0.004	0.010	0.3
INC.UW	7.6	0.04	0.00	0.009	0.001	0.012	0.001	0.43	0.29	0.080	0.009	0.008	0.002	0.001	0.012	0.006	0.012	1.0
INC.UW	7.4	0.28	0.02	0.018	0.002	0.020	0.003	0.33	0.24	0.125	0.018	0.007	0.003	0.001	0.018	0.007	0.011	8.2
PO.UW	7.7	0.43	0.01	0.024	0.001	0.028	0.002	0.39	0.30	0.089	0.011	0.012	0.002	0.001	0.014	0.005	0.010	0.5
PO.UW	7.7	0.72	0.01	0.041	0.007	0.044	0.009	1.11	0.29	0.139	0.045	0.018	0.005	0.002	0.016	0.007	0.010	0.5
PO.UW	7.6	0.49	0.02	0.036	0.002	0.040	0.003	0.38	0.30	0.078	0.011	0.013	0.002	0.001	0.016	0.005	0.010	0.3
PO.UW	7.6	0.51	0.02	0.024	0.003	0.028	0.004	0.37	0.31	0.116	0.019	0.025	0.009	0.001	0.014	0.006	0.010	0.3
PO.SEL	7.6	0.21	0.00	0.023	0.001	0.024	0.001	0.05	0.38	0.049	0.003	0.010	0.001	0.001	0.014	0.004	0.010	0.6
PO.LG	7.5	0.56	0.00	0.039	0.001	0.054	0.002	0.06	0.27	0.046	0.004	0.009	0.001	0.001	0.012	0.004	0.010	1.6
PO.SEL	7.3	0.23	0.00	0.022	0.001	0.028	0.001	0.08	0.37	0.019	0.001	0.005	0.002	0.001	0.024	0.009	0.016	0.9
PO.LG	6.9	0.72	0.01	0.116	0.003	0.060	0.002	0.05	0.08	0.023	0.002	0.005	0.002	0.001	0.009	0.002	0.005	3.2
PO.SEL	6.8	0.27	0.00	0.045	0.002	0.032	0.001	0.05	0.33	0.018	0.001	0.005	0.002	0.001	0.014	0.003	0.010	2.1
PO.LGP5	5.3	1.23	0.02	0.100	0.006	0.052	0.002	0.02	0.08	0.040	0.005	0.012	0.002	0.001	0.014	0.004	0.010	19.2
PO.SEL	5.3	0.28	0.01	0.032	0.005	0.020	0.001	0.03	0.20	0.018	0.002	0.007	0.002	0.001	0.018	0.005	0.010	5.5
PO.LGP5	4.8	0.79	0.02	0.096	0.009	0.030	0.001	0.02	0.07	0.030	0.004	0.009	0.003	0.001	0.021	0.008	0.011	23.4
INC.LG	4.1	0.67	0.01	0.273	0.034	0.052	0.003	0.00	0.07	0.014	0.002	0.008	0.002	0.001	0.008	0.002	0.004	19.6
PO.LGP5	4.0	0.99	0.04	0.063	0.007	0.020	0.001	0.01	0.03	0.017	0.003	0.007	0.002	0.001	0.009	0.004	0.010	8.5
PO.LGP5	3.9	0.98	0.03	0.334	0.015	0.049	0.001	0.01	0.14	0.026	0.004	0.014	0.002	0.001	0.009	0.003	0.010	29.6
INC.LG	3.7	0.56	0.01	0.173	0.020	0.032	0.002	0.00	0.04	0.012	0.002	0.009	0.003	0.001	0.025	0.017	0.026	18.4

Table 2.16 Spearman correlation coefficients for significant correlations between extractable element concentrations and other properties of the wasterock.

	pH	avail.P	Sand	Fe AAO	Fe EDTA	Al AAO	Al EDTA	Si AAO	Si EDTA	Ca EDTA	Ca Ac	Mg AAO	Mg EDTA	Mg Ac	Na AAO	Na Ac	K AAO	K EDTA	K Ac
Quartz	-0.75	0.68	0.64	0.80		0.75	0.80			-0.64	-0.82	-0.49							
K feldspar																			
Plagioclase	-0.50	0.52		0.75		0.63	0.56	0.54			-0.52								
Chlorite					-0.55			0.45					-0.57						-0.45
Biotite																			
Sericite	0.68	-0.51	-0.55			-0.60				0.74		0.79	0.78	0.48					
Kaolinite																			
Calcite	0.93	-0.83	-0.68	-0.77		-0.89	-0.80	-0.58		0.88	0.72	0.72	0.56						
Mafic Ph.													-0.52						
Felsic Ph.	0.51		-0.55			-0.53				0.49		0.65	0.64	0.48					
Al									-0.49										
Ba								-0.49											
C					0.54									0.48					
Ca	0.95	-0.81	-0.74	-0.69		-0.81	-0.81			0.88	0.77	0.78	0.60						
Fe				0.57		0.46		0.53											
K				-0.50				-0.45	-0.48										
Mg																			
Na	-0.65	0.63		0.79		0.84	0.73	0.70		-0.53	-0.61	-0.47							
P																			
S	0.77	-0.62	-0.70			-0.62				0.81		0.90	0.86	0.57					
Si	-0.84	0.65	-0.73	0.48		0.59	0.55			-0.79	-0.58	-0.79	-0.68	-0.55					
Ti	-0.53	0.65		0.47		0.59					-0.61								

Ph. : phyllosilicates

correlations with extractable Mg were with total S. The most likely explanation for this is a relationship between dolomite and pyrite. According to Steininger (1985), at the same time as hydrothermal alteration creates sericite from plagioclase, Fe and Mg may be released from biotite and chlorite. Released Fe forms pyrite, while Mg, along with Ca, forms dolomite.

The removal of dolomitic Mg by the extractants may be responsible for the high concentrations of AAO- and EDTA-Mg in the unweathered wasterock. The low AAO- and EDTA-Mg levels in the more acidic samples indicate that weathering removed dolomite. Dolomite is soluble under acidic conditions, and thus can be expected to weather faster than mafic silicates like biotite and chlorite.

The negative correlations for Fe and Al with pH, indicate that Al and Fe released by weathering reprecipitated in-situ. AAO was the most effective extractant for both Fe and Al. For Al, although AAO extracted from 5 to 40 times more than EDTA, the correlations for the two extractants with pH were the same strength (r=-0.77). However with other properties in most other cases, the correlations with AAO-Al were stronger. The strongest correlation with AAO-Al was with calcite (r=-0.89).

As expected from the large number of Al containing minerals, neither AAO- or EDTA-Al were strongly correlated with total-Al or a particular Al mineral. Weak correlations

of extractable Al with plagioclase and sericite, resulted from coincidental associations between lithology and the sites of maximum plant growth.

Concentrations of AAO-Fe were all significantly larger than those of AAO-Al. In the exposed wasterock this may be attributed to the presence of amorphous Fe released from oxidized pyrite. However, the relatively high AAO-Fe concentrations in the unweathered potassic samples suggest that AAO was also capable of extracting Fe from primary minerals. The weak correlation between AAO-Fe and pH ($r = -0.59$) resulted from the low levels in some of the exposed wasterock (LG.INC and PO.SEL). In the high pH, low sulphur SEL.PO samples, the low levels of AAO-Fe were probably due to a lack of pyrite oxidation. In the very acidic LG.INC samples, the almost complete absence of S suggests that Fe released from pyrite oxidation has been removed by leaching.

Unlike the cations previously discussed, measures of extractable Si, K, and Na showed no change as a result of changes in pH. The lack of change in these elements results from their occurrence in common minerals, the stability of these minerals, and, in the case of K and Na, the mobility of the element when released.

The only anion measured, available P was strongly correlated with pH ($r=-0.89$) and organic-C ($r=0.87$). The lack of a correlation between total-P and pH indicates that P released by weathering was conserved. The lack of a correlation between total and available P suggests that

chemical conditions, rather than total P supply, were the primary factors controlling P availability.

3.4 Summary

In this section, samples of wasterock from the abandoned dumps were analysed to see the effects of 10 years weathering and pedogenesis. Of the various properties measured decreases in pH and increases in organic-C were most indicative of pedogenic development. The strongest correlations with pH were with calcite (r=0.93), and properties associated with it (e.g., Ca r=0.95). The pH was also positively, correlated with levels of extractable Mg (e.g., AAO-Mg r=0.78), a factor attributed to the dissolution of dolomite.

Low S concentrations in the more acidic samples, and the correlation between S and pH (r=0.77), indicate that sulphide oxidation had occurred. The lowest S concentrations were in the low pH incompetent wasterock samples. Decreases in pH resulted in increases in extractable Fe and Al. Pyrite oxidation was apparently responsible for the greater increase in extractable Fe. Very little of either AAO-Fe or -Al was organically complexed (EDTA extractable).

The lack of changes in trace element concentrations suggests that metals released by sulphide oxidation were complexed by Fe, and thus not readily leached. The failure to detect changes in trace element concentrations, or

particle size, may also be due to the great lithological variability of the wasterock. The only evidence of mineral transformation on the dumps was the appearance of an 11.5 mm peak in the < 2 mm XRD scans.

4. PROPERTIES OF NATURAL SOILS ADJACENT TO THE MINESITE

4.1 Objectives

The objectives of this section were: 1) to measure the effect of natural soil development on soil properties, and 2) to determine the conditions under which these changes occurred. An understanding of pedogenesis and the properties of natural soils adjacent to the mine is important, as, with a similar climate and flora, the dump slopes should alter in a similar fashion.

4.2 Materials and Methods

4.2.1 Sample Selection

Ideally, to predict how the incompetent wasterock will alter, one would study soils developed from incompetent rock. However, the area in which the incompetent rock might have outcropped had already been mined, so it was necessary to look at other parent materials. In the sample selection process,the objective was to select soil profiles developed under conditions similar to a dump slope. e.g. deep, coarse parent materials, on steep slopes, at the same elevation as the mine.

The criteria of steep slopes was easily achieved as most of the surrounding terrain was steep, with many natural slopes matching the angle of repose of the dump slopes. Coarse parent materials were also common, as most of the unconsolidated mineral material was colluvium. It was more

difficult to find deep parent materials. On most slopes around the mine the unconsolidated mineral layer was less than 40 cm thick. Above the cohesive bedrock of the coast plutonic complex, which after the Kitsault intrusive complex was the closest large source of igneous rock, the unconsolidated mineral layer rarely exceeded 20 cm..

Although much of its surface had been disturbed, the largest source of soils matching the criteria outlined were parent materials derived from the Kitsault intrusive complex. Two soil profiles were selected, one developed from hornfels (HN), the other developed from quartz diorite (QD) rock. Both soils, like all the well developed soils on steep coarse parent materials in this region , were podzols.

4.2.2 Site Description

Aspect, topography and vegetative cover were recorded along with the 1) depth, 2) thickness, boundary 3) coarse fragment content, 4) matrix colour, 5) mottle colour, 6) structure, and 7) abundance of roots, 8) boundary distinctness and form for each horizon.

4.2.3 Sample Analysis

The fractions analyzed and the analyses carried out are listed in Table. 2.17. Coarse fragment content, particle size, coarse fragment and < 2 mm mineralogy (XRD), < 2 um mineralogy (XRD), major and minor elements (XRF), total-C (Leco Induction furnace), pH (0.01M $CaCl_2$), available P

Table 2.17 Analyses carried out on samples from the natural soils.

	Particle Size	XRD powder	XRD oriented	Heavy Mineral	XRF major	XRF trace	%C	pH	avail. P	AAO	Pyr
Quartz Diorite											
Coarse Fragments		X			X	X	X				
< 2 mm	X	X			X	X	X	X	X	X	X
< 2 mm (-AAO)					X	X					
Sand & Coarse Silt		X		X							
20-2 um			X								
< 2 um			X								
Hornfels											
Coarse Fragments		X			X	X	X				
< 2 mm	X	X			X	X	X	X	X	X	X
< 2 um			X								

AAO : acid ammonium oxalate

Pyr : Na pyrophosphate

(Bray Pl), and amorphous Fe, Al, Si, Mg, Na, and K (AAO) analyses and pretreatments were carried out in the same manner as in the previous section. Organically bound Fe, Al, and Si were extracted with 0.1 M sodium pyrophosphate (pyr) (Bascomb, 1968) and the levels of Fe, Al, and Si extracted were determined by flame atomic absorption spectroscopy. The XRF data was reported on an ignited weight basis to remove the diluting effect of differences in organic matter concentrations. All other results were reported on an oven dry weight basis. Total-C analysis carried out on the unweathered coarse fragments showed there were no carbonates present. Therefore the measure of total-C was a measure of organic-C.

In addition to analyzing the major cations in the AAO extract, a measure of the AAO extractable concentrations of major and minor elements in the quartz diorite samples were measured using XRF. In this procedure, the major and minor elemental composition of the residue was determined after the AAO extraction and compared with the concentrations in the original samples.

The proportion of each mineral detected in the coarse fragments, the < 2 mm fraction, and individual sand and the coarse silt-size fractions were estimated in the same manner as that used for the < 2 mm fraction in section 2. The correction factor used to account for the relative strengths of reflectance for sericite and kaolinite (x2) was also used for the peak intensities of vermiculite (1.15 mm) and Al-

vermiculite (1.35 mm). The term illite is used here to refer to the clay-mineral muscovite, rather than sericite, to indicate that pedogenesis may have played a role in its origin (Gary et al., 1972). The term sericite is used where the origin of muscovite is strictly hydrothermal.

The < 2 um and 2-20 um phyllosilicate minerals were identified by the following combinations of treatments and peak locations.

Kaolinite: K 300°C 0.7 nm;

Chlorite: Mg 1.4 nm; Mg glycerol 1.4 nm; K 1.4 nm; K 300°C 1.4 nm; K 500°C 1.4 nm;.

Illite: Mg 1.0 nm;

Smectite: Mg 1.38 nm; Mg glycerol 1.76 nm; K 1.2-1.0 nm;

Smectite/Illite: Mg 1.2 nm; Mg glycerol 1.30 nm; K 1.1-1.0 nm;

Vermiculite: Mg 1.33 nm; Mg glycerol 1.33 nm; K 1.13 nm;

Chloritized-Vermiculite: Mg 1.4 nm; Mg glycerol 1.4 nm ; K 1.4 1.35 nm; K 300°C 1.39-1.07 nm; K 550°C 1.38-1.0 nm;

Ch-Vm/Illite: Mg 1.24-1.18 nm; Mg glycerol 1.24-1.18 nm ; K 1.21-1.15 nm; K 300°C 1.06-1.00 nm; K 550°C 1.0 nm;

With the exception of chlorite, kaolinite and illite, peaks were generally broad mounds and thus only the approximate peak intensities were determined. The correction factors applied to account for the relative strengths of reflectance of the < 2 um minerals were 0.5 for quartz and feldspar and 2 for smectite, vermiculite,

chloritized vermiculite, and the interstratified minerals (Islam and Lotse, 1986).

Heavy mineral analysis was carried out on the fine sand (250-100 um), very fine sand (100-50 um), and coarse silt (50-20 um) size fractions from selected QD soil samples. Minerals with different densities were separated with a separatory funnel, using methyl iodide to separate minerals whose density was > 3.31 g/cm^3, and bromoform to collect minerals whose density was from 2.89 to 3.31 g/cm^3. Analysis was limited to particles < 250 um to avoid multi-mineral grains.

The mineralogy of the >3.31 g/cm^3 100 to 50 um fractions was determined using back scattered electrons on a scanning electron microscope (SEM) to differentiate grains with different average atomic numbers, energy dispersive X-ray emission spectroscopy (EDXS) to create emission maps for Ca, Fe, S, and Ti, and a reflected light microscope to differentiate between magnetite and grains comprised of oxidized iron. SEM and EDXS were carried out with a Semco Naro Lab 7.

4.3 Results and Discussion

4.3.1 Site and Profile Descriptions

The HN soil profile was mid slope, on the northwest side of a small hill, overlooking the low grade ore dump. The slope was approximately 20^{o}. The QD profile was on a long (200 m), undulating slope, south of the junction

between the east wall of the pit and Patsy creek. The profile was excavated from a steep section (36°), approximately a quarter of the way up the main slope. At both sites, the overstory vegetation was a mix of western and mountain hemlock, with some amabalis fir. The understory was a scattered cover of vaccinium. Most of the surface was covered with moss, with a number of rotting logs close by.

Descriptions of each profile are given in Table 2.18. The two forest floors were the same thickness (approximately 20 cm deep) and both were covered by a few centimeters of loose needles, leaves, and twigs. Below this were 5 to 10 cm of matted, more highly decomposed material, laced with fungal hyphae. The lower 10 cm was massive and greasy, and all the plant material was well decomposed.

At both sites, rooting was concentrated in the forest floor, with no evidence of faunal activity mixing the surface litter into the mineral layers below. The depth of the surface organic layers also indicated that the site had not recently been disturbed by fire or tree throw. According to Gill (1978), the average pH values of LFH layers in the region were 3.3 to 3.5.

Both soils had high coarse fragment contents. In the HN profile, the coarse fragment content ranged from 35% at the surface to 70% in the C horizon. Unlike coarse fragments in the QD soil, all the HN coarse fragments were all < 7.5 cm in diameter. The lack of large fragments

Table 2.18 Profile descriptions for the natural soils.

	Depth (cm)	Thickness min	Thickness max	% Coarse Fragments by wt	<7.5 cm	7.5-25cm	>25 cm	Matrix Colour		Structure	Roots #	Boundary dist	Boundary form
Hornfels													
											a		
LFH	22-0	20	25								p		
Ae	0-5	2	10	35	100	-	-	reddish grey	5YR 5/2	w.sb	f	c	w
Bf1	5-15	5	12	50	100	-	-	yellowish red	5YR 5/6	w.sb	f	d	i
Bf2	15-35	15	25	55	100	-	-	strong brown	7.5YR 5/8	w.sb	f	d	i
Bf3	35-50	9	19	65	100	-	-	brown	10YR 4/3	sg	v	c	w
Cg	50+			70	100	-	-	dark grey	7.5YR 4/0	sg		c	w
								**(strong brown	7.5YR 5/8)				
Quartz Diorite													
											a		
LHF	20-0	15	25								p		
Ae	0-4	0	6	55	80	15	5	light yel. brown	10YR 6/4	sg	p	c	w
Bhf1	4-19	0	30	55	80	15	5	black	10R 2.5/1	w.sb	p	c	w
Bhf2	19-29	0	20	85	80	15	5	dark red	2.5YR 2.5/5	w.sb	p	d	i
Bf	29-39	0	20	85	70	20	10	yellowish red	5YR 4/6	w.sb	f	d	i
BC1	39-74	30	40	80	60	25	15	brownish yellow	10YR 6/6	sg	f	d	i
BC2	74-90			80	40	30	30	yellowish brown	10YR 5/6	sg	v	c	w
BC3	90-110			85	40	30	30	yellowish red	5YR 4/6	sg	v		
BC4	110-130			85	20	30	50	brown	7.5YR 4/4	sg	v		
BC5	130-150			80	20	30	50	yellowish brown	10YR 5/6	sg			

** mottles colour

indicates that the HN parent material was glacial till, rather than colluvium or fractured bedrock.

The proportion of coarse fragments in the QD soil ranged from 55 to 85%, values comparable to wasterock. Like the HN soil, the QD coarse fragment content was lowest at the surface. However, the coarse fragment content did not increase regularly with depth, remaining 80 to 85% from 19 to 150 cm.

The proportion of QD coarse fragments larger than 25.cm increased from 5% in the Ae and Bhf to 50% in the BC4 and BC5. The size of the coarse fragments in lower sections of the QD soil was comparable to the wasterock.

Also like the wasterock, and unlike the HN soil, QD coarse fragments in all but the Ae and Bhfl were sharply angular. In part, rougher, sharper surfaces will result from the larger grain size of the rock. They also indicate that the QD profile was comprised of fractured bedrock or colluvium, rather than till. The less angular, lower coarse fragment material at the surface might be a thin layer of till, or till reworked by colluvial processes. Rounder stones and lower amounts of coarse fragments may also be due to weathering, as these features were also evident at the surface of the HN soil. In the HN coarse fragments, colour changes indicative of weathering were restricted to the weathering rinds. In the QD coarse fragments reddish stains indicative of Fe oxidation were more extensive.

In both soils, the lower horizons were single grained. Weak sub-angular blocky structures in the B horizons were attributable to the accumulation of organic matter and sesquioxides. The HN Ae also had a weak subangular blocky structure. In the QD profile the Ae, which was low in sesquioxides and organic matter, was single grained.

With little structure development, the main criteria for separating horizons was their colour. In the HN profile, there were distinct differences between the bleached A, the red-brown B horizons, and a gray C horizon. The gray colour, and mottles, indicated that the HN C horizon was usually waterlogged.

The red brown colours in the B horizons and the grey Ae indicate the illuviation and eluviation of amorphous iron, respectively. Although most of the exposed surfaces in the A and B horizons of the HN profile were the colours listed in Table 2.18, each horizon also contained a number of small, darker stained patches. These appeared to be a result of organic matter deposition along root channels and preferred drainage pathways.

The QD profile contained many similar horizons to the HN soil. The presence of a black coloured layer at the top of the B horizon indicated that the illuviation of organic matter was greater in the QD than in the HN profile. Another difference from the HN soil was the presence of a second reddish horizon at approximately 90 to 110 cm. The yellowish red colour of the BC3 horizon was the same as that

of the BF horizon, suggesting that it was also enriched in amorphous Fe. The lack of a gray C horizon in the QD profile indicated that, at least to the depth excavated, it was not waterlogged.

In the HN profile, the upper horizons had very irregular boundaries, the low points of which probably occurred in places where leaching was concentrated. Despite the undulations, horizons in the HN soil were essentially parallel to the surface.

The range in horizon thickness was much greater in the QD soil. This was especially true of the Bhf and Bf horizons, parts of which were almost perpendicular to the surface. The vertical components of the illuvial horizons indicate that drainage, root growth and the movement and precipitation of organic matter and sesquioxides was not uniformly distributed. One reason for this is that large coarse fragments create preferred pathways of drainage and root growth through the solum.

4.3.2 Extractable Elements

Both soils had the low soil pH values, high illuvial organic-C concentrations, and high extractable Fe and Al concentrations typical of podzols (Table 2.19). Even in the lowest horizons, pH values were lower than 5, and several of the upper horizons had pH values lower than 4. In both soils, pH values increased with depth. With rooting

Table 2.19 Extractable element concentrations in the natural soils.

	%C	pH	%Fe		%Al		%Si		Mg	Na	K	avail.P
		CaCl	AAO	Pyr	AAO	Pyr	AAO	Pyr	AAO	AAO	AAO	Bray
									ppm	ppm	ppm	ppm
Hornfels												
Ae	4.7	3.3	0.8	0.6	0.5	0.4	0.0	0.0	231	84	368	2.1
Bf1	3.5	3.4	3.1	2.6	0.8	0.5	0.2	0.1	755	77	437	0.1
Bf2	2.5	4.1	1.6	0.9	1.2	0.7	0.4	0.2	423	67	446	0.8
Bf3	2.0	4.3	1.2	0.7	1.4	0.8	0.5	0.2	615	104	698	2.6
Cg	0.8	4.4	0.9	0.1	0.8	0.3	0.3	0.1	355	61	446	12.7
Quartz Diorite												
Ae	3.7	2.7	0.2	0.1	0.2	0.1	0.0	0.0	71	142	516	0.8
Bhf1	13.7	3.1	1.7	1.5	1.3	1.3	0.1	0.1	185	65	239	12.0
Bhf2	9.7	3.7	3.2	3.2	2.8	2.3	1.0	0.3	220	55	176	0.2
Bf	4.5	4.3	3.3	0.9	3.9	1.3	1.4	0.2	110	77	241	0.2
BC1	1.0	4.7	1.3	0.0	1.4	0.3	0.6	0.1	123	72	236	7.2
BC2	1.0	4.5	2.0	0.2	0.9	0.3	0.3	0.1	174	72	287	59.4
BC3	0.5	4.8	4.4	0.1	0.9	0.3	0.4	0.0	183	51	204	13.2
BC4	0.8	4.8	2.8	0.1	0.9	0.3	0.3	0.1	234	71	224	10.2

Table 2.20 AAO extractable element concentrations in the quartz diorite soil (in total composition before and after AAO extraction.)

	%Wt	%Al	%Fe	%P	%S	%Ti	Mn	Mo
							- ppm -	
Ae	1.4	-0.8	-0.2	0.02	0.00	0.00	-31	3
Bhf1	29.0	2.7	2.3	0.05	0.00	0.35	66	235
Bhf2	34.5	4.4	5.6	0.05	0.04	0.23	98	175
Bf	31.7	5.8	4.4	0.04	0.17	0.14	124	163
BC1	10.1	0.7	1.1	0.07	0.16	0.00	59	166
BC2	9.7	0.1	1.7	0.18	0.00	0.00	126	541
BC3	14.2	0.5	4.2	0.17	0.01	0.00	1463	1355
BC4	10.5	0.4	3.4	0.12	0.12	0.02	1503	506
BC5	10.1	1.4	3.2	0.19	1.17	0.05	587	821

concentrated in the organic layer, most of the C in the mineral horizons was added by leaching.

In the HN profile, C levels decreased with depth from maximum concentrations in the Ae. AAO- and pyr-Fe levels were highest in the Bf1, while AAO- and pyr-Al and Si peaked in the Bf3. In the Ae and Bf1, concentrations of AAO- and pyr-Fe were very similar, as were concentrations of AAO- and pyr-Al, indicating that almost all the amorphous Fe and Al in the upper horizons was organically complexed.

By comparison to the HN Ae, the QD Ae contained almost no extractable Fe and Al and had lower concentrations of organic-C. The HN Ae contained approximately double the proportion of clay found in the QD Ae (Table 2.25). Thus, physical retention as a result of smaller pore size, and the formation of clay-organic complexes, are possible explanations for the higher organic-C concentrations in the HN Ae. The higher Ae clay content may also account for the higher extractable Fe and Al in the HN soil, and for the lower C illuviation into the HN B horizons.

As the black and dark red colours of the QD horizons indicated, C concentrations in the QD Bhf1 (13.7%) and Bhf2 (9.7) were higher than in the HN Bf (3.5%). Like the HN Bf, almost all the extractable Fe and Al in the QD Bhf horizons was organically complexed. In the QD soil, the pyr-Fe and -Al concentrations peaked in the Bhf2. AAO-Fe and -Al concentrations peaked in the Bf.

In contrast to the HN soil where the red colour of oxidized Fe stopped at 50 cm, in the QD soil, coarse fragments and fines were stained red throughout the depth examined (150 cm). The AAO-Fe concentrations in the reddish BC horizons exceeded the AAO-Fe concentrations in the B horizons. The low concentrations of AAO-Al and -Si in the BC horizons indicate that the source of AAO-Fe were not aluminosilicate minerals. The most likely source of AAO-Fe in the QD profile BC horizons was pyrite. This is suggested by the high S content (1.8 to 3.6%) in the unweathered coarse fragments, and a lack of S in all but the BC5 < 2 mm fraction (Table 2.26). The deep, well drained nature of the QD profile was conducive to sulphide oxidation. Much lower pyrite concentration (0.24% S) and poor drainage precluded similarly high AAO-Fe concentrations in the lower HN horizons.

The primary cause of the variation in AAO-Fe was probably some form of redistribution after Fe was released. At the moderately acid pH values and low organic matter concentrations found in the BC horizons, Fe movement is not likely to occur through solution or chelation. An alternative mechanism for Fe movement is by suspended flocs, in the same manner as clay translocation. The flocs, or inorganic gels, eventually accumulated where porosity, and hence leaching, were restricted. One source of evidence supporting the inorganic gel translocation theory was the occurrence of flocs of amorphous Fe in puddles at the base

of a small section of highly fractured rock in the center of the pit.

Organic matter complexes amorphous Fe. As a result in the A and B horizons, floc migration would have predate the accumulation of organic acids. Subsequently Fe and Al would move as soluble organic chelates, precipitating when the ratio of sesquioxides:organic matter or the pH increases (McKeague et al., 1983). Notably in both soils, the horizons with the highest concentrations of AAO-Al had same pH values (4.3).

Results of the AAO-extractable concentrations of major and minor elements, determined by comparing the total composition before and after AAO extraction are given in Appendix D. For most elements losses in the AAO extraction, which were probably neglible, were hidden by the variation among subsamples. However, the XRF measurements did show that AAO extracted significant proportions of the total Al, Fe, P, S, Ti, Mn, and Mo (Table 2.20). Concentrations of AAO-Al and -Fe, determined by XRF, were similar to those measured in the AAO- extract. The concentrations of P, Mn, and Mo extracted were all highest in the BC horizons. For Mn, this may be explained by the fact that it commonly occurs as a trace component of pyrite. For P and Mo, it suggests that their primary mineral forms, apatite and molybdenite, weathered at the same time or shortly after the Fe was released.

AAO extracted almost all the S present in the < 2 mm fractions, incicating that all the pyrite in this fraction had been oxidized. The highest AAO-S concentrations were in the lowest horizon. By contrast, the concentration of AAO-Ti was highest in the Bhfl horizon, indicating that primary Ti minerals were only weathering in the upper horizons.

Many horizons in both soils contained almost no extractable P. In the HN profile, only the Cg contained more than 5 ppm available P. By far the highest available P levels in either soil were extracted from the BC2 of the QD soil. The location of the extractable P peak above that of amorphous
Fe, indicates that the dissolution of apatite occurred after the weathering of the Fe source, and that extractable P was complexed with Fe. The lack of extractable P in the lower B horizons of either soil suggest that the dissolution of apatite and subsequent leaching of P occurred prior to the Fe depositon or that complexed P was unavailable.

In the QD soil, a smaller extractable P peak occurred in the Bhfl. As this was the horizon with the highest amount of organic matter, this indicates that the P was added in this form.

4.3.3 Coarse Fragment and < 2 mm Mineralogy

Although the same minerals were found in both soils, they were present in different amounts (Table 2.21). Coarse fragments from the HN soil contained 75% quartz, 20% plagioclase, and 5 % chlorite.

Table 2.21 Estimated mineralogy of the coarse fragments and < 2 mm fractions of the natural soils.

		Quartz	K feldspar	Plagioclase	Hornblende	Chlorite	Biotite	Sericite	Kaolinite	Vermiculite
		(Estimated Percentage of)								
Hornfels										
Ae	< 2mm	85	5	10						
Bf1	< 2mm	75	5	10		5		5		
Bf2	< 2mm	70	5	15		5		5		
Bf3	< 2mm	70	tr	15		5		5	5	
Cg	< 2mm	65	tr	20		5		5	5	
Bf3	rock	75		20		5				
Quartz Diorite										
Ae	< 2mm	75	5	20	1					
Bhf1	< 2mm	45	20	35	tr					
Bhf2	< 2mm	45	20	35	tr		tr			
Bf	< 2mm	45	20	35			tr			
BC1	< 2mm	40	20	40			tr	1	1	1
BC2	< 2mm	35	20	40			1	1	2	3
BC3	< 2mm	40	20	35			2	1	1	3
BC4	< 2mm	35	20	40			1	1	2	2
BC5	< 2mm	30	20	40			2	1	1	2
BC3	rock	15	5	75	1	1	2	2		
BC4	rock	15	5	75	1	2	1	1		
BC5	rock	10	5	80	tr	1	2	1		

Compared to the coarse fragments, < 2 mm fractions from the lower horizons of the HN profile contained similar amounts of plagioclase (20%) and chlorite (5%), lower amounts of quartz (65%), and higher amounts of sericite (5%), kaolinite (5%). While some weathering may have occurred, the decline in relatively resistant minerals like quartz suggests that the differences between the coarse fragments and the < 2 mm fraction were a result of either selective disintegration in the original bedrock or changes in parent material.

Moving up through the HN profile there was a gradual decline in < 2 mm plagioclase and an increase in quartz. The decrease in plagioclase probably resulted from weathering, while the increase in quartz, may be attributed to negative enrichment. At the low pH values found in the upper horizons, quartz solubility is very low.

Three phyllosilicates were detected in the HN < 2 mm fractions Kaolinite was found in the Bf3 and Cg, and chlorite and sericite were found in all the horizons except the Ae. Notably the lowest horizons containing kaolinite (Bf3) and chlorite (Bf1) contained the most AAO-Al and AAO-Fe, suggesting that weathering kaolinite and chlorite were primary sources of amorphous Al and Fe, respectively.

According to various researchers (McKeague et al., 1983; Kodama, 1979), under acid conditions chlorite generally weathers faster than kaolinite. The removal of kaolinite in preference to chlorite may result from several

factors, such as the kaolinite grains being smaller or because chlorite was continually replenished by grains released from the coarse fragments. The resilience of chlorite might also be a result of pedogenic chlorite replacing primary chlorite lost through weathering.

The unweathered QD coarse fragments from the lower BC horizons contained from 75 to 80% plagioclase, 10 to 15% quartz, and 5% K feldspar, along with small amounts of hornblende, chlorite, biotite, and sericite. By comparison, the < 2 mm fractions from the same horizons contained several times more quartz (35 to 40%) and K feldspar (20%), and only half as much plagioclases (35 to 45 %). The < 2 mm fractions also lacked hornblende and chlorite, and contained kaolinite and a 1.15 nm mineral, that was probably vermiculite.

Changes in the proportion of quartz, K feldspar, plagioclase, and kaolinite probably resulted from the selective disintegration of the bedrock. Although weathering was probably not responsible for the large changes in the tectosilicate content, it could account for the loss of hornblende and chlorite and the formation of the vermiculite. Of the minerals commonly found in podzols, hornblende and chlorite are considered the most weatherable, while vermiculite is the most common product of phyllosilicate alteration (McKeague et al., 1983).

Moving up the QD profile, the proportion of < 2 mm quartz increased from 30 % in the BC5 to 45 % in the Bhf1.

This was apparently a result of negative enrichment. The lack of phyllosilicates above the BC horizons indicates either that the supply of these minerals in the coarse fragments was exhausted or that the rate of weathering in the < 2 mm fraction was fast enough to remove any new additions. The absence of changes in the proportion of coarse fragments in the lower B horizons indicate that very little coarse fragment breakdown occurred.

One unusual feature of the QD soil was the presence of hornblende in the Ae and Bhf horizons. Hornblende weathers rapidly under acidic conditions, which explains its absence from the < 2 mm fraction of the BC horizons. However this also suggests that hornblende would be even less common near the surface. A likely explanation for the occurence of hornblendes in the upper horizons is a change in the parent material, either due to variation in the host bedrock or through surface inputs (till or colluvial). Notably, intrusive rock rich in hornblende (10% according to Steininger, 1985), from the Eastern Stock, outcropped nearby.

From the Bhf1 to the Ae there was a 30% increase in the < 2 mm quartz, and 15% increases each in the < 2 mm plagioclase and < 2 mm K feldspar. With the lowest pH, greatest organic acid leaching, and almost no amorphous Fe and Al to protect grain surfaces, particles in the Ae were exposed to the most intense weathering. However, as suggested for hornblende, the increase in quartz may result

from surface additions of some other rock types (e.g., hornfels).

Mineralological data from individual sand fractions showed that changes in < 2 mm mineralogy did not occur uniformly in all the fractions. (Table 2.22). For example, decreases in plagioclase and increases in quartz were most pronounced in the coarser fractions.

As expected from the < 2 mm data, phyllosilicate concentrations were greatest in the BC3. No phyllosilicates were detected in the intensely weathered Ae. In the Bhf1 small amounts of sericite and kaolinite were found in the coarse sand. The absence of kaolinite and sericite in finer fractions, equivalent to their grain size, indicates that neither mineral was stable. The persistence of kaolinite and sericite in the coarse sand may be due to occlusion within clusters of more resistant minerals.

In contrast to the Bhf1, in the Bf kaolinite persisted in all four sand fractions. However, sericite was only found in the coarse sand. The presence of vermiculite and the absence of sericite in the finer fractions suggests that sericite altered into vermiculite. Biotite, which was also restricted to the larger sand fractions, may also have been weathering into vermiculite.

Kaolinite and vermiculite were the most common phyllosilicates in the Bf and the BC3. Again the restriction of < 2 mm sericite to the larger fractions indicates that it was unstable and readily altered,

Table 2.22 Estimated mineralogy of the sand and coarse silt fractions of the Ae, Bhf1, Bf, and BC3 horizons of the quartz diorite soil.

Horizon	Fraction (um)	Wt %	Quartz	K feldspar	Plagioclase	Hornblende	Biotite	Sericite	Kaolinite	Vermiculite	Al-Vermiculite
						(Estimated Percentage of)					
Ae	2000-500	7	90	5	3	1					
	500-250	12	85	10	5	tr					
	250-100	19	70	15	15	tr					
	100-50	20	45	20	35	2					
	50-20	5	55	15	30	3					
Bhf1	2000-500	9	55	25	15	1		1	1		
	500-250	15	70	15	15	1			1		
	250-100	21	50	20	30	1					
	100-50	20	25	15	60	2					
	50-20	10	35	20	40	3					
Bf	2000-500	20	20	20	60		1	1	1		
	500-250	14	35	15	45	1	1		3		
	250-100	13	50	15	30	1			2	2	
	100-50	10	35	20	40	1			3	2	2
	50-20	13	40	25	35	4					
BC3	2000-500	43	20	25	55		1	1	1		
	500-250	16	20	35	40		1	1	3	1	1
	250-100	11	25	20	50		1	tr	3	3	
	100-50	8	30	20	25		4		9	11	
	50-20	6	35	25	25		4		7	7	

presumably, to vermiculite. In contrast, vermiculite, biotite and kaolinite were all more common in the finer fractions.

Like the < 2 mm samples, hornblende was found in the strongly weathered horizons but not in the BC3, the reverse of what one might expect for a relatively easily weathered mineral.

4.3.4 Heavy Minerals in the Quartz Diorite (QD) Soil

The proportion of heavy minerals was measured in the fine (250-100 um) and very fine (100 to 50 um) sand and the coarse silt (50 to 20 um) fractions of the Ae, Bhf1 and BC3 horizons of the QD soil (Table 2.23). In the two sand fractions, the concentration of the > 3.31 g/cm^3 fraction decreased with depth, while that of particles 2.89 to 3.31 g/cm^3 increased. In the coarse silt the > 3.31 g/cm^3 fraction was largest in the Ae, while the 2.89 to 3.31 g/cm^3 fraction was significantly larger in the BC. When converted to proportions of the < 2 mm fraction, the weight of > 3.31 g/cm^3 particles in both sand fractions decreased with depth, where as the amount of 2.89 to 3.31 g/cm^3 particles in the Bhf1 and BC horizons were no longer substantially different.

The 2.89 to 3.31 g/cm^3 fraction was a similar proportion of all three size fractions. The > 3.31 g/cm^3 fraction was largest in the fine sand fraction. In all three size fractions, the weight of 2.89 to 3.31 g/cm^3 particles was much larger than that of the > 3.31 g/cm^3

Table 2.23 Heavy mineral contents in selected horizons of the quartz diorite soil.

Horizon	Size Fraction	Total % of < 2mm	% of Size Fraction A	% of Size Fraction B	% of < 2 mm Fraction A	% of < 2 mm Fraction B
Ae	50-20u	5	2.7	2.06	0.1	0.10
Bhf1	50-20u	10	4.1	0.16	0.4	0.02
Bf	50-20u	13	1.7	0.21	0.2	0.03
BC	50-20u	5	20.4	0.13	1.1	0.01
Ae	100-50u	20	3.9	0.38	0.8	0.08
Bhf1	100-50u	20	7.2	0.23	1.4	0.05
BC	100-50u	11	11.2	0.11	1.1	0.01
Ae	250-100u	19	2.2	1.52	0.4	0.29
Bhf1	250-100u	21	4.7	1.06	1.0	0.22
Bf	250-100u	13	8.4	0.83	1.1	0.11
BC	250-100u	13	8.8	0.76	1.2	0.10

A : 2.89 - 3.31 g/cm3 B : > 3.31 g/cm3

particles, and the two density fractions combined rarely exceeded 10%.

Data from the < 3.31 g/cm^3 100 to 50 um fraction of the Ae, Bhf1, and BC horizons showed that the proportion of sphene, oxidized Fe, pyrite, and scheelite decreased substantially in the surface horizons (Table 2.24). while the proportions of magnetite and hornblende were much larger than their concentrations in the BC horizons. Magnetite and hornblende accounted for 80% of the > 3.31 g/cm^3 fraction in the Ae, but only 38% in the BC horizon.

Changes in heavy mineral concentrations may result from a number of factors including negative enrichment, greater coarse fragment disintegration, differences in the bedrock, or the addition of surface contaminants (e.g. colluvium). Notably the few pyrite grains found all had thick rinds of oxidized Fe. The presence of 100 to 50 um grains of oxidized Fe supports the assumption that some of the illuvial Fe had recrystallized into secondary Fe oxides and hydroxides.

4.3.5 Particle Size

In both soils the proportion of sand increased with depth (Table 2.25), with a difference in particle size content between the Ae and the lower horizon of 20 to 25% for sand and 10 to 13% each for silt and clay.

In the HN profile, the Ae and the Bf1 horizons were clay loams, while the lower B and Cg horizons were

Table 2.24 Proportion of individual heavy minerals in the > 3.31 g/cm3, 100-50 um fraction of selected horizons in the quartz diorite soil.

Horizon	Magnetite	Ilmenite	Rutile	Sphene	Oxidized Iron	Hornblende	Pyrite	Scheelite
				(Average)				
Ae	49	7	4	6	3	31	0.1	0.0
Bhf1	27	9	5	19	8	33	0.3	0.0
BC	23	6	7	28	21	15	0.5	0.3
std				(Standard Deviation)				
Ae	2	0	0	1	1	0	0.1	0.0
Bhf1	1	1	1	3	4	5	0.2	0.0
BC	5	2	2	1	7	2	0.3	0.2
				(Ratio with Magnetite)				
Ae		7	12	8	17	2	361	0
Bhf1		3	6	1	3	1	78	0
BC		4	3	1	1	2	47	70

Table 2.25 Particle size distribution in the < 2 mm fractions of the natural soils.

	Depth (cm)	Sand	Silt	Clay	VCSa	CSa	MSa	FSa	VFSa	CSi	MFSi	Texture
		(Percentage of the < 2 mm Fraction)										
Hornfels												
Ae	0-5	26	46	28	3	3	5	7	8	7	39	cl
Bf1	5-15	25	46	30	3	4	5	6	7	6	40	cl
Bf2	15-35	38	42	21	6	7	8	8	8	4	38	l
Bf3	35-50	44	35	21	8	9	9	9	8	5	30	l
Cg	50+	50	35	15	8	10	11	12	9	4	31	l
Quartz Diorite												
Ae	0-4	58	27	15	2	5	12	19	20	5	22	sl
Bhf1	4-16	64	25	10	2	7	15	21	20	10	15	sl
Bhf2	16-28	62	30	8	5	10	15	17	16	9	21	sl
Bf	28-48	57	33	10	7	13	14	13	10	13	20	sl
BC1	48-70	75	20	5	11	18	18	15	12	8	13	ls
BC2	70-90	77	20	3	16	18	17	14	12	7	13	ls
BC3	90-110	79	16	5	21	22	16	11	8	6	9	ls
BC4	110-130	85	13	2	16	22	20	15	12	4	9	ls
BC5	130-150	80	17	4	16	21	18	14	11	8	9	ls

Sa: 2000-50um VCSa: 2000-1000um FSa: 250-100um
Si: 50-2um CSa: 1000-500um VFSa: 100-50um
Cl: < 2um MSa: 500-250um CSi: 50-20um MFSi: 20-2um

cl : clay loam l : loam sl : sand loam ls : loamy sand

classified as loams. The proportion of all the individual HN sand fractions, except the very fine sand (100 - 50 um), steadily increased with depth. Most of the decrease with depth in the finer fractions occurred in the medium fine silt (20-2 um) and the clay (< 2 um). Little change with depth occurred in the fractions (100 to 20 um) corresponding to the dominant grain size in the HN rock.

In the QD soil, the BC horizons had a loamy sand texture and the A and B horizons were sandy loams. From BC2 to BC5 there was no relationship between particle size and depth. From BC1 to the surface there was a consistent decrease in very coarse (2000 to 1000 um) and coarse sand (1000 - 500 um), an irregular decrease in medium sand (500 - 250 um), and an irregular increase in fine (250 - 100 um) and very fine (100 - 50 um) sand. Again changes primarily occurred in the fractions larger than the modal grain size, which was fine to medium sand-sized. Particles 2000 to 250 um were generally multi-grain aggregates, and thus fragmentation was probably the main factor responsible for the decrease in the proportion of these particles.

One divergence from the regular changes in particle size with depth was the high silt contents of the QD Bhf2 and Bf. High amorphous Fe and Al in these horizons suggest that the high silt contents resulted from the accumulation of sesquioxides either as cements or as discrete grains. The deep red colour of these fractions indicate that the

pretreatment with citrate bicarbonate dithionite was not sufficient to remove all the Fe oxides and hydroxides.

4.3.6 Major Elements

Mineralogical differences accounted for many of the differences observed in elemental composition (Table 2.26). For example, Si levels were highest in the HN soil and in the Ae horizons, samples containing relatively high amounts of quartz. In the HN soil, the relatively low Si concentrations in the B horizons, can be attributed to the diluting effect of additions of Fe and Al.

Removing amorphous Fe and Al with an AAO pretreatment significantly increased the Si concentrations in the QD samples. After the AAO pretreatment, Si concentrations in the QD samples increased from 30.3% in the BC5 to 33.8% in the BC1, 37.2% in the Bhf1 and 40.2% in the Ae. The other major elements whose concentrations were significantly increased by the AAO pretreatment were Ca, K, and Na. In the HN profile, the decrease in Ca and Na towards the surface indicate a decline in the plagioclase content. Like the plagioclase levels, total Ca and Na levels in the QD soil fluctuated throughout the B and BC samples, exhibiting no relationship with depth. The only significant differences were the low Ca and Na concentrations in the Ae.

In both profiles concentrations of Mg increased with depth. As very little Mg was AAO extractable and Mg, like other base cations, is rapidly leached from acid soils, the

Table 2.26 Major element composition of the coarse fragments and < 2 mm fraction of the natural soils.

Horizon	Fraction	%Al	%Ca	%Fe	%K	%Mg	%Na	%P	%S	%Si	%Ti
Hornfels (+AAO)											
Ae	<2mm	6.2	0.15	1.8	1.9	0.4	1.0	0.05	0.05	37.0	0.65
Bf1	<2mm	7.4	0.17	7.8	1.5	1.3	1.1	0.03	0.05	31.5	0.57
Bf2	<2mm	8.3	0.23	5.1	1.5	1.6	1.4	0.03	0.06	31.5	0.51
Bf3	<2mm	8.5	0.29	5.0	1.5	1.6	1.5	0.06	0.13	31.2	0.50
Cg	<2mm	8.4	0.37	4.9	1.7	1.7	1.7	0.08	0.11	33.3	0.49
Bf3	rock	6.7	0.27	6.1	0.8	2.1	1.9	0.18	0.24	36.4	0.45
Quartz Diorite (+AAO)											
Ae	<2mm	6.6	1.06	2.3	2.9	0.2	1.6	0.03	0.00	35.0	0.66
Bhf1	<2mm	9.3	1.63	4.3	3.0	0.4	2.1	0.08	0.00	29.9	0.98
Bhf2	<2mm	10.5	1.49	9.7	2.4	0.6	1.9	0.10	0.04	24.4	0.71
Bf	<2mm	12.5	1.31	8.3	2.6	0.8	1.9	0.07	0.20	25.9	0.59
BC1	<2mm	9.7	1.48	5.5	3.1	0.9	2.4	0.12	0.21	28.0	0.49
BC2	<2mm	9.3	1.45	6.7	3.6	1.1	2.2	0.26	0.06	27.1	0.54
BC3	<2mm	8.5	1.16	9.3	3.6	1.3	1.8	0.26	0.03	25.7	0.53
BC4	<2mm	9.0	1.64	9.0	3.5	1.2	2.0	0.24	0.14	25.6	0.56
BC5	<2mm	9.7	1.67	7.3	3.8	1.3	2.2	0.27	1.19	28.4	0.58
BC5	rock	9.6	2.88	4.1	2.6	1.2	3.2	0.23	3.58	28.3	0.48
BC4	rock	9.4	2.65	4.1	3.0	1.1	2.9	0.19	3.14	29.5	0.46
BC3	rock	10.2	3.21	4.8	2.7	1.3	3.3	0.26	1.82	29.2	0.57
Quartz Diorite (-AAO)											
Ae	<2mm	7.5	1.20	2.6	3.3	0.2	1.7	0.01	0.00	40.2	0.76
Bhf1	<2mm	9.2	1.95	2.8	3.6	0.5	2.7	0.03	0.00	37.2	0.88
Bhf2	<2mm	9.3	1.95	6.2	3.2	0.9	2.7	0.07	0.00	32.6	0.73
Bf	<2mm	9.9	1.78	5.6	3.6	1.0	2.8	0.05	0.05	33.1	0.65
BC1	<2mm	10.1	1.76	5.0	3.9	1.2	2.9	0.05	0.05	33.8	0.54
BC2	<2mm	10.1	1.79	5.5	4.3	1.3	2.9	0.10	0.08	33.8	0.62
BC3	<2mm	9.3	1.38	5.9	4.4	1.6	2.5	0.10	0.02	31.1	0.63
BC4	<2mm	9.6	1.91	6.2	4.2	1.4	2.4	0.13	0.02	30.3	0.60
BC5	<2mm	9.2	1.78	4.5	4.1	1.3	2.5	0.09	0.02	30.3	0.59

decline in Mg can be attributed to a decline in mafic minerals. In the HN profile, sizable drops in Mg content occurred between the coarse fragments and the < 2 mm fractions and between the < 2 mm Bf1 and Ae samples.

In the HN profile, higher Al concentrations in the < 2 mm fractions, compared to the coarse fragments, can be attributed to the higher sericite and kaolinite concentrations in the former. Subtracting the AAO-Al from total Al would give the following Al concentrations: Cg 7.6%, Bf3 7.1%, Bf2 7.1%, Bf1 6.6%, and Ae 5.7%. The decline in Al in the upper horizons can be attributed to losses of sericite, kaolinite, and plagioclase. However the 5.7% Al in the HN Ae indicates that the proportion of aluminosilicate minerals was greater than that estimated from the XRD peak intensities, and perhaps closer to that of the QD Ae, which had a similar Al concentration.

The AAO pretreatment removed large amounts of Al values from the QD B horizons. As a result, there was very little variation in total Al below the Ae.

Subtracting AAO-Fe, Fe concentrations in the HN profile were Cg 4.0%, Bf3 3.8%, Bf2 3.5%, Bf1 4.7%, and Ae 1.0%. The relatively high Fe levels in the Bf1, probably result from the presence of secondary crystalline Fe, not extracted by AAO and not detected by XRD. With the exception of the Bf1, all the HN < 2 mm fractions had lower total-Fe levels than the coarse fragments .

In contrast to the HN soil, in the QD profile, only the Ae and the Bhf1 contained less total -Fe that the coarse fragments. The concentrations of total-Fe in Bhf2, BC3, and BC5 < 2 mm fractions (Bhf2, BC3, and BC5) were more than double those of the coarse fragments.

The most likely explanation for the elevated < 2 mm Fe levels in the QD profile is that Fe released from the coarse fragments by weathering was conserved in the < 2 mm fraction. Coarse fragments accounted for most of the soils mass, and thus even if only a small proportion of the coarse fragment Fe was released, it would significantly increase the < 2 mm Fe levels.

The high concentrations of S indicate that the unweathered QD coarse fragments contained high concentrations of pyrite, a mineral that weathers very quickly under aerobic conditions. Only unweathered coarse fragments from the base of the profile were analyzed, so there is no conclusive proof that pyrite oxidation occurred within the coarse fragments. The abundance of reddish stains along fractures and veins indicate that Fe oxidation had occurred within coarse fragments in the A and B horizons. The consistently high coarse fragment content was evidence that, below the Ae and Bhf1, weathering was not intense enough to cause the coarse fragments to disintegrate.

Judging from the low S concentrations in the QD < 2 mm fractions, most of the S released as pyrite weathered was

removed from the profile. Only the BC5 < 2 mm fraction contained a significant amount of S, almost all of which was AAO extractable and therefore probably sulphate-S complexed with amorphous-Fe.

4.3.6 Trace Elements

Trace element concentrations varied both between and within soil profiles (Table 2.27). Like the wasterock, the natural soils contained anomalously high concentrations of Co, Mo, Pb, and Se. As the high S concentrations indicated, the QD parent material was highly mineralized and Mo and Pb concentrations in its coarse fragments were similar to the potassic and incompetent rock (Table XXX). Concentrations of Cu, Mo, Pb, and Sr in the QD coarse fragments were at least double those of the HN soil coarse fragments. The HN soil was relatively enriched in Co and Cr.

Manganese was the commonest trace element in both soils, and in both profiles < 2 mm Mn concentrations increased with depth, being depleted with regard to the coarse fragments in the upper horizons, and enriched in the lower horizons. Although Mn is often associated with Fe hydroxides, neither soil had high Mn concentrations in the B horizon. The highest Mn concentration in the HN soil were found in the Cg.

In the QD soil, Mn was associated with the high total and AAO-Fe concentrations in the BC horizons and like Fe, a large proportion of the Mn was AAO extractable. One possible explanation for the association between Fe and Mn

Table 2.27 Minor element concentrations in the coarse fragments and < 2 mm fractions of the natural soils.

Horizon	Fraction	Co	Cr	Cu	Mn	Mo	Pb	Se	Sr	Zn	Zr
Hornfels (+AAO)											
Ae	<2mm	234	210	14	167	88	24	15	87	22	192
Bf1	<2mm	182	281	38	705	144	39	16	98	95	178
Bf2	<2mm	149	264	47	770	71	38	13	117	102	150
Bf3	<2mm	108	227	54	1022	26	22	12	125	106	131
Cg	<2mm	49	207	65	1371	25	19	7	147	99	129
Bf3	rock	31	274	58	816	2	15	0	147	109	131
Quartz Diorite (+AAO)											
Ae	<2mm	190	38	30	266	366	8	10	453	20	292
Bhf1	<2mm	95	35	35	441	611	25	48	601	34	260
Bhf2	<2mm	22	31	76	454	605	19	42	588	63	182
Bf	<2mm	34	39	74	500	474	25	28	564	60	174
BC1	<2mm	15	25	91	487	801	17	9	727	76	171
BC2	<2mm	20	17	108	598	1450	72	8	710	83	157
BC3	<2mm	38	20	133	2139	2361	1229	9	559	140	152
BC4	<2mm	39	11	156	2076	1070	605	8	702	128	163
BC5	<2mm	19	12	145	1108	1279	291	0	850	125	221
BC5	rock	54	10	161	969	146	44	0	1292	119	181
BC4	rock	56	11	125	632	256	48	0	1192	95	167
BC3	rock	59	12	135	804	232	65	0	1463	123	183
Quartz Diorite (-AAO)											
Ae	<2mm	229	17	25	301	369	12	0	531	14	344
Bhf1	<2mm	78	0	27	528	530	22	0	786	34	311
Bhf2	<2mm	53	0	94	543	656	24	0	898	80	251
Bf	<2mm	60	0	81	551	454	22	0	880	76	221
BC1	<2mm	147	0	94	475	707	24	0	970	78	200
BC2	<2mm	95	0	133	522	1006	91	0	966	98	206
BC3	<2mm	52	0	153	787	1172	1590	0	704	171	213
BC4	<2mm	64	0	163	640	630	615	0	916	149	194
BC5	<2mm	67	0	117	579	509	306	0	851	115	210

note : all trace element concentrations in ppm

in the BC horizon was that Mn was a trace component of pyrite (Aubert & Pinta, 1977). If so the distribution of Mn might parallel the distribution of Fe released from pyrite.

Although the Mo concentrations were significantly higher in the QD soil, concentrations in both profiles greatly exceeded the levels commonly found in soils (Adriano, 1986). At the minesite, Mo occurs in the mineral molybdenite, a sulphide mineral which one would expect to weather at a similar rate to pyrite. In the QD soil, the concentration of Mo, like Mn, increased with depth, reaching a maximum in the BC3 (2361 ppm). Like Mn, this suggests that the release of Mo occurred at the same time as pyrite and that Mo was subsequent complexed by Fe.

Unlike Mn, all the QD < 2 mm Mo concentrations were greater than those of the coarse fragments. One possible explanation for the relatively high < 2 mm Mo concentrations, was that all the Mo in the coarse fragments is released into and conserved in the < 2 mm fraction. The greater enrichment of Mo, compared to Fe and Mn, may be explained by the fact that Mo only occurred as a sulphide mineral, while Fe and Mn were found in a number of aluminosilicate minerals more resistant to weathering than sulphides. Selective disintegration of the fraction of the rock containing most of the molybdenite probably also contributed to the high Mo concentrations.

In the HN profile, the maximum Mo concentrations were found in the Bf1 (144 ppm) and the Ae (88 ppm).

In the HN profile the differences between the Mo concentrations of the unweathered coarse fragments and the < 2 mm fractions were too large to be solely a result of the conservation of Mo released by weathering.

One explanation, suggested by the relatively high concentration of Mo in the Ae, was that Mo was added at the surface. Dust is raised by blasting, by moving trucks, when rock is dumped, and by the wind blowing over dry dumps. All common occurrences at a mine, and at a Mo mine the dust will contain high concentrations of Mo. Due to the lower background concentrations of Mo in the HN soil, and its position downwind from the low grade ore dump, atmospheric additions could significantly increase its Mo content. Similar additions to the more highly mineralized QD soil would have a less dramatic effect.

Unlike the anomalously large differences in Mo, which were limited to the HN profile, very low coarse fragment and much higher < 2 mm Se contents also occurred in the QD soil. Selenium concentrations in the < 2 mm fractions of both soils were far in excess of the values normally found in soils (Archer & Hodgson, 1987). The similarities between the two soils in this regard, and the occurrence, in both, of greater Se concentrations near the surface, suggest that Se was added at the surface either organically or through wet or dry deposition. In both soils, the highest Se contents were in the horizons with the highest organic -C levels.

The high concentrations of Co and Cr in the HN soil were more typical of ultramafic rocks, than rock with a sizeable quartz content. Cobalt levels were also relatively high in the QD samples. In both soils, the highest Co concentrations were found in the Ae horizons. According to Aubert and Pinta (1977), Co is generally mobile under acidic conditions, accumulating in illuvial B horizons, with relatively low concentrations in podzolic Ae horizons. However, as Co in rocks is generally a contaminant in Fe minerals (Kabata-Pendias & Pendias, 1984), its concentration in the Ae may result from the higher content of magnetite (Table 2.24).

The < 2 mm Cr values in the HN soil were comparable to the coarse fragments. Although the variation in values was not as large (207 to 281 ppm), the distribution generally paralleled that of Fe, with a maximum in the Bf1 and minimums in the Ae and Cg. By comparison Cr values in the QD soil generally declined with depth, reaching values (11 to 12 ppm) similar to the coarse fragments in BC4 and BC5.

The levels of Cu (125 to 161 ppm), Pb (44 to 65 ppm), and Zn (95 to 123 ppm) in the QD coarse fragments were in the upper part of the range normally found in soils (Adriano, 1986). Like Mn, all three were depleted relative to the coarse fragments in the upper horizons, but increased with depth. As all three were metals, one would expect their mobility to increase as the pH decreased. For Cu and Zn maximum < 2 mm concentrations in the lower BC horizons

were only as high as those in the coarse fragments. Assuming that the Cu and Zn values in all the QD < 2 mm fractions were originally equivalent to those in the coarse fragments, there had been a net loss of Cu and Zn from the profile. By contrast, < 2 mm Pb values in the BC3, BC4, and BC5, like Mo, were an order of magnitude greater than those of the coarse fragments, indicating that Pb released by weathering was deposited at the base of the profile.

In the HN soil, > 2 mm Cu values also increased with depth, reaching the concentration found in the coarse fragments only at the base of the profile. The < 2 mm Pb and Zn values in the Cg horizon were also similar to the HN coarse fragments. However, unlike Cu, < 2 mm Zr values were only depleted in the Ae. For Pb the lowest < 2 mm concentrations occurred in the Cg. The maximum concentrations of Pb (38 to 39 ppm) were found in the Bf1 and Bf2.

In both profiles, < 2 mm Zr concentrations were similar to the coarse fragments in the lowest horizons, and steadily increased towards the surface. As the primary mineral form of Zr, zircon, is very resistant to weathering, the increase in < 2 mm Zr can be attributed to negative enrichment.

4.3.7 < 2 um and 2 - 20 um Mineralogy

The mineralogical composition was measured on the < 2 um fraction from the HN soil, and the < 2 um and 2 - 20 um fractions from the QD soil.

In all three fractions, there were both residual minerals and minerals formed during pedogenesis (Table 2.28). The most common minerals in the B and BC horizons of the QD 2 - 20 um fractions were kaolinite, chloritized vermiculite and interstratified chloritized vermiculite-illite. In the highly leached Ae horizon the most common minerals were smectite, interstratified smectite-illite, and there was a higher proportion of quartz, plagioclase and illite.

In the QD < 2 um fraction, the dominant minerals were vermiculite and chloritized vermiculite, with lesser amounts of quartz and kaolinite. Chloritized vermiculite was the most common mineral in the Bhf2 and BC3 horizons, with vermiculite dominating in horizons with lower concentrations of AAO-Al plus Fe. No strong peaks were detected in the QD Bf < 2 um fraction, a factor attributed to the high levels of amorphous Fe and Al. Like the QD 2 - 20 um fraction, in the Ae, < 2 um vermiculite was completely replaced by the smectite. Moderate amounts of < 2 um smectite found in the QD BC3 probably originated in the Ae. The lack of interstratified minerals in the < 2 um fractions can be explained by the greater access of weathering agents to smaller particles. Limited removal of hydroxides released during mineral alteration may also explain why chloritized vermiculite, but not vermiculite, was found in the QD < 2 - 20 um fraction.

Table 2.28 Estimated mineralogy of the < 2 um and 2-20 um fractions of natural soils.

Horizon	Qt	Kf	Pl	Hb	Ch	Il	Kao	Sm	Vm	Ch.Vm	Sm/Il	Ch.Vm/Il
Hornfel : < 2um												
Ae	XX					X	XX		XXXX			
Bf1	XX					X	XX		XX	XXX		
Bf2	XX		X		XX	tr	X		XXXX			
Bf3	X				X		XX		XXXX			
Cg	XX				X	XX	XXX		XX			
Quartz Diorite : < 2 um												
Ae	XX						X	XXXX				
Bhf1	X						X		XXXX			
Bhf2	XX									XXXX		
Bf									tr			
BC1	tr						tr		XXXX			
BC2							XX		XXX	XXX		
BC3	X						XX	XX	XX	XXX		
BC4	X						X		XXXX	XX		
Quartz Diorite : 2-20 um												
Ae	XX	tr	XX	tr		X		XX			XX	
Bhf1	X	tr	XX	tr	tr	tr	XX			XX		XX
Bhf2	tr	tr	XX	tr		tr	XX			XXX		XX
Bf	X	tr	X				XX			XXXX		XX
BC1	tr	tr	X			tr	XX			XX		XXX
BC2	tr	X	X	tr		tr	XX			XX		XXX
BC3	X	X	X	tr		X	XX			XX		XXX
BC4	tr	X	X	tr		tr	XX			XX		XXX

Qt : quartz
Kf : potassium feldspar
Pl : plagioclase
Hb : hornblende
Ch : chlorite
Ch.Vm : chloritized vermiculite

Il : illite
Se : sericite
Ka : kaolinite
Sm : smectite
Vm : vermiculite

XXXX : > 50 %
XXX : 31 - 50 %
XX : 11 - 30 %
X : 5 - 10 %
tr : < 5 %
/ : intergrade

Compared to the QD < 2 um fraction, the HN < 2 um contained more kaolinite and less chloritized vermiculite. The higher concentrations of residual minerals, like kaolinite, chlorite and illite, in the HN < 2 um fraction indicates that the hornfels profile was less intensely weathered. The limited occurrence of chloritized vermiculite can be attributed to the lower concentrations of amorphous Fe and Al. Chloritized vermiculite was only found in the HN Bf1, the horizon with highest AAO-Fe and Al. In HN Ae, the dominant mineral was vermiculite. The formation of smectite in the QD Ae, may be attributed to the greater organic matter eluviation.

4.4 Summary

A survey of soils adjacent to the minesite showed that soil development and tree growth can occur on slopes as steep as the wasterock's angle of repose. As a result of the cool, humid conditions, the surface was covered by a deep forest floor. With rooting concentrated in the forest floor, most of the C in the mineral horizons was added by leaching. The two soils studied had low pH values and high illuvial organic-C concentrations, properties typical of west coast podzols and conditions conducive to rapid weathering. Even in the lowest horizons, pH values were lower than 5, and several of the upper horizons had pH values lower than 4.

In both soils, there was a decrease in the proportion of silt and clay with depth. In the HN profile, the Ae and Bf1 horizons were clay loams, while the Lower B and Cg horizons were classified as loams. In the QD profile, the BC horizons were loamy sands while A and B horizons were sandy loams.

The QD soil was developed on a 36^{o} slope and contained a high proportion of large coarse fragments, conditions identical to a wasterock dump. In comparison, the HN soil was developed on a 20^{o} and the coarse fragment content was not as large. Within the QD profile the only decrease in coarse fragment content occurred in the upper 19 cm. The cohesiveness of coarse fragments in the rest of the profile resulted from the resilience of the main rock forming minerals plagioclase, quartz, and K feldspar. The only decrease in the QD < 2 mm plagioclase and K feldspar content occurred in the Ae.

Mafic and phyllosilicate minerals were less stable, with hornblende and chlorite removed first, followed by sericite, biotite, and kaolinite. Differences in the rate of removal were affected by the size and quantity of the mineral (e.g. sericite versus biotite), in addition to the weatherability. In the QD profile, only traces of the phyllosilicates were found in the < 2 mm fractions in the upper 40 cm. In the less intensely leached HN profile, chlorite and sericite were common in all but the Ae horizon. Analysis of the 100 to 50 um heavy mineral fraction from the

QD soil showed that the proportion of sphene decreased substantially in the surface horizons, while that of magnetite and scheelite increased. The only sulphide mineral found was pyrite. The few pyrite grains, which were almost completely oxidized, were found in the BC horizon.

Vermiculite and chloritized vermiculite were the most common < 2 um minerals in both the QD and HN profiles, with chloritized vermiculite highest in horizons with high concentrations of amorphous Fe and Al. The formation of smectite in the QD Ae may be attributed to the greater organic matter eluviation.

Major elemental concentrations in the < 2 mm fractions of the two soils reflected changes in mineralogy and the accumulation of illuvial Fe and Al. One of the most striking differences from the unweathered quartz diorite coarse fragments was the almost complete lack of S in the < 2 mm fraction. The opposite was true for Fe. In many horizons the < 2 mm total-Fe concentrations were at least double those of the unweathered coarse fragments. The loss of S presumably resulted from the oxidation of pyrite and the subsequent leaching of sulphate-S. The release of Fe from pyrite in coarse fragments was the most likely source for the high amounts of Fe. The lack of a similar Fe enrichment in the hornfels profile can be attributed to reduced coarse fragment weathering, a lower pyrite content and, in the lower horizons, to waterlogging.

As a result of weathering, both soils contained high concentrations of extractable Fe and Al. In HN profile, pedogenesis was limited by waterlogging to the upper 50 cm In the coarser QD profile, surfaces showed evidence of Fe oxidation to at least 150 cm, and there was a region of AAO-Fe enrichment from 75 to 130 cm.

Like the wasterock, the natural soils contained anomalously high concentrations of Co, Mo, Pb and Se. The HN soil was especially enriched in Co, while the QD soil .. contained very high levels of Mo and Pb, associated with the high BC horizon AAO-Fe concentrations. The spacial association between AAO-Fe, Mn, Mo, and P suggested a temporal association in the weathering of their primary mineral forms.

5 SIMULATED WEATHERING

5.1 Introduction

Data from the abandoned wasterock dumps and from natural soils adjacent to the minesite provided information about the type and strength of weathering processes in this environment, information that can be used to predict how the incompetent wasterock will weather. While similarities in mineralogy and chemistry, allow one to extrapolate information gathered from other materials, each material will exert its own specific effects. As there were no natural examples of long-term incompetent rock weathering, it was necessary to use laboratory techniques to simulate weathering. The technique used was a Soxhlet distillation with acetic acid (Singleton and Lavkulich, 1978). In previous research, this technique successfully duplicated elemental changes observed in a "west coast" podzol chronosequence on Vancouver Island (Singleton, 1978). Seven to eight weeks of Soxhlet leaching removed similar elemental concentrations to 100 years of weathering.

5.2 Objective

The objective of this section was to replicate the weathering changes that will occur in a veneer of incompetent wasterock after 100 years of weathering, using the Soxhlet technique developed by Singleton and Lavkulich (1978).

5.3 Materials and Methods

5.3.1 Samples

The three materials used covered the range of compositions found in the incompetent wasterock. All were obtained from the unweathered incompetent wasterock samples examined in section III 2. Fraction 1 (CF) was a composite of the gravel (4.75 - 2 mm) fractions. In that there was no difference between the stone and gravel fractions, CF was representative of the modal composition of coarse fragments found in the incompetent wasterock. Fraction 2 (FI) was a composite of the < 2 mm fraction from these same samples. Fraction 3 (GM) was the < 2 mm fraction of an incompetent wasterock sample entirely comprised of groundmass.

5.3.2 Soxhlet Methods and Sample Analysis

The free draining model of Soxhlet was used (Singleton & Lavkulich, 1978). The Soxhlets accommodate 43 x 123 mm cellulose extraction thimbles. 80 g of the designated material was placed in a pre-leached, pre-weighed thimble, capped with two pieces of filter paper, and placed in the Soxhlet barrel. The barrels were attached to 500 ml flat bottomed flasks containing 200 ml of pH 2.5 0.5 M acetic acid. Three boil ease Teflon beads were added to facilitate boiling. The leaching rate was controlled by the temperature of the burners. Leaching was carried out at a rate of 1 litre/day. Over the duration of the study the temperature just above the

thimbles varied from 40 to 60°C. The leachate was replaced with fresh acetic acid each week. Duplicates of each material plus blanks were leached for 2, 4, and 8 weeks.

After the prescribed amount of leaching, the thimble was removed, freeze dried, and weighed to determine weight loss from the residue. Subsamples were then taken and analyzed for carbonate-C, particle size (hydrometer), and total elemental composition (XRF). The < 2 um fraction from the particle size analysis was used for mineralogical analysis (XRD). All analyses were carried out in the manner used in section III 2.

After it cooled, the pH of the liquid leachate in the Erlenmeyer flasks was measured. The liquid portion of the leachate was then poured into dishes. Material precipitated on the sides of the flasks was dislodged using ultrasonic treatments, concentrated HCl, and by physically scraping. It was then also washed into the dishes. Material in the dishes was concentrated through evaporation, washed to dilute any acid, and re-concentrated, being careful not to let it dry out. The resulting suspension was freeze dried and weighed.

Subsamples of the freeze dried leachate were digested with aqua-regia and HF according to the method of Rantala and Loring (1973). The elemental composition of the digest was determined by emission spectrophotometry with a Jarrell-Ash Atom Comp Series 1100 inductively coupled argon plasma emission spectrophotometer (ICP).

5.4 Results and Discussion

5.4.1 Weight Loss and Calcite Dissolution

Data for weight loss, calcite dissolution, and leachate pH from the three fractions is presented in Table 2.29. Calcite dissolution was estimated from the change in C and Ca concentrations in the residues and from the weight of Ca recovered in the leachate. Calcite estimates made from changes in C levels were higher than those based on changes in Ca, indicating that other forms of carbonate were present in the samples.

Over the 8 week period, acetic acid leaching removed significant amounts of material. In all three fractions, the high Ca levels in the leachate indicates that most of the weight loss resulted from the dissolution of calcite. Calcite dissolution was also indicated by the decreases in the C and Ca concentrations of the residue. Assuming that all the C was calcite, the change in carbonate-C concentrations suggest that over the 8 weeks 80% of the weight loss from the CF samples resulted from calcite dissolution. In the FI and GM samples the proportion of weight loss attributable to calcite dissolution was 70% and 94%, respectively.

Total weight losses were 8.3% from the CF, 10.8% from the FI, and 16.9% from the GM. Reasons for the smaller weight loss from the CF samples include the smaller calcite content, smaller surface area, and the occlusion of easily weathered minerals within the larger fragments. Differences in calcite

Table 2.29 Average weight loss and other properties of the Soxhlet residue and leachate.

Sample	Residual Wt (g)	Residual %	Leachate Wt (g)	Leachate %	Residual %C	Residual Cal-A (g)	Residual %Ca	Residual Cal-B (g)	Leachate Ca (g)	Leachate Cal-C (g)	Leach pH
CF.1			4.8	6.0					1.5	3.9	5.5
CF.2	5.9	7.4	5.7	7.1	0.8	5.3	2.2	4.4	1.8	4.5	3.8
CF.3			5.9	7.4					1.8	4.6	3.1
CF.4	6.8	8.5	6.2	7.7	0.8	5.3	2.3	4.6	1.8	4.6	3.1
CF.5			6.3	7.9					1.8	4.6	3.0
CF.6			6.4	8.1					1.9	4.6	3.0
CF.7			6.7	8.3					1.9	4.6	3.0
CF.8	6.6	8.3	6.9	8.6	0.8	5.3	2.3	4.6	1.9	4.7	2.9
Fl.1			5.6	7.0					1.8	4.4	6.8
Fl.2	7.1	8.9	6.9	8.6	0.9	6.0	2.6	5.2	2.1	5.2	3.9
Fl.3			7.4	9.2					2.1	5.3	3.2
Fl.4	7.1	8.9	7.7	9.6	0.9	6.0	2.6	5.2	2.1	5.3	3.1
Fl.5			8.0	9.9					2.1	5.4	3.1
Fl.6			8.1	10.1					2.1	5.4	3.0
Fl.7			8.4	10.5					2.2	5.4	3.1
Fl.8	8.6	10.8	8.7	10.9	0.9	6.0	2.6	5.2	2.2	5.4	3.1
GM.1			5.5	6.9					1.8	4.5	6.8
GM.2	9.4	11.8	9.5	11.9	1.3	8.7	3.3	6.6	3.1	7.8	4.8
GM.3			11.6	14.4					3.8	9.4	4.3
GM.4	12.6	15.8	12.7	15.9	1.8	12.0	4.7	9.4	4.1	10.3	4.0
GM.5			13.2	16.5					4.2	10.6	3.5
GM.6			13.4	16.7					4.3	10.7	3.3
GM.7			13.6	17.0					4.3	10.8	3.0
GM.8	13.5	16.9	13.8	17.3	1.9	12.7	5.2	10.4	4.4	10.9	3.0

GM.8 : material.week
Cal-A : calcite calculated from %C
Cal-B : calcite calculated from %Ca
Cal-C : calcite calculated from Ca (g)

content account for the larger weight loss from the GM, compared to the FI fraction. Notably, the GM material also had a finer texture, and hence greater surface area.

Over the first week acetic acid removed 6.0% of the CF, 7.0% of the FI, and 6.9% of the GM. In the second week the weight loss from the CF and FI declined to 0.3% and 1.6%, respectively. According to the residue C data, all the carbonate minerals had been removed from the CF and FI samples by the end of the second week. Subsequent weight loss in the CF samples, was only 0.2 to 0.3% per week. In the FI samples, weight loss for the remainder of the trial was 0.2 to 0.4% per week.

As a result of a higher initial carbonate content, it took approximately 5 weeks to remove carbonate-C from the GM samples. From the second to the fifth week, the weight loss from the GM samples were 5.0%, 2.5%, 1.5% and 0.6%. Over the last three weeks of leaching, weight loss from the GM samples (0.2 to 0.3%) was similar to that observed in the other samples.

Leachate pH values were strongly correlated with the leachate weight and Ca content. For example, the pH of the CF leachate declined from 5.5 to 3.8 to 3.1 over the first three weeks. Over the next five weeks, the CF leachate pH gradually declined to 2.9. Like leachate weight, the leachate pH values were higher in the FI than the CF samples. The lowest FI leachate pH value, in the sixth week, corresponded to the period with the lowest weight loss (0.2%). The higher weight

losses from the GM samples over the first 5 weeks resulted in higher leachate pH values than the other samples. Over the last two weeks (7 and 8), lower weight losses from the GM samples resulted in lower leachate pH values than the FI samples.

5.4.2 Particle Size

Simulated weathering increased the proportion of finer particles in all three fractions (Table 2.30). As one would expect the largest increase in finer particles occurred in the GM samples. Over the 8 weeks of leaching, the proportion of particles < 50 um in the GM samples increased from 39 to 49%. Most of this increase occurred during the first two weeks (39 to 46%) and was concentrated in the silt fraction, which increased from 25 to 33%. The largest decrease occurred in the very coarse sand (7 to 3%). After 8 weeks of leaching, the texture of the GM samples had changed from sandy loam to loam. While a reduction in particle size will affect physical properties, with skeletal coarse fragments maintaining the volume, adverse effects will be moderated by the large loss of weight (18%).

Of the three materials tested the largest change in particle size occurred in the CF, the fraction representative of the incompetent wasterock's coarse fragments. In the CF fraction the proportion of particles < 2 mm increased from 4 to 17%. Again most of the change happened over the first 2 weeks (4 to 16%) in association with the removal of calcite.

Table 2.30 Average particle size distribution after Soxhlet leaching.

Sample	%Wt	> 2 mm	2mm-50um	2-1 mm	1-0.5 mm	500-250 um	250-100 um	100-50um	50-2um	< 2 um
CF.0	100	96	4	3	0	0	0	0	0	0
CF.2	93	84	16	8	3	2	2	1	0	0
CF.4	92	83	17	8	3	2	2	1	0	0
CF.8	92	83	17	7	3	3	3	1	0	0
Fl.0	100	0	69	13	15	16	15	10	20	11
Fl.2	91	0	68	12	15	16	15	10	20	12
Fl.4	91	0	66	12	15	16	15	9	22	12
Fl.8	89	0	66	9	14	17	16	10	20	14
GM.0	100	0	61	7	12	15	16	11	25	14
GM.2	88	0	54	5	12	13	14	11	32	14
GM.4	84	0	53	4	10	13	14	10	33	14
GM.8	83	0	51	3	10	13	14	11	33	16

Losses from the gravel fractions resulted in the formation of sand-sized particles. In the CF samples there was no detectable silt or clay formation. Increases of 3 to 4% occurred in all the sand fractions, except the very fine sand which increased from 0 to 1%. The formation of sand illustrated the value of the coarse fragments as a source of fines. However, the reduction in particle size was limited. The stability of over 80% of the CF gravel particles illustrates the resilience of incompetent wasterock coarse fragments to this kind of weathering.

A similar resilience was noted in the sand-sized particles of the FI samples. Over the entire leaching period, the proportion of sand, the largest particles in the FI samples, only decreased from 69 to 66%. The greatest change in an individual fraction of the FI samples occurred in the very coarse sand (13 to 9%) and the clay (11 to 14%). Unlike the GM samples, there was no noticeable change in the proportion of silt.

5.4.3 2-20 um and 2 um Mineralogy

The mineralogy of the 2-20 um and < 2 um fractions of the FI and GM samples before and after 8 weeks of acetic acid leaching are shown in Table 2.31. There were very few differences between the leached and the unleached samples. In the FI samples, the only detectable changes were slight increases in the 2-20 um K feldspar and the < 2 um quartz and kaolinite, and slight decreases in the 2-20 um sericite. In

Table 2.31 Estimated mineralogy of the < 2 and 2-20 um fractions of the FI and GM samples before and after 8 weeks of Soxhlet leaching.

Fraction	Sample	Quartz	K feldspar	Sericite	Kaolinite	Smectite	Vermiculite
2-20 um	FI.0	XX	X	XXX	XX	XX	
	FI.8	XX	XX	XX	XX	XX	
< 2 um	FI.0			XX	XX	XX	XX
	FI.8	tr		XX	XXX	XX	XX
2-20 um	GM.0			XXXX	tr		tr
	GM.8			XXXX			tr
< 2 um	GM.0			XXXX	tr		X
	GM.8			XXXX	tr		tr

XXXX : > 51%
XXX : 31-50%
XX : 11-30%
X : 5-10%
tr : < 5%
GM.8 : material.week

the GM samples, the only noticeable changes were decreases in the 2-20 um kaolinite and the < 2 um vermiculite. None of the changes were large enough to have a significant effect on soil properties.

5.4.4 Major Element Composition

The elemental composition of the residue, along with the concentrations, cumulative weight gains, and proportions of the initial sample weight recovered in the leachate, for each fraction x week x replicate combination are listed in Appendix D. The average major element composition of the residues, and average cumulative weight and proportions of major elements recovered in the leachate for each fraction x week combination are shown in Tables 2.32 and 2.33. Similar data for the trace elements is shown in Tables 2.35 and 2.36. A comparison of weight losses from the residues and weight gains in the leachate is given in Table 2.34.

The comparison of weight loss from the residues and weight gain in the leachate showed a number of discrepancies. Differences between the leachate and residue data were greatest for the trace elements and for major elements where the rate of release was small. Discrepancies were due to variation in initial residue composition and from the use of different techniques to analyse the leachate (ICP) and residues (XRF). As the original residue composition was only determined by XRF, the residue data gives a more accurate measure of the extracted proportion of each element. While

Table 2.32 Average major element composition of the Soxhlet residues.

Sample	Wt	C	Al	Ca	Fe	K	Mg	Na	P	S	Si	Ti
	Concentration of Elements (major elements in %, trace elements in ppm)											
CF.0	100	0.8	5.4	2.4	0.8	4.3	0.4	0.33	0.07	0.3	35.1	0.2
CF.2	93	0.0	5.7	0.2	0.9	4.4	0.2	0.27	0.05	0.6	37.6	0.2
CF.4	92	0.0	5.7	0.1	0.6	4.6	0.2	0.32	0.04	0.4	37.6	0.2
CF.8	92	0.0	6.0	0.1	0.7	4.6	0.2	0.27	0.02	0.4	37.3	0.2
FI.0	100	0.9	7.6	2.7	1.4	4.9	0.6	0.20	0.11	1.1	30.9	0.3
FI.2	91	0.0	8.3	0.1	1.2	5.2	0.4	0.23	0.06	1.0	34.0	0.3
FI.4	91	0.0	8.2	0.1	1.1	5.2	0.3	0.20	0.04	0.9	34.3	0.3
FI.8	89	0.0	8.2	0.1	1.0	5.2	0.3	0.24	0.00	0.9	34.2	0.3
GM.0	100	1.9	13.8	5.3	3.0	6.5	1.5	0.03	0.28	3.5	18.9	0.6
GM.2	88	0.6	15.1	2.0	3.6	7.3	1.0	0.01	0.25	4.2	20.9	0.7
GM.4	84	0.1	15.6	0.6	3.3	7.7	0.9	0.00	0.21	3.8	21.6	0.7
GM.8	83	0.0	16.2	0.1	3.3	7.7	0.9	0.01	0.05	3.7	22.1	0.8
	Weight of Elements (major elements in g, trace elements in mg)											
CF.0	80.0	0.64	4.3	1.92	0.65	3.40	0.34	0.26	0.06	0.22	28.1	0.17
CF.2	74.1	0.00	4.2	0.12	0.65	3.24	0.15	0.20	0.04	0.47	27.8	0.17
CF.4	73.2	0.01	4.1	0.09	0.47	3.37	0.16	0.24	0.03	0.28	27.5	0.17
CF.8	73.4	0.01	4.4	0.05	0.50	3.34	0.13	0.20	0.01	0.27	27.4	0.17
FI.0	80.0	0.71	6.1	2.17	1.12	3.95	0.49	0.16	0.09	0.86	24.7	0.23
FI.2	72.9	0.00	6.0	0.10	0.85	3.78	0.27	0.17	0.04	0.71	24.8	0.23
FI.4	72.9	0.01	6.0	0.08	0.82	3.77	0.23	0.14	0.03	0.69	25.0	0.23
FI.8	71.4	0.01	5.9	0.04	0.71	3.70	0.22	0.17	0.00	0.65	24.4	0.23
GM.0	80.0	1.50	11.0	4.27	2.37	5.20	1.16	0.02	0.23	2.81	15.1	0.49
GM.2	70.6	0.40	10.7	1.38	2.52	5.18	0.72	0.01	0.17	2.96	14.7	0.48
GM.4	67.4	0.05	10.5	0.39	2.21	5.18	0.60	0.00	0.14	2.56	14.5	0.49
GM.8	66.5	0.00	10.8	0.08	2.17	5.12	0.57	0.01	0.04	2.45	14.7	0.50
	Percent Remaining from Initial Weight											
CF.2	93	0	98	6	99	95	46	76	68	211	99	99
CF.4	92	3	97	4	72	99	48	91	49	126	98	98
CF.8	92	2	102	3	76	98	38	76	21	121	98	102
FI.2	91	1	99	4	76	96	55	105	49	82	100	101
FI.4	91	1	98	3	74	95	47	89	30	80	101	102
FI.8	89	1	96	2	64	94	45	109	2	75	99	101
GM.2	88	30	97	32	106	100	62	25	78	106	97	97
GM.4	84	4	95	9	93	100	52	0	62	91	96	100
GM.8	83	0	98	2	91	98	49	35	16	87	97	103

Table 2.33 Average cumulative and proportion of initial major element weight recovered in the leachate.

Sample	Wt (g)	Al	Ca	Fe	K	Mg	Na	P	Si	Ti
		Cumulative Weight (mg)								
CF.1	4.8	33	1545	26	625	121	2	3	8	0.1
CF.2	5.7	50	1790	46	741	154	2	15	38	0.1
CF.3	5.9	60	1823	62	774	163	-1	26	58	0.1
CF.4	6.2	68	1839	76	807	171	3	29	85	0.2
CF.5	6.3	76	1847	86	833	176	4	32	104	0.2
CF.6	6.4	80	1852	93	856	179	5	32	118	0.2
CF.7	6.7	91	1857	102	883	184	15	33	153	0.3
CF.8	6.9	102	1878	109	914	187	15	43	175	0.3
CF Orig	80.0	4281	1921	655	3404	335	261	59	28051	170
Fl.1	5.6	61	1774	55	734	153	13	6	48	0.0
Fl.2	6.9	93	2076	106	911	202	16	31	132	0.0
Fl.3	7.4	116	2116	139	963	216	15	54	190	0.0
Fl.4	7.7	130	2136	163	1010	225	14	58	235	0.0
Fl.5	8.0	148	2145	184	1049	233	13	62	284	0.1
Fl.6	8.1	156	2147	192	1070	237	12	63	301	0.1
Fl.7	8.4	178	2151	205	1110	244	21	64	364	0.2
Fl.8	8.7	202	2153	217	1147	249	25	64	423	0.2
Fl Orig	80.0	6115	2175	1116	3953	487	160	88	24673	228
GM.1	5.5	2	1790	24	714	200	9	17	17	0.0
GM.2	9.5	39	3111	28	1257	371	7	34	26	0.0
GM.3	11.6	61	3760	31	1528	454	4	55	32	0.0
GM.4	12.7	75	4110	37	1651	496	2	77	41	0.0
GM.5	13.2	80	4245	47	1705	511	1	95	52	-0.1
GM.6	13.4	82	4298	50	1727	516	3	101	52	0.0
GM.7	13.6	86	4327	63	1749	517	4	113	67	0.0
GM.8	13.8	94	4373	75	1779	519	7	134	77	0.0
GM Orig	80	11008	4275	2374	5198	1160	21	225	15098	489
		Proportion of Initial Sample Weight Recovered in Leachate (%)								
CF.1	6	1	80	4	18	36	1	5	0.0	0.0
CF.2	7	1	93	7	22	46	1	25	0.1	0.0
CF.3	7	1	95	9	23	49	0	45	0.2	0.1
CF.4	8	2	96	12	24	51	1	50	0.3	0.1
CF.5	8	2	96	13	24	52	1	55	0.4	0.1
CF.6	8	2	96	14	25	53	2	55	0.4	0.1
CF.7	8	2	97	16	26	55	6	57	0.5	0.2
CF.8	9	2	98	17	27	56	6	74	0.6	0.2
Fl.1	7	1	82	5	19	31	8	7	0.2	0.0
Fl.2	9	2	95	9	23	42	10	36	0.5	0.0
Fl.3	9	2	97	12	24	44	9	61	0.8	0.0
Fl.4	10	2	98	15	26	46	9	66	1.0	0.0
Fl.5	10	2	99	16	27	48	8	71	1.2	0.0
Fl.6	10	3	99	17	27	49	8	71	1.2	0.0
Fl.7	11	3	99	18	28	50	13	72	1.5	0.1
Fl.8	11	3	99	19	29	51	15	73	1.7	0.1
GM.1	7	0	42	1	14	17	43	7	0.1	0.0
GM.2	12	0	73	1	24	32	32	15	0.2	0.0
GM.3	14	1	88	1	29	39	21	25	0.2	0.0
GM.4	16	1	96	2	32	43	9	34	0.3	0.0
GM.5	17	1	99	2	33	44	3	42	0.3	0.0
GM.6	17	1	101	2	33	44	-13	45	0.3	0.0
GM.7	17	1	101	3	34	45	20	50	0.4	0.0
GM.8	17	1	102	3	34	45	32	60	0.5	0.0

GM.8 : material.week Orig : weight initially in residue

Table 2.34 A comparison of weight losses from the residues and weight gains in the leachate.

Sample	Al	Ca	Fe	K	Mg	Na	P	Si	Ti	Co	Cr	Cu	Mn	Mo	Pb	Sr	Zn	Zr
	(major elements in mg, trace elements in ug)																	
Soxhlet Leachate Weight Gain																		
CF 0-2	50	1790	46	741	154	2	15	38	0.1	29	25	70	15903	20	471	13237	361	6
CF 2-4	17	49	29	67	16	1	15	47	0.1	15	3	16	531	7	316	1176	161	4
CF 4-8	34	40	34	107	17	12	14	90	0.2	18	0	47	395	11	575	1134	244	8
FI 0-2	93	2076	106	911	202	16	31	132	0.0	56	136	1772	19690	42	3064	29771	1935	21
FI 2-4	37	60	57	99	23	0	27	103	0.0	26	45	277	620	18	1105	1412	309	7
FI 4-8	72	17	54	137	24	11	6	188	0.2	26	14	134	465	19	894	989	330	12
GM 0-2	39	3111	28	1257	371	7	34	26	0.0	31	18	243	28096	33	1130	29032	434	18
GM 2-4	36	999	9	394	125	0	43	15	0.0	9	78	53	9003	12	355	5700	164	5
GM 4-8	19	262	38	128	22	5	58	36	0.0	12	28	158	1696	6	1376	1759	91	7
CF 0-8	102	1878	109	914	187	15	43	175	0.3	63	27	133	16829	38	1362	15546	766	18
FI 0-8	202	2153	217	1147	249	25	64	423	0.2	109	195	2183	20774	79	5064	32172	2574	40
GM 0-8	94	4373	75	1779	519	7	134	77	0.0	52	124	454	38794	51	2861	36491	688	30
Soxhlet Residue Weight Loss																		
CF 0-2	85	1797	7	166	181	63	19	212	1.5	4409	119	350	25072	11313	-168	16141	390	553
CF 2-4	51	38	174	-136	-7	-39	11	321	2.0	-3973	-24	703	-444	-10626	-5614	4692	-3406	225
CF 4-8	-240	37	-27	31	35	38	17	150	-6.9	2042	-12	-437	224	12407	2550	-210	1472	-1944
FI 0-2	88	2078	265	169	221	-7	45	-91	-1.7	630	67	4795	27673	-1432	1855	43780	1524	-762
FI 2-4	32	21	28	19	35	25	16	-266	-2.1	256	-5	451	690	-2184	-351	-1862	422	-71
FI 4-8	135	37	114	63	11	-32	25	599	2.6	-1126	11	202	549	3808	-3373	3698	-1539	-264
GM 0-2	338	2891	-144	16	436	15	50	378	13.1	-136	77	1397	39289	-338	-4196	40721	-4800	906
GM 2-4	164	995	309	-1	120	5	34	180	-11.1	716	35	43	13039	-877	5949	8987	5911	-1495
GM 4-8	-275	308	42	63	36	-7	105	-140	-17.2	-205	16	796	3040	143	1300	3139	759	2233
Leachate Weight Gain / Residue Weight Loss																		
CF 0-2	0.6	1.0	6.3	4.5	0.9	0.0	0.8	0.2	0.0	0.0	0.2	0.2	0.6	0.0	-2.8	0.8	0.9	0.0
CF 2-4	0.3	1.3	0.2	-0.5	-2.3	0.0	1.4	0.1	0.1	0.0	-0.1	0.0	-1.2	0.0	-0.1	0.3	0.0	0.0
CF 4-8	-0.1	1.1	-1.3	3.4	0.5	0.3	0.8	0.6	0.0	0.0	0.0	-0.1	1.8	0.0	0.2	-5.4	0.2	0.0
FI 0-2	1.1	1.0	0.4	5.4	0.9	-2.1	0.7	-1.4	0.0	0.1	2.0	0.4	0.7	0.0	1.7	0.7	1.3	0.0
FI 2-4	1.2	2.9	2.0	5.2	0.7	-0.1	1.6	-0.4	0.0	0.1	-9.8	0.6	0.9	0.0	-3.2	-0.8	0.7	-0.1
FI 4-8	0.5	0.5	0.5	2.2	2.2	-0.4	0.3	0.3	0.1	0.0	1.3	0.7	0.8	0.0	-0.3	0.3	-0.2	0.0
GM 0-2	0.1	1.1	-0.2	77.2	0.9	0.4	0.7	0.1	0.0	-0.2	0.2	0.2	0.7	-0.1	-0.3	0.7	-0.1	0.0
GM 2-4	0.2	1.0	0.0	-363	1.0	-0.9	1.2	0.1	0.0	0.0	2.2	1.2	0.7	0.0	0.1	0.6	0.0	0.0
GM 4-8	-0.1	0.9	0.9	2.0	0.6	-0.6	0.5	-0.3	0.0	-0.1	1.7	0.2	0.6	0.0	1.1	0.6	0.1	0.0

GM 0-2 sample 1 0 - 2 weeks

the leachate data was probably less accurate in terms of weight removed, the leachate samples were collected more often and thus give a better picture of the timing of release. In all cases where a substantial proportion of the element was extracted, the relative ranking of the three fractions, in terms of loss from the residues and gain to the leachate, were the same.

As noted earlier, C and Ca were rapidly removed from all three fractions. After 8 weeks of leaching, 97 to 98% of the Ca had been removed from the residues. Possible sources of the remaining Ca include apatite and trace amounts of anorthite.

Magnesium was also removed in substantial amounts in the first few weeks. Magnesium dissolution occurred in two stages. An initial rapid dissolution of 45 to 55% of the Mg, followed by a slow rate of approximately 1% per week. The latter slow rate of Mg release paralleled a similar slow but regular release of Fe, and is thus likely due to the dissolution of mafic minerals.

The rapid initial rate of Mg release can be attributed to the rapid dissolution of dolomite. In contrast to Ca, in the first week the lowest weight loss of Mg was from the GM fraction. One explanation for this is that dolomite is less soluble than calcite. As a result of the larger surface area and higher calcite content, the increase in leachate pH above values at which dolomite was soluble probably happened faster in the finer textured GM samples, than in the fractions.

According to the leachate data, leaching removed 27 to 34% of the K, while the residue data showed losses of only 2 to 6%. The lack of change in the content of K bearing minerals in the < 2 um and 2-20 um fractions, and in the content of other elements (e.g., Al and Si) found in K bearing minerals suggest that the residue data was correct and that K leaching was not very high.

According to the leachate data, the release of K occurred almost entirely over the first two weeks from the CF and FI samples, and over the first five weeks from the GM fraction. This parallels the periods of carbonate leaching. Assuming that K was only present in the K minerals, muscovite and K feldspar, observed in thin sections and found in the XRD scans, the source of K was probably loosely bound K at the edge of grains and in poorly ordered fine crystals.

In all three fractions, P release occurred steadily throughout the 8 weeks of leaching. According to the residue data, after 2, 4, and 8 weeks of leaching 32, 51, and 79% of the P in the CF fraction had been removed. For the FI fraction it was 51, 70, and 98%, and for the GM fraction it was 22, 38, and 84%. Higher P dissolution in the FI than the CF fraction can be attributed to the larger surface area and less likelihood of occlusion in the former. The higher proportion of P dissolved in the FI than the GM fraction can be attributed to the much higher initial P concentration in the GM fraction. The weight of P extracted from the GM fraction was significantly higher than that leached from the

FI fraction.

Another factor that appeared to affect the P dissolution was leachate pH. In the leachate data from the CF and FI fractions there was a lag in P dissolution in the first week, the period when the leachate pH was over 5. In the CF and FI fractions, P extraction was highest in the second and third weeks. In the GM fractions, P extraction was highest in the third and fourth weeks.

The irregular distribution of S in the residues of all three fractions results both from a nugget effect and from the variable number of veins. In the two < 2 mm fractions, FI and GM, the proportion of the initial S concentrations remaining in the leached residues ranged from 75 to 106%. This indicates that the rate of sulphide dissolution was significantly slower than that of carbonate dissolution.

In both the leachate and residue data, the ranking of fractions in terms of the weight of Fe removed was FI > CF > GM. According to the leachate data, similar proportions of total Fe were extracted from the FI and CF fractions. A much lower proportion was extracted from the GM fraction, which had the highest concentrations of total-Fe. With regard to Fe, the main difference between the GM and the FI and CF fractions was the absence of mafic aluminosilicates in the former.

The ratio of Fe to S in pyrite is 0.87. The pre-leached Fe:S ratios of the CF, FI, and GM fractions were 2.7, 1.3, and 0.86, respectively. The Fe:S ratio in the GM fraction after 8 weeks of leaching was 0.89, indicating that the lack of Fe

extraction was not due to reprecipitation. While the longer duration of low pH conditions might be partially responsible for the slower Fe release from the GM fraction, the theory that mafic silicates (e.g., biotite) were more soluble that pyrite was supported by the decline in the Fe:S ratios of the FI and the CF fractions to from 1.3 to 1.1 and from 2.7 to 1.8, respectively, after 8 weeks of leaching.

The relatively rapid rate of mafic silicates breakdown, compared to that of pyrite, was the reverse of what was observed in the natural soils, indicating that the Soxhlet acetic acid leaching disproportionately favoured dissolution over oxidation. A lack of microbial activity and the saturation of the residues are possible causes for the lack of oxidation. Over the 8 weeks of leaching the residues retained their initial greyish colour. The only evidence of Fe oxidation were reddish Fe stains at the base of the thimbles.

Both the leachate and residue data showed that leaching removed very little Al, Si, or Ti According to the leachate data the relative proportions removed were Al > Si > Ti. Leachate weight gains of Al were 2% in the CF, 3% in the FI, and 1% in the GM fraction. The greater removal of Al from the FI than CF fraction can be attributed to the larger surface area of the former. The larger Al weight loss from the FI compared to the GM fraction can be in part be attributed to the longer duration of low pH leaching in the FI fraction. The low rate of K, Al, and Si removal from all three fractions

indicates that sericite dissolution was occurring at a very slow rate.

5.4.5 Trace Element Composition

In many cases the percentage of trace elements remaining in the leached residues were higher than those in the unleached sample. The best example of this was Pb. In the CF fraction, the concentration of Pb remaining in the leached residues was 109%, 406%, and 271% after 2, 4, and 8 weeks of leaching. The great variation in Pb levels was in part due to the heterogeneous distribution of metal containing veins. There was also a nugget effect for trace elements, because of their low concentrations.

As a result of the variability in the residues, the leachate data was a better guide to the timing of trace elements release. According to the leachate data, Pb was released steadily over the whole 8 weeks, in proportions similar to P. Copper and zinc, like magnesium, were released in relatively high amounts initially, and at a reduced rate for the rest of the leaching study. The release patterns for As, Cd, Mn, and Sr were similar to that of Ca.

The trace elements extracted in the smallest proportions were Co, Mo, and Zr. These elements were extracted in even smaller proportions than Si. For all three, the highest weights and proportions were extracted from the FI fraction. The low rate at which Co and Zr dissolved can be explained by their occurrence in the resistant minerals, magnetite and

Table 2.35 Average trace element composition of the Soxhlet residues.

Sample	Wt	C	Co	Cr	Cu	Mn	Mo	Pb	Sr	Zn	Zr
	(%)	(%)	Concentration (ppm)								
CF.0	100	0.8	197	10	17	326	433	24	519	45	95
CF.2	93	0.0	153	9	14	14	314	28	343	43	95
CF.4	92	0.0	209	10	4	20	463	104	283	90	93
CF.8	92	0.0	181	10	10	17	293	70	285	70	119
FI.0	100	0.9	105	10	80	375	383	79	772	166	129
FI.2	91	0.0	106	10	22	31	440	61	247	162	151
FI.4	91	0.0	103	10	15	22	470	66	272	156	152
FI.8	89	0.0	121	10	13	15	427	114	226	181	159
GM.0	100	1.9	23	9	40	702	251	73	687	180	273
GM.2	88	0.6	28	9	25	238	289	141	201	272	296
GM.4	84	0.1	19	8	26	56	316	60	77	197	332
GM.8	83	0.0	22	8	14	12	318	42	31	189	303
	(g)	(g)	Weight (mg)								
CF.0	80.0	0.64	15.8	0.8	1.4	26.1	34.6	1.9	41.6	3.6	7.6
CF.2	74.1	0.00	11.3	0.7	1.0	1.0	23.3	2.1	25.4	3.2	7.0
CF.4	73.2	0.01	15.3	0.7	0.3	1.5	33.9	7.7	20.7	6.6	6.8
CF.8	73.4	0.01	13.3	0.7	0.8	1.2	21.5	5.1	20.9	5.1	8.7
FI.0	80.0	0.71	8.4	0.8	6.4	30.0	30.6	6.3	61.8	13.3	10.3
FI.2	72.9	0.00	7.8	0.7	1.6	2.3	32.1	4.5	18.0	11.8	11.0
FI.4	72.9	0.01	7.5	0.7	1.1	1.6	34.3	4.8	19.8	11.4	11.1
FI.8	71.4	0.01	8.6	0.7	0.9	1.0	30.5	8.2	16.1	12.9	11.4
GM.0	80.0	1.50	1.9	0.7	3.2	56.1	20.1	5.8	54.9	14.4	21.8
GM.2	70.6	0.40	2.0	0.6	1.8	16.8	20.4	10.0	14.2	19.2	20.9
GM.4	67.4	0.05	1.3	0.6	1.7	3.8	21.3	4.1	5.2	13.3	22.4
GM.8	66.5	0.00	1.5	0.6	0.9	0.8	21.1	2.8	2.1	12.5	20.2
			Percent Remaining from Initial Weight								
CF.2	93	0	72	85	74	4	67	109	61	89	93
CF.4	92	3	97	88	23	6	98	406	50	184	90
CF.8	92	2	84	90	55	5	62	271	50	143	115
FI.2	91	1	92	91	25	8	105	71	29	89	107
FI.4	91	1	89	92	18	5	112	76	32	85	108
FI.8	89	1	103	91	14	3	99	130	26	97	111
GM.2	88	30	107	89	56	30	102	172	26	133	96
GM.4	84	4	69	83	55	7	106	70	10	92	103
GM.8	83	0	80	81	30	1	105	48	4	87	92

GM.8 : material.week

Table 2.36 Average cumulative and proportion of initial trace element weight recovered in the leachate.

Sample	Wt	As	Cd	Co	Cr	Cu	Mn	Mo	Pb	Se	Sr	Zn	Zr
	(g)					Cumulative Weight (ug)							
CF.1	4.8	34	4	22	-3	54	13672	15	249	151	11243	245	2.9
CF.2	5.7	39	6	29	25	70	15903	20	471	180	13237	361	5.6
CF.3	5.9	39	6	37	28	81	16236	24	619	191	13886	434	7.5
CF.4	6.2	39	8	45	28	86	16435	27	787	208	14413	522	9.9
CF.5	6.3	38	8	50	30	90	16566	30	929	218	14779	572	11.7
CF.6	6.4	37	8	54	28	106	16643	32	979	227	14976	628	12.8
CF.7	6.7	37	9	58	28	119	16741	35	1119	243	15258	709	14.7
CF.8	6.9	36	9	63	27	133	16829	38	1362	264	15546	766	17.7
CF Orig	80.0	nd	nd	15758	807	1369	26101	34614	1891	nd	41565	3578	7561
Fl.1	5.6	42	15	24	-2	649	16365	23	1150	182	26435	1339	14.9
Fl.2	6.9	50	28	56	136	1772	19690	42	3064	237	29771	1935	20.9
Fl.3	7.4	51	30	71	168	1946	20062	54	3818	275	30607	2125	24.1
Fl.4	7.7	52	32	82	181	2049	20309	60	4169	295	31183	2244	28.0
Fl.5	8.0	52	33	92	188	2111	20493	66	4427	324	31584	2349	31.6
Fl.6	8.1	51	34	95	189	2124	20568	68	4489	335	31723	2377	32.7
Fl.7	8.4	51	35	102	193	2148	20681	74	4801	370	31973	2478	36.4
Fl.8	8.7	51	37	109	195	2183	20774	79	5064	402	32172	2574	39.7
Fl Orig	80.0	nd	nd	8380	787	6366	29957	30648	6314	nd	61752	13310	10278
GM.1	5.5	40	13	19	-3	212	17019	18	851	174	21384	303	12.6
GM.2	9.5	68	15	31	18	243	28096	33	1130	300	29032	434	18.3
GM.3	11.6	82	18	36	16	258	34078	40	1286	361	32692	537	22.7
GM.4	12.7	89	19	39	96	296	37099	45	1485	395	34732	597	22.9
GM.5	13.2	91	20	43	91	360	38239	47	1888	409	35615	620	24.6
GM.6	13.4	90	20	44	83	381	38637	48	1892	411	35965	635	24.4
GM.7	13.6	90	20	48	128	426	38727	49	2369	414	36194	658	26.6
GM.8	13.8	90	19	52	124	454	38794	51	2861	422	36491	688	29.6
GM Orig	80	nd	nd	1862	682	3174	56137	20062	5828	nd	54928	14417	21806
						Proportion of Initial Sample Weight Recovered in Leachate (%)							
CF.1	6	nd	nd	0.1	0	4	52	0.0	13	nd	27	7	0.0
CF.2	7	nd	nd	0.2	3	5	61	0.1	25	nd	32	10	0.1
CF.3	7	nd	nd	0.2	3	6	62	0.1	33	nd	33	12	0.1
CF.4	8	nd	nd	0.3	3	6	63	0.1	42	nd	35	15	0.1
CF.5	8	nd	nd	0.3	4	7	63	0.1	49	nd	36	16	0.2
CF.6	8	nd	nd	0.3	3	8	64	0.1	52	nd	36	18	0.2
CF.7	8	nd	nd	0.4	3	9	64	0.1	59	nd	37	20	0.2
CF.8	9	nd	nd	0.4	3	10	64	0.1	72	nd	37	21	0.2
Fl.1	7	nd	nd	0.3	0	10	55	0.1	18	nd	43	10	0.1
Fl.2	9	nd	nd	0.7	17	28	66	0.1	49	nd	48	15	0.2
Fl.3	9	nd	nd	0.9	21	31	67	0.2	60	nd	50	16	0.2
Fl.4	10	nd	nd	1.0	23	32	68	0.2	66	nd	50	17	0.3
Fl.5	10	nd	nd	1.1	24	33	68	0.2	70	nd	51	18	0.3
Fl.6	10	nd	nd	1.1	24	33	69	0.2	71	nd	51	18	0.3
Fl.7	11	nd	nd	1.2	24	34	69	0.2	76	nd	52	19	0.4
Fl.8	11	nd	nd	1.3	25	34	69	0.3	80	nd	52	19	0.4
GM.1	7	nd	nd	1.0	0	7	30	0.1	15	nd	39	2	0.1
GM.2	12	nd	nd	1.7	3	8	50	0.2	19	nd	53	3	0.1
GM.3	14	nd	nd	2.0	2	8	61	0.2	22	nd	60	4	0.1
GM.4	16	nd	nd	2.1	14	9	66	0.2	25	nd	63	4	0.1
GM.5	17	nd	nd	2.3	13	11	68	0.2	32	nd	65	4	0.1
GM.6	17	nd	nd	2.4	12	12	69	0.2	32	nd	65	4	0.1
GM.7	17	nd	nd	2.6	19	13	69	0.2	41	nd	66	5	0.1
GM.8	17	nd	nd	2.8	18	14	69	0.3	49	nd	66	5	0.1

GM.8 : material.week

zircon respectively. As a result of their resistance to weathering, both Co and Zr were found in high concentrations in the Ae horizons of the two natural soils examined in section III 4.

The low rate of Mo removal was surprising given its apparent mobility in the natural soils. One would expect a sulphide mineral, like molybdenite, to weather quickly under well aerated, acidic conditions. While low solubility in acidic solutions may play a role in the retention of Mo, its retention was further evidence that the technique used to simulate weathering resulted in relatively little oxidation.

5.5 Summary

Simulated weathering resulted in weight losses of 8.3% from the incompetent wasterock coarse fragments (CF), 10.8% from the < 2 mm fraction (FI), and 16.9% from the groundmass (GM). Most of the weight losses were associated with calcite removal. Calcite dissolution took two weeks in the CF and FI fractions, which contained 6.7 and 7.5% calcite respectively, and four weeks in the GM fraction, which contained 15.8% calcite. Subsequently weight loss occurred at between 0.2 to 0.4% per week.

A number of elements (e.g., Mg, Mn, Sr) were removed in substantial amounts in the first few weeks, indicating that a significant proportion of their total weight occurred in carbonate minerals. Other elements, such as Fe, P, and Pb, were released steadily over the entire eight weeks, the rate

of removal varying for each element. After the initial period of rapid Mg dissolution, presumably from dolomite, the proportion of Mg release was similar to that of Fe, suggesting that the two elements were released from the same minerals (e.g., biotite). The relatively rapid rate of mafic silicate breakdown, compared to that of pyrite, was the reverse of what was observed in the natural soils, and indicates that the Soxhlet technique disproportionately favoured dissolution over oxidation. The lack of Mo removal was also evidence of this.

Of the three materials tested, the largest change in particle size occurred in the CF, the fraction representative of the incompetent wasterock's coarse fragments. In the CF fraction, the proportion of sand-sized particles increased from 4 to 17%. However, there was no detectable silt or clay formation. A similar resilience of the sand-sized particles was noted in the FI samples. Over the entire leaching period, the proportion of sand, the largest particles in the FI samples, only decreased from 69 to 66%. As one would expect the largest increase in silt and clay occurred in the GM samples (39 to 49%). While a reduction in particle size may reduce the rate of drainage, the large loss of weight (18%) will have the reverse effect. With the soil volume maintained by the skeletal course fragments, any weight loss should increase the porosity. Like the weight loss, most of the changes in particle size happened in association with the removal of calcite.

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IV. CONCLUSIONS

1. Plant and Soil factors Limiting Reclamation

Plant invasion on abandoned surfaces at the mine showed that the most difficult areas to vegetate will be the wasterock dumps. This concurs with the findings at other mines (Lavkulich et al., 1976). Within the dumps, the plant invasion was poor on the terraced dumps and non-existent on dump slopes. Greater invasion and growth on the naturally unconsolidated materials, than on the wasterock, can be ascribed to higher levels of organic matter, N, and available P. On the wasterock benches, fertility problems can be resolved by adding fertilizer and by using plant species adapted to the infertile conditions. If fertilized, the wasterock is a better substrate for plant growth than the stockpiled naturally unconsolidated materials.

The vigorous plant growth in field trials indicated that a number of materials and methods can be used to achieve a sustained vegetative cover. In order to evaluate the long term performance of these techniques, results from Kitsault were compared with the sequence of natural soil and forest development on recently exposed moraines in S.E. Alaska. The initial stages of plant succession and soil development on the wasterock dumps resembled those on the

moraines. Similarities in environmental conditions, available flora, and substrates, indicate that many of the same processes will operate in the future.

The most productive plant species on the wasterock dumps was Sitka alder. Five years after they were planted, the average height growth of alder seedlings was over 25 cm per year, and litter layers were forming beneath their prostrate branches. On the moraines, alder was the main source of litter and N, and litter and N were the driving forces for further plant and soil development. If alder is to be used in reclaiming the dumps, it will have to be introduced. Natural alder invasion was very slow.

The other woody species growing vigorously on the dumps were willow and cottonwood. Willow and cottonwood averaged 10 to 20 cm growth per year, and, unlike the alder, were prolific invaders. Their invasion was greatest on fertilized areas sown with annual grasses (34 per 100 m^2).

Natural invasion of hemlock and vaccinium, the species which dominated the surrounding forest, was even more prolific (50 to 100 per 100 m^2). However once established, neither species was able to grow. This was also the case for coniferous seedlings planted in the field trials. The best growth of Sitka spruce and western hemlock (6 cm per year) was by seedlings adjacent to birdsfoot trefoil, indicating that a lack of N was one of the constraints on conifer growth. On the moraines, conifer seedlings remained dormant until the litter layer was at least 6 cm deep. The

first conifer to grow vigorously on the moraines was Sitka spruce. Spruce invasion at the minesite was very slow, indicating that if spruce was included in the reclamation plan, it would have to be introduced.

A number of agronomic species grew vigorously in the field trials, their growth protecting exposed surfaces from erosion, producing large amounts of litter, and in some cases adding N. A number of grass species quickly produced a dense, protective ground cover. The best of these was red fescue, which, without further additions of fertilizer, was able to sustain a good cover for at least 10 years. One problem associated with vigorous plant growth is that it can limit the growth of other species, either through direct competition or by providing a cover for voles. The competitive aspects of grass growth are avoided by using annual ryegrass. Annual ryegrass produced a 40% cover in the first year, and the stubble and litter provided residual surface protection. For litter and N additions, clearly the most productive agronomic species was birdsfoot trefoil. Trefoil was still producing 300 to 400 g/m^2 dry aerial biomass, 15 years after it was established.

Clearly the most productive plant cover would be alder seedlings interspersed with a ground cover of birdsfoot trefoil. Eventually the alder should shade out the trefoil, allowing the natural invasion of hemlock.

Plant growth dramatically increased the organic matter content of the surface soil. For example, ten years of

strong agronomic growth produced a 2 to 3 cm thick litter layer and increased 0.5 cm N levels (0.39 kg N/m^3) and available P (8.3 g/m^3) above those found in the stockpiled overburden. Nitrogen levels were highest beneath the birdsfoot trefoil. Most of the pedogenic changes observed in the wasterock (e.g. decreased bulk density) were associated with the addition of litter. As a result, changes were greatest near the surface. In some cases marked changes only occurred in the upper 5 cm.

The surface pH values (0.01 M $CaCl_2$) of the wasterock dumps decreased from between 7 and 8 to as low as 3. While the greatest pH decreases resulted from plant growth, some variation also occurred as a result of differences in lithology, topography, and surface treatments. The low pH values were similar to those of the surrounding natural soils and did not appear to reduce the growth of the native vegetation.

On untreated sites the increase in acidity was strongly correlated with an increase in available P (Bray P1) levels. Lowering the pH appeared to accelerate apatite weathering. Metal solubilities should also increase as the pH declines, however there were no visual symptoms of metal toxicities or element imbalances.

On the dump benches, natural plant invasion was greatest on sites with the highest proportion of < 2 mm particles. This was not the case in the field trials, where the vigorous growth of a number of different species

indicated that an average of 15 to 25% < 2 mm particles was adequate if the wasterock was fertilized. The average < 2 mm content of the natural unconsolidated materials stripped prior to mining ranged from 15 to 30%. Differences in lithology affected the proportion of fines in the wasterock. The average proportion of soil-sized particles in the potassic (19 to 26%) and incompetent (31 to 36%) wasterock were adequate for plant growth, while that in the hornfels wasterock (10 to 13%) was too low.

The greatest differences in particle size on the dumps were between the benches and the slopes. On the bench surfaces conditions were conducive to plant growth and thus the reclamation problems were a matter of selecting the best materials and methods for forest development. On the slopes, the absence of soil-sized particles precluded plant growth. The absence of fines was caused both by the high proportion of coarse fragments in the wasterock and the method used to build the dumps. The resulting foundation of boulders is crucial for dump stability, but as a result boulders cover the slopes making plant growth impossible.

In their present condition, the slopes require an addition of soil-sized particles to establish vegetation. One potential source of fines is the naturally unconsolidated material that covered the surface prior to mining. However most of this contained the same proportion of coarse fragments as the wasterock.

The other alternative was to use the wasterock itself. Observations from the dumps suggested that some of the exposed wasterock quickly disintegrated. Following up on this observation, a veneer of incompetent wasterock was tested in Trial 82.4. After three years, 85% of the slope surface contained a high enough proportion of < 2 mm particles (> 15%) to support plant growth. By comparison only 5% of the surrounding slopes contained detectable fines. The short term results of Trial 82.4 indicated that the incompetent wasterock was a good source of fines.

2. Long Term Performance of the Incompetent Wasterock, Used as a Source of Fines on Angle of Repose Slopes

The comparison of the rock types and of the different size fractions in the wasterock indicated that the greater fragmentation in the incompetent rock resulted from the larger proportion of calcite and sericite. Sericite contributed to fragmentation by the lack cohesion among sericite grains, which reduced the ability of the rock to withstand the rough treatment during dump construction. While data from soils adjacent to the minesite showed that sericite is unstable under low pH conditions, the lack of K, Al, or Si removal and the lack of change in the mineralogy of the < 2 um and 2-20 um fractions after acetic acid leaching indicated that the chemical weathering of sericite was a slow process, that will take many hundreds or

thousands of years. Calcite contributed to fragmentation through its rapid dissolution. This was illustrated by the temporal association between decreases in particle size and carbonate removal in the weathering simulation.

The other mineral that might contribute to fragmentation is pyrite. Data from the wasterock dumps, suggests that significant pyrite oxidation occurred within ten years. However most of the S in the unweathered incompetent wasterock was already in the < 2 mm fraction, and thus the potential effects of pyrite oxidation on rock stability are limited.

While the breakdown into 20 to 40% soil-sized particles is a desirable property, further reduction in the coarse fragment content could lower the angle of repose, leading to erosion and mass wasting. Results from the weathering simulation showed that over 80% of the coarse fragments were resistant to acid leaching. This, combined with the stability of all the fractions after the removal of the carbonates, suggest that after the dump settles and calcite is removed, further decreases in the coarse fragment content will occur very slowly.

Other evidence supporting the assumption that further fragmentation will be limited was the stability of coarse fragments in the quartz diorite soil profile. According to XRD estimates, quartz plus feldspar comprised 92% of the unweathered quartz diorite coarse fragments. The modal composition of quartz and K feldspar in the incompetent

wasterock were 89% in the stones and 88% in the gravel fractions. The high proportion of these resistant phenocrysts should ensure a similar stability to the quartz diorite coarse fragments.

Another possible problem in terms of surface stability is if finer particles formed by weathering clog pores, restricting drainage. Again results from the weathering simulation suggest that this will not occur. After 8 weeks of leaching, the proportion of silt and clay in the modal < 2 mm fraction only increased by 3%. No detectable amounts of silt and clay were produced from the coarse fragments. In the groundmass fraction the proportion of silt and clay increased from 39 to 49%. However this was accompanied by a 17% weight loss, which, with skeletal coarse fragments maintaining the soil volume, should significantly increase porosity.

In the two natural soils studied, the proportion of silt and clay increased towards the surface. However even in the clay loam textured hornfels soil, drainage was adequate. High coarse fragment contents and weight loss from weathering will contribute to good drainage. In both soils, weight loss was indicated by the negative enrichment of quartz and Zr.

The high concentrations of calcite-Ca, dolomite-Mg, apatite-P, and sericite-K should make the incompetent wasterock a better source of these nutrients than other wasterock types or the mineral layers of natural soils. The

availability of Ca, Mg, and P was illustrated by their release during simulated weathering. The highest concentrations of extractable Ca, Mg, and P were found in the groundmass samples, which explains why the incompetent rock will be a better source of these elements than other rocks found in the waste.

Of the trace elements analysed, five, Co, Mo, Pb, Se, and Zn, were present in all three wasterock types in higher concentrations than commonly found in soils and rock. However none of these elements were associated with a particular rock type, so in this regard there appeared to be no disadvantage in placing the incompetent wasterock on the surface. Comparing the different incompetent wasterock fractions leached in the weathering simulation, the coarse fragments were relatively enriched and the groundmass depleted in Co and Mo. Levels of Pb and Zn were highest in the < 2 mm fraction.

Trace element concentrations in natural soils developed adjacent to the minesite were comparable to those in the wasterock. In the quartz diorite soil, Mo and Pb released by weathering were complexed by secondary Fe compounds and conserved in the < 2 mm fraction. Amorphous Fe enriched in Mo and Pb accumulated at the base of the soil, where the material was densely packed, and presumably leaching was restricted. In the deeper, well drained wasterock dumps, trace element deposition may occur in depressions at the

base of the dumps and in sections of the dumps adjacent to preferred drainage pathways.

In conclusion the findings of this study indicate that in the long term, a veneer of incompetent wasterock can contribute to the goal of forest development. The high proportion of resistant coarse fragments should ensure that the veneer of incompetent wasterock retains its angle of repose, while between 20 to 40% soil-sized particles is comparable to that of surrounding soils, and thus sufficient for forest development. The high proportion of coarse fragments and sand will ensure that the surface is well drained. A high base status and high concentrations of sericite-K and apatite-P make the incompetent wasterock a relatively fertile substrate for N fixing plant species. With the addition incompetent wasterock as a source of fines, and some small modifications, such as the use of a tackifier to stick seed and fertilizer to steep surfaces, materials and methods selected on the dump benches should also result in forest development on the slopes.

With regards to using the results from this study elsewhere, many mines lack sufficient reserves of natural soil-like materials to use as growth media, either because the mine had been developed before the necessity of soil conservation was realized or because the quality and quantity of the unconsolidated soil-like material is low in steep, glaciated mountain landscapes. Thus, although the conclusions reached vis a vis identifying and using

different wasterock types specifically refer to Kitsault, the methodology is generally applicable and the potential benefits of optimally placing different rock types have wider significance.

The use of natural analogues (e.g., primary succession) and methods like artificial weathering to predict the long term performance of reclamation techniques have an even wider application. In the increasingly impatient world of environmental restoration, the long term implications of quick-fix actions should not be overlooked.

APPENDICES

APPENDIX A : DESCRIPTIONS OF THE FIELD TRIALS

1.1 70.1 Bench : Species/Amendment Trial

1.2 70.3 Bench : Conifer Trial

1.3 75.1 Slope : Grass/Legume Trial

1.4 77.1 Bench : Sitka Alder Trial

1.5 81.1 Slope : Overburden Trial

1.6 82.1 Bench : Species/Amendment Trial

1.7 82.4 Slope : Incompetent Wasterock Trial

1.1 70.1 Bench : Species/Amendment Trial

Study Period:

Established July 9th, 1970, the trial is ongoing.

Objectives:

To determine

- whether the dump will support vegetative growth
- the best grass and legume species
- whether a treatment of peat and fertilizer will accelerate the growth of grasses and legumes

Experimental Design:

The plot layout is described in Table 1. Treatments were 4 surface treatments X 3 herbaceous seed mixes, plus 4 other seed mixes that were tested on only 2 amendments.

Location:

Bench top of low grade ore dump

Materials:

Listed in Tables 1 and 2.

Trial Preparation:

Dump was built eight months before seeding. A grader was used to level the site. The large boulders (greater than

SEED:

Mix 1 - 4 x 5 lbs. for use in Blocks A, B, C1, C2. (272.25 lbs/ac)
2 - 2.5 lbs. for use in Blocks A, B. (136 lbs/ac)
3 - 2 x 4 lbs. for use in Blocks A, B. (217.8 lbs/ac)
4 - 2 x 2 lbs. for use in Blocks A, B. (108.9 lbs/ac)
5 - 4 x 2 lbs. for use in Blocks A, B, C1, C2. (108.9 lbs/ac)
6 - 4 x 4 lbs. for use in Blocks A, B, C1, C2. (217.8 lbs/ac)
7 - 2 x 5 lbs. for use in Blocks D1. D2. (90.75 lbs/acre)

FERTILIZER:

13-16-10 (N-P-K)

Block B used 6 x 10 lbs. - 544.5 lbs/acre
Block C2 used 3 x 10 lbs.

Block D2 used 1 x 10 lbs. - 181.5 lbs/acre

MUSKEG:

Block C used approx. 17 cubic feet of muskeg/strip of plots = 0.648 cm deep spread over 800 square feet. This information in the original trial plan conflicts with Dr. Thirgood's recollection that peat was applied to at least a depth of 4.0cm.
Muskeg obtained from a meadow adjacent to the plot.

TRIAL GROUND AREA:

200 feet by 120 feet

The area is divided into 4 blocks: A, B, C, and D, each 30 feet by 200 feet. Blocks A, B, & C are further divided into 6 strips each 200 feet by 5 feet. Block D is separated into 2 strips. Each 200 foot long strip is composed of 20 8ft. long plots, with a 2 ft. wide separation in between each plot. The plots in Blocks A, B, & C are 5 feet wide. The 20 plots are set out in 4 blocks: A, B, C, and D as follows:

Block A - 6 plots: Waste rock. Seed mixtures #1-6, one per strip.

Block B - 6 plots: Waste rock plus fertilizer. Seed mixtures #1-6, one per strip.

Block C1 - 3 plots: Waste rock plus muskeg. Seed mixture #1,5 and 6, one per strip.
C2 - 3 plots: Waste rock plus muskeg plus fertilizer. Seed mixtures #1, 5 and 6, one per strip. Muskeg added from area opposite the plot.

Block D1 - 1 plot: Waste rock. Seed mixture #7
D2 - 1 plot: Waste rock plus fertilizer. Seed mixture #7

Table 1 - Materials applied in Trial 70.1.

1. 30% Perennial ryegrass (Lolium perenne)
   20% Creeping red fescue (Festuca rubra)
   20% Chewings fescue (Festuca pratensis)
   20% Kentucky bluegrass (Poa trivalis)
   5% Red top (Agrostis alba)
   5% White dutch clover (Trifolium repens)

2. 20% Annual ryegrass (Lolium species)
   25% Creeping red fescue (Festuca rubra)
   20% Chewings fescue (Festuca pratensis)
   15% Kentucky bluegrass (Poa trivalis)
   15% Canada bluegrass (Poa compressa)
   5% Highland bent (Agrostis species)

3. Buckerfield's M-11 mix:
   20% Double cut red clover (Trifolium pratense)
   18% Alsike clover (Trifolium hybridum)
   15% New Zealand perennial ryegrass (Lolium perenne)
   10% Climax Timothy (Phleum pratense)
   5% HI ryegrass (Lolium species)
   10% Tall fescue (Festuca arundinacea)
   5% Red top (Agrostis alba)
   12% U.S. perennial ryegrass (Lolium perenne)
   5% New Zealand wild white clover (Trifolium repens)

4. Reed canarygrass - solid stand (Phalaris arundinacea)

5. Legume mixture:
   50% Sainfoin (Onobrychis viciafolia)
   50% Birdsfoot trefoil (Lotus corniculatus)

6. 30% Timothy (Phleum pratense)
   20% Perennial ryegrass (Lolium perenne)
   30% Meadow fescue (Festuca species)
   10% Red top (Agrostis alba)
   10% Alsike clover (Trifolium hybridum)

7. 33.3% Spring rye (Secale cereale)
   33.3% Barley (Hordeum vulgare)
   33.3% Winter vetch (Vicia species)

   All legumes to be double inoculated

Table 2 - Seed mixes applied in Trial 70.1.

one foot in diameter) found on the surface were removed. Seed and other amendments were applied on July 9th, 1970.

Monitoring:

(a) Visual Evaluation

Made annually except 1979. A quantitative evaluation of plant species cover was made in 1980, 1981 and 1983. Species frequency was measured in 1976.

(b) Soil and Plant Analysis

A thorough sampling program was carried out in 1980. The samples have been analyzed as part of this study. Samples of birdsfoot trefoil were collected in 1983 and 1984 to estimate aerial biomass production.

1.2 70.3 Bench : Conifer Trial

Study Period:

Established October, 1970, the trial is ongoing.

Objective:

The original objective was to test four conifers on wasterock treated with various surface amendments. Subsequently the objective was expanded to include an examination of the rate of invasion and growth of native woody species.

Experimental Design:

The original plan was to plant the trees in rows between the plots in Trial 70.1. The within row spacing of the trees was to be four feet. The spacing between rows was ten feet (this was determined by the width of the grass/legume plots). The prescribed layout was not carefully followed. More than the specified number of trees, 500, were planted, and some trees were planted within the plots.

Materials:

Sitka spruce, western hemlock, amabalis fir, and lodgepole pine seedlings were planted. The seedlings, grown from seed collected by Canadian Cellulose Ltd., were obtained from a nursery near Kitimat. The seedlings were bare root stock.

Planting Procedure:

The seedlings were planted in October, in holes prepared with a pick mattock. A handful of 13-16-10 fertilizer was spread on the surface around each seedling. As a result of poor planting, in a number of cases the roots were left exposed.

Monitoring:

(a) Visual Evaluation - made annually with the exception of 1979. Conifer survival was measured in 1971, 1972, 1974 and 1976.

(b) Height Measurement - The height of naturally invading and introduced species were measured in 1980, 1981, 1982, 1984 and 1985.

1.3 75.1 Slope : Grass/Legume Trial

Study Period:

August, 1975 to September, 1980.

Objective:

To determine: 1. Whether the waste dump slopes will support grass and legume growth. 2. Which grass and legume species grow best on the waste dump slopes.

Location:

North west facing slope of the low grade ore dump.

Experimental Design:

The trial consisted of ten 1/10 acre plots, each 20 feet by 200 feet long. Plot corners were well marked with metal rods, red paint on suitable rock surfaces, and wooden markers carrying red plastic tape. A ten foot interval was left between plots at the top of the slope.

Because of the curve of the slope these intervals fanned out to between twenty and fifty feet at the lower end.

Material:

The components of each seed mix and quantities applied are outlined in the text. Growth in Trial 70.1 was used to choose plant species. 333 lbs/acre of 12-6-10 NPK fertilizer was applied to each plot.

Trial Preparation:

The slope, which was at the natural angle of repose, was built by dumping over an advancing dump face. Seed and fertilizer were hand broadcast. The number of replications was limited by the quantity of seed present.

The slope was extremely unstable. To measure surface movement, three red paint bands, each fifteen feet long and six inches wide, were painted across the slope, in the rows between the plots. Movement would be indicated by discontinuities in these bands.

Seed and fertilizer were sown in early August, 1975.

Monitoring:

(a) Visual evaluation - Made annually from 1975 to 1980, with the exception of 1979. Species percent cover was estimated in 1980.

(b) Soil Analysis - samples were collected in 1980 and analyzed as part of this study.

1.4 77.1 Bench : Sitka Alder Trial

Study Period:

Established in 1977, the trial is ongoing.

Objective:

To test the growth of Sitka alder in the wasterock

Location:

The alder test plot is located at the 2,200 feet elevation, on the southwestern edge of the low-grade ore dump, adjacent to the 70.1 grass/legume plot trial site.

Materials:

The alder transplants were collected in late October 1977 after most of the leaves had fallen from the trees. Twenty six small alders were selected for transplanting. The alders were collected from the slope just below the primary crusher. This area has an altitude of approximately 1,700 feet and an exposure similar to the dump trial site.

The transplanted seedlings ranged from eight inches to two feet tall. They were removed from the ground by

vertical pulling and no attempt was made to retain surrounding soil and fine roots. However most did retain some fine roots and soil.

Soil Preparation:

No special procedures were observed during planting beyond the usual precautions; swift transportation to the test site to minimize root exposure; holes of sufficient size to accommodate root systems; tamping around trees to prevent air pockets forming around the roots. Within an hour, all the alders had been replanted at the test site. The plants were not watered following transplanting because of existing wet ground conditions.

Monitoring:

(a) Visual Evaluation: Conducted annually except 1979

(b) Height Measurement: Made annually since 1980

1.5 81.1 Slope: Overburden Trial

Objective:

The objective was to test the ability of different rates of peaty overburden, used as sources of fines, on angle of repose slopes.

Study Period:

From the end of the first growing season to the present.

Experimental Design:

The main treatments were 0, 6, 12, and 24 cm deep topsoil layers. Each plot received one topsoil depth. Fertilizer and limestone were added to half of each plot. In 1982 sections of all the slope plots had been buried preventing any further comparison of individual treatments.

Materials:

The seed and fertilizer applied are listed in the text. The topsoil used was recently excavated peat. Almost entirely organic and containing relatively few stones, this appeared to be the best of the stockpiled material.

Trial Preparation:

The dump was built just prior to creating the trial. Overburden was dropped over the crest by a front end loader. Seed and fertilizer were broadcast by hand.

Monitoring:

The vegetative cover and species composition was estimated each year.

1.6 82.1 Bench : Amendment Trial

Objective:

The goal of this trial was to identify the best combination of amendments (recipe) for growing a forest. In the short term the objective was to maximise shrub growth and litter deposition. Studies of natural reforestation from areas with a similar climatic conditions and with the same flora, showed that a dense shrub cover and thick litter layer will stimulate forest development.

A secondary objective of the trial was to test proposals made in the companies reclamation plan. Most important of these was the proposal to respread overburden prior to vegetation establishment.

Experimental Design:

The selected amendments were 5 different rooting medias, 4 herbaceous seed mixes, and 2 tree species. The experimental design is a randomised complete block, split-split-split plot design. This design was chosen to make the most efficient use of the available space and materials. There were five 8.0 x 8.0 m^2 plots in each block. Each overburden type was assigned to one plot in each block. Each of the herbaceous seed mixes was broadcast on one of the four 4.0 x 4.0 m^2 split plots

created on the main plots. Each of the seedling types were planted in one of the four 2.0 x 2.0 m^2 split-split plots in each seed mix split plot. Seedlings were planted in a configuration like that of a five on a die. The last factor in the experimental design was time of sampling.

Materials:

The seed and fertilizer applied are listed in the text. The terrace was mainly comprised of the potassic alteration rock type. The dump was built during the winter prior to the establishment of the trial. The two overburden types used were typical of the material found in the overburden stockpiles, most of which appears to have a similar particle size distribution to wasterock on terraced bench tops.. The overburden can be distinguished from wasterock by its darker brown (oxidation) colour.

The amount of fertilizer applied on the overburden plots differed from that applied to the wasterock. On the overburden treated plots the fertilizer rate was halved and limestone was applied to avoid the negative effect noted when a high rate of fertilizer was added to overburden in Trial 70.1. This remedy was successful in Trial 81.1. The liming rate was equivalent to the acid-forming ability of the fertilizer.

In the original trial plan, four seedling types were to be tested. However, the propagation of sitka willow and black cottonwood was unsuccessful, so only lodgepole pine and sitka alder were planted. The seedlings were originally ordered for Trial 81.1, and thus were planted a year ahead of schedule.

Trial Preparation:

Prior to applying the treatments, a grader ripped the dump surface to a depth of 25 cm. Overburden was put on the plots by a front end loader and spread by a backhoe. Fertilizer, seed, and limestone were broadcast by hand in June, 1982. Tree seedlings were planted in May, 1983. A teaspoon of 12:39:12 fertilizer was spread around each seedling.

Monitoring:

Herbaceous cover was measured in 1982, 1983 and 1984. Aerial biomass was measured in 1984. Seedling survival and height were measured each year starting in 1983. Sampling the above ground biomass production was only done once because it was destructive. Seedling heights were measured to the highest above ground part.

Data Analysis:

The assignment of experimental units and the selection of where within each split plot to sample the biomass was done randomly. As there was only a small number of samples it was not possible to test for a normal distribution. However all the data was tested for homogeneity of variance. In testing for homogeneity of variance, where there were no block-treatment replicates (e.g., herbaceous cover and seedling survival) the variance within the second highest order of interaction was tested. Equality of variance data is shown in Table 5. Untransformed the seedling survival data met the homogeneous variance requirement, while seedling heights, herbaceous percent cover and herbaceous biomass did not. Various transformations were tried. A logarithmic transformation was required to homogenize the variances of the herbaceous biomass and percent cover. No transformation was found to successfully homogenize seedling height treatment variances, so an AOV was not carried out on this data.

Table 3. The probability of equality of variance (E.O.V.) for different types of monitoring data.

Type of Data	Treatment Groups Evaluated	Transfor-mation	E.O.V. Probability
TREE SURVIVAL (for all dates)	BSHT	NONE	.0755
	YBSH	"	1.0
	YBHT	"	.1256
	YSHT	"	.5753
	YBST	"	.0343
TREE SURVIVAL (for 1985)	SBH	NONE	1.0
	SBT	"	.4183
	SHT	"	.5054
	BHT	"	.2571
HERBACEOUS PERCENT COVER	YBS	LOG e	.0848
	YBH	LOG e	.0136
	YSH	LOG e	.7561
BIOMASS	YBSH	LOG e	.6169
TREE HEIGHT	YBSHT	LOG e	.0000
		POWER 0.2995	.0000

Y: YEAR, SAMPLING DATE
B: BLOCK
T: SEEDLING SPECIES
S: SOIL TYPE
H: HERBACEOUS SEED MIX

Factors included in the AOV model for percent cover were blocks (4), soil types (5), herbaceous seed mixes (4), and year (3). As the treatment combinations were not replicated, the highest order interaction was used as the experimental error.

Factors in the AOV model for biomass were blocks (4), soil types (5), and herbaceous seed mixes (3). By the third year the annual grass had largely died out and thus it was not sampled. Two biomass samples were taken from each treatment combination. The variation between samples from the highest order of interaction was used as the experimental error.

Factors in the AOV model for seedling survival were blocks (4), soil types (5), herbaceous seed mixes (4), tree species (2), and year (3). As treatment combinations were not replicated, the highest order interaction was used as the experimental error.

A Duncans multiple range test was carried out to show which means were significantly different.

1.7 82.4 Slope : Incompetent Wasterock Trial

Objective:

To examine the characteristics of a capping of incompetent waste rock.

Study Period:

1982 to the present, and ongoing.

Location:

Terrace slope in the Clary dump.

Experimental Design:

The trial is comprised of 2 plots. The southern plot is 40 m wide, 97 m long, and covers an area of 5,040 m^2. The northern plot is 65 m wide, 134 m long, and covers an area of 11,850 m^2.

Materials:

The trial site is a west facing terrace slope, over 120 m long at the north end, and standing at 36^{o}, the natural angle of repose of the wasterock. When reclaimed the slope will be broken up into shorter lengths. For experimental purposes it posed a rigorous test. The slope surface, prior to dumping the incompetent waste rock, was comprised of hornfels.

The incompetent rock was distinguished by its lack of cohesion when handled. The incompetent wasterock came from the center of the pit. 15,000 tonnes of incompetent wasterock were applied.

Trial Preparation:

Two plots, 20 m wide were marked out on the crest of the slope, and berms were built along the bottom for avalanche and sediment control. In the usual truck and shovel operation, the incompetent wasterock was brought to the site and then a bulldozer pushed it over the crest. Gravity spread it out.

APPENDIX B : SOIL RESOURCES RAW DATA

Table 1. Surface Cover

Table 2. Soil Physical Properties

Table 3. Soil Chemical Properties

Table 1. Surface cover data for individual soil sample sites.

Group	Rock	Fines	Peat	Moss	Vascular Plant	Grass	Legume	Litter	Moss + Litter + Peat	Moss+ Vas.Plant	Organic Matter Depth
75.1	75	10	0	15	10	0	0	0	15	25	0.5
	60	0	0	40	11	1	10	1	41	51	1.0
	60	10	0	30	3	0	0	0	30	33	1.0
	40	0	0	60	1	1	0	0	60	61	1.0
	60	0	0	40	3	3	0	0	40	43	0.5
	80	0	0	20	5	4	1	0	20	25	0.5
	85	5	0	10	26	1	25	10	20	36	0.5
	99	0	0	1	0	0	0	0	1	1	0.0
	82	0	0	18	30	30	0	0	18	48	0.5
	40	0	0	60	21	20	0	0	60	81	2.0
	50	0	0	50	10	10	0	0	50	60	1.0
	60	0	0	40	13	2	10	0	40	53	1.0
	75	0	0	25	5	0	0	1	26	30	1.0
	90	0	0	10	2	0	0	0	10	12	0.0
	65	30	0	5	0	0	0	0	5	5	0.5
	20	0	0	80	22	2	20	5	85	102	2.0
	80	0	0	20	3	3	0	0	20	23	0.5
SELPO.V	82	5	5	8	8	0	0	0	13	16	1.0
	90	10	0	0	5	0	0	0	0	5	1.0
	85	15	0	0	5	0	0	1	1	5	0.0
	88	0	0	12	10	0	0	0	12	22	0.0
	0	0	0	95	15	0	0	35	130	110	1.5
SELPO.U	95	5	0	0	0	0	0	0	0	0	0.0
	60	40	0	0	0	0	0	0	0	0	0.0
	90	10	0	0	0	0	0	0	0	0	0.0
SELHN	100	0	0	0	0	0	0	0	0	0	0.0
	100	0	0	0	0	0	0	0	0	0	0.0
	100	0	0	0	0	0	0	2	2	0	0.0
SELHNV	98	0	0	2	5	0	0	1	3	7	0.0
LG.V	55	0	0	45	50	0	0	0	45	95	0.5
	78	5	0	17	8	0	0	0	17	25	0.5
	70	5	0	25	75	0	0	0	25	100	0.0
	3	0	0	97	0	0	0	0	97	97	2.5
	86	7	0	7	25	0	0	0	7	32	1.0
	70	15	0	15	25	0	0	0	15	40	0.5
	25	35	35	40	1	0	0	0	75	41	0.5
LG.U.B	95	0	0	5	8	0	0	0	5	13	1.0
	90	5	0	5	0	0	0	0	5	5	0.0
	84	0	8	9	2	0	0	0	17	11	0.0
	80	10	5	5	0	0	0	0	10	5	0.5
	75	20	0	5	0	0	0	0	5	5	0.0
	94	5	0	0	5	0	0	1	1	5	0.0
	80	10	0	5	5	0	0	5	10	10	0.0
	85	15	0	5	5	2	0	5	10	10	0.0
	85	10	0	5	5	0	0	0	5	10	0.0
LG.U.S	55	30	0	15	0	0	0	0	15	15	0.5
	55	45	0	1	0	0	0	1	2	1	0.0
	70	30	0	0	0	0	0	0	0	0	0.0
	70	25	0	5	0	0	0	0	5	5	0.0
	80	10	0	10	0	0	0	0	10	10	0.5
	94	5	0	1	0	0	0	0	1	1	0.0

Note : except for organic matter Depth, all measurements are percent cover

Table 1. Surface cover data for individual soil sample sites (continued).

Group	Rock	Fines	Peat	Moss	Vascular Plant	Grass	Legume	Litter	Moss + Litter + Peat	Moss+ Vas.Plant	Litter Depth
70R	79	5	0	15	1	1	0	0	15	16	0.0
	80	5	0	10	1	1	0	0	10	11	0.0
	58	35	0	3	4	4	0	0	3	7	0.5
	75	2	0	25	2	0	0	0	25	27	0.0
	85	0	0	15	1	1	0	0	15	16	0.5
	90	0	0	10	2	1	1	0	10	12	0.5
	85	0	2	13	2	2	0	0	15	15	0.0
	92	3	0	5	0	0	0	0	5	5	0.5
	82	0	8	10	2	1	0	0	18	12	0.5
70PF	40	0	30	30	5	5	0	0	60	35	4.0
	15	0	30	55	20	18	2	0	85	75	3.0
	1	0	20	80	31	30	1	0	100	111	2.5
	15	0	82	3	12	12	0	0	85	15	2.0
	25	0	30	30	1	1	0	14	74	31	7.5
	40	0	25	35	3	3	0	0	60	38	2.0
	10	0	30	55	14	9	5	10	95	69	2.0
	60	0	0	15	2	2	0	0	15	17	2.0
	25	0	50	25	1	1	0	0	75	26	4.0
	40	0	30	25	2	1	0	0	55	27	1.5
	5	0	0	95	10	10	0	0	95	105	2.5
	30	0	20	40	3	3	0	0	60	43	2.0
70F1	25	0	35	25	15	10	5	0	60	40	0.0
	30	0	10	40	9	6	3	20	70	49	1.0
	5	0	0	40	30	30	0	35	75	70	2.5
	4	0	0	80	30	15	15	0	80	110	2.0
70F5	25	0	0	75	6	1	5	2	77	81	2.0
	20	0	0	75	40	5	35	5	80	115	2.0
	0	0	0	80	91	1	90	20	100	171	2.5
	0	0	0	60	76	1	75	40	100	136	2.5
70F6	68	0	2	30	8	2	6	2	34	38	2.0
	60	0	10	30	4	4	0	0	40	34	2.0
	1	0	0	99	9	1	8	0	99	108	2.0
	10	0	0	70	7	7	0	25	95	77	2.5
70P1	5	0	5	90	1	1	0	0	95	91	7.0
	1	0	0	70	65	65	0	0	70	135	3.5
	1	0	7	32	61	61	0	0	39	93	2.5
	3	0	0	95	25	20	5	0	95	120	4.0
70P5	16	0	5	85	27	1	26	3	93	112	7.5
	0	0	0	90	32	17	15	15	105	122	4.0
	0	0	0	70	76	6	70	30	100	146	5.0
	5	0	0	80	44	4	40	20	100	124	4.5
70P6	3	0	10	87	0	5	0	0	97	87	5.0
	1	0	0	99	2	2	0	1	100	101	3.5
	0	0	0	100	3	3	0	0	100	103	3.5
	0	0	4	96	8	7	1	0	100	104	3.0
70AI	70			30	61	3	8	70	100	91	3.0
	97			2	1			8	10	2	0.5
	42			22	77	5		35	57	99	1.5
70.OB	10			90	71	2		20	110	161	12.0
	10			90	35	5		35	125	125	3.0
	5			90	46	6	40	35	125	136	10.0
	40			60	37	17		45	105	97	1.5

Note : except for organic matter Depth, all measurements are percent cover

Table 2. Soil physical data for individual sample sites.

Treatment	Year	Site	Weight (g)		Volume (cm3)		Bulk Density (kg/m3)		% stones		% gravel		% <2.0mm		< 2mm/m3 (kg/m3)	
Depth			0-5	5-10	0-5	5-10	0-5	5-10	0-5	5-10	0-5	5-10	0-5	5-10	0-5	5-10
75.1	1980	100	1931	2126	1125	1125	1716	1890	75	49	16	33	9	17	162	327
	1980	101	1998	2343	1125	1125	1776	2083	48	55	29	25	23	20	400	420
	1980	102	2324	1936	1125	1125	2066	1721	59	50	26	33	15	17	310	294
	1980	103	1471	1931	1125	1125	1308	1717	37	53	36	26	28	20	363	345
	1980	104	1574	2386	1125	1125	1399	2121	20	45	40	32	39	23	548	491
	1980	105	1917	2143	1125	1125	1704	1905	83	28	10	41	7	31	117	589
	1980	106	2126	2352	1125	1125	1889	2091	73	51	15	28	12	21	227	433
	1980	107	1809	2008	1125	1125	1608	1785	63	48	29	35	7	17	120	303
	1980	108	1314	1900	1125	1125	1168	1689	20	47	46	28	34	26	399	432
	1980	109	1456	2462	1125	1125	1295	2188	32	55	33	26	35	19	449	422
	1980	110	1932	2366	1125	1125	1717	2103	29	68	34	18	36	14	624	294
	1980	111	1791	1849	1125	1125	1592	1643	66	50	16	27	18	23	286	380
	1980	112	1689	2124	1125	1125	1502	1888	57	39	26	35	17	26	255	496
	1980	113	1684	2116	1125	1125	1497	1881	85	52	8	28	7	19	105	359
	1980	114	1096	2139	1125	1125	974	1902	42	66	34	20	24	14	235	271
	1980	115	1785	2032	1125	1125	1587	1806	18	40	43	35	40	26	630	464
	1980	116	1780	1528	1125	1125	1582	1358	57	46	29	38	14	16	225	220
SEL.PO.V	1980	23	2127	1850	1125	1125	1891	1645	35	40	35	32	30	28	571	454
	1980	24	2159	2063	1125	1125	1919	1833	40	27	36	34	24	39	459	720
	1980	25	1659	2053	1125	1125	1474	1825	30	54	40	25	30	21	439	378
	1980	27	2626	2733	1125	1125	2334	2430	78	67	14	22	9	11	202	272
	1980	29	1534	2621	1125	1125	1363	2330	30	44	43	35	27	21	363	491
SEL.PO.U	1980	22	1672	2164	1125	1125	1486	1924	37	26	33	36	30	38	442	732
	1980	30	2090	2026	1125	1125	1857	1801	41	41	31	31	28	29	522	518
	1980	35	1994	2051	1125	1125	1772	1823	40	52	39	32	22	16	389	298
SEL.HN.U	1980	26	2164	2100	1125	1125	1923	1867	73	50	16	32	11	19	211	348
	1980	31	2395	2591	1125	1125	2129	2303	77	62	15	26	8	11	178	262
	1980	33	1758	2651	1125	1125	1563	2356	81	74	13	18	6	8	101	194
SEL.HN.V	1980	32	2088	2590	1125	1125	1856	2303	54	62	30	27	16	11	302	259
LG.V	1980	1	1753	2766	1125	1125	1558	2459	26	68	34	12	40	19	630	476
	1980	2	1823	1712	1125	1125	1621	1522	21	43	32	24	46	33	749	498
	1980	5	1863	1550	1125	1125	1656	1378	62	42	15	26	23	32	381	439
	1980	6	1029	919	1125	1125	915	817	14	36	34	28	52	36	477	290
	1980	7	1569	1669	1125	1125	1395	1484	40	38	22	21	38	41	529	604
	1980	8	2123	1786	1125	1125	1887	1588	54	25	25	31	21	44	401	703
	1980	9	1821	1783	1125	1125	1618	1585	36	28	25	27	38	45	618	720
LG.U.B	1980	3	1574	1497	1125	1125	1399	1330	64	46	20	27	16	27	224	353
	1980	10	2150	2167	1125	1125	1911	1926	44	57	27	23	29	19	560	372
	1980	13	2124	1449	1125	1125	1888	1288	49	36	27	39	24	24	449	315
	1980	14	2310	2312	1125	1125	2054	2055	58	57	21	24	22	20	442	402
	1980	15	1897	2046	1125	1125	1686	1818	59	55	21	27	20	17	330	317
	1980	17	2265	2160	1125	1125	2013	1920	77	56	14	31	9	13	182	255
	1980	117	1766	2271	1125	1125	1570	2018	45	67	31	22	23	11	366	222
	1980	118	1921	1804	1125	1125	1708	1603	49	42	31	37	21	21	354	331
	1980	119	2359	2075	1125	1125	2097	1844	50	42	26	37	24	20	503	376

Treatment	Year	Site	Weight (g)	%<2.0mm
Depth			0-10	0-10
82.1	1984	6EG1	1456	19
	1984	6EG2	1098	12
	1984	8EG1	783	23
	1984	8EG2	1238	20
	1984	6L1	1253	24
	1984	6L2	1479	25
	1984	8L1	1621	17
	1984	8L2	1506	14
77.1	1984	1.8	866	26
	1984	1.1	944	19
	1984	2.8	1469	17
	1984	3.3	901	17
82.4	1984	A20	1550	44
	1984	B20	912	33
	1984	A40	1432	27
	1984	B40	1224	33
	1984	A60	1783	37
	1984	B60	1453	38
	1984	A80	2371	43
	1984	B80	1306	27
	1984	A100	2437	13
	1984	B100	1457	31
	1984	B120	2354	37
	1984	SA10	1788	44
	1984	SB10	1529	57
	1984	SC10	2111	17
	1984	SA20	1603	38
	1984	SB20	1617	29
	1984	SC20	1645	42
	1984	SAB35	1036	66
	1984	SC35	1283	24
	1984	SA45	1501	44
	1984	SB45	1702	25
	1984	SC45	2115	21
	1984	SA55	1401	22
	1984	SB55	1189	29
	1984	SBC55	2296	20
	1984	SC55	1891	16
	1984	SA65	1566	11
	1984	SB65	1970	23

stones : > 12.7 mm gravel : 12.7 - 2.0 mm
0-5 : 0-5 cm 5-10 : 5-10 cm 0-10 : 0-10 cm

Table 2. Soil physical data for individual sample sites (continued).

Treatment	Year	Site	Weight (g)		Volume (cm3)		Bulk Density (kg/m3)		% stones		% gravel		% <2.0mm		< 2mm/m3 (kg/m3)	
Depth			0-5	5-10	0-5	5-10	0-5	5-10	0-5	5-10	0-5	5-10	0-5	5-10	0-5	5-10
LG.U.S	1980	11	1890	1822	1125	1125	1680	1619	67	19	17	45	16	36	265	575
	1980	12	1850	2142	1125	1125	1644	1904	29	42	35	29	36	29	595	550
	1980	18	2213	2012	1125	1125	1967	1788	62	42	23	36	14	22	283	388
	1980	19	2267	1922	1125	1125	2015	1709	39	37	33	35	28	28	573	477
	1980	20	2105	1450	1125	1125	1871	1289	39	38	36	39	25	24	470	303
	1980	21	1829	2487	1125	1125	1626	2211	54	51	27	29	19	20	307	439
70R	1980	41	1720	1968	1125	1125	1529	1750	79	47	13	38	8	15	122	264
	1980	42	2154	3595	1125	1125	1915	3195	60	83	20	10	19	7	370	216
	1980	43	2784	1741	1125	1125	2474	1548	75	53	16	26	9	21	229	331
	1980	44	2385	2464	1125	1125	2120	2190	56	52	25	33	18	15	392	333
	1980	45	2300	2520	1125	1125	2045	2240	63	39	26	34	12	28	241	622
	1980	46	2147	2560	1125	1125	1908	2275	71	69	16	17	13	14	248	327
	1980	47	2758	2891	1125	1125	2451	2570	64	74	21	17	15	9	362	244
	1980	48	2430	1694	1125	1125	2160	1505	53	34	29	39	17	27	376	400
	1980	49	1710	1965	1125	1125	1520	1747	53	42	27	32	20	25	310	442
70PF	1980	74	2924	3170	1125	1125	2599	2818	79	68	9	18	12	15	324	410
	1980	75	1708	1845	1125	1125	1518	1640	67	51	20	33	13	16	196	264
	1980	76	1095	1681	1125	1125	973	1494	67	42	15	33	18	25	172	378
	1980	77	1695	2817	1125	1125	1507	2504	41	65	29	21	30	14	452	343
	1980	78	2112	3333	1125	1125	1877	2963	61	90	15	5	25	5	464	154
	1980	79	2352	2948	1125	1125	2090	2620	76	78	14	12	11	10	223	267
	1980	80	1902	2176	1125	1125	1691	1934	49	73	29	16	22	11	375	218
	1980	81	1940	2814	1125	1125	1724	2501	94	88	2	7	4	5	68	121
	1980	82	2105	2229	1125	1125	1871	1981	83	61	7	26	10	13	195	263
	1980	83	1613	1092	1125	1125	1434	970	89	45	5	29	6	26	89	254
	1980	84	1480	1997	1125	1125	1315	1775	85	70	6	19	9	11	119	193
	1980	85	1942	2208	1125	1125	1726	1962	89	63	5	23	6	14	110	269
70F1	1980	50	1444	1783	1125	1125	1283	1585	49	37	30	40	20	23	260	363
	1980	51	1932	1968	1125	1125	1717	1750	58	57	25	25	17	18	292	320
	1980	52	1334	2069	1125	1125	1186	1839	48	49	26	31	25	21	299	380
	1980	53	1531	1936	1125	1125	1361	1721	75	58	13	27	12	15	161	266
70F5	1980	54	1898	2526	1125	1125	1687	2245	71	57	20	29	9	14	153	316
	1980	55	1758	2201	1125	1125	1562	1957	62	60	24	25	14	15	214	289
	1980	56	1173	1942	1125	1125	1043	1726	65	28	19	46	16	25	168	438
	1980	57	1194	2191	1125	1125	1062	1948	57	50	17	29	26	21	271	405
70F6	1980	58	2643	2501	1125	1125	2349	2223	93	85	2	11	4	5	100	102
	1980	59	1664	2037	1125	1125	1479	1811	92	81	4	13	4	6	62	116
	1980	60	1416	1416	1125	1125	1259	1259	42	42	37	37	22	22	271	271
	1980	61	1576	2544	1125	1125	1401	2262	57	61	22	24	21	15	288	338
70P1	1980	62	955	3197	1125	1125	849	2842	31	75	25	12	43	13	369	363
	1980	63	1327	1620	1125	1125	1179	1440	77	78	11	15	12	7	142	100
	1980	64	1626	2280	1125	1125	1446	2026	67	70	17	18	15	11	218	225
	1980	65	1210	2229	1125	1125	1076	1981	54	60	23	24	23	16	250	320
70P5	1980	66	1427	3091	1125	1125	1269	2747	62	82	11	9	27	9	342	247
	1980	67	430	1439	1125	1125	382	1279	25	48	35	34	40	18	155	226
	1980	68	1158	1893	1125	1125	1030	1683	89	76	3	14	9	10	92	169
	1980	69	1524	3000	1125	1125	1355	2667	84	80	8	11	9	9	117	230
70P6	1980	70	1675	2861	1125	1125	1489	2543	68	69	15	19	17	11	258	288
	1980	71	694	2409	1125	1125	617	2141	62	49	22	32	16	18	102	393
	1980	72	833	1915	1125	1125	741	1702	46	67	31	21	23	11	170	194
	1980	73	793	1875	1125	1125	705	1667	21	64	53	20	26	16	186	274
70AI	1980	91	2387	2006	1125	1125	2122	1784	90	67	7	22	3	11	72	202
	1980	92	2594	2294	1125	1125	2305	2040	79	59	14	26	7	15	155	310
	1980	93	2341	2158	1125	1125	2081	1919	68	60	20	23	12	17	245	318
70.OB	1980	86	227	256.	1125	1125	202	228	17	8	34	50	49	41	98	94
	1980	90	1761	1796	1125	1125	1565	1597	79	60	12	24	10	16	151	253
	1980	89	567	1817	1125	1125	504	1615	31	74	24	11	45	15	228	245
	1980	87	793	1677	1125	1125	705	1491	73	90	11	4	16	7	110	102

stones : > 12.7 mm gravel : 12.7 - 2.0 mm
0-5 : 0-5 cm 5-10 : 5-10 cm 0-10 : 0-10 cm

Table 2. Soil physical data for individual sample sites (continued).

Treatment	Year	Site	Weight (g)	Volume (cm3)	Bulk Density (kg/m3)	% stones	% gravel	% <2.0mm	< 2mm/m3 (kg/m3)
Depth			0-10	0-10	0-10	0-10	0-10	0-10	0-10
82.1	1982	4	1450	750	1944	41	28	31	599
	1982	7	1455	750	1937	33	35	31	603
	1982	8	1461	750	1947	44	30	26	497
	1982	10	1671	875	1910	56	25	19	358
	1982	12	1603	950	1687	49	24	27	481
	1982	14	1897	1150	1597	71	18	11	193
KM82.4	1982	1.1	2897	1400	2069	35	31	34	694
	1982	1.2	3100	1700	1824	30	32	38	692
	1982	1.3	2446	1300	1882	34	35	32	596
	1982	1.4	2728	1500	1819	42	31	28	502
	1982	2.1	3902	2150	1815	18	29	52	951
	1982	2.2	3132	1800	1740	46	26	28	487
	1982	2.3	2298	1400	1641	43	34	23	381
	1982	2.4	3687	2050	1799	20	33	47	843
OB.SH	1982	2	1113	775	1436	65	19	16	232
	1982	5	1318	625	2213	66	17	17	397
	1982	7	1412	675	2099	65	19	16	347
	1982	10	1586	750	2115	72	16	11	237
	1982	12	1245	800	1556	63	20	17	257
OB.59	1982	2	1253	825	1453	50	24	26	339
	1982	4	1161	925	1253	33	37	30	372
	1982	7	988	800	1322	32	31	37	493
	1982	10	895	900	994	43	25	32	311
	1982	11	1175	875	1356	46	28	26	351
82.1	1982	4.1	1473	700	2104	55	22	23	488.
	1982	4.2	1427	800	1784	26	34	40	709
	1982	7.1	1586	800	1983	43	31	26	521
	1982	7.2	1324	700	1891	24	40	36	684
	1982	8.1	1197	750	1596	39	35	26	416
	1982	8.2	1724	750	2299	49	26	25	579
	1982	10.1	1701	900	1890	50	31	20	373
	1982	10.2	1641	850	1931	63	19	18	342
	1982	12.1	2110	950	2221	38	31	31	685
	1982	12.2	1096	950	1154	59	17	24	276
	1982	14.1	1233	950	1298	81	12	7	88
	1982	14.2	2561	1350	1897	61	23	16	298
OB.SH	1982	2.1	1132	800	1415	71	15	14	195
	1982	2.2	1093	750	1457	59	23	18	268
	1982	5.1	1266	750	1688	75	12	13	217
	1982	5.2	1369	500	2738	58	21	21	576
	1982	7.1	1328	700	1897	75	13	12	229
	1982	7.2	1495	650	2300	54	25	20	465
	1982	10.1	1518	750	2024	73	18	9	184
	1982	10.2	1654	750	2205	72	15	13	291
	1982	12.1	1386	800	1733	65	20	15	253
	1982	12.2	1104	800	1380	60	21	19	261
OB.59	1982	2.1	744	650	1145	27	37	36	414
	1982	2.2	1761	1000	1761	73	12	15	264
	1982	4.1	1274	1000	1274	33	40	27	349
	1982	4.2	1048	850	1233	33	35	32	395
	1982	7.1	1004	600	1673	29	33	38	635
	1982	7.2	971	1000	971	35	29	36	350
	1982	10.1	726	900	807	41	23	36	288
	1982	10.2	1064	900	1182	45	27	28	333
	1982	11.1	1087	750	1449	47	29	24	347
	1982	11.2	1263	1000	1263	45	27	28	356

stones : > 12.7 mm gravel : 12.7 - 2.0 mm
0-5 : 0-5 cm 5-10 : 5-10 cm 0-10 : 0-10 cm

Table 3. Soil chemistry data for individual sample sites.

Treatment	Year	Site	pH	%C	%N	avail.P (ppm)	pH	%C	%N	avail.P (ppm)	C/m3 (kg/m3)	N/m3 (kg/m3)	avail.P/m3 (g/m3)	C/m3 (kg/m3)	N/m3 (kg/m3)	avail.P/m3 (g/m3)	C/N	C/N	N/avail.P	N/avail.P
Depth			0-5	0-5	0-5	0-5	5-10	5-10	5-10	5-10	0-5	0-5	0-5	5-10	5-10	5-10	0-5	5-10	0-5	5-10
75.1	1980	100	6.7	0.50	0.025	66.0	7.3	0.45	0.006	40.1	0.81	0.041	10.72	1.47	0.020	13.12	20	75	4	1
	1980	101	6.4	0.56	0.031	18.4	6.6	0.15	0.008	8.3	2.24	0.124	7.36	0.63	0.034	3.49	18	19	17	10
	1980	102	7.3	0.33	0.018	20.1	7.6	0.38	0.004	4.7	1.02	0.056	6.23	1.12	0.012	1.38	18	95	9	9
	1980	103	7.0	0.82	0.039	16.2	7.2	0.47	0.006	1.5	2.98	0.142	5.89	1.62	0.021	0.52	21	78	24	40
	1980	104	5.4	0.42	0.018	5.8	6.5	0.18	0.006	1.8	2.30	0.099	3.18	0.88	0.029	0.88	23	30	31	33
	1980	105	6.4	1.32	0.055	60.0	6.9	0.43	0.010	11.9	1.55	0.064	7.03	2.53	0.059	7.01	24	43	9	8
	1980	106	4.4	0.74	0.027	21.1	6.3	0.14	0.008	10.7	1.68	0.061	4.78	0.61	0.035	4.63	27	18	13	7
	1980	107	4.1	0.08	0.008	8.6	3.8		0.004	4.6	0.10	0.010	1.03		0.012	1.39	10		9	9
	1980	108	5.4	0.87	0.032	41.5	6.6	0.29	0.009	15.0	3.47	0.128	16.56	1.25	0.039	6.48	27	32	8	6
	1980	109	6.0	0.81	0.029	16.2	6.3	0.43	0.007	5.8	3.64	0.130	7.27	1.82	0.030	2.45	28	61	18	12
	1980	110	5.2	0.56	0.024	14.4	6.2	0.79	0.009	8.3	3.49	0.150	8.98	2.32	0.026	2.44	23	88	17	11
	1980	111	5.6	0.41	0.029	41.1	6.0	0.10	0.007	14.3	1.17	0.083	11.77	0.38	0.027	5.43	14	14	7	5
	1980	112	5.8	0.23	0.025	23.5	6.8	0.18	0.007	9.5	0.59	0.064	5.99	0.89	0.035	4.71	9	26	11	7
	1980	113	5.2	0.70	0.032	14.8	6.2	0.20	0.005	4.6	0.73	0.034	1.55	0.72	0.018	1.65	22	40	22	11
	1980	114	6.9	0.75	0.015	2.3	7.0	0.23	0.004	1.6	1.76	0.035	0.54	0.62	0.011	0.43	50	58	65	25
	1980	115	5.1	0.63	0.089	15.0	6.3	0.17	0.006	2.8	3.97	0.561	9.45	0.79	0.028	1.30	7	28	59	21
	1980	116	6.6	0.56	0.027	12.3	7.4	0.25	0.007	3.1	1.26	0.061	2.77	0.55	0.015	0.68	21	36	22	23
SEL.PO.V	1980	23	5.3	0.29	0.022	3.9	7.2	0.18	0.006	1.2	1.65	0.126	2.23	0.82	0.027	0.54	13	30	56	50
	1980	24	7.1	0.48	0.008	1.5	6.9	0.55	0.005	1.0	2.20	0.037	0.69	3.96	0.036	0.72	60	110	53	50
	1980	25	6.8	0.33	0.007	1.6	6.8	0.40	0.003	3.4	1.45	0.031	0.70	1.51	0.011	1.28	47	133	44	9
	1980	27	6.8	0.48	0.017	2.0	7.2	0.26	0.010	1.0	0.97	0.034	0.40	0.71	0.027	0.27	28	26	85	100
	1980	29	6.3	1.96	0.057	6.0	7.0	0.79	0.010	1.0	7.11	0.207	2.18	3.88	0.049	0.49	34	79	95	100
SEL.PO.U	1980	22	7.3	0.33	0.005	0.4	7.4	0.25	0.002	0.3	1.46	0.022	0.18	1.83	0.015	0.22	66	125	125	67
	1980	30	7.6	0.74	0.006	0.4	7.9	0.72	0.003	0.2	3.86	0.031	0.21	3.73	0.016	0.10	123	240	150	150
	1980	35	7.7	0.48	0.012	0.4	7.7	0.53	0.008	0.2	1.87	0.047	0.16	1.58	0.024	0.06	40	66	300	400
SEL.HN.U	1980	26	7.3	0.82	0.016	1.0	6.8	0.74	0.017	1.0	1.73	0.034	0.21	2.57	0.059	0.35	51	44	160	170
	1980	31	7.2	0.76	0.010	0.5	7.3	0.94	0.007	1.2	1.35	0.018	0.09	2.46	0.018	0.31	76	134	200	58
	1980	33	7.3	0.90	0.012	1.5	7.1	0.99	0.008	1.0	0.91	0.012	0.15	1.92	0.016	0.19	75	124	80	80
SEL.HN.V	1980	32	7.2	0.69	0.023	1.5	7.0	0.50	0.018	1.2	2.08	0.069	0.45	1.30	0.047	0.31	30	28	153	150
LG.V	1980	1	4.8	0.85	0.027	15.8	4.7	0.74	0.022	26.0	5.36	0.170	9.96	3.52	0.105	12.36	31	34	17	8
	1980	2	4.1	1.04	0.033	19.1	4.2	0.80	0.021	23.5	7.79	0.247	14.30	3.98	0.105	11.70	32	38	17	9
	1980	5	4.0	1.18	0.034	20.7	4.1	1.08	0.035	17.5	4.50	0.130	7.89	4.74	0.154	7.69	35	31	16	20
	1980	6	3.7	2.78	0.056	6.5	3.2		0.040	33.0	13.27	0.267	3.10		0.116	9.57	50		86	12
	1980	7	3.8	0.95	0.038	9.3	3.9	0.43	0.012	13.3	5.03	0.201	4.92	2.60	0.072	8.03	25	36	41	9
	1980	8	4.2	0.39	0.021	2.3	4.8	0.43	0.012	7.7	1.56	0.084	0.92	3.02	0.084	5.41	19	36	91	16
	1980	9	3.9	1.24	0.054	13.2	3.9	0.48	0.019	13.6	7.66	0.334	8.15	3.45	0.137	9.79	23	25	41	14
LG.U.B	1980	3	6.4	0.38	0.011	2.0	6.7	0.76	0.011	4.6	0.85	0.025	0.45	2.69	0.039	1.63	35	69	55	24
	1980	10	6.2	0.32	0.018	3.9	6.4	0.51	0.016	7.5	1.79	0.101	2.18	1.90	0.060	2.79	18	32	46	21
	1980	13	5.7	0.26	0.020	4.2	7.2	0.41	0.010	1.6	1.17	0.090	1.89	1.29	0.032	0.50	13	41	48	63
	1980	14	5.4	0.35	0.023	6.2	6.6	0.29	0.011	7.4	1.55	0.102	2.74	1.17	0.044	2.97	15	26	37	15
	1980	15	6.8	0.36	0.020	0.8	7.4	0.32	0.011	0.2	1.19	0.066	0.26	1.02	0.035	0.06	18	29	250	550
	1980	17	7.1	1.77	0.036	0.0	7.5	0.62	0.012	1.0	3.23	0.066	0.00	1.58	0.031	0.26	49	52		120
	1980	117	7.3	0.37	0.015	1.0	7.5	0.32	0.004	1.0	1.36	0.055	0.37	0.71	0.009	0.22	25	80	150	40
	1980	118	6.9	0.49	0.024	0.3	7.2	0.81	0.026	1.5	1.73	0.085	0.11	2.68	0.086	0.50	20	31	2967	173
	1980	119	6.9	0.32	0.016	1.8	7.3	0.51	0.007	1.9	1.61	0.080	0.91	1.92	0.026	0.71	20	73	150	37

0-5 : 0-5 cm 5-10 : 5-10 cm 0-10 : 0-10 cm

Table 3. Soil chemistry data for individual sample sites (continued).

Treatment	Year	Site	pH	%C	%N	avail.P (ppm)	pH	%C	%N	avail.P (ppm)	C/m3 (kg/m3)	N/m3 (kg/m3)	avail.P/m3 (g/m3)	C/m3 (kg/m3)	N/m3 (kg/m3)	avail.P/m3 (g/m3)	C/N	C/N	N/avail.P	N/avail.P
Depth			0-5	0-5	0-5	0-5	5-10	5-10	5-10	5-10	0-5	0-5	0-5	5-10	5-10	5-10	0-5	5-10	0-5	5-10
LG.U.S	1980	11	5.8	0.34	0.024	10.1	6.4	0.24	0.011	12.0	0.90	0.064	2.68	1.38	0.063	6.90	14	22	24	9
	1980	12	4.0	0.38	0.021	21.7	4.0	0.27	0.013	21.7	2.26	0.125	12.90	1.49	0.072	11.94	18	21	10	6
	1980	18	7.5	0.26	0.005	1.4	7.3	0.22	0.002	1.6	0.74	0.014	0.40	0.85	0.008	0.62	52	110	36	13
	1980	19	6.7	0.14	0.008	1.0	7.3	0.18	0.001	0.5	0.80	0.046	0.57	0.86	0.005	0.24	18	180	80	20
	1980	20	7.6	0.17	0.003	1.1	7.4	0.18	0.006	1.3	0.80	0.014	0.52	0.55	0.018	0.39	57	30	27	46
	1980	21	5.8	0.10	0.007	1.8	6.2	0.10	0.005	1.6	0.31	0.021	0.55	0.44	0.022	0.70	14	20	39	31
70R	1980	41	6.2	1.45	0.065	1.0	7.4	0.55	0.020	1.0	1.76	0.079	0.12	1.45	0.053	0.26	22	28	650	200
	1980	42	6.9	1.33	0.047	2.3	7.4	0.57	0.022	0.4	4.92	0.174	0.85	1.23	0.047	0.09	28	26	204	550
	1980	43	7.0	1.07	0.048	1.8	7.3	0.93	0.021	1.1	2.45	0.110	0.41	3.07	0.069	0.36	22	44	267	191
	1980	44	5.2	0.48	0.017	1.5	7.4	1.01	0.022	0.0	1.88	0.067	0.59	3.36	0.073	0.00	28	46	113	
	1980	45	5.5	0.39	0.019	3.4	7.6	0.53	0.013	0.0	0.94	0.046	0.82	3.29	0.081	0.00	21	41	56	
	1980	46	6.3	0.49	0.029	1.6	7.3	0.73	0.020	0.0	1.22	0.072	0.40	2.39	0.065	0.00	17	37	181	
	1980	47	3.6	0.51	0.018	8.0	5.6	1.09	0.035	3.9	1.85	0.065	2.90	2.65	0.085	0.95	28	31	23	90
	1980	48	4.0	0.14	0.016	4.6	7.1	0.52	0.015	1.0	0.53	0.060	1.73	2.08	0.060	0.40	9	35	35	150
	1980	49	5.7	0.36	0.023	3.8	7.1	0.34	0.016	0.5	1.11	0.071	1.18	1.50	0.071	0.22	16	21	61	320
70PF	1980	74	4.3	7.17	0.180	13.9	6.6	0.96	0.025	1.5	23.20	0.582	4.50	3.94	0.103	0.62	40	38	13	167
	1980	75	3.8	4.18	0.175	16.7	4.5	0.36	0.017	39.0	8.20	0.343	3.28	0.95	0.045	10.30	24	21	7	4
	1980	76	3.9	8.37	0.240	20.8	4.5	0.35	0.048	4.5	14.41	0.413	3.58	1.32	0.182	1.70	35	7	115	107
	1980	77	6.4	2.18	0.066	1.5	7.4	0.61	0.006	0.0	9.84	0.298	0.68	2.09	0.021	0.00	33	102	440	
	1980	78	3.7	10.78	0.185	8.1	4.3	4.48	0.102	5.3	50.01	0.858	3.76	6.89	0.157	0.81	58	44	228	192
	1980	79	4.3	1.80	0.088	8.3	4.8	0.28	0.004	7.9	4.01	0.196	1.85	0.75	0.011	2.11	20	70	106	5
	1980	80	4.1	2.72	0.092	8.9	5.0	0.23	0.014	4.7	10.20	0.345	3.34	0.50	0.031	1.03	30	16	103	30
	1980	81	4.6	8.16	0.422	9.1	6.3	0.96	0.036	1.5	5.51	0.285	0.61	1.17	0.044	0.18	19	27	464	240
	1980	82	4.0	9.45	0.240	7.1	6.8	0.97	0.024	0.0	18.45	0.468	1.39	2.55	0.063	0.00	39	40	338	
	1980	83	3.5	4.93	0.288	19.3	4.3	0.43	0.022	7.0	4.40	0.257	1.72	1.09	0.056	1.78	17	20	149	31
	1980	84	3.9	8.95	0.313	40.0	4.5	0.84	0.038	8.0	10.64	0.372	4.75	1.62	0.073	1.54	29	22	78	48
	1980	85	3.9	5.32	0.239	13.1	6.1	0.53	0.026	3.7	5.83	0.262	1.43	1.43	0.070	1.00	22	20	182	70
70F1	1980	50	3.9	1.24	0.066	12.3	6.0	1.19	0.044	20.7	3.22	0.171	3.19	4.32	0.160	7.51	19	27	54	21
	1980	51	3.5	2.02	0.061	21.5	4.9	0.83	0.023	5.7	5.90	0.178	6.28	2.66	0.074	1.82	33	36	28	40
	1980	52	5.0	5.07	0.135	3.4	7.4	0.05	0.012	21.5	15.15	0.403	1.02	0.19	0.046	8.17	38	4	397	6
	1980	53	4.5	9.73	0.307	35.0	6.0	0.98	0.035	61.0	15.69	0.495	5.64	2.61	0.093	16.24	32	28	88	6
70F5	1980	54	4.5	9.90	0.216	51.9	6.9	0.84	0.030	4.0	15.11	0.330	7.92	2.66	0.095	1.26	46	28	42	75
	1980	55	3.8	0.94	0.092	19.1	4.1	0.50	0.027	6.7	2.01	0.197	4.08	1.44	0.078	1.94	10	19	48	40
	1980	56	5.5	8.95	0.154	72.0	5.1	1.17	0.074	9.2	15.04	0.259	12.10	5.13	0.324	4.03	58	16	21	80
	1980	57	4.9	8.38	0.280	34.0	7.3	0.73	0.051	35.0	22.69	0.758	9.21	2.96	0.207	14.17	30	14	82	15
70F6	1980	58	4.3	6.13	0.241	36.0	5.9	1.49	0.074	20.0	6.16	0.242	3.62	1.53	0.076	2.05	25	20	67	37
	1980	59	3.7	2.26	0.171	37.9	4.5	0.89	0.044	18.5	1.41	0.106	2.36	1.03	0.051	2.14	13	20	45	24
	1980	60	3.8	3.20	0.079	25.2	6.3	0.54	0.025	2.8	8.68	0.214	6.83	1.46	0.068	0.76	41	22	31	89
	1980	61	4.6	3.20	0.200	25.2	7.0	0.64	0.033	3.4	9.23	0.577	7.27	2.16	0.111	1.15	16	19	79	97
70P1	1980	62	3.8	14.79	0.259	31.0	4.1	5.48	0.146	36.0	54.62	0.957	11.45	19.92	0.531	13.08	57	38	84	41
	1980	63	3.8	12.39	0.283	26.8	4.5	0.59	0.026	12.3	17.56	0.401	3.80	0.59	0.026	1.23	44	23	106	21
	1980	64	3.8	12.68	0.333	31.0	4.3	0.62	0.018	26.1	27.66	0.726	6.76	1.39	0.040	5.87	38	34	107	7
	1980	65	4.6	9.28	0.245	31.0	6.6	0.95	0.030	9.3	23.18	0.612	7.74	3.04	0,096	2.97	38	32	79	32

0-5 : 0-5 cm 5-10 : 5-10 cm 0-10 : 0-10 cm

Table 3. Soil chemistry data for individual sample sites (continued).

Treatment	Year	Site	pH	%C	%N	avail.P (ppm)	pH	%C	%N	avail.P (ppm)	C/m3 (kg/m3)	N/m3 (kg/m3)	avail.P/m3 (g/m3)	C/m3 (kg/m3)	N/m3 (kg/m3)	avail.P/m3 (g/m3)	C/N	C/N	N/avail.P	N/avail.P
Depth			0-5	0-5	0-5	0-5	5-10	5-10	5-10	5-10	0-5	0-5	0-5	5-10	5-10	5-10	0-5	5-10	0-5	5-10
70P5	1980	66	3.3	11.17	0.029	24.5	3.9	8.76	0.190	27.5	38.16	0.099	8.37	21.60	0.468	6.78	39	46	12	69
	1980	67	4.2	13.31	0.584	29.0	4.0	0.93	0.041	5.9	20.59	0.903	4.49	2.10	0.092	1.33	23	23	201	69
	1980	68	4.6	17.42	0.841	24.0	4.8	1.15	0.078	21.6	16.10	0.777	2.22	1.94	0.132	3.64	21	15	350	36
	1980	69	4.1	16.26	0.641	37.0	5.3	0.74	0.148	9.4	18.98	0.748	4.32	1.70	0.340	2.16	25	5	173	157
70P6	1980	70	3.7	14.85	0.190	38.0	5.9	1.74	0.046	8.3	38.33	0.490	9.81	5.01	0.133	2.39	78	38	50	55
	1980	71	3.8	10.89	0.378	32.0	3.9	0.53	0.015	11.5	11.07	0.384	3.25	2.08	0.059	4.52	29	35	118	13
	1980	72	3.7	11.20	0.249	13.6	3.9	1.02	0.015	7.3	19.09	0.425	2.32	1.98	0.029	1.42	45	68	183	21
	1980	73	5.5	5.38	0.399	25.6	7.1	1.10	0.052	3.4	9.99	0.741	4.76	3.01	0.142	0.93	13	21	156	153
70AI	1980	91	4.3	2.13	0.131	56.6	4.7	0.37	0.022	12.5	1.54	0.095	4.09	0.75	0.045	2.53	16	17	23	18
	1980	92	4.8	0.54	0.019	8.2	4.8	0.20	0.008	0.6	0.84	0.029	1.27	0.62	0.025	0.19	28	25	23	133
	1980	93	5.0	1.07	0.045	12.3	6.8	0.33	0.014	2.8	2.62	0.110	3.01	1.05	0.045	0.89	24	24	37	50
70OB	1980	86	3.0	38.32	0.764	40.0	2.7	33.76	0.560	36.0	37.54	0.748	3.92	31.90	0.529	3.40	50	60	191	156
	1980	90	4.3	8.41	0.182	21.3	6.8	1.82	0.056	19.5	12.67	0.274	3.21	4.60	0.141	4.93	46	33	85	29
	1980	89	3.8	13.30	0.286	32.0	3.9	9.80	0.210	10.0	30.28	0.651	7.28	24.05	0.515	2.45	47	47	89	210
	1980	87	4.1	12.30	0.293	39.0	5.8	4.35	0.131	86.7	13.56	0.323	4.30	4.44	0.134	8.85	42	33	75	15
Depth							0-10	0-10	0-10	0-10				0-10	0-10	0-10		0-10		0-10
82.1	1982	4					7.7	1.17		0.5				7.16		0.30				
	1982	7					7.6	1.04		0.3				6.29		0.18				
	1982	10					7.7	1.17		0.5				4.19		0.18				
	1982	12					7.6	1.03		0.3				4.76		0.14				
82.4	1982	1					7.7	1.25		0.3				8.65		0.21				
	1982	2					7.7	0.89		0.3				4.47		0.15				
	1982	3					7.4	0.93		8.2				8.84		7.80				
	1982	4					7.6	2.41		1.0				9.18		0.38				
OB.SH	1982	5					6.6	1.43	0.12	5.99				3.31	0.277	1.39		12		200
	1982	7					6.5	1.96	0.11	6.33				6.63	0.372	2.19		18		174
	1982	10					6.0	2.74	0.12	5.33				6.45	0.282	1.26		23		225
	1982	12					6.8	0.96	0.09	7.33				2.50	0.234	1.88		11		123
OB.59	1982	2					4.0	1.57	0.11	8.99				5.83	0.408	3.05		14		122
	1982	4					4.3	2.98	0.06	7.32				11.10	0.223	2.72		50		82
	1982	7					4.3	1.65	0.12	8.65				8.07	0.586	4.26		14		139
	1982	10					4.7	1.47	0.07	7.66				4.67	0.222	2.38		21		91

0-5 : 0-5 cm 5-10 : 5-10 cm 0-10 : 0-10 cm

APPENDIX C : PLANT GROWTH DATA

Table 1. Cover data from Trial 70.1 in 1980.

Table 2. Cover data from Trial 70.1 in 1980.

Table 3. Cover data from Trial 70.1 in 1980.

Table 4. Foliar chemistry data from Trial 70.1 in 1980.

Table 5. Number and size of invading woody species in Trial 70.3.

Table 6. The height of Sitka alder in Trial 77.1.

Table 7. Data Collected from Trial 82.1 in 1982.

Table 8. Data Collected from Trial 82.1 in 1983.

Table 9. Data Collected from Trial 82.1 in May 1984.

Table 10. Data Collected from Trial 82.1 in September 1984.

Table 11. Data Collected from Trial 82.1 in 1985.

Table 12. Data Collected from Trial 82.1 in 1987.

Table 13. Results of the analysis of variance carried out on herbaceous cover data collected from Trial 82.1 in 1982, 1983, and 1984.

Table 14. Results of the analysis of variance carried out on herbaceous biomass data collected from Trial 82.1 in 1984.

Table 15. Results of the analysis of variance carried out on third year seedling survival data.

TRIAL 70.1 : LEGEND

ST : status YR : year TR : treatment

: plot number B : buried W : ponded

Treatment **

R : unfertilized wasterock

F : fertilized wasterock

P : peat (plus fertilizer)

PF : peat

AG1 : fertilized wasterock plus annual grass

AG2 : unfertilized wasterock plus annual grass

** For treatments R, F, P, and PF, numbers following treatment refer to seed mixes

Cover Types

M : moss P : peat

F : soil-sized mineral material

Li : lichen W : liverwort

V : grass plus legume

G : grass L : legume

I : naturally invading plant species

TRIAL 70.1 : LEGEND (continued)

Grasses

AG	Agrostis gigantea (Red Top)
DG	Dactylis glomerata (Orchard Grass)
FA	Festuca arundinacea (Tall Fescue)
FP	Festuca pratensis (Chewing Fescue)
FR	Festuca rubra (Red Fescue)
HV	Hordeum vulgare (Barley)
LP	Lolium perene (Perenial Ryegrass)
PA	Phalaris arundinacea (Reed Canary Grass)
PP	Phleum pratense (Timothy)
PC	Poa compressa (Canada Bluegrass)
PP	Poa pratensis (Kentucky Bluegrass)

Legumes

LC	Lotus corniculatus (Birdsfoot Treefoil)
MS	Medicago sativa (Alfalfa)
SN	Onobrychis viciafolia (Sainfoin)
TH	Trifolium hybridium (Alsike Clover)
TP	Trifolium pratense (Red Clover)
TR	Trifolium repense (White Clover)
V	Vicia species (Vetch)

Invading Plant Species

AZ	Achillea millefolium (Yarrow)
Co	Cornus canadensis (Bunchberry)
F	Epilobium angustifolium (Fireweed)
Fern	Polypodiacea species (Fern)
He	Tsuga spp. (Hemlock)
Po	Populus trichocarpa (Black Cottonwood)
R	Epilobium latifolium (Willow Herb)
SS	Picea sitchensis (Sitka Spruce)
V	Vaccinium species
W	Salix species (Willow)

Table 1. Cover data collected from Trial 70.1 in 1980.

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	R1		1	5	0			5	5						
			2	2	0			5	5						
			3	5	0			5	5						
			4	3	0			1	1						
			5	2	0			1	1						
			6	2	0			1	1						
			7	2	0			1	1						
			10	10	0			0	0						
			11	15	0			0	0						
			12	10	10			0	0						
			16	3	20			2	2						
			17	5	17			3	3						
			18	5	17			2	2						
			19	5	20			10	10						
			20	10	10			11	10	1			1		
			X	6	6			3	3						
			SD	4	8			3	3						
		W	8	10	0			1	1						
		W	9	17	0			3	3						
		W	13	13	7			0	0						
		W	14	5	15			5	5						
		W	15	5	15			5	5						
			X	10	7			3	3						
			SD	5	7			2	2						

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
	R2		1	20	0			10	10						
			2	10	0			2	2						
			3	12	0			5	5						
			4	10	0			5	5						
			5	15	0			0	0						
			6	7	7			0	0						
			7	10	0	2		0	0						
			10	10	10			2	2						
			11	7	7			0	0						
			12	15	10			0	0						
			14	5	15			5	5						
			15	10	10			7	7						
			16	5	10			2	2						
			17	5	15			0	0						
			18	5	20			5	5						
			19	5	10			2	2						
			20	10	0			10	10						
			X	9	7			3	3						
			SD	4	6			3	3						
		W	8	10	0			3	3						
		W	9	20	0			5	5						
		W	13	6	15			5	5						
			X	12	5			4	4						
			SD	6	7			1	1						

Table 1. Cover data collected from Trial 70.1 in 1980 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
	R3		1	15				8	8						
			2	8				6	6						
			3	12				6	6						
			4	5				3	3						
			5	15				2	2						
			6	10				0	0						
			7	8				1	1						
			10	8				6	6						
			11	3				1	1						
			12	8				3	3						
			15	2	2			0	0						
			16	2				1	1						
			17	1				2	2						
			18	5				2	2						
			19	10				5	5						
			20	10				15	15						
			X	8				4	4						
			SD	4				4	4						
		W	8	5				1	1						
		W	9	10				9	9						
		W	13	3				1	1						
		W	14	2				3	3						
			X	5				4	4						
			SD	3				3	3						

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	R4		1	15				8	8	0	0				
			2	20				0	0	0	0				
			3	20				5	5	0	0				
			4	20				8	8	0	0				
			5	15				4	4	0	0				
			6	12				4	4	0	0				
			7	15				0	0	0	0				
			10	40				14	11	3	2	1			
			11	20				1	1	0	0				
			14	45				2	2	0	0				
			15	30				0	0	0	0				
			16	20				0	0	0	0				
			17	10				4	4	0	0				
			18	30				5	5	0	0				
			19	25				6	6	0	0				
			20	20				14	4	10	10				
			X	22				5	4	1	1				
			SD	9				4	3	2	2				
		W	8	20				1	1						
		W	9	40				3	3						
		W	12	35				3	3						
		W	13	40				2	2						
			X	34				2	2						
			SD	8				1	1						

Table 1. Cover data collected from Trial 70.1 in 1980 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	R5		1	20				5	5	0				0	0
			2	25				11	6	5				5	0
			3	20				8	7	1				1	0
			4	30				0	0	0				0	0
			5	10				0	0	0				0	0
			6	5				0	0	0				0	0
			7	20				2	2	0				0	0
			9	30				27	12	15				15	0
			10	30				12	10	2				2	0
			11	15				0	0	0				0	0
			14	10				6	3	3				3	0
			15	25				2	0	2				2	0
			16	40				15	7	8				0	8
			17	20				4	4	0				0	0
			18	10				5	3	2				1	1
			19	10				40	15	25				5	20
			20	15				7	6	1				0	1
			X	19				8	5	4				2	2
			SD	10				10	5	7				4	5
		W	8	25				4	4						
		W	12	25				0	0						
		W	13	20				3	3						
			X	23				2	2						
			SD	2				2	2						

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	R6		1	20				12	8	4	4				
			2	15				7	7	0	0				
			3	10				5	5	0	0				
			4	15				6	6	0	0				
			5	10				4	4	0	0				
			6	17				4	2	2	2				
			7	27				3	2	1	1				
			9	40				6	6	0	0				
			10	45				3	3	0	0				
			11	40				5	5	0	0				
			12	40				3	3	0	0				
			13	35				6	6	0	0				
			14	40				8	5	3	3				
			15	25				5	5	0	0				
			16	50				11	11	0	0				
			17	30				6	6	0	0				
			18	40				10	7	3	0			2	1
			19	50				17	13	4	2			2	
			20	20				13	12	1	1				
			X	30				7	6	1	1				
			SD	13				4	3	1	1				
		W	8	35				3	2	1	1				

Table 1. Cover data collected from Trial 70.1 in 1980 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	F1		1	60				28	28	0			0		
			2	50				33	23	10			10		
			3	60				30	30	0			0		
			4	50				26	26	0			0		
			5	60				60	45	15			15		
			6	80				28	25	3			3		
			7	70				20	20	0			0		
			10	80				26	26	0			0		
			11	90				30	30	0			0		
			12	80				56	41	15			15		
			13	70				30	30	0			0		
			14	90				52	40	12			12		
			15	95				52	50	2			2		
			16	90				40	40	0			0		
			17	80				30	30	0			0		
			18	50				75	60	15			15		
			19	40				67	60	7	4		3		
			20	50				42	40	2			2		
			X	69				40	36	5			4		
			SD	17				16	12	6			6		
		W	8	70				15	15						
		W	9	50				25	25						
			X	60				20	20						
			SD	10				5	5						

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	F2		1	60				45	45	0			0		
			2	30				21	20	1			1		
			3	65				35	35	0			0		
			4	20				40	40	0			0		
			5	30				40	40	0			0		
			6	40				25	25	0			0		
			7	60				20	20	0			0		
			10	80				10	10	0			0		
			11	90				15	15	0			0		
			12	90				28	25	3			0		
			13	85				35	35	0			0		
			14	85				35	30	5			5		
			15	95				55	50	5			5		
			16	95				47	45	2			2		
			17	95				43	40	3			3		
			18	80				46	40	6	4		2		
			19	70				38	30	8			8		
			20	60				22	20	2			2		
			X	68				33	31	2			2		
			SD	24				12	11	2			2		
		W	8	70				15	15						
		W	9	60				17	17						
			X	65				16	16						
			SD	5				1	1						

Table 1. Cover data collected from Trial 70.1 in 1980 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	F3		1	50				9	9	0	0	0	0		
			2	85				37	29	8	8	0	0		
			3	90				60	33	27	25	2	0		
			4	60				65	30	35	15	0	20		
			5	35				38	26	12	2	0	10		
			6	65				46	35	11	2	2	7		
			7	70				40	25	15	15	0	0		
			11	90				22	20	2	2	0	0		
			12	80				43	33	10	10	0	0		
			13	90				30	30	0	0	0	0		
			14	98				44	41	3	1	2	0		
			15	95				63	58	5	0	0	5		
			16	95				58	53	5	5	0	0		
			17	90				48	44	4	4	0	0		
			18	99				52	42	10	10	0	0		
			19	96				65	60	5	0	5	0		
			20	70				45	32	13	5	0	8		
			X	80				45	35	10	6	1	3		
			SD	18				15	13	9	7	1	5		
		W	8	50				20	20						
		W	9	35				25	25						
		W	10	70				31	31						
			X	52				25	25						
			SD	14				4	4						

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	F4		1	30				30	25	5				5	
			2	50				25	14	11	0	1	0	10	
			3	40				11	8	3	0	1	2	0	
			4	25				5	4	1	1		0	0	
			5	30				14	5	9	0	1	0	8	
			6	25				19	19	0	0		0	0	
			7	45				17	10	7	2		0	5	
			8	45				18	18	0	0		0	0	
			11	85				11	9	2	0		0	2	
			12	80				21	20	1	0		1	0	
			13	75				30	30	0	0		0	0	
			14	90				23	12	11	0	1	10	0	
			15	90				32	32	0	0		0	0	
			16	85				42	27	15	15		0	0	
			17	50				8	7	1	0	1	0	0	
			18	95				32	20	12	12		0	0	
			19	90				40	20	20	20		0	0	
			20	80				46	37	9	0		1	8	
			X	62				24	18	6	3		1	2	
			SD	25				12	9	6	6		2	3	
		W	9	55				33	33						
		W	10	80				25	25						
			X	68				29	29						
			SD	13				4	4						

Table 1. Cover data collected from Trial 70.1 in 1980 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	F5		1	60				69	26	43				30	13
			2	60				55	15	40			5	35	0
			3	40				41	26	15				15	0
			4	50				26	16	10				10	0
			5	60				52	22	30				30	0
			6	50				56	16	40				40	0
			7	95				97	47	50				50	0
			11	90				35	20	15				15	0
			12	90				60	30	30				30	0
			13	85				80	45	35				35	0
			14	99				83	23	60				60	0
			15	85				80	50	30				30	0
			16	85				50	30	20				20	0
			17	80				50	20	30				20	10
			18	99				80	30	50				50	0
			19	98				101	41	60				60	0
			20	98				52	37	15				15	0
			X	78				63	29	34				32	1
			SD	19				21	11	15				15	4
		W	8	40				45	25	20				20	
		W	9	50				48	40	8				8	
		W	10	70				40	25	15				15	
			X	53				44	30	14				14	
			SD	12				3	7	5				5	

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	F6		1	70				43	38	5	5			0	
			2	70				32	30	2	2			0	
			3	40				18	16	2	2			0	
			4	10				15	15	0	0			0	
			5	35				23	21	2	2			0	
			6	35				28	20	8	0			8	
			7	40				40	24	16	2		4	10	
			8	60				36	33	3	0			3	
			10	80				20	16	4	0			4	
			11	80				16	16	0	0			0	
			12	90				20	18	2	0			2	
			13	85				48	18	30	15			15	
			14	90				43	13	30	10			20	
			15	95				35	20	15	15			0	
			16	95				32	22	10	5			5	
			17	95				23	15	8	8			0	
			18	97				39	24	15	15			0	
			19	95				59	24	35	5			30	
			20	98				31	18	13	3			10	
			X	72				32	21	11	5			6	
			SD	26				12	6	10	5			8	
		W	9	50				37	32	5				5	

Table 1. Cover data collected from Trial 70.1 in 1980 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
	P1		3	92				25	17	8	0		0	8	
			4	80				30	25	5	0		0	5	
			5	90				75	55	20	0		5	15	
			6	70				36	30	6	0		3	3	
			7	85				42	32	10	0		0	10	
			8	90				92	70	22	0		0	22	
			9	80				63	60	3	0		0	3	
			10	90				77	72	5	0		0	5	
			11	92				80	80	0	0		0	0	
			12	92				96	81	15	0		0	15	
			13	95				42	42	0	0		0	0	
			14	93				37	37	0	0		0	0	
			15	98				105	80	25	0		25	0	
			16	95				78	65	13	3		10	0	
			17	98				68	60	8	3		5	0	
			18	98				99	66	33	15		15	3	
			19	97				75	53	22	2		20	0	
			20	98				75	60	15	0		15	0	
			X	91				66	55	12	1		5	5	
			SD	7				24	19	9	3		8	6	
		S	1	70				57	50	7			5	2	
		S	2	70				28	28	0			0	0	
			X	70				43	39	4			3	1	
			SD	0				15	11	4			3	1	

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	P5		3	98				40	10	30				30	
			4	98				52	22	30				30	
			5	90				65	30	35				35	
			6	85				75	45	30				30	
			7	90				65	35	30				30	
			8	95				45	30	15				15	
			9	95				65	40	25				25	
			10	98				60	40	20				20	
			11	98				95	45	50				50	
			12	95				70	30	40				40	
			13	95				95	45	50				50	
			14	90				65	30	35				35	
			15	98				90	45	45				45	
			16	99				88	45	43				40	3
			17	98				88	40	48	5			40	3
			18	99				90	40	50				50	
			19	92				85	45	40				40	
			20	99				102	42	60				60	
			X	95				74	37	38				37	
			SD	4				18	9	12				11	
		S	1	80				85	55	30				30	
		S	2	95				60	30	30				30	
			X	88				73	43	30				30	
			SD	8				13	13	0				0	

Table 1. Cover data collected from Trial 70.1 in 1980 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	P6		3	85				26	6	20	5			15	
			4	90				12	8	4	2			2	
			5	85				23	16	7	2			5	
			6	95				45	17	28	8			20	
			7	80				14	6	8	0			8	
			8	75				16	8	8	0			8	
			9	90				24	13	11	1			10	
			10	95				34	17	17	2			15	
			11	97				38	28	10	0			10	
			12	95				41	27	14	4			10	
			13	95				57	32	25	5			20	
			14	97				32	18	14	4			10	
			15	92				16	9	7	6			1	
			16	98				65	36	29	25			4	
			17	99				71	46	25	25			0	
			18	99				62	42	20	20			0	
			19	93				36	26	10	10			0	
			20	90				29	23	6	6			0	
			X	92				36	21	15	7			8	
			SD	7				18	12	8	8			7	
		S	1	75				27	19	8	8				
		S	2	90				26	18	8	8				
			X	83				27	19	8	8				
			SD	8				1	1	0	0				

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	PF1		3	80				15	15	0	0		0		
			4	80				20	20	0	0		0		
			5	70				11	11	0	0		0		
			6	80				22	22	0	0		0		
			7	60				33	27	6	0		6		
			8	70				28	25	3	0		3		
			9	80				59	51	8	0		8		
			10	75				35	31	4	0		4		
			11	92				87	82	5	0		5		
			12	95				88	87	1	0		1		
			13	95				84	80	4	0		4		
			14	90				65	57	8	0		8		
			15	80				21	20	1	0		1		
			16	80				66	51	15	0		15		
			17	80				41	41	0	0		0		
			18	90				51	41	10	0		10		
			19	80				46	31	15	10		5		
			20	70				11	10	1	0		1		
			X	80				44	39	5	1		4		
			SD	9				25	24	5	2		4		
		S	1	80				60	60	0			0		
		S	2	65				32	27	5			5		
			X	73				46	44	3			3		
			SD	8				14	17	3			3		

Table 1. Cover data collected from Trial 70.1 in 1980 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	PF5		3	60				4	4	0				0	
			4	40				4	3	1	1			0	
			5	50				6	5	1				1	
			6	40				17	15	2				2	
			7	60				17	17	0				0	
			8	60				16	16	0				0	
			9	40				9	1	8				8	
			10	50				23	11	12	2			10	
			11	75				33	21	12	2			10	
			12	95				52	27	25				25	
			13	95				41	21	20				20	
			14	70				34	19	15				15	
			15	65				20	18	2				2	
			16	75				7	7	0				0	
			17	75				40	15	25				25	
			18	75				46	26	20				20	
			19	60				26	12	14				12	2
			20	40				7	4	3				3	
			X	63				22	13	9				9	
			SD	17				15	8	9				9	
		S	1	99				40	15	25				25	
		S	2	70				25	10	15				15	
			X	85				33	13	20				20	
			SD	15				8	3	5				5	

YR	TR	ST	#	M	P	F	W	V	G	L	TH	TP	TR	LC	SN
80	PF6		4	50				0	0	0	0			0	
			5	70				12	6	6	6			0	
			6	80				9	9	0	0			0	
			7	80				6	6	0	0			0	
			8	60				13	9	4	4			0	
			9	50				12	2	10	10			0	
			10	70				19	7	12	12			0	
			11	70				23	15	8	8			0	
			12	90				47	29	18	6	B		4	
			13	80				38	34	4	4			0	
			14	65				42	37	5	5			0	
			15	70				23	23	0	0			0	
			16	70				2	2	0	0			0	
			17	70				42	21	21	16			5	
			18	50				35	23	12	8			4	
			19	50				21	6	15	15			0	
			20	30				14	14	0	0			0	
			X	65				21	14	7	6			1	
			SD	15				14	11	7	5			2	
		S	1	99				32	29	3	3				
		S	2	80				26	26	0	0				
		S	3	80				2	1	1	1				
			X	86				20	19	1	1				
			SD	9				13	13	1	1				

Table 2. Cover data collected from Trial 70.1 in 1981.

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	R1		1	7	0			4	4					4																			
			2	11	0			3	3					3																			
			3	14	0			0	0					0																			
			4	5	0			0	0					0																			
			5	8	0			0	0					0																			
			6	4	0			0	0					0																			
			7	4	0			0	0					0																			
			10	3	0			0	0					0																			
			11	3	0			0	0					0																			
			12	8	0			0	0					0																			
			17	1	20			0	0					0																			
			18	1	20			0	0					0																			
			19	8	30			6	6					4				2															
			20	3	15			8	8					8																			
	R1		X	6	6			2	2					1																			
	R1		SD	4	10			3	3					2																			
		W	8	20				0	0					0																			
		W	9	5				3	3					3																			
		W	13	8				2	1		1			1											1								
		W	14	1				1	1					1																			
	R1	W	X	9				2	1					1																			
	R1	W	SD	7				1	1					1																			
		BW15																															
		B	16																														

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	R2		1	10	4			0	0																								
			2	2	0			0	0																								
			3	3	0			0	0																								
			4	1	0			0	0																								
			5	2	0			0	0																								
			6	1	2			0	0																								
			7	3	1			0	0																								
			10	4	5			0	0																								
			11	2	5			0	0																								
			12	3	7			0	0																								
			14	0	5			0	0																								
			15	0	2			0	0																								
			17	0	15			0	0																								
			18	0	15			0	0																								
			19	0	20			0	0																								
			20	5	20			3	2	1				2								1											
	R2		X	2	6			0	0																								
	R2		SD	3	7			1	0																								
		W	8	3	1			0	0																								
		W	9	12	2			0	0																								
		W	13	2	3			0	0																								
	R2	W	X	6	2			0	0																								
	R2	W	SD	4	1			0	0																								
		B	16																														

Table 2. Cover data collected from Trial 70.1 in 1981 (continued).

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	R3		1	7	0			0	0																								
			2	4	0			0	0																								
			3	3	0			0	0																								
			4	2	0			0	0																								
			5	5	0			0	0																								
			6	3	0			0	0																								
			7	3	0			0	0																								
			10	2	1			0	0																								
			11	1	2			0	0																								
			12	1	2			0	0																								
			15	0	8			0	0																								
			16	0	10			0	0																								
			17	0	8			0	0																								
			18	1	4			0	0																								
			19	3	3			0	0																								
			20	4	4			1	1								1																
	R3		X	2	3			0	0																								
	R3		SD	2	3			0	0																								
		W	8	1	0			0	0																								
		W	9	1	1			0	0																								
		W	13	0	3			0	0																								
		W	14	0	2			0	0																								
	R3	W	X	1	2			0	0																								
	R3	W	SD	1	1			0	0																								

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	R4		1	15	1			0	0	0																							
			2	20	1			0	0	0																							
			3	10	2			0	0	0																							
			4	15	2			0	0	0																							
			5	5	1			0	0	0																							
			6	10	1			0	0	0																							
			7	8	2			0	0	0																							
			10	10	20			0	0	0																							
			11	2	5			0	0	0																							
			15	2	3			0	0	0																							
			16	1	5			0	0	0																							
			17	1	4			0	0	0																							
			18	3	6			0	0	0																							
			19	10	2			1	0	1									1														
			20	20	5			9	0	9									8	1													
	R4		X	9	4			1	0	1																							
	R4		SD	6	5			2	0	2																							
		W	8	10	3			0	0	0																							
		W	9	10	20			0	0	0																							
		W	12	1	5			0	0	0																							
		W	13	3	5			0	0	0																							
	R4	W	X	6	8			0	0	0																							
	R4	W	SD	4	7			0	0	0																							
		B	14																														

Table 2. Cover data collected from Trial 70.1 in 1981 (continued).

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	R5		1	10	0			0	0	0													0	0									
			2	15	0			2	0	2													2	0									
			3	10	0			2	0	2													2	0									
			4	10	0			0	0	0													0	0									
			5	2	0			0	0	0													0	0									
			6	2	0			0	0	0													0	0									
			7	10	1			0	0	0													0	0									
			9	15	1			4	1	3						1							3	0									
			10	5	2			2	2	0						1		1					0	0									
			11	3	1			0	0	0													0	0									
			14	2	2			0	0	0													0	0									
			15	1	4			0	0	0													0	0									
			16	1	1			11	1	10		1											0	10									
			17	1	2			2	0	0	2												0	0	2								
			18	2	2			6	1	4	1				1								2	2	1								
			19	4	1			25	2	23				1				1					3	20									
			20	6	1			1	0	1									1				0	0									
	R5		X	6	1			3	0	3													1	2									
	R5		SD	5	1			6	1	6													1	5									
		W	8	10	1			0	0	0													0										
		W	12	2	2			0	0	0													0										
		W	13	5	2			0	0	0													0										
	R5	W	X	6	2			0	0	0													0										
	R5	W	SD	3	0			0	0	0													0										

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	R6		1	15	2			4	2	2	0	2							2														
			2	15	2			2	2	0	0	2							0														
			3	6	1			1	1	0	0	1							0														
			4	8	0			1	1	0	0	1							0														
			5	4	2			0	0	0	0								0														
			6	8	2			2	1	1	0	1							1														
			7	25	3			0	0	0	0								0														
			9	30	10			1	0	0	1			1					0														1
			10	30	10			0	0	0	0								0														
			11	10	20			0	0	0	0								0														
			12	15	15			2	0	0	2								0						2								
			13	15	10			0	0	0	0								0														
			14	20	10			4	1	0	3								3						3								
			15	15	10			2	1	0	1								0						1								
			16	15	10			2	1	0	1								0								1						
			17	10	15			0	0	0	0								0														
			18	15	5			9	1	4	4								0				2	2		2		2					
			19	25	5			9	1	6	2								3				3				2						
			20	10	0			6	1	5	0								3		2												
	R6		X	15	7			2	1	1	1								1														
	R6		SD	7	6			3	1	2	1								1														
	R6	W	8	20	10			0	0	0	0																						

Table 2. Cover data collected from Trial 70.1 in 1981 (continued).

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	F1		1	20	10			10	10	0		2		8					0		0												
			2	20	10			14	10	4		2		8					0		4												
			3	20	10			16	15	1				15					0		1												
			4	15	5			10	10	0				10					0		0												
			5	55	10			15	10	5				10					0		5												
			6	60	10			8	5	3				5					0		3												
			7	65	20			4	4	0	1	1		3					0		0					1							
			10	60	25			7	7	0		2		5					0		0												
			11	70	20			15	15	0				15					0		0												
			12	90	0			29	21	8		1		20					0		8												
			13	90	2			12	10	2				10					0		2												
			14	85	0			25	20	5				20					0		5												
			15	70	0			40	30	10				30					0		10												
			16	94	0			10	10	0				10					0		0												
			17	94	0			10	10	0				10					0		0												
			18	90	0			35	20	15				20					5		10												
			19	70	0			35	20	15				20					5		10												
			20	60	0			42	30	12				30					2		10												
	F1		X	63	7			19	14	4				14					1		4												
	F1		SD	27	8			12	7	5				8					2		4												
		W	8	15	30			1	1	0	1			1													1						
		W	9	40	15			5	5	0	0			5													0						
	F1	W	X	28	23			3	3	0	1			3													1						
	F1	W	SD	13	8			2	2	0	1			2													1						

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	F2		1	70	10			18	18	0		5		10			3				0												
			2	30	0			8	8	0				8							0												
			3	25	20			11	10	1				10					1		0												
			4	5	5			10	10	0				10							0												
			5	25	10			15	15	0				15							0												
			6	25	10			12	10	1	1			10					1		0							1					
			7	35	10			11	10	0	1			10							0							1					
			10	15	15			7	5	0	2			5							0					2							
			11	50	20			5	3	0	2			3							0					2							
			12	75	10			8	8	0				8							0												
			13	75	10			10	10	0				10							0												
			14	75	10			15	10	5				10							5												
			15	90	0			25	15	10				15							5	5											
			16	90	0			18	15	3				15							3												
			17	90	0			18	12	6				12					2		4												
			18	90	0			18	10	7				10					5		2												
			19	65	0			7	5	2	1			5							2					1							
			20	30	0			6	5	1				5							1												
	F2		X	53	7			12	10	2				10							1												
	F2		SD	29	7			5	4	3				3							2												
		W	8	15	15			6	5	0	1	0		5			0									1							
		W	9	15	5			8	8	0	0	2		5			1									0							
	F2	W	X	15	10			7	7	0	1	1		5			1									1							
	F2	W	SD	0	5			1	2	0	1	1		0			1									1							

Table 2. Cover data collected from Trial 70.1 in 1981 (continued).

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	F3		1	55	0			6	6	0		2	3	0			1		0	0	0												
			2	85	5			18	8	10		2	2	2		2			8	0	2												
			3	85	10			23	9	13	1	1		8					12	0	1								1				
			4	50	10			21	6	15		1		5					5	0	10												
			5	30	15			13	9	4		1		8					2	0	2												
			6	60	10			38	25	11	2	4		20	1				10	1	0					1		1					
			7	60	5			19	7	12	1	5		2					10	0	2							1					
			8	25	5			5	4	1		1		2				1	1	0	0												
			11	85	10			9	5	3	1	2		3					3	0	0					1							
			12	75	0			14	10	3	1	2	1	5		2			2	1	0					1							
			13	95	0			15	15	0		0		15					0	0	0												
			14	90	0			14	18	2		8		10					1	1	0												
			15	85	0			35	30	4	1	5		25		3			2	0	2					1							
			16	80	0			31	28	3		3		25					3	0	0												
			17	70	0			38	33	5		1	1	30			1		5	0	0												
			18	35	0			78	63	15		2	1	60					15	0	0												
			19	40	0			85	65	20		5		60					10	10	0												
			20	50	0			23	7	16		2		5					8	0	8												
	F3		X	64	4			27	19	8		3		16					5	1	2												
	F3		SD	22	5			22	18	6		2		18					4	2	3												
		W	8	25	5			5	4	1	0	1		2		0		1	1								0						
		W	9	18	2			12	10	0	2	0		10		0		0	0								2						
		W	10	20	20			7	7	0	0	1		1		5		0	0								0						
	F3	W	X	21	9			8	7	0	1	1		4		2		0	0								1						
	F3	W	SD	3	8			3	2	0	1	0		4		2		0	0								1						

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	F4		1	30	0			6	4	1	1		0	1		1		1	0				1			1							
			2	70	0			11	7	4	0		2			5			0				4										
			3	40	0			2	0	2	0		0			0			1		1		0										
			4	25	0			1	0	1	0		0			0			0		1		0										
			5	25	0			5	0	4	1		0			0		1	0				4		1								
			6	20	5			7	6	1	0	2	3			0		1	0				1										
			7	35	10			6	1	3	2		0			1			0				3				2						
			8	60	0			9	7	0	2		0	3		4			0				0				2						
			11	85	5			2	0	2	0		0			0			0				2										
			12	80	0			5	5	0	0		0			5			0				0										
			13	85	0			7	6	1	0		4			2			0				1										
			14	90	0			3	2	1	0		2			0			0		1		0										
			15	90	0			14	11	0	3	1	0			10			0				0					3					
			16	88	0			27	7	19	1	2	3			2			0				4		1								
			17	45	15			4	2	2	0		2			0			2				0										
			18	60	15			21	6	15	0		4			2			15				0										
			19	80	5			23	7	16	0	1	5	1		0			15				1										
			20	50	0			13	8	5	0	2	2	3		1			1		1		3										
	F4		X	59	3			9	4	4	1		2			2			2				1										
	F4		SD	25	5			7	3	6	1		2			3			5				2										
		BW	9																														
	F4	W	10	60	20			6	6	0				3		3																	

Table 2. Cover data collected from Trial 70.1 in 1981 (continued).

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	F5		1	65	0			38	16	22		3	0	0		10		3					20	2									
			2	45	0			19	4	15		0	0	0		4		0					15	0									
			3	20	0			12	2	10		0	0	2		0		0					10	0									
			4	40	0			10	0	10		0	0	0		0		0					10	0									
			5	40	0			15	0	15		0	0	0		0		0					15	0									
			7	80	0			64	14	50		2	0	8		4		0					50	0									
			11	90	0			8	3	5		0	0	2		1		0					5	0									
			14	80	0			101	31	70		5	5	5		15		3					70	0									
			15	90	0			48	23	25		5	10	0		8		0					25	0									
			16	90	0			65	20	45		10	0	0		10		0					45	0									
			17	80	0			30	7	23		5	2	0		0		0					15	8									
			18	95	0			88	23	65		0	3	5		10		5					65	0									
			19	95	0			115	45	70		5	15	0		15		10					70	0									
			20	95	0			125	45	80		5	20	15		5		0					80	0									
	F5		X	72	0			53	17	36		3	4	3		6		2					35	1									
	F5		SD	24	0			39	15	25		3	6	4		5		3					26	2									
		BW	8																														
		BW	9																														
		BW	10																														
		B	6																														
		B	12																														
		B	13																														

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	F6		1	70				9	7	2		5		2				0	2				0										
			2	80				9	6	3		6		0				0	0				0										
			3	15				5	3	1	1	3		0				0	0				0				1						
			4	5				5	2	3		1		1				0	0				3										
			5	30				4	2	2		1		1				0	2				0										
			6	30				12	4	8		3		1				0	0				8										
			7	25				12	4	8		2		2				0	3				5										
			11	85				7	5	2		2		3				0	0				2										
			16	95				30	10	20		10		0				0	10				10										
			17	90				24	17	7		15		2				0	7				0										
			18	98				45	10	35		5		0				5	20				15										
			19	100				58	18	40		10		1		2		5	0				40										
			20	98				45	25	20		15		5				5	0				20										
	F6		X	63				20	9	12		6		1				1	3				8										
	F6		SD	35				18	7	13		5		1				2	6				11										
		B	8																														
		B	10																														
		B	12																														
		B	13																														
		B	14																														
		B	15																														
		BW	9																														

Table 2. Cover data collected from Trial 70.1 in 1981 (continued).

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	P1		3	95				26	10	10	0			10					0		0		10										
			4	90				11	10	5	0			10					0		0		5										
			5	75	5			20	20	12	0			20					0		2		10										
			6	75				15	15	5	0			15					0		3		2										
			7	70				32	30	8	0			30					0		0		8										
			8	60				20	60	5	2			60					0		0		5				2						
			11	30				80	75	0	5			75					0		0		0					5					
			17	50				64	50	14	0			50					2		2		10										
			18	60				60	35	25	0			35					10		5		10										
			19	90				51	30	21	0			30					5		8		8										
			20	95				50	35	15	0			35					0		10		5										
	P1		X	72				39	34	11	1			34					2		3		7										
	P1		SD	20				22	20	7	1			20					3		3		3										
		S	1	75	10			26	21	5		1		20							2		3										
		S	2	90	0			11	11	0		1		10							0		0										
	P1	S	X	83	5			19	16	3		1		15							1		2										
	P1	S	SD	8	5			8	5	3		0		5							1		2										
		B	9																														
		B	10																														
		B	12																														
		B	13																														
		B	14																														
		B	15																														
		B	16																														

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	P5		3	95	0			19	4	15		1	2	1				0	0				15	0								
			4	97	0			51	21	30		3	10	8				0	0				30	0								
			5	90	3			62	22	40		2	10	10				0	0				40	0								
			6	90	0			55	25	30		0	8	5				12	0				30	0								
			7	95	0			68	8	60		3	0	5				0	0				60	0								
			8	95	0			21	10	10	1	5	0	5				0	0				10	0				1				
			9	85	5			43	23	20		2	1	20				0	0				20	0								
			10	90	5			28	13	15		1	0	12				0	0				15	0								
			11	50	0			127	52	70	5	0	2	50				0	0				70	0				5				
			14	85	0			85	35	50		5	5	25				0	0				50	0								
			15	95	0			111	31	80		1	15	15				0	0				80	0								
			16		0			127	37	90		5	0	30				2	0				85	5								
			17	75	0			70	20	50		0	0	20				0	10				35	5								
			18	100	0			110	40	70		10	0	30				0	0				70	0								
			19	96	0			78	38	40		8	0	25				5	0				40	0								
			20	100	0			124	44	80		0	0	40				4	0				80	0								
	P5		X	89	1			74	26	47		3	3	19				1	1				46	1								
	P5		SD	12	2			36	13	25		3	5	13				3	2				25	2								
		S	1	85	2			60	10	50		5	0	5			0						50									
		S	2	90	0			39	14	25		2	5	5			2						25									
	P5	S	X	88	1			50	12	38		4	3	5			1						38									
	P5	S	SD	3	1			11	2	13		2	3	0			1						13									
		B	12																														
		B	13																														

Table 2. Cover data collected from Trial 70.1 in 1981 (continued).

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	P6		3	85	5			14	1	13		1		0				0	3				10										
			4	95	2			6	2	4		2		0				0	2				2										
			5	92	5			12	6	6		3		0				3	1				5										
			6	97	2			23	3	20		0		0			1	2	5				15										
			7	80	5			8	3	5		2		1				0	0				5										
			8	80	5			6	3	3		1		2				0	1				2										
			9	95	0			15	5	10		2		2				1	0				1										
			10	98	0			12	5	7		2		1				2	2				5										
			11	93	0			20	9	11		2		5				2	1				10										
			12	96	0			19	8	11		1		6				1	1				10										
			14	95	2			23	13	10		5		8				0	0				10										
			15	87	5			11	2	8		2		0				0	0				8						1				
			16	97	0			33	8	25		1		5				2	15				10										
			17	95	0			52	22	30		1		10				1	25				5										
			18	97	0			34	11	23		3		8				0	15				8										
			19	85	4			33	13	20		2		10				1	5				15										
			20	88	2			15	2	13		0		2				0	3				10										
	P6		X	91	2			20	7	13		2		4				1	5				8										
	P6		SD	6	2			12	5	8		1		4				1	7				4										
		S	1	98	0			37	21	15	1	20		1					5		0		10					1	0				0
		S	2	90	5			35	6	21	8	4		2					5		1		15					3	3				2
	P6	S	X	94	3			36	14	18	5	12		2					5		1		13					2	2				1
	P6	S	SD	4	3			1	8	3	4	8		1					0		1		3					1	2				1
		B	13																														

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	PF1		3	65	15			1	1	0				1					0		0											
			4	65	15			2	2	0				2					0		0											
			5	40	20			1	1	0				1					0		0											
			6	64	15			2	2	0				2					0		0											
			7	55	10			13	10	1	2			10					0		1					2							
			8	65	10			8	8	0				8					0		0											
			9	75	5			25	20	5				20					0		5											
			10	77	8			14	10	4				10					1		3											
			11	90	1			51	50	1				50					0		1											
			12	95	0			65	65	0				65					0		0											
			13	99	0			51	50	1				50					1		0											
			14	90	10			25	22	3		2		20					0		3											
			15	65	10			8	8	0				8					0		0											
			16	75	15			11	5	6				5					4		2											
			17	83	10			20	15	5				15					2		2		1									
			18	50	45			31	25	6				25					1		5											
			19	65	10			21	15	6				15					3		3											
			20	45	15			3	2	1				2					1		0											
	PF1		X	70	12			20	17	2				17					1		1											
	PF1		SD	16	10			19	19	2				19					1		2											
		S	1	65	1			37	35	0	2	15		30							0				2							
		S	2	55	15			8	6	2	0	0		6							2				0							
	PF1	S	X	60	8			23	21	1	1	8		18							1				1							
	PF1	S	SD	5	7			15	15	1	1	8		12							1				1							

Table 2. Cover data collected from Trial 70.1 in 1981 (continued).

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	PF5		3	25	15			1	1	0	0	1		0									0										
			4	15	15			2	0	0	2	0		0									0					2					
			5	15	15			0	0	0	0	0		0									0										
			6	12	13			3	1	2	0	0		1									2										
			7	20	10			4	3	0	1	0		3									0					1					
			8	32	8			5	4	0	1	0		4									0					1					
			9	15	10			5	4	0	1	1		3									0					1					
			10	30	10			15	2	11	2	0		2						1			0			1		1					
			11	50	20			25	13	10	2	0		12						1			10			2							
			12	93	5			38	18	20	0	0		18									20										
			13	88	2			35	15	20	0	0		15									20			2							
			14	30	5			28	8	20	0	3		5									20										
			15	25	15			5	4	0	1	2		2									0										1
			16	25	15			1	1	0	0	0		1									0										
			17	40	20			27	5	22	0	1	1	3						2			20										
			18	20	40			15	7	8	0	2		5									8										
			19	30	20			20	8	12	0	0		8									10	2									
			20	15	15			2	1	1	0	1		0									1										
	PF5		X	32	14			13	5	7	1	1		5									6										
	PF5		SD	23	8			12	5	8	1	1		5									8										
		S	1	80	0			98	45	30	23	15		30									30			20			3				
		S	2	45	5			12	11	1	0	10		1									1			0			0				
	PF5	S	X	63	3			55	28	16	12	13		16									16			10			2				
	PF5	S	SD	18	3			43	17	15	12	3		15									15			10			2				

YR	TR	ST	#	M	P	LI	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN	Po	V	W	He	F	R	Az	SS	Co
81	PF6		4	40				15	11	0	4	5		5				5							2		0	0		2			
			5	25				5	0	0	5	0		0											5		0	0					
			6	30				3	3	0	0	1		2											0		0	0					
			7	70				10	6	3	1	3		3									3		0		0	0		1			
			8	30				6	4	0	2	2		2											1		0	1					
			9	30				4	1	0	3	1		0											2		0	1					
			10	25				11	3	1	7	3		0					1						4		1	2					
			11	30				14	3	3	8	2		0				1	3				0		6		1	1					
			12	40				11	3	0	8	2		1									0		4	1	1	2					
			13	60				11	3	0	8	3		0									0		0		4	4					
			14	30				27	3	15	9	3		0					1		2		12		4	1	2	2					
			15	25				39	8	15	16	6		2									15		2		13	1					
			16	40				39	8	0	31	2		6									0		10		20	1					
			17	50				7	4	0	3	1		3									0		0	1	1	1					
			18	30				10	1	2	7	1		0					2				0		5	2	0	0					
			19	40				15	4	3	8	1		3					3				0		5		2	1					
			20	40				9	3	0	6	3		0									0		1	1	3	1					
	PF6		X	37				14	4	2	7	2		2					2				3		3		3	1					
	PF6		SD	12				11	3	5	7	1		2					1				5		3		5	1					
		S	1	80				58	22	3	33	20		0				1					3			5			20	0			
		S	2	80				34	18	0	16	15		2				1					0			5			10	0			
		S	3	60				33	22	0	11	20		1				0					0		1	0			0	10			
	PF6	S	X	73				42	21	1	20	18		1				1					1			3			10	3			
	PF6	S	SD	9				12	2	1	9	2		1				0					1			2			8	5			

Table 3. Cover data collected from Trial 70.1 in 1983.

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	R1		1	20	0	5		0	0		0													
			2	20	0	5		0	0		0													
			3	20	0	2		0	0		0													
			4	20	0	2		0	0		0													
			5	15	0	2		0	0		0													
			6	15	0	1		0	0		0													
			7	15	0	1		0	0		0													
			10	10	15	0		0	0		0													
			11	10	5	0	1	1	0		1													
			12	5	10	0		1	0		1													
			17	2	5	0		2	0		2													
			18	2	10	0		0	0		0													
			19	5	10	0		2	1		1			1										
			20	10	10	0		2	2		0			2										
	R1		X	12	5	1		1	0		0													
	R1		SD	7	5	2		1	1		1													
		W	8	25	5			1	1		0			1										
		W	9	10	10			1	1		0			1										
		W	13	5	30			1	0		1			0										
		W	14	2	30			1	1		0			1										
	R1	W	X	11	19			1	1		0			1										
	R1	W	SD	9	11			0	0		0			0										
		BW	15	1	2			3	1		2			1										
		B	16	1	2			3	2		1			2										

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	R2		1	20	1	5		0	0		0			0										
			2	20	0	2		0	0		0			0										
			3	15	0	2		0	0		0			0										
			4	10	0	2		0	0		0			0										
			5	20	0	2		0	0		0			0										
			6	10	1	0		0	0		0			0										
			7	25	0	0		0	0		0			0										
			10	15	5	0		1	0		1			0										
			11	10	2	0		0	0		0			0										
			12	5	5	0		1	0		1			0										
			14	1	5	0		1	1		0			1										
			15	2	2	0		4	1		3			1										
			17	2	5	0		2	0		2			0										
			18	1	5	0		3	0		3			0										
			19	2	10	0		2	1		1			1										
			20	15	10	0		2	1	1	0			1							1			
	R2		X	11	3	1		1	0		1			0										
	R2		SD	8	3	1		1	0		1			0										
		W	8	30	2			3	0		3			0										
		W	9	50	2			3	0		3			0										
		W	13	1	5			5	1		4			1										
	R2	W	X	27	3			4	0		3			0										
	R2	W	SD	20	1			1	0		0			0										
		B	16	2	2			7	1		6			1										

Table 3. Cover data collected from Trial 70.1 in 1983 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	R3		1	30	0	5		0	0		0													
			2	20	0	5		1	0		1													
			3	20	0	5		1	0		1													
			4	25	0	5		0	0		0													
			5	30	0	5		2	0		2													
			6	20	0	2		1	0		1													
			7	20	0	1		3	0		2	1												
			10	7	1	0		2	1		1						1							
			11	5	1	0		0	0		0													
			12	5	1	0		1	0		1													
			15	5	2	0		3	0		3													
			16	5	1	0		1	0		1													
			17	3	1	0		2	0		2													
			18	2	1	0		0	0		0													
			19	5	1	0		0	0		0													
			20	5	11	0		2	1		1						1							
	R3		X	13	1	2		1	0		1													
	R3		SD	10	3	2		1	0		1													
		W	8	15	2			2	0		2						0							
		W	9	5	2			3	1		2						1							
		W	13	4	2			5	1		4						1							
		W	14	5	1			1	1		0			1			0							
	R3	W	X	7	2			3	1		2						1							
	R3	W	SD	4	0			1	0		1						1							

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	R4		1	40	2	0		2	1	0	1	1												
			2	50	1	0		1	0	0	1													
			3	35	2	0		0	0	0	0													
			4	30	1	0		0	0	0	0													
			5	25	1	1		0	0	0	0													
			6	25	1	1		0	0	0	0													
			7	20	2	0		0	0	0	0													
			10	10	10	0		1	1	0	0													
			11	5	5	0		0	0	0	0													
			15	3	1	0		1	0	0	1													
			16	5	0	0		1	1	0	0						1							
			17	5	2	0		1	0	0	1													
			18	5	2	0		2	0	0	2													
			19	15	2	0		1	1	0	0	1												
			20	20	0	1		4	1	3	0	1							3					
	R4		X	20	2	0		1	0	0	0													
	R4		SD	14	2	0		1	0	1	1													
		W	8	20	5			0			0													
		W	9	10	10			2	1		1	1												
		W	12	5	10			1			1													
		W	13	10	5			0			0													
	R4	W	X	11	8			1			1													
	R4	W	SD	5	3			1			1													
		B	14																					

Table 3. Cover data collected from Trial 70.1 in 1983 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	R5		1	40	0	2		1	1	0	0	1											0	0
			2	50	0	1		4	1	3	0	1											3	0
			3	30	0	2		2	0	2	0												2	0
			4	40	0	2		0	0	0	0												0	0
			5	20	0	2		1	0	0	1												0	0
			6	15	0	2		0	0	0	0												0	0
			7	30	0	2		0	0	0	0												0	0
			9	40	0	0		7	1	3	3					1							3	0
			10	30	5	0		3	2	1	0					1		1					1	0
			11	15	5	0		2	0	0	2												0	0
			14	15	0	0		1	1	0	0	1											0	0
			15	10	5	0		0	0	0	0												0	0
			16	5	0	0		13	1	10	2	1											0	10
			17	3	0	0		3	0	0	3												0	0
			18	10	0	0		6	2	2	2	1				1							1	1
			19	15	0	0		19	3	16	0		1	1		1							1	15
			20	10	0	2		6	0	4	2								1				1	2
	R5		X	22	1	1		4	1	2	1												1	2
	R5		SD	14	2	1		5	1	4	1												1	4
		W	8	40	0	0		2	0		2	0												
		W	12	15	3	0		4	2		2	1					1							
		W	13	25	1	1		2	1		1	1												
	R5	W	X	27	1	0		3	1		2	1												
	R5	W	SD	10	1	0		1	1		0	0												

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	R6		1	20	0	2		2	1	1	0	1							1					
			2	30	0	0		1	1	0	0	1												
			3	20	0	3	1	1	1	0	0	1												
			4	30	0	3	1	1	1	0	0	1												
			5	30	0	5		1	1	0	0	1												
			6	30	0	2		0	0	0	0	0												
			7	45	0	2		3	1	1	1	1							1					
			9	50	5	0		4	1	0	3	0		1										
			10	50	5	0		1	1	0	0	1												
			11	15	15	0		3	2	0	1	1		1										
			12	25	10	0		5	2	0	3	1		1										
			13	40	5	0		1	0	0	1	0												
			14	20	5	1		5	1	0	4	0		1										
			15	15	10	0		1	0	0	1	0												
			16	15	15	0		1	0	0	1	0												
			17	10	5	0		1	0	0	1	0												
			18	15	0	0		11	0	6	5	0							1				3	2
			19	40	0	0		6	0	2	4	0							2					
			20	20	0	0		5	0	3	2	0							1		1		1	
	R6		X	27	4	1		3	1	1	1	0												
	R6		SD	12	5	1		3	1	1	2	0												
	R6	W	8	30	5	1		1	1			1												

Table 3. Cover data collected from Trial 70.1 in 1983 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	F1		1	15	10			1	1	0				1							0			
			2	20	10			4	2	2		1		1					1		1			
			3	7	10			2	2	0				2							0			
			4	10	7			2	2	0				2							0			
			5	70	5		2	4	3	1				3							1			
			6	55	20		1	3	2	1				2							1			
			7	60	30	1		2	1	0	1			1							0			
			10	35	45			2	2	0		1		1							0			
			11	50	40			1	1	0				1							0			
			12	85	10			5	2	2	1			2							2			
			13	85	10	1	1	2	1	1				1							1			
			14	90	5			6	2	4				2							4			
			15	80	15			6	1	5				1							5			
			16	80	15			1	1	0				1							0			
			17	80	15			1	1	0				1							0			
			18	85	10			7	2	5				2							5			
			19	80	15			10	0	10				0					5		5			
			20	60	15			11	3	7	1			3					2		5			
	F1		X	58	16			4	2	2				2							2			
	F1		SD	28	11			3	1	3				1							2			
		W	8	20	20			2	1		1			1										
		W	9	50	15			1	1		0			1										
	F1	W	X	35	18			2	1		1			1										
	F1	W	SD	15	3			1	0		1			0										

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	F2		1	75	15		0	6	6	0	0	1		5							0			
			2	20	15		1	1	1	0	0			1							0			
			3	15	25		4	3	3	0	0			3							0			
			4	7	15	1	1	2	2	0	0			2							0			
			5	20	20		5	4	3	1	0			3							1			
			6	10	20		1	3	2	0	1			2							0			
			7	15	20		0	2	1	0	1			1							0			
			10	15	30		0	1	0	0	2			0							0			
			11	30	45		0	0	0	0	0			0							0			
			12	60	30		1	3	1	0	2			1							0			
			13	50	30		3	1	1	0	0			1							0			
			14	60	15		4	3	2	1	0			2							1			
			15	75	15	1	3	6	2	4	0			2							2	2		
			16	75	20		1	1	1	0	0			1							0			
			17	60	30		0	3	1	2	0			1							2			
			18	70	15		0	4	1	2	1			1					1		1			
			19	45	15		1	2	0	1	1			0							1			
			20	25	10	1	3	2	0	1	1			0							1			
	F2		X	40	21		2	3	2	1	1			1							1			
	F2		SD	25	8		2	2	1	1	1			1							1			
		W	8	15	15			2	1		1			1										
		W	9	20	30			3	2		1			2										
	F2	W	X	18	23			3	2		1			2										
	F2	W	SD	3	8			1	1		0			1										

Table 3. Cover data collected from Trial 70.1 in 1983 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	F3		1	45	15			4	4	0		2	1	0			2		0		0			
			2	85	10			6	6	0		1	1	1		3			0		0			
			3	80	15			10	5	5		1		4					5		0			
			4	40	20			12	4	8		2		2					3		5			
			5	15	15			4	4	0		2		2					0		0			
			6	50	25		3	9	7	2		2		5					2		0			
			7	55	20	1		11	5	5	1	3		2					5		0			
			11	65	30			3	0	3		0		0					3		0			
			12	70	15			4	2	2	1	0		2					1		1			
			13	80	10			9	2	7		0		2					5		2	1		
			14	85	10		1	2	2	0		0		2					0		0			
			15	85	10			7	5	1	1	1		3					1		0			
			16	87	10			4	3	1		1		2					1		0			
			17	80	15			7	5	2		0		5					2		0			
			18	70	15			27	23	4		3		20					4		0			
			19	80	10			21	21	0		1		20					1		0			
			20	55	15			6	3	3		1		2					2		1			
	F3		X	66	15			9	6	3		1		4					2		1			
	F3		SD	20	6			6	6	2		1		6					2		1			
		W	8	40	20			2	2		0	1		1										
		W	9	35	25			3	2		1	0		2										
		W	10	20	30			3	3		0	1		1		1								
	F3	W	X	32	25			3	2		0	1		1										
	F3	W	SD	8	4			0	0		0	0		0										

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	F4		1				1	11	9	1	1	0	1	1		0			0				1	
			2	45	5	1	2	21	12	9	0	0	2			0			1				8	
			3	25	5	1	0	9	3	5	1	1	1			1			0				0	
			4	10	5	1	3	3	2	1	0	1	1			0			0				1	
			5	20	5	0	2	4	1	3	0	0	0			1			1				2	
			6	15	10	0	0	7	4	3	0	1	2			1			1				2	
			7	30	10	0	5	14	1	5	8	0	0			1			0				5	
			8	40	20	0	0	9	3	0	6	0	0	1		2			0				0	
			11	50	30	0	0	4	2	2	0	0	0	1		1			0				2	
			12	50	20	0	2	6	5	0	1	0	0			5			0				0	
			13	65	15	1	5	8	4	4	0	1	2			1			0				4	
			14	50	30	1	3	6	2	4	0	1	1			0			1		1		2	
			15	75	15	0	1	10	6	2	2	1	0			0			0				2	
			16	80	10	0	2	19	9	1	0	1	3			5			7				3	
			17	35	25	0	0	2	0	1	1	0	0			0			1				0	
			18	80	15	0	1	13	3	7	3	0	2			1			7				0	
			19	85	10	1	0	10	2	6	2	0	1			1			3				3	
			20	50	10	0	1	11	6	5	0	2	2	2		0			0		1		4	
	F4		X	47	14	0	2	9	4	3	1	1	1			1			1				2	
	F4		SD	23	8	0	2	5	3	2	2	1	1			1			2				2	
		BW	9	80	10			8	2		6			1		1								
	F4	W	10	60	20			3	3		0			2		1								

Table 3. Cover data collected from Trial 70.1 in 1983 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	F5		1	70	0	0	1	37	14	23		3	0	0		10		1	0				20	2
			2	80	0	1	0	27	7	20		2	0	0		5		0	0				20	0
			3	65	0	1	1	19	4	15		1	0	2		0		1	0				15	0
			4	60	0	0	0	15	0	15		0	0	0		0		0	0				15	0
			5	80	0	1	0	20	0	20		0	0	0		0		0	0				20	0
			7	95	0	0	0	52	12	40		1	0	5		5		1	0				40	0
			11	80	10	0	0	11	3	8		0	0	2		1		0	0				8	0
			14	90	0	1	1	71	11	60		2	0	2		5		2	0				60	0
			15	85	5	0	3	47	7	40		1	3	0		3		0	0				40	0
			16	80	10	1	0	74	24	50		3	5	0		5		1	0				50	0
			17	70	10	1	1	32	4	28		1	2	0		1		0	0				20	8
			18	100	0	0	0	95	15	80		0	5	0		10		0	10				70	0
			19	95	0	0	0	100	25	75		0	5	2		15		3	0				75	0
			20	70	0	0	0	98	28	70		1	5	10		10		2	0				70	0
	F5		X	80	3	0	1	50	11	39		1	2	2		5		1	1				37	1
	F5		SD	12	4	0	1	31	9	23		1	2	3		5		1	3				23	2
		BW	8																					
		BW	9																					
		BW	10	75	20			11	4	5	2			3		1							5	
		B	6																					
		B	12																					
		B	13	70	5			69	19	50		2	5			10		2					50	

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	F6		1	45	10			6	6	1		5		1				0	1				0	
			2	50	20			5	5	0		5		0				0	0				0	
			3	15	5			5	2	3	1	2		0				0	1				2	
			4	20	0			9	1	8		1		0				0	0				8	
			5	35	0			3	1	2		1		0				0	1				1	
			6	50	0			11	1	10		1		0				0	0				10	
			7	50	0			8	3	5		1		2				0	0				5	
			11	80	10			5	2	3		1		1				0	0				3	
			16	87	10			13	3	10		3		0				0	0				10	
			17	85	10			16	4	12		3		1				0	10				2	
			18	95	2			19	4	15		3		0				1	10				5	
			19	100	0			22	7	15		5		0				2	5				10	
			20	95	0			32	17	15		10		3				4	0				15	
	F6		X	62	5			12	4	8		3		1				1	2				5	
	F6		SD	28	6			8	4	5		3		1				1	4				5	
		B	8	70	10			6	4	2		2		2					0				2	
		B	10																					
		B	12																					
		B	13																					
		B	14	50	0			14	8	6		5		3					1				5	
		B	15	85	0			12	4	8	1	3		1					3				5	
		BW	9																					

Table 3. Cover data collected from Trial 70.1 in 1983 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	P1		3	80	15			7	4	3	0			4							0		3	
			4	75	20			7	2	5	0			2							0		5	
			5	80	10			16	5	11	0			5							1		10	
			6	60	15			7	3	4	0			3							2		2	
			7	75	10			8	4	4	0			4							0		4	
			8	90	5			32	30	1	1			30							0		1	
			11	95	3			22	15	1	6			15							0		1	
			17	85	12			30	15	15	0			15					1		4		10	
			18	95	2			32	20	12	0			20							5		7	
			19	95	4		1	14	10	4	0			10					2		0		0	
			20	95	3			21	10	11	0			10							6		5	
	P1		X	84	9			18	11	6	1			11							2		4	
	P1		SD	11	6			10	8	5	2			8							2		3	
		S	1	70	15			3	2	1		1		1									1	
		S	2	65	25			3	3	0		0		3									0	
	P1	S	X	68	20			3	3	1		1		2									1	
	P1	S	SD	3	5			0	1	1		1		1									1	
		B	9																					
		B	10																					
		B	12																					
		B	13																					
		B	14																					
		B	15																					
		B	16	95	2			26	20	6				20					1		5			

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	P5		3	90	5			22	2	20	0	1		0				1					20	0
			4	95				38	3	30	5	1		2				0					30	0
			5	95				58	8	50	0	3		5				0					50	0
			6	95				76	16	60	0	1		10				5					60	0
			7	95				56	6	50	1	4		2				0					50	0
			8	95				22	5	10	7	2		3				0					10	0
			9	95				48	17	30	1	2		15				0					30	0
			10	95				43	23	20	0	2		20				1					20	0
			11	95				57	17	40	0	2		15				0					40	0
			14	95				80	20	60	0	0		20				0					60	0
			15	95				83	13	70	0	2		10				1					70	0
			16	95				96	24	72	0	2		20				2					70	2
			17	95				57	7	50	0	2		5				0					40	10
			18	95				81	11	70	0	1		10				0					70	0
			19	95				67	5	60	2	0		5				0					60	0
			20	95				96	16	80	0	0		15				1					80	0
	P5		X	95				61	12	48	1	2		10				1					48	1
	P5		SD	1				22	7	21	2	1		7				1					20	2
		S	1	85	5			56	25	30	1	10		15									30	
		S	2	90	5			48	2	30	16	1		1									30	
	P5	S	X	88	5			52	14	30	9	6		8									30	
	P5	S	SD	3	0			4	12	0	8	5		7									0	
		B	12	95				57	15	40	2			15									40	
		B	13																					

Table 3. Cover data collected from Trial 70.1 in 1983 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	P6		3	85	10		1	10	4	6	0	2		1				1	1				5	
			4	90	5			2	1	1	0	1		0					1				0	
			5	90	8			10	3	6	1	2		1					1				5	
			6	95	3			34	5	29	0	3		0				2	4				2	
			7	90	5			6	3	3	0	2		1					0				3	
			8	85	7		2	6	2	3	1	1		1					1				2	
			9	95	0		1	9	3	5	1	1		2					0				5	
			10	95	2			9	4	5	0	3		1					0				5	
			11	95	4			17	5	10	2	0		5					0				10	
			12	95	2			22	11	11	0	1		10					1				10	
			14	95	0			39	19	20	0	4		15					0				20	
			15	95	0			24	4	20	0	2		2					0				20	
			16	95	0			26	5	20	1	3		2					5				15	
			17	95	0			24	9	15	0	5		3					5				10	
			18	95	0			19	6	13	0	5		1					2		1		10	
			19	90	5			31	10	21	0	5		5					1				20	
			20	90	5			18	5	13	0	2		3					3				10	
	P6		X	92	3			18	6	12	0	2		3					1				9	
	P6		SD	3	3			10	4	8	1	1		4					2				6	
		S	1	90	5			8	5	3	0	5		0					1				2	
		S	2	90	5			15	4	5	4	2		2					0				5	
	P6	S	X	90	5			12	5	4	2	4		1					1				4	
	P6	S	SD	0	0			4	1	1	2	2		1					1				2	
		B	13																					

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	PF1		3	45	30			1	0	0	1			0							0			
			4	40	40			2	0	0	2			0							0			
			5	25	35			1	1	0	0	1		0							0			
			6	65	20			3	2	1	0	1		1					1		0			
			7	45	15			5	2	1	2			2							1			
			8	60	15			4	2	1	1			2							1			
			9	80	10			8	5	3	0			5							3			
			10	80	15			8	6	2	0	1		5					1		1			
			11	90	5			30	30	0	0			30							0			
			12	90	5			33	30	1	2			30							0		1	
			13	95	5			31	30	0	1			30							0			
			14	70	15			14	11	2	1	1		10							1		1	
			15	70	15			3	3	0	0			3							0			
			16	75	15		1	9	5	4	0			5					1		3			
			17	75	20			13	7	5	1			7					1		3		1	
			18	45	50			13	10	3	0			10							3			
			19	60	15			5	3	1	1			3							1			
			20	40	10			1	1	0	0			1							0			
	PF1		X	64	19			10	8	1	1			8							1			
	PF1		SD	20	12			10	10	1	1			10							1			
		S	1	60	0			51	40		1	10		30										
		S	2	40	35			5	3		2	0		3										
	PF1	S	X	50	18			28	22		2	10		17										
	PF1	S	SD	10	18			23	19		1	0		14										

Table 3. Cover data collected from Trial 70.1 in 1983 (continued).

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	PF5		3	40	20			0	0	0	0			0									0	
			4	15	25			3	0	0	3			0									0	
			5	5	25			1	0	1	0			0									1	
			6	5	15			3	0	3	0			0									3	
			7	15	10			1	1	0	0			1									0	
			8	40	15			2	1	0	1			1									0	
			9	25	15			1	0	1	0			0									1	
			10	45	15			12	1	10	1			1									10	
			11	70	15			15	5	7	1			5									7	
			12	95	2			36	10	25	1			10									25	
			13	95	2			26	5	20	1			5									20	
			14	60	10			14	4	10	0	1		3									10	
			15	50	15			4	0	1	3			0									1	
			16	40	20			1	0	0	1			0									0	
			17	45	20			23	2	20	1	1		1									20	
			18	20	35			16	6	10	0	1		5									10	
			19	40	20	1		14	2	12	0			2									10	2
			20	30	15	1		0	0	0	0			0									0	
	PF5		X	41	16			10	2	7	1			2									7	
	PF5		SD	26	8			10	3	8	1			3									8	
		S	1	80	5			55	15	10	30	5		10									10	
		S	2	35	15			7	7	0	0	5		2									0	
	PF5	S	X	58	10			31	11	5	15	5		6									5	
	PF5	S	SD	23	5			24	4	5	15	0		4									5	

YR	TR	ST	#	M	P	F	W	V	G	L	I	AG	DG	FR	LP	PA	PC	PP	TH	TP	TR	MS	LC	SN
83	PF6		4	15	35			4	1	0	3	1		0					0				0	
			5	15	25			2	0	2	0	0		0					1				1	
			6	10	30			0	0	0	0	0		0					0				0	
			7	35	10			2	1	1	0	1		0					1				0	
			8	40	10	1		4	1	2	1	1		0					2				0	
			9	25	10			3	1	1	1	1		0					1				0	
			10	30	10			6	2	2	2	1		1					2				0	
			11	70	5			7	3	2	2	2		1					2				0	
			12	95	0			8	3	5	0	1		1				1	0				5	
			13	85	5			6	3	2	1	2		1					1				1	
			14	80	5			7	3	4	0	1		2					2				2	
			15	40	20			3	3	0	0	1		2					0				0	
			16	30	20			1	1	0	1	1		0					0				0	
			17	50	40			9	3	4	2	2		1					1				3	
			18	15	60			11	5	6	0	3		2					3				3	
			19	70	10	1		10	2	7	0	1		1					2				5	
			20	60	10	1		6	1	5	0	1		0					0				0	
	PF6		X	45	18			5	2	3	1	1		1					1				1	
	PF6		SD	26	15			3	1	2	1	1		1					1				2	
		S	1					25	5		20	5												
		S	2	85	5			20	10		10	10												
		S	3	30	30			3	1		2	1												
	PF6	S	X	58	18			16	5		11	5												
	PF6	S	SD	28	13			9	4		7	4												

Table 4. Foliar chemistry data from Trial 70.1 in 1980.

GROUP	PLOT	%C	%N	%P	%K	%Ca	%Mg	Wt/m2
70R	41					0.46	0.37	0.44
	42							0.00
	43		1.34	0.06	0.50	0.20	0.08	7.89
	44	36.27	0.64	0.05	0.52	0.14	0.02	8.33
	45	36.57						1.33
	46	39.36	1.81	0.15	0.59	1.27	0.29	11.44
	47	33.73	0.75	0.13	0.88	0.23	0.07	13.22
	48							
	49	42.80	0.78	0.09	0.22	0.32	0.01	8.11
70PF	74	40.17	0.59	0.07	0.37	0.29	0.08	11.11
	75	37.31	1.18	0.12	0.85	0.52	0.10	37.22
	76	38.37	0.83	0.09	0.58	0.36	0.09	36.67
	77	38.33	0.74	0.06	0.59	0.48	0.10	15.56
	78	39.46	0.66	0.07	0.28	0.11	0.29	9.78
	79	36.87	0.59	0.08	0.35	0.30	0.07	34.11
	80	38.83	0.93	0.08	0.45	0.39	0.09	77.89
	81	38.20	0.59	0.06	0.31	0.35	0.08	8.56
	82		0.55	0.08	0.40	0.09	0.26	4.89
	83	40.51		0.15		0.67	0.10	4.56
	84	38.93	0.69	0.10	0.62	0.24	0.08	71.67
	85	38.65	0.51	0.07	0.36	0.31	0.09	17.00
70F1	50	39.81	1.74	0.10	0.87	0.95	0.13	6.89
	51	38.96	1.16	0.09	0.59	0.32	0.12	17.22
	52	39.60	0.76	0.10	0.56	0.53	0.10	34.11
	53	38.63	1.83	0.13	0.98	0.85	0.18	56.00
70F5	54	41.29	1.75	0.06	0.59	0.46	0.11	39.78
	55	41.44	2.16	0.12	1.28	0.68	0.14	163.00
	56	40.20	2.07	0.09	1.19	0.52	0.15	909.78
	57	40.68	2.09	0.11	1.25	0.60	0.17	447.11
70F6	58	39.42	2.24	0.12	1.16	0.97	0.27	35.56
	59	37.89	0.73	0.10	0.54	0.24	0.09	29.33
	60	38.88	1.73	0.13	1.20	0.80	0.22	27.00
	61	40.24	0.77	0.12	0.73	0.32	0.12	59.11
70P1	62	39.96	0.83	0.12	0.66	0.29	0.12	15.44
	63	38.84	0.72	0.09	0.48	0.25	0.08	104.00
	64	39.93	0.77	0.11	0.60	0.31	0.07	119.11
	65	39.37	1.60	0.14	1.08	0.60	0.13	33.11
70P5	66	42.03	2.52	0.14	1.30	0.60	0.15	124.33
	67	41.18	1.60	0.10	1.06	0.45	0.14	129.67
	68	40.93	2.23	0.13	1.17	0.49	0.16	300.33
	69	42.71	1.93	0.16	1.15	0.54	0.13	298.67
70P6	70	37.52	0.72	0.10	1.42	0.56	0.16	25.67
	71	40.64	1.04	0.15	0.90	0.37	0.10	25.78
	72	40.02	0.66	0.08	0.40	0.22	0.07	30.33
	73	38.56	1.06	0.11	0.68	0.49	0.15	73.78

Table 5. Number and size of invading woody species in Trial 70.1.

Species	Treatment	Year	0-9cm Plot	0-9cm Inter-Row	10-19cm Plot	10-19cm Inter-Row	20-39cm Plot	20-39cm Inter-Row	40-69cm Plot	40-69cm Inter-Row	>70cm Plot	>70cm Inter-Row
Hemlock												
	R	1980			11	20						
		1982	535	619	30	52		10				
		1985					6	10				
	F-5	1980				12						
		1982	7	124	10		7					
		1985					3	12				
	F5	1980				63						
		1982		63				63				
		1985						63				
	P16	1980				69		35				
		1982	10	69		35		35				
		1985				35		69				
	P5	1980			17	63						
		1982		63		63		63				
		1985						63		63		
	PF	1980			36	100	5	20				
		1982		305	127	240	36	40				
		1985					56	100	10	20		
	AG1	1980			132	105	11					
		1982	211	295	237	232	26	21				
		1985					95	42	11	21		
	AG2	1980			55							
		1982		284	154			20				
		1985					20	20				
Vaccinium												
	R	1980										
		1982	96	142	6							
		1985					3					
	F-5	1980										
		1982	133	755	39	161						
		1985					19	87				
	F5	1980										
		1982	58	443		127						
		1985					19	63				
	P16	1980										
		1982	135	1458	58	174						
		1985					48	278				
	P5	1980										
		1982	17	127		190						
		1985					253					
	PF	1980										
		1982	274	500	51	60	5					
		1985					61	40				
	AG1	1980										
		1982	58	63	47	63						
		1985					26	21				
	AG2	1980										
		1982	60	40	5							
		1985					10	20				

Table 5. Number and size of invading woody species in Trial 70.1 (continued).

Species	Treatment	Year	0-9cm Plot	0-9cm Inter-Row	10-19cm Plot	10-19cm Inter-Row	20-39cm Plot	20-39cm Inter-Row	40-69cm Plot	40-69cm Inter-Row	>70cm Plot	>70cm Inter-Row
Cottonwood												
	R	1980			8	30	3	20				
		1982	17	31	14	20	19	30	14	10		
		1985					25	20	25	30	3	
	F-5	1980			7		3	12		12		
		1982			7		7	25		25		12
		1985					10	25				37
	F5	1980						63				
		1982						63				
		1985							19		19	
	P16	1980				35						
		1982					10	35				
		1985					10	35				
	P5	1980					17		63			
		1982					17		63			
		1985					17				63	
	PF	1980			10	20						
		1982			5		5	40	5	5		
		1985						40	5	10		
	AG1	1980			47	21	58	42	58	42	16	42
		1982	11		26	42	47	21	74	42	69	105
		1985					42	84	69	21	95	105
	AG2	1980			20	20	40		25		25	
		1982	30	40	45	60	55		20		30	
		1985					35	60	55		40	
Willow												
	R	1980			6	20	14	30		10		
		1982	33	10	11	10	25	10	11	51	3	
		1985					19	10	16	41	8	20
	F-5	1980						25		25		
		1982	3	12		12		25				25
		1985						37				25
	F5	1980										
		1982										
		1985										
	P16	1980						35				
		1982								35		
		1985								35		
	P5	1980										
		1982										
		1985										
	PF	1980					5	20		20		
		1982				20		20		20	5	20
		1985						40		40	5	20
	AG1	1980			26	21	21	21	16	42	16	
		1982	11		16		37	42	26	21	21	42
		1985					37	21	32		26	63
	AG2	1980			20		10		15		10	
		1982	20		15		25		15		20	
		1985					20		15		25	

Table 6. The height of Sitka alder in Trial 77.1.

Years		3rd ht	4th ht	width		5th ht	width		6th ht	width		7th ht	8th ht	10th ht
				E-W	N-S		E-W	N-S		E-W	N-S			
	#	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm	cm
ROW 1	1	54	74	118	79	106	160	140	130	190	180	152	161	197
	2	50	75	115	140	92	165	146	110	125	175	128	102	146
	3	60	55	61	86	65	90	101	95	120	135	120	130	152
	4	50	53	88	63	65	114	80	85	140	105	95	96	127
	5	36	38	24	31	46	34	37	60	60	55	65	65	79
	6	97	140	110	130	160	137	170	190	165	165	225	230	289
	7	34	33	38	38	31	40	37	45	60	70	61	64	116
	8	40	40	90	60	62	112	123	90	115	145	127	141	192
	9	28	30	56	46	33	59	52	60	85	95	87	105	166
	10	44	55	60	53	65	88	75	110	125	110	132	145	216
ROW 2	1	54	78	138	125	80	146	160	110	175	175	115	158	230
	2	35	106	40	63	93	45	100	120	70	65	142	160	215
	3	43	32	77	72	50	86	86	60	90	80	75	83	95
	4	30	28	37	38	26	46	48	35	55	65	52	67	106
	5	20	27	52	58	35	69	78	55	75	75	70	75	108
	6	35	36	47	44	40	39	42	45	45	50	45	48	73
	7	28	40	41	32	54	62	43	75	65	95	113	120	171
	8	55	87	127	142	127	180	180	180	150	190	217	220	266
	9	36	74	82	110	85	120	137	105	145	110	127	132	173
	10*	34	65			107			130			160	180	231
	11	47	57	96	75	75	112	92	100	145	120	137	154	193
ROW 3	1	36	47	55	62	77	86	107	100	150	145	125	133	172
	2	39	48	72	71	45	80	87	55	85	85	55	60	106
	3	34	49	78	91	62	96	108	80	110	115	87	95	116
	4	35	43	80	64	71	112	80	100	120	100	118	133	179
	5	40	44	42	62	51	50	70	60	65	100	71	75	96

*cottonwood

Trial 82.1 : LEGEND

Soil Type

A : wasterock
B : 10 cm Spy Hill overburden
C : 30 cm Spy Hill overburden
D : 10 cm 594 Bench overburden
E : 30 cm 594 Bench overburden

Seed Mix Type

A : annual grass
L : legume
EC : erosion control
GL : grass plus legume

Table 7. Data collected from Trial 82.1 in 1982.

Year	Block	Soil Type	Seed Mix	% Cover
82A	1	A	A	45
82A	1	A	L	20
82A	1	A	E	35
82A	1	A	G	30
82A	1	B	A	30
82A	1	B	L	5
82A	1	B	E	25
82A	1	B	G	10
82A	1	C	A	10
82A	1	C	L	5
82A	1	C	E	5
82A	1	C	G	5
82A	1	D	A	30
82A	1	D	L	15
82A	1	D	E	30
82A	1	D	G	20
82A	1	E	A	15
82A	1	E	L	2
82A	1	E	E	15
82A	1	E	G	10
82A	2	A	A	40
82A	2	A	L	20
82A	2	A	E	25
82A	2	A	G	20
82A	2	B	A	30
82A	2	B	L	7
82A	2	B	E	10
82A	2	B	G	15
82A	2	C	A	20
82A	2	C	L	2
82A	2	C	E	10
82A	2	C	G	10
82A	2	D	A	35
82A	2	D	L	20
82A	2	D	E	25
82A	2	D	G	35
82A	2	E	A	25
82A	2	E	L	10
82A	2	E	E	15
82A	2	E	G	15
82A	3	A	A	50
82A	3	A	L	15
82A	3	A	E	30
82A	3	A	G	25
82A	3	B	A	35
82A	3	B	L	10
82A	3	B	E	20
82A	3	B	G	20
82A	3	C	A	30
82A	3	C	L	2
82A	3	C	E	15
82A	3	C	G	5
82A	3	D	A	30
82A	3	D	L	10
82A	3	D	E	20
82A	3	D	G	15
82A	3	E	A	35
82A	3	E	L	5
82A	3	E	E	20
82A	3	E	G	10
82A	4	A	A	50
82A	4	A	L	20
82A	4	A	E	35
82A	4	A	G	20
82A	4	B	A	35
82A	4	B	L	10
82A	4	B	E	35
82A	4	B	G	15
82A	4	C	A	30
82A	4	C	L	5
82A	4	C	E	20
82A	4	C	G	10
82A	4	D	A	50
82A	4	D	L	15
82A	4	D	E	35
82A	4	D	G	35
82A	4	E	A	35
82A	4	E	L	5
82A	4	E	E	20
82A	4	E	G	15

Table 8. Data collected from Trial 82.1 in 1983.

Year	Block	Soil Type	Seed Mix	% Cover	Biom (g/m2)	Alder #	Height(cm)					Pine #	Height(cm)				
83A	1	A	A	8	76.7	5	45	40	17	14	14	5	30	27	26	25	17
83A	1	A	L	35	301.1	3	55	42	35			3	30	20	17		
83A	1	A	E	90	491.1	0						2	17	16			
83A	1	A	G	45	376.7	4	55	50	50	28		1	25				
83A	1	B	A	3	68.9	5	50	50	47	30	25	5	32	28	28	25	24
83A	1	B	L	12	16.7	5	50	45	43	29	19	5	36	32	27	23	19
83A	1	B	E	35	51.1	3	57	40	23			4	34	27	26	14	
83A	1	B	G	35	134.4	4	55	30	22	14		5	30	27	25	17	15
83A	1	C	A	2		5	67	35	35	27	20	3	30	15	15		
83A	1	C	L	5		5	65	55	55	20	10	1	27				
83A	1	C	E	7		5	55	47	30	22	15	1	25				
83A	1	C	G	5		4	30	30	10	10		2	30	20			
83A	1	D	A	5		2	30	28				4	30	25	20	20	
83A	1	D	L	30		1	30					5	25	18	17	12	10
83A	1	D	E	70		4	41	20	18	7		3	25	22	20		
83A	1	D	G	60		4	33	18	15	8		5	20	18	17	15	13
83A	1	E	A	5		5	35	25	15	15	15	4	30	30	30	25	
83A	1	E	L	7		4	45	30	30	25		5	40	35	30	20	10
83A	1	E	E	50		5	20	13	10	10	5	5	35	30	30	30	20
83A	1	E	G	30		5	24	1	1	1	1	4	35	35	30	15	
83A	2	A	A	5	86.7	5	45	34	28	22	22	2	27	22			
83A	2	A	L	35	80.0	4	45	45	24	20		3	23	20	15		
83A	2	A	E	95	146.7	1	12					3	22	21	20		
83A	2	A	G	90	423.3	1	45					0					
83A	2	B	A	8		4	40	35	30	13		5	30	30	28	25	20
83A	2	B	L	15		5	45	45	40	30	25	5	32	30	25	25	25
83A	2	B	E	50		4	60	20	9	5		4	30	28	24	23	
83A	2	B	G	25		5	27	20	15	15	10	5	25	23	21	20	20
83A	2	C	A	5		5	38	35	23	20	10	5	30	27	25	23	15
83A	2	C	L	3		5	35	25	23	23	17	3	30	25	8		
83A	2	C	E	20		5	35	20	12	7	7	3	30	27	22		
83A	2	C	G	15		5	55	33	30	17	9	4	25	20	20	15	
83A	2	D	A	6	91.1	5	64	37	31	15	15	4	31	30	25	20	
83A	2	D	L	35	140.0	5	45	20	20	18	17	2	22	12			
83A	2	D	E	95	200.0	4	60	36	8	5		4	22	20	15	12	
83A	2	D	G	70	118.9	5	47	47	37	19	16	5	28	21	17	14	11
83A	2	E	A	9	287.8	5	47	43	40	38	13	0					
83A	2	E	L	30	77.8	4	50	47	45	22		3	30	30	28		
83A	2	E	E	80	202.2	4	16	13	4	1		4	28	25	22	12	
83A	2	E	G	70	542.2	5	28	18	16	9	6	4	30	20	15	10	
83A	3	A	A	10		5	45	30	25	25	15	2	30	25			
83A	3	A	L	30		5	40	35	35	32	25	1	30				
83A	3	A	E	100		1	22					2	23	20			
83A	3	A	G	80		0						1	30				
83A	3	B	A	7	0.0	5	22	21	20	18	10	2	22	17			
83A	3	B	L	30	211.1	5	25	19	15	10	7	1	10				
83A	3	B	E	60	22.2	4	10	8	6	2		2	32	25			
83A	3	B	G	65	212.2	3	23	7	1			1	30				
83A	3	C	A	10	107.8	5	55	45	40	37	25	2	20	18			
83A	3	C	L	20	35.6	4	65	48	27	23		4	38	30	28	25	
83A	3	C	E	50	98.9	3	40	33	23			0					
83A	3	C	G	40	51.1	5	61	50	48	37	35	3	40	23	20		
83A	3	D	A	15		5	36	25	25	25	12	4	35	30	20	15	
83A	3	D	L	25		5	50	37	30	30	10	5	30	25	20	20	15

Table 8. Data collected from Trial 82.1 in 1983 (continued).

Year	Block	Soil Type	Seed Miix	% Cover	Biom (g/m2)	Alder #	Height(cm)					Pine #	Height(cm)				
83A	3	D	E	90		5	60	45	37	10	5	3	25	25	23		
83A	3	D	G	75		3	35	34	20			5	30	28	27	27	25
83A	3	E	A	5	85.6	5	60	30	30	19	15	4	25	25	22	20	
83A	3	E	L	40	64.4	5	55	45	45	15	10	4	25	25	15	10	
83A	3	E	E	75	233.3	4	23	20	10	5		5	35	35	35	30	20
83A	3	E	G	65	46.7	5	50	28	20	15	5	5	30	25	23	23	20
83A	4	A	A	8		4	37	30	15	5		3	35	35	25		
83A	4	A	L	70		3	32	20	20			1	28				
83A	4	A	E	95		0						2	28	5			
83A	4	A	G	70		0						2	30	30			
83A	4	B	A	8		1	2					5	30	28	28	25	25
83A	4	B	L	20		5	40	40	35	20	5	5	36	30	25	20	10
83A	4	B	E	80		2	30	22				1	30				
83A	4	B	G	70		1	2					5	30	28	28	25	25
83A	4	C	A	5	146.7	5	60	42	35	30	20	1	23				
83A	4	C	L	15	33.3	5	55	55	50	45	35	1	25				
83A	4	C	E	50	107.8	5	50	40	40	40	30	1	30				
83A	4	C	G	35	298.9	4	50	35	25	10		0					
83A	4	D	A	5	92.2	5	60	30	30	27	25	4	25	24	24	15	
83A	4	D	L	40	117.8	5	65	45	40	15	15	2	20	7			
83A	4	D	E	80	463.3	3	25	25	12			3	25	20	15		
83A	4	D	G	75	268.9	3	75	35	15			4	30	22	15	12	
83A	4	E	A	8		3	60	55	45			3	30	25	25		
83A	4	E	L	25		5	60	60	40	32	30	4	25	23	20	15	
83A	4	E	E	80		0						3	30	28	25		
83A	4	E	G	40		4	50	15	8	5		2	25	2			

Table 9. Data collected from Trial 82.1 in May, 1984.

Year	Block	Soil Type	Seed Mix	Alder #	Pine #
84S	1	A	A	4	3
84S	1	A	L	1	0
84S	1	A	E	1	1
84S	1	A	G	1	1
84S	1	B	A	0	0
84S	1	B	L	1	0
84S	1	B	E	0	0
84S	1	B	G	2	0
84S	1	C	A	5	1
84S	1	C	L	2	1
84S	1	C	E	1	0
84S	1	C	G	3	2
84S	1	D	A	2	3
84S	1	D	L	1	3
84S	1	D	E	4	3
84S	1	D	G	1	4
84S	1	E	A	4	2
84S	1	E	L	1	3
84S	1	E	E	1	3
84S	1	E	G	2	3
84S	2	A	A	3	0
84S	2	A	L	0	0
84S	2	A	E	0	0
84S	2	A	G	0	0
84S	2	B	A	4	1
84S	2	B	L	5	3
84S	2	B	E	2	3
84S	2	B	G	4	3
84S	2	C	A	5	3
84S	2	C	L	2	1
84S	2	C	E	2	3
84S	2	C	G	4	0
84S	2	D	A	2	1
84S	2	D	L	1	0
84S	2	D	E	2	0
84S	2	D	G	0	2
84S	2	E	A	4	0
84S	2	E	L	1	0
84S	2	E	E	0	0
84S	2	E	G	0	0
84S	3	A	A	3	1
84S	3	A	L	4	2
84S	3	A	E	0	0
84S	3	A	G	0	0
84S	3	B	A	2	0
84S	3	B	L	1	0
84S	3	B	E	2	0
84S	3	B	G	0	0
84S	3	C	A	5	1
84S	3	C	L	4	1
84S	3	C	E	1	0
84S	3	C	G	4	1
84S	3	D	A	2	2
84S	3	D	L	1	2
84S	3	D	E	2	2
84S	3	D	G	2	3
84S	3	E	A	4	4
84S	3	E	L	2	0
84S	3	E	E	2	1
84S	3	E	G	0	1
84S	4	A	A	1	1
84S	4	A	L	0	0
84S	4	A	E	0	0
84S	4	A	G	0	0
84S	4	B	A	2	1
84S	4	B	L	1	1
84S	4	B	E	1	0
84S	4	B	G	0	0
84S	4	C	A	3	0
84S	4	C	L	2	1
84S	4	C	E	0	0
84S	4	C	G	2	0
84S	4	D	A	4	0
84S	4	D	L	3	0
84S	4	D	E	3	0
84S	4	D	G	1	0
84S	4	E	A	2	0
84S	4	E	L	2	0
84S	4	E	E	0	0
84S	4	E	G	3	0

Table 10. Data collected from Trial 82.1 in September, 1984.

Year	Block	Soil Type	Seed Mix	% Cover	Biomass (g/m2)		Alder #	Height (cm)					Pine #	Height (cm)				
84A	1	A	A	0.0	0.0	0.0	4	25	13	13	10		1	5				
84A	1	A	L	20.0	153.3	428.9	3	15	15	5			0					
84A	1	A	E	75.0	186.7	511.1	0						0					
84A	1	A	G	40.0	214.4	127.8	2	34	15				0					
84A	1	B	A	1.0	0.0	0.0	5	52	36	35	25	23	3	27	13	10		
84A	1	B	L	15.0	556.7	115.6	3	40	37	36			0					
84A	1	B	E	15.0	30.0	87.8	2	84	27				2	20	18			
84A	1	B	G	15.0	16.7	73.3	3	40	24	3			2	30	22			
84A	1	C	A	0.0	0.0	0.0	5	114	66	62	45	34	3	20	16	14		
84A	1	C	L	4.0	0.0	12.2	5	90	54	40	17	15	1	30				
84A	1	C	E	10.0	91.1	52.2	4	37	34	24	15		1	18				
84A	1	C	G	7.0	80.0	18.9	4	44	40	16	13		2	28	27			
84A	1	D	A	0.0	0.0	0.0	2	68	40				4	37	23	23	10	
84A	1	D	L	20.0	80.0	344.4	1	20					4	30	25	24	10	
84A	1	D	E	30.0	125.6	165.6	5	22	18	12	12	3	3	28	25	25		
84A	1	D	G	25.0	113.3	201.1	4	17	14	5	4		4	25	25	23	22	
84A	1	E	A	0.5	0.0	0.0	4	20	20	20	23		3	34	32	13		
84A	1	E	L	3.0	36.7	41.1	4	40	36	34	25		5	43	34	27	26	12
84A	1	E	E	35.0	146.7	188.9	5	28	30	11	18	18	4	39	36	35	14	
84A	1	E	G	12.0	68.9	97.8	3	13	10	7			3	42	40	36		
84A	2	A	A	2.0	0.0	0.0	3	33	28	3			0					
84A	2	A	L	18.0	174.4	43.3	0						2	20	5			
84A	2	A	E	85.0	650.0	411.1	0						0					
84A	2	A	G	70.0	211.1	335.6	0						0					
84A	2	B	A	0.0	0.0	0.0	4	60	52	50	21		5	20	14	14	12	2
84A	2	B	L	8.0	110.0	46.7	5	47	44	44	43	71	4	27	26	23	15	
84A	2	B	E	15.0	175.6	195.6	4	83	57	10	5		3	32	30	30		
84A	2	B	G	12.0	76.7	167.8	5	40	36	35	27	25	3	35	31	24		
84A	2	C	A	0.0	0.0	0.0	5	56	45	42	42	40	5	30	30	18	16	13
84A	2	C	L	5.0	0.0	47.8	4	42	38	25	8		1	33				
84A	2	C	E	15.0	40.0	140.0	5	44	26	23	20	20	3	30	28	26		
84A	2	C	G	10.0	37.8	61.1	5	42	38	35	23	5	0					
84A	2	D	A	6.0	0.0	0.0	5	33	31	30	27	22	3	36	23	13		
84A	2	D	L	34.0	144.4	436.7	1	9					0					
84A	2	D	E	55.0	202.2	222.2	3	43	2	2			0					
84A	2	D	G	40.0	343.3	138.9	0						2	32	32			
84A	2	E	A	3.0	0.0	0.0	5	53	48	30	27	22	0					
84A	2	E	L	22.0	167.8	221.1	2	60	2				0					
84A	2	E	E	70.0	187.8	194.4	0						3	32	31	31		
84A	2	E	G	75.0	335.6	334.4	0						0					
84A	3	A	A	1.0	0.0	0.0	4	40	22	15	15		1	22				
84A	3	A	L	11.0	98.9	267.8	4	50	40	40	38		1	16				
84A	3	A	E	75.0	292.2	173.3	0						0					
84A	3	A	G	35.0	207.8	265.6	0						0					
84A	3	B	A	0.0	0.0	0.0	5	46	21	15	12	10	0					
84A	3	B	L	18.0	426.7	73.3	4	51	18	13	8		0					
84A	3	B	E	25.0	161.1	181.1	2	7	5				0					
84A	3	B	G	40.0	103.3	144.4	0						0					
84A	3	C	A	0.0	0.0	0.0	5	55	55	40	40	37	0					
84A	3	C	L	20.0	121.1	95.6	4	140	52	51	48		3	24	8	6		
84A	3	C	E	28.0	150.0	106.7	2	33	27				0					
84A	3	C	G	20.0	72.2	608.9	5	46	42	21	20	12	1	40				
84A	3	D	A	0.0	0.0	0.0	4	21	21	20	12		3	40	23	8		
84A	3	D	L	15.0	113.3	86.7	3	33	32	20			3	30	30	8		
84A	3	D	E	60.0	487.8	292.2	3	5	2	2			2	31	28			
84A	3	D	G	70.0	710.0	121.1	3	40	10	6			3	45	40	20		
84A	3	E	A	1.0	0.0	0.0	5	40	34	30	13	3	4	33	30	25	22	
84A	3	E	L	23.0	130.0	721.1	3	10	5	3			0					
84A	3	E	E	30.0	110.0	267.8	3	10	6	5			1	34				
84A	3	E	G	40.0	96.7	503.3	0						1	5				
84A	4	A	A	0.0	0.0	0.0	3	35	28	5			1	33				

Table 10. Data collected from Trial 82.1 in September, 1984 (continued).

Year	Block	Soil Type	Seed Mix	% Cover	Biomass (g/m2)		Alder #	Height (cm)					Pine #	Height (cm)		
84A	4	A	L	20.0	1142.2	94.4	2	10	7				0			
84A	4	A	E	75.0	855.6	255.6	0						0			
84A	4	A	G	25.0	227.8	164.4	0						0			
84A	4	B	A	1.0	0.0	0.0	5	53	38	28	28	27	1	27		
84A	4	B	L	10.0	0.0	106.7	5	45	40	35	15	4	3	34	15	6
84A	4	B	E	45.0	110.0	160.0	3	25	8	7	7	7	0			
84A	4	B	G	50.0	964.4	584.4	1	2					0			
84A	4	C	A	0.0	0.0	0.0	5	64	54	40	38	20	0			
84A	4	C	L	10.0	34.4	127.8	5	66	50	47	18	12	0			
84A	4	C	E	20.0	42.2	87.8	4	60	29	8	2		0			
84A	4	C	G	35.0	218.9	108.9	5	54	54	44	34	5	0			
84A	4	D	A	2.0	0.0	0.0	4	41	33	30	14		0			
84A	4	D	L	15.0	54.4	136.7	1	16					0			
84A	4	D	E	45.0	123.3	163.3	1	5					0			
84A	4	D	G	35.0	217.8	340.0	1	3					0			
84A	4	E	A	0.0	0.0	0.0	3	62	31	26			0			
84A	4	E	L	20.0	138.9	245.6	0	53	33	26	12		0			
84A	4	E	E	25.0	235.6	284.4	0						0			
84A	4	E	G	30.0	184.4	238.9	3	16	15	10			0			

Table 11. Data collected from Trial 82.1 in 1985.

Year	Block	Soil Type	Seed Mix	Alder #	Height (cm)					Pine #	Height (cm)				
85U	1	A	A	4	45	38	34	22		2	17	7			
85U	1	A	L	3	37	27	13			0					
85U	1	A	E	0						0					
85U	1	A	G	2	34	22				0					
85U	1	B	A	5	80	67	53	42	38	3	29	13	10		
85U	1	B	L	3	63	56	47			0					
85U	1	B	E	2	106	50				2	20	18			
85U	1	B	G	4	37	29	13	10		3	32	23	7		
85U	1	C	A	5	132	87	94	67	57	3	22	14	13		
85U	1	C	L	5	79	74	72	43	18	1	27				
85U	1	C	E	4	46	40	39	20		0					
85U	1	C	G	5	59	50	41	18	5	2	30	27			
85U	1	D	A	2	80	52				4	41	24	22	10	
85U	1	D	L	1	30					4	41	32	23	10	
85U	1	D	E	5	41	31	30	29	8	3	31	30	24		
85U	1	D	G	4	27	24	13	9		4	26	24	23	23	
85U	1	E	A	4	44	40	32	24		3	37	31	13		
85U	1	E	L	4	54	52	36	30		5	47	42	35	27	19
85U	1	E	E	5	49	46	30	28	21	3	39	35	30		
85U	1	E	G	3	28	26	25			3	42	35	33		
85U	2	A	A	2	23	12				0					
85U	2	A	L	1	7					0					
85U	2	A	E	0						0					
85U	2	A	G	0						0					
85U	2	B	A	4	82	77	73	43		5	18	18	13	5	2
85U	2	B	L	5	91	63	35	35	23	5	27	24	23	11	3
85U	2	B	E	4	98	34	14	13		3	27	26	10		
85U	2	B	G	5	65	58	57	54	50	3	39	30	23		
85U	2	C	A	5	89	75	71	68	55	5	30	26	21	21	13
85U	2	C	L	4	64	46	23	20		1	29				
85U	2	C	E	4	75	46	40	10		3	28	28	26		
85U	2	C	G	5	66	64	53	44	16	1	4				
85U	2	D	A	5	70	57	47	43	41	2	39	24			
85U	2	D	L	1	13					0					
85U	2	D	E	3	31	12	7			0					
85U	2	D	G	0						3	32	31	21		
85U	2	E	A	4	70	64	46	45		0					
85U	2	E	L	3	31	13	11			0					
85U	2	E	E	0						2	35	32			
85U	2	E	G	0						0					
85U	3	A	A	4	64	39	31	29		0					
85U	3	A	L	3	65	60	13			0					
85U	3	A	E	0						0					
85U	3	A	G	0						0					
85U	3	B	A	4	61	37	23	18		0					
85U	3	B	L	4	30	6	5	2		0					

Table 11. Data collected from Trial 82.1 in 1985 (continued).

Year	Block	Soil Type	Seed Mix	Alder #	Height (cm)					Pine #	Height (cm)			
85U	3	B	E	3	21	12	9			0				
85U	3	B	G	0						0				
85U	3	C	A	5	75	73	70	64	47	0				
85U	3	C	L	4	122	89	71	31		2	22	13		
85U	3	C	E	2	59	33				0				
85U	3	C	G	5	81	62	49	37	26	2	63	40		
85U	3	D	A	4	30	21	18	13		3	45	26	8	
85U	3	D	L	3	29	18	14			2	19	13		
85U	3	D	E	2	5	7				2	30	25		
85U	3	D	G	3	25	14	6			3	50	44	44	
85U	3	E	A	5	61	58	50	31	19	4	34	32	26	25
85U	3	E	L	3	22	21	4			0				
85U	3	E	E	3	19	16	11			1	38			
85U	3	E	G	4	13	13	11	8		1	11			
85U	4	A	A	3	46	35	12			2	34	8		
85U	4	A	L	1	23					0				
85U	4	A	E	0						0				
85U	4	A	G	0						2	18	4		
85U	4	B	A	5	77	52	51	41	34	1	27			
85U	4	B	L	5	70	56	26	24	19	2	8	5		
85U	4	B	E	3	45	13	6			0				
85U	4	B	G	0						0				
85U	4	C	A	5	83	71	63	63	50	0				
85U	4	C	L	5	76	62	47	41	15	0				
85U	4	C	E	4	73	52	51	29		0				
85U	4	C	G	4	80	13	13	8		0				
85U	4	D	A	4	55	51	46	28		1	5			
85U	4	D	L	1	14					0				
85U	4	D	E	1	12					0				
85U	4	D	G	2	20	9				0				
85U	4	E	A	0						0				
85U	4	E	L	4	54	47	47	15		0				
85U	4	E	E	0						0				
85U	4	E	G	3	29	17	16			0				

Table 12. Data collected from Trial 82.1 in 1987.

Year	Block	Soil Type	Seed Mix	Alder #	Alder Height (cm)					Pine #	Pine Height (cm)				
85U	1	A	A	5	124	98	95	90	58	0					
85U	1	A	L	3	95	70	69			0					
85U	1	A	E	0						0					
85U	1	A	G	2	90	83				0					
85U	1	B	A	5	155	153	142	132	122	3	43	36	30		
85U	1	B	L	3	136	123	120			0					
85U	1	B	E	2	158	124				2	22	2			
85U	1	B	G	4	119	108	104	84		3	39	30	8		
85U	1	C	A	5	209	191	171	167	161	3	28	21	16		
85U	1	C	L	5	182	170	162	144	94	1	53				
85U	1	C	E	4	140	122	121	91		0					
85U	1	C	G	4	161	131	117	98		2	52	32			
85U	1	D	A	2	164	142				4	52	32	31	17	
85U	1	D	L	1	75					4	60	47	32	20	
85U	1	D	E	5	125	119	104	101	85	3	32	31	31		
85U	1	D	G	4	95	91	85	71		4	45	30	28	25	
85U	1	E	A	4	91	90	71	45		4	53	50	43	17	
85U	1	E	L	4	136	129	108	103		5	50	48	47	34	29
85U	1	E	E	5	115	108	102	78	51	3	53	43	35		
85U	1	E	G	3	93	75	56			3	47	44	39		
85U	2	A	A	2	107	91				0					
85U	2	A	L	0						0					
85U	2	A	E	0						0					
85U	2	A	G	1	76					0					
85U	2	B	A	4	162	156	151	129		4	21	13	11	8	
85U	2	B	L	5	144	144	127	118	110	5	38	32	29	12	6
85U	2	B	E	4	160	118	94	88		3	38	31	31		
85U	2	B	G	5	142	141	136	134	125	3	60	46	23		
85U	2	C	A	5	176	162	148	148	136	5	38	36	27	25	22
85U	2	C	L	4	160	128	110	101		1	35				
85U	2	C	E	4	164	141	126	94	87	3	44	35	33		
85U	2	C	G	5	146	137	120	118	101	0					
85U	2	D	A	5	152	138	135	134	112	3	53	32	25		
85U	2	D	L	1	69					0					
85U	2	D	E	3	95	88	70			0					
85U	2	D	G	0						2	46	39			
85U	2	E	A	4	168	164	137	106		0					
85U	2	E	L	3	154	96	85			0					
85U	2	E	E	1	77					2	49	41			
85U	2	E	G	1	66					0					
85U	3	A	A	4	123	112	110	93		0					
85U	3	A	L	3	133	116	98			1	5				
85U	3	A	E	0						0					
85U	3	A	G	1	49					0					
85U	3	B	A	4	160	110	103	95		0					
85U	3	B	L	5	109	70	50	31	27	0					

Table 12. Data collected from Trial 82.1 in 1987 (continued).

Year	Block	Soil Type	Seed Mix	Alder #	Height (cm)					Pine #	Height (cm)			
85U	3	B	E	3	97	92	70			0				
85U	3	B	G	1	78					0				
85U	3	C	A	5	180	177	176	164	116	0				
85U	3	C	L	4	218	191	164	136		2	28	24		
85U	3	C	E	2	139	133				0				
85U	3	C	G	5	152	140	132	120	118	1	50			
85U	3	D	A	4	107	94	84	84		3	50	31	24	
85U	3	D	L	3	118	104	92			0				
85U	3	D	E	2	66	26				2	38	34		
85U	3	D	G	3	122	74	64			2	57	50		
85U	3	E	A	5	170	158	150	120	88	4	45	42	37	36
85U	3	E	L	3	117	105	90			0				
85U	3	E	E	3	118	98	90			2	41	7		
85U	3	E	G	3	125	76	29			0				
85U	4	A	A	3	113	100	62			2	37	8		
85U	4	A	L	1	69					0				
85U	4	A	E	0						0				
85U	4	A	G	2	52	34				0				
85U	4	B	A	5	173	139	120	106	102	0				
85U	4	B	L	5	135	129	116	105	94	0				
85U	4	B	E	5	131	97	56	52	3	0				
85U	4	B	G	0						0				
85U	4	C	A	5	180	177	170	167	143	0				
85U	4	C	L	5	181	180	170	125	104	0				
85U	4	C	E	4	160	147	134	120		0				
85U	4	C	G	4	176	125	100	67		0				
85U	4	D	A	4	150	139	120	109		0				
85U	4	D	L	1	60					0				
85U	4	D	E	1	90					0				
85U	4	D	G	2	95	90				0				
85U	4	E	A	3	171	130	86			1				
85U	4	E	L	4	160	150	138	82		0				
85U	4	E	E	1	65					0				
85U	4	E	G	3	110	90	71			0				

Table 13. Results of the analysis of variance carried out on herbaceous cover data collected from Trial 82.1 in 1982, 1983 and 1984.

	Log Percent Cover Data			
source	df	mean sq	F value	F prob
a	4	7.95	81.11	0.00 *
b	3	2.61	26.59	0.00 *
ab	12	0.71	7.32	0.00 *
c	3	31.50	321.17	0.00 *
ac	12	0.24	2.53	0.00 *
bc	9	0.07	0.73	0.68
abc	36	0.14	1.48	0.08 *
d	2	10.97	111.93	0.00 *
ad	8	0.22	2.27	0.03 *
bd	6	0.38	3.91	0.00 *
abd	24	0.14	1.38	0.15
cd	6	16.70	170.34	0.00 *
acd	24	0.09	0.97	0.52
bcd	18	0.11	1.21	0.27
abcd	72	0.09		

a : soil type
b : block
c : seed mix
d : year
* : significant at the 0.05 level of probability

Table 14. Results of the analysis of variance carried out on herbaceous biomass data collected from Trial 82.1 in 1984.

	Biomass Data			
source	df	mean sq	F value	F prob
a	4	5.36	9.61	0.00 *
b	3	2.16	4.84	0.00 *
ab	12	0.56	1.25	0.27
c	2	2.28	4.10	0.07
ac	8	0.29	0.37	0.93
bc	6	0.56	1.25	0.30
abc	24	0.77	1.73	0.04 *
	60	0.44		

a : soil type
b : block
c : seed mix
* : significant at the 0.05 level of probability

Table 15. Results of the analysis of variance carried out on third year seedling survival data.

	Seedling Survival Data			
source	df	mean sq	F value	F prob
a	4	17.90	11.85	0.00 *
b	3	13.77	9.12	0.00 *
ab	12	6.28	4.16	0.00 *
c	3	12.87	8.52	0.00 *
ac	12	1.35	0.90	0.56
bc	9	0.74	0.49	0.87
abc	36	1.59	1.05	0.44
d	1	105.60	69.93	0.00 *
ad	4	7.66	5.07	0.00 *
bd	3	2.74	1.82	0.16
abd	12	1.57	1.04	0.44
cd	3	2.48	1.64	0.20
acd	12	1.15	0.76	0.68
bcd	9	0.57	0.38	0.94
abcd	36	1.51		

a : soil type
b : block
c : seed mix
d : tree species
* : significant at the 0.05 level of probability

APPENDIX D : LONG TERM PERFORMANCE OF INCOMPETENT WASTEROCK

Table 1. The grain size distribution in different rock types.

Table 2. Mineralogy of hornfels, potassic, and incompetent rock and wasterock

Table 3. Proportion and size of different minerals in potassic and incompetent rock thin sections

Table 4. Major element concentrations in the rock samples and the < 2 mm fraction of the wasterock

Table 5. Mineralogy of the < 2 um fractions of the wasterock and the crushed rock

Table 6. Trace element concentrations in the rock and the < 2 mm fractions of the wasterock

Table 7. AAO extractable element concentrations in quartz diorite soil

Table 8. Particle size distribution after simulated weathering

Table 9. Elemental composition of soxhlet residues

Table 10. Concentration of elements in soxhlet leachate

Table 11. Cumulative weight gain in soxhlet leachate

Table 12. Proportion of initial sample weight recovered in leachate

Table 1. The grain size distribution of different rock types.

Rock Type	% Grain Size 2000-500um	500-100um	100-50um	< 50um
HN.1	0	0	17	83
HN.2	0	20	24	56
HN.3	0	14	10	76
HN.4	0	0	17	83
PO.1	64	30	5	1
PO.2	52	33	5	10
PO.3	63	28	1	8
PO.4	72	17	6	5
PO.5	59	24	6	11
INC.1	72	10	4	14
INC.2	48	33	18	1
INC.3	27	35	7	31
INC.4	0	18	12	70
INC.5	0	13	10	77

HN : hornfels PO : potassic
INC : incompetent

Table 2. Mineralogy of hornfels, potassic, and incompetent rock and wasterock.

Sample	Fraction	Quartz	Kfeldspar	Plagioclase	Chlorite	Biotite	Sericite	Kaolinite	Calcite
		(estimated proportion in %)							
HN.1	rock	42	9	29	6	17	2	4	0
HN.2	rock	43	2	18	9	23	3	2	0
HN.3	rock	65	5	23	6	0	1	0	0
HN.4	rock	61	27	12	0	0	0	0	0
HN.5	rock	75	0	18	7	0	0	0	0
HN.WR1	< 2mm	39	11	6	6	18	7	7	6
HN.WR2	< 2mm	58	11	8	0	0	14	5	4
HN.WR3	< 2mm	34	12	10	7	14	10	6	6
PO.1	rock	48	33	11	1	3	0	0	2
PO.2	rock	62	25	1	0	3	8	2	2
PO.3	rock	39	45	4	0	3	7	0	3
PO.4	rock	54	30	2	0	2	5	4	3
PO.5	rock	47	37	0	0	2	5	6	3
PO.UW1	com	48	34	2	0	1	6	4	3
PO.UW2	com	56	27	2	0	2	5	3	3
PO.UW3	com	46	26	9	2	5	8	2	3
PO.UW4	com	57	26	3	0	1	7	2	3
PO.UW1	stone	54	37	2	0	1	3	2	2
PO.UW2	stone	64	27	2	0	1	2	2	2
PO.UW3	stone	47	27	11	2	5	5	0	2
PO.UW4	stone	63	27	4	0	0	3	1	2
PO.UW1	gravel	57	32	2	1	0	3	1	2
PO.UW2	gravel	64	24	2	0	3	2	1	3
PO.UW3	gravel	54	27	7	1	3	5	2	1
PO.UW4	gravel	64	26	2	0	0	3	2	3
PO.UW1	< 2mm	27	31	2	0	3	14	11	7
PO.UW2	< 2mm	31	32	2	2	5	13	6	6
PO.UW3	< 2mm	36	22	7	2	6	16	6	6
PO.UW4	< 2mm	35	25	4	1	3	18	6	5
INC.1	rock	56	14	6	0	3	14	1	5
INC.2	rock	32	31	7	3	24	0	0	2
INC.3	rock	68	2	0	0	0	23	1	5
INC.4 GM	rock	0	0	0	0	0	69	0	30
INC.5 GM	rock	0	0	0	0	0	78	0	22
INC.UW1	com	48	21	1	0	1	16	4	7
INC.UW2	com	41	38	1	0	1	9	4	5
INC.UW3	com	55	25	3	0	1	14	1	3
INC.UW4	com	6	3	1	0	0	60	0	26
INC.UW1	stone	73	15	1	0	0	5	1	5
INC.UW2	stone	31	59	1	0	0	3	2	3
INC.UW3	stone	65	25	2	0	1	4	1	2
INC.UW4	stone	9	7	1	0	0	49	0	35
INC.UW1	gravel	52	32	1	0	0	7	2	6
INC.UW2	gravel	61	27	1	0	0	5	2	4
INC.UW3	gravel	65	26	2	0	0	5	1	1
INC.UW4	gravel	9	3	1	0	0	42	1	30
INC.UW1	< 2mm	21	18	0	0	3	34	9	9
INC.UW2	< 2mm	32	28	0	0	2	17	7	7
INC.UW3	< 2mm	36	23	4	0	1	31	2	6
INC.UW4	< 2mm	0	0	0	0	0	86	0	14
INC.UW5	< 2mm	44	33	0	0	0	15	0	9
INC.UW6	< 2mm	47	26	3	0	0	11	3	10
INC.UW7	< 2mm	47	21	4	0	0	23	1	4
INC.UW8	< 2mm	19	4	4	0	0	61	2	15

UW : unweathered wasterock com : wasterock composite, weighted average of 3 fractions GM : groundmass

Table 3. Proportion and size of different minerals in potassic and incompetebt rock thin sections.

Sample	Mineral	Total %	2000-500um %	500-100um %	100-50um %	<50um %
PO.1	Quartz	38	33	5	0	0
	K feldspar	48	14	27	7	0
	Plagioclase	10	8	3	0	0
	Felsic Phyl.	4	0	0	0	4
PO.2	Quartz	54	29	20	5	0
	K feldspar	39	26	13	0	0
	Felsic Phyl.	6	0	0	0	6
	Isotropic	1	0	0	1	0
PO.3	Quartz	36	24	10	1	0
	K feldspar	44	31	13	0	0
	Plagioclase	4	2	2	0	0
	Felsic Phyl.	7	0	0	0	7
	Isotropic	4	0	0	4	0
	Calcite	2	0	0	0	2
	Biotite	3	2	1	0	0
PO.4	Quartz	46	32	9	5	0
	K feldspar	40	33	6	1	0
	Felsic Phyl.	11	0	0	0	11
	Isotropic	1	0	0	0	1
	Calcite	2	0	0	1	1
PO.5	Quartz	46	37	7	2	0
	K feldspar	39	21	14	4	0
	Felsic Phyl.	10	0	0	0	10
	Isotropic	3	0	1	1	1
	Calcite	2	0	0	2	0
INC.1	Quartz	50	47	3	0	0
	K feldspar	49	39	7	3	0
	Biotite	1	0	0	1	0
INC.2	Quartz	30	11	16	3	0
	K feldspar	60	43	6	11	0
	Biotite	6	2	2	2	0
	Calcite	1	0	1	0	0
	Isotropic	3	1	0	1	1
INC.3	Quartz	64	24	29	3	8
	Calcite	12	0	0	6	6
	Isotropic	3	0	0	0	3
	Felsic Phyl.	21	0	0	0	21
INC.4 GM	Felsic Phyl.	69	0	2	5	62
	Calcite	31	0	16	7	9
INC.5 GM	Felsic Phyl.	78	0	2	5	71
	Calcite	22	0	11	5	6

Phyl : Phyllosilicates

Table 4. Major element concentrations in the rock samples and the < 2 mm fractions of the wasterock.

Sample	Fraction	%Al	%Ba	%C	%Ca	%Fe	%K	%Mg	%Na	%P	%S	%Si	%Ti
HN.1	rock	7.0	0.1	0.8	2.1	4.7	1.7	0.8	2.6	0.1	1.5	31.0	0.4
HN.2	rock	7.9	0.1	0.1	1.0	3.6	2.0	2.3	2.3	0.1	0.4	31.7	0.5
HN.3	rock	5.5	0.1	0.0	0.2	3.2	1.5	2.0	1.5	0.0	0.0	35.9	0.4
HN.4	rock	5.8	0.2	0.0	0.1	1.8	4.9	0.3	1.2	0.1	0.1	36.3	0.2
HN.5	rock	6.2	0.1	0.0	0.2	5.7	0.8	1.9	1.7	0.2	0.2	33.7	0.4
HN.WR1	< 2mm	8.4	0.1	0.8	2.9	4.9	3.5	1.1	1.1	0.1	2.4	27.8	0.5
HN.WR2	< 2mm	7.7	0.1	0.7	1.3	3.9	3.5	0.7	0.7	0.1	3.2	31.2	0.4
HN.WR3	< 2mm	7.9	0.1	0.9	3.0	4.9	3.3	1.1	1.0	0.2	2.7	28.0	0.5
PO.1	rock	5.1	0.2	0.6	1.3	2.3	4.8	0.3	0.9	0.1	1.0	35.2	0.2
PO.2	rock	5.8	0.3	0.5	0.8	1.5	5.1	0.4	0.3	0.1	1.4	35.2	0.3
PO.3	rock	6.6	0.3	1.0	1.2	3.6	6.7	0.4	1.0	0.1	3.1	30.6	0.2
PO.4	rock	5.8	0.2	0.4	1.2	1.0	5.7	0.2	0.4	0.1	0.4	35.5	0.2
PO.5	rock	5.9	0.2	0.6	1.3	0.8	6.0	0.2	0.3	0.1	0.8	35.0	0.2
PO.UW1	< 2mm	6.8	0.3	1.2	2.9	2.1	5.2	0.7	0.4	0.1	1.7	30.9	0.3
PO.UW2	< 2mm	7.1	0.3	1.0	2.5	2.4	4.9	0.9	0.4	0.2	1.7	30.9	0.3
PO.UW3	< 2mm	6.8	0.2	1.2	2.3	3.1	4.3	0.8	0.8	0.1	2.2	30.8	0.3
PO.UW4	< 2mm	6.6	0.3	1.0	2.0	1.9	4.5	0.6	0.4	0.1	1.7	32.7	0.3
INC.1	rock	5.5	0.2	0.8	2.1	1.6	3.8	0.4	0.6	0.1	1.3	34.7	0.2
INC.2	rock	7.1	0.2	0.3	1.1	2.1	5.4	1.2	0.8	0.1	0.3	32.9	0.4
INC.3	rock	5.0	0.1	0.8	2.0	1.2	2.2	0.3	0.1	0.1	0.8	37.0	0.2
INC.4 GM	rock	11.4	0.1	3.7	11.5	2.7	5.8	1.7	0.0	0.3	3.0	14.8	0.4
INC.5 GM	rock	13.0	0.0	3.2	8.2	2.5	6.5	1.3	0.0	0.3	3.1	16.7	0.6
INC.UW1	< 2mm	8.4	0.3	1.3	3.5	1.2	5.5	0.6	0.2	0.1	1.1	29.6	0.3
INC.UW2	< 2mm	7.1	0.3	0.9	2.9	1.3	5.0	0.5	0.2	0.1	0.9	32.0	0.3
INC.UW3	< 2mm	7.1	0.3	0.9	2.0	1.1	4.6	0.6	0.4	0.1	1.0	32.8	0.3
INC.UW4	< 2mm	13.6	0.2	2.4	5.6	3.1	6.7	1.4	0.1	0.3	3.5	18.3	0.6

Table 5. Mineralogy of the < 2 um fractions of the wasterock and the crushed rock.

Sample	Material	% Wt < 2 um	Quartz	K feldspar	Plagioclase	Chlorite	Sericite	Kaolinite	Smectite
			(estimated proportion in %)						
HN.WR1	wasterock	4.4				5	5	40	50
HN.WR2	wasterock	5.2				5	15	35	45
HN.WR3	wasterock	5.0				5	10	40	45
PO.UW1	wasterock	3.5		tr		5	10	50	35
PO.UW2	wasterock	3.4				5	10	30	55
PO.UW3	wasterock	4.9		5		10	10	35	40
PO.UW4	wasterock	4.9		tr		10	20	30	40
INC.UW1	wasterock	2.6		tr			15	25	60
INC.UW2	wasterock	3.4	tr				10	25	60
INC.UW3	wasterock	2.2		5			60	15	25
INC.UW4	wasterock	4.3					90	5	5
HN.1	rock	0.3	10		5	40	20	25	
HN.2	rock	1.2	30		10	25	10	20	
PO.1	rock	0.2	30	20	5	25	10	10	
PO.2	rock	1.9	5	5			25	15	50
PO.3	rock	0.4	10	15	5	20	40		5
PO.4	rock	1.1		tr	tr	tr	5	30	65
PO.5	rock	6.6		tr			10	80	15
INC.1	rock	1.7	10	5			35	15	35
INC.2	rock	2.1		tr			tr	tr	95
INC.3	rock	3.8		tr			70	10	20
INC.4 GM	rock	2.1					95	tr	5
INC.5 GM	rock	0.5					95	tr	5

Table 6. Trace element concentrations in the rock and the < 2 mm fractions of the wasterock.

Sample	Fraction	Co	Cr	Cu	Mn	Mo	Nb	Ni	Pb	Ru	Se	Sr	V	Y	Zn	Zr
HN.1	rock	56	73	75	1255	23	3	26	34	95	1	250	126	27	211	108
HN.2	rock	51	425	32	387	2	7	145	5	100	1	264	218	16	56	142
HN.3	rock	23	463	8	327	0	0	69	15	48	0	236	87	13	60	106
HN.4	rock	40	17	18	216	113	0	1	26	175	0	172	39	27	49	131
HN.5	rock	28	254	54	756	1	0	149	14	34	0	136	95	30	101	121
HN.WR1	< 2mm	15	29	141	2137	2310	6	13	90	153	5	176	154	39	224	158
HN.WR2	< 2mm	18	29	130	1417	1197	6	12	220	165	5	144	138	29	416	134
HN.WR3	< 2mm	28	102	185	2230	2317	7	34	241	147	6	196	182	38	347	160
INC.1	rock	158	8	17	468	759	5	0	296	112	2	263	58	8	371	90
INC.2	rock	64	15	26	334	268	5	0	8	127	3	406	101	8	55	99
INC.3	rock	131	18	9	371	351	4	0	42	95	3	105	35	7	60	79
INC.4 GM	rock	21	0	15	961	81	8	0	45	235	13	807	65	11	405	154
INC.5 GM	rock	20	5	13	703	52	11	0	95	260	10	741	36	11	130	210
PO.1	rock	167	46	58	861	287	4	1	105	156	0	372	56	9	330	78
PO.2	rock	187	10	16	322	234	5	0	185	158	2	245	59	7	238	90
PO.3	rock	124	16	85	879	19	6	0	137	239	2	417	86	7	1436	99
PO.4	rock	234	11	12	243	126	4	0	9	144	2	311	58	8	32	90
PO.5	rock	125	6	9	375	165	4	0	15	174	2	253	44	7	227	74
INC.UW1	< 2mm	52	7	39	480	299	9	0	116	162	6	912	82	9	127	123
INC.UW2	< 2mm	107	6	53	364	349	7	0	155	133	5	649	93	8	195	102
INC.UW3	< 2mm	107	6	41	300	492	9	0	35	132	3	381	80	10	82	91
INC.UW4	< 2mm	13	9	24	665	245	19	0	63	264	7	589	123	17	127	235
PO.UW1	< 2mm	61	19	36	758	285	8	2	235	166	4	331	113	10	280	99
PO.UW2	< 2mm	63	41	67	669	354	8	7	148	159	4	358	112	10	292	108
PO.UW3	< 2mm	52	29	97	864	553	7	10	145	143	3	307	124	17	302	108
PO.UW4	< 2mm	62	16	53	802	207	8	3	309	160	4	323	115	11	703	110
Granite	range	1-15	2-90	4-30		1-6		2-20	6-30				9-90		5-140	
*1	mean	5	20	15		1.4		8	18		0.05		60		40	
Shale/	range	5-25	30-	18-120				20-	16-50				30-		18-180	
Clay *1			590					250					200			
	mean	20	120	50		2.5		68	20		0.06		130		90	
Soil *1	range	<2-80	5-	<10-	200-	1-5		10-	<20-80				20-250			
			3000	100	5000			800								

*1 data from Adriano 1986

note: all trace element concentrations in ppm

Table 7. AAO extractable element concentrations in quartz diorite soil (difference in total composition between original and residue after AAO extraction).

	%Al	%Ba	%Ca	%Fe	%K	%Mg	%Na	%P	%S	%Si
Ae	-0.8	0.00	-0.1	-0.2	-0.3	-0.1	-0.1	0.02	0.00	-4.7
Bhf1	2.7	0.05	0.2	2.3	0.4	0.0	0.1	0.05	0.00	3.5
Bhf2	4.4	0.00	0.2	5.6	0.3	0.0	0.1	0.05	0.04	3.1
Bf	5.8	-0.02	0.1	4.4	0.1	0.0	0.0	0.04	0.17	3.3
BC1	0.7	-0.04	-0.1	1.1	-0.3	-0.2	-0.2	0.07	0.16	-2.4
BC2	0.1	-0.03	-0.2	1.7	-0.4	-0.1	-0.3	0.18	-0.01	-3.4
BC3	0.5	-0.02	0.0	4.2	-0.2	-0.1	-0.3	0.17	0.01	-1.0
BC4	0.4	-0.04	-0.1	3.4	-0.2	0.0	-0.2	0.12	0.12	-1.5
BC5	1.4	-0.01	0.1	3.2	0.1	0.1	0.0	0.19	1.17	1.2

	%Ti	Co	Cr	Cu	Mn	Mo	Nb	Ni	Pb
Ae	-0.09	-36	21	4	-31	3	13	0	-3
Bhf1	0.35	40	35	16	66	235	18	0	9
Bhf2	0.23	-12	31	15	98	175	11	0	4
Bf	0.14	-7	39	19	124	163	10	0	9
BC1	0.00	-117	25	6	59	166	8	2	-4
BC2	-0.02	-66	17	-13	126	541	11	0	-10
BC3	-0.01	-6	20	1	1463	1355	10	1	-135
BC4	0.02	-18	11	10	1503	506	11	0	54
BC5	0.05	-41	12	40	587	821	10	4	16

	Ru	Se	Sr	V	Y	Zn	Zr
Ae	-14	10	-70	26	-2	6	-47
Bhf1	7	48	42	95	-2	10	39
Bhf2	5	42	0	101	4	11	17
Bf	1	28	-37	83	5	8	22
BC1	-15	9	-145	58	2	6	-9
BC2	-29	8	-163	59	0	-6	-29
BC3	-18	9	-45	54	1	-7	-30
BC4	-19	8	-118	63	2	-5	-11
BC5	29	0	85	-4	-1	21	32

Table 8. Particle size distribution after simulated weathering.

Sample	%Wt	%C	> 2 mm	2mm-50um	2-1 mm	1-0.5 mm	500-250 um	250-100 um	100-50um	50-2um	< 2 um
CF.0.1	100	0.9	97	3	3	0	0	0	0	0	0
CF.0.2	100	0.7	96	4	4	0	0	0	0	0	0
CF.2.1	92	0.0	84	16	7	3	3	2	1	0	0
CF.2.2	93	0.0	84	16	9	2	2	2	1	0	0
CF.4.1	92	0.0	83	17	8	3	3	2	1	0	0
CF.4.2	91	0.0	83	17	9	3	2	2	1	0	0
CF.8.1	92	0.0	84	16	7	4	3	3	2	0	0
CF.8.2	91	0.0	82	18	7	3	3	2	1	0	0
Fl.0.1	100	0.9	0	69	14	15	16	15	10	19	12
Fl.0.2	100	0.9	0	69	13	15	16	15	10	21	11
Fl.2.1	91	0.0	0	68	12	14	16	16	10	20	13
Fl.2.2	91	0.0	0	68	12	15	16	15	9	20	12
Fl.4.1	91	0.0	0	66	14	15	16	13	8	23	12
Fl.4.2	91	0.0	0	67	10	14	16	16	10	22	12
Fl.8.1	89	0.0	0	65	7	14	17	16	11	21	14
Fl.8.2	90	0.0	0	68	11	14	16	16	10	18	14
GM.0.1	100	1.9	0	62	6	12	15	16	12	25	14
GM.0.2	100	1.9	0	61	7	12	14	16	11	26	14
GM.2.1	88	0.4	0	53	5	11	13	14	10	33	14
GM.2.2	89	0.7	0	55	5	12	13	14	11	31	14
GM.4.1	84	0.0	0	54	5	10	13	14	11	32	14
GM.4.2	85	0.1	0	52	4	11	13	14	10	34	14
GM.8.1	84	0.0	0	52	3	10	13	14	11	32	16
GM.8.2	82	0.0	0	51	3	10	13	14	11	33	16

GM.8.2 : material.week.replicate

Table 9. Composition of soxhlet residues.

Sample	Wt	C	Al	Ba	Ca	Fe	K	Mg	Na	P	S	Si	Ti	Co	Cr	Cu	Mn	Mo	Nb	Ni	Pb	Ru	Sr	Zn	Zr
Total Element Concentrations (major elements in %, trace elements in ppm)																									
CF.0.1	100	0.9	5.2	0.3	2.6	0.9	4.2	0.5	0.3	0.07	0.4	34.7	0.2	185	10	15	348	325	3	4	26	137	548	48	88
CF.0.2	100	0.7	5.5	0.2	2.2	0.7	4.3	0.4	0.3	0.07	0.2	35.5	0.2	209	10	19	305	540	0	6	21	139	491	41	101
CF.2.1	92	0.0	5.8	0.5	0.2	1.1	4.4	0.2	0.2	0.06	1.0	36.9	0.2	198	9	15	2	295	4	2	24	150	375	39	100
CF.2.2	93	0.0	5.5	0.5	0.2	0.7	4.4	0.3	0.3	0.05	0.3	38.3	0.2	108	9	13	26	334	0	3	32	122	312	47	89
CF.4.1	92	0.0	5.6	0.3	0.1	0.7	4.6	0.3	0.4	0.05	0.5	37.4	0.2	209	10	5	20	501	0	3	195	128	301	148	90
CF.4.2	91	0.0	5.8	0.3	0.1	0.6	4.6	0.2	0.3	0.03	0.3	37.8	0.2	210	10	4	21	425	3	4	13	130	265	31	96
CF.8.1	92	0.0	5.9	0.3	0.1	0.7	4.4	0.2	0.3	0.01	0.5	37.4	0.2	195	10	9	6	388	2	4	112	146	281	36	115
CF.8.2	91	0.0	6.0	0.2	0.1	0.6	4.7	0.2	0.3	0.02	0.2	37.2	0.2	167	10	11	28	198	0	3	27	157	290	104	123
FI.0.1	100	0.9	7.7	0.3	2.7	1.4	5.0	0.6	0.1	0.11	1.1	31.2	0.3	109	10	83	374	402	11	6	95	188	757	186	131
FI.0.2	100	0.9	7.6	0.3	2.7	1.3	4.9	0.6	0.3	0.11	1.1	30.5	0.3	100	10	76	376	364	4	8	63	185	788	147	126
FI.2.1	91	0.0	8.3	0.2	0.1	1.1	5.2	0.4	0.3	0.06	0.9	34.0	0.3	114	10	23	31	426	5	4	25	193	243	131	147
FI.2.2	91	0.0	8.2	0.2	0.1	1.2	5.2	0.4	0.2	0.06	1.1	34.0	0.3	99	10	20	32	455	6	6	97	195	251	192	156
FI.4.1	91	0.0	8.1	0.3	0.1	1.1	5.2	0.3	0.3	0.06	0.9	34.2	0.3	122	10	17	26	426	6	5	105	194	297	144	147
FI.4.2	91	0.0	8.3	0.2	0.1	1.1	5.2	0.3	0.1	0.02	1.0	34.5	0.3	84	10	14	18	514	2	1	27	197	248	167	158
FI.8.1	89	0.0	8.4	0.2	0.1	1.0	5.2	0.3	0.3	0.00	0.8	34.3	0.3	116	10	11	14	477	0	3	29	194	220	236	157
FI.8.2	90	0.0	8.1	0.2	0.1	1.0	5.2	0.3	0.2	0.01	1.0	34.1	0.3	126	10	15	16	377	5	6	199	200	232	126	162
GM.0.1	100	1.9	13.9	0.1	5.3	2.9	6.5	1.4	0.1	0.29	3.5	18.9	0.6	25	8	46	738	255	22	8	78	328	696	186	273
GM.0.2	100	1.9	13.6	0.1	5.4	3.0	6.5	1.5	0.0	0.28	3.6	18.9	0.6	22	9	33	666	247	23	7	68	319	678	174	273
GM.2.1	88	0.4	15.4	0.1	1.6	3.9	7.4	1.0	0.0	0.25	4.6	21.0	0.7	27	9	25	191	282	18	6	72	322	152	224	292
GM.2.2	89	0.7	14.9	0.1	2.3	3.3	7.2	1.1	0.0	0.24	3.8	20.7	0.7	29	9	26	285	296	19	5	211	360	250	320	301
GM.4.1	84	0.0	15.6	0.1	0.4	3.3	7.8	0.9	0.0	0.20	3.9	21.6	0.7	20	9	21	19	331	21	6	59	386	49	207	325
GM.4.2	85	0.1	15.6	0.1	0.8	3.3	7.6	0.9	0.0	0.22	3.7	21.5	0.7	18	8	30	94	300	16	8	62	386	105	188	339
GM.8.1	84	0.0	16.2	0.1	0.2	3.3	7.7	0.9	0.0	0.10	3.8	22.0	0.8	28	9	16	12	356	17	6	54	338	37	188	300
GM.8.2	82	0.0	16.2	0.1	0.0	3.3	7.7	0.8	0.0	0.01	3.6	22.1	0.8	17	8	12	11	279	20	8	29	339	26	189	307
Weight of Elements (major elements in mg, trace elements in ug)																									
CF.0.1	80.0	0.72	4.2	0.21	2.12	0.72	3.37	0.38	0.27	0.06	0.30	27.7	0.17	14.8	0.8	1.2	27.8	26.0	0.2	0.4	2.1	11.0	43.8	3.8	7.0
CF.0.2	80.0	0.56	4.4	0.19	1.73	0.59	3.44	0.29	0.26	0.06	0.14	28.4	0.17	16.7	0.8	1.5	24.4	43.2	0.0	0.5	1.7	11.1	39.3	3.3	8.1
CF.2.1	73.9	0.00	4.3	0.38	0.11	0.79	3.24	0.12	0.17	0.04	0.72	27.2	0.17	14.7	0.7	1.1	0.1	21.8	0.3	0.1	1.8	11.1	27.7	2.9	7.4
CF.2.2	74.3	0.00	4.1	0.35	0.14	0.50	3.24	0.19	0.23	0.04	0.23	28.4	0.17	8.0	0.7	1.0	1.9	24.8	0.0	0.2	2.4	9.1	23.2	3.5	6.6
CF.4.1	73.9	0.01	4.1	0.22	0.10	0.49	3.40	0.19	0.27	0.03	0.36	27.6	0.16	15.4	0.7	0.4	1.5	37.0	0.0	0.2	14.4	9.5	22.2	10.9	6.6
CF.4.2	72.6	0.01	4.2	0.21	0.08	0.46	3.34	0.14	0.20	0.02	0.20	27.4	0.17	15.2	0.7	0.3	1.5	30.9	0.2	0.3	1.0	9.4	19.3	2.3	7.0
CF.8.1	73.7	0.01	4.4	0.23	0.04	0.55	3.25	0.12	0.19	0.01	0.38	27.6	0.17	14.4	0.7	0.7	0.5	28.6	0.1	0.3	8.3	10.7	20.7	2.6	8.5
CF.8.2	73.0	0.01	4.4	0.17	0.06	0.45	3.44	0.14	0.21	0.02	0.16	27.2	0.18	12.2	0.7	0.8	2.0	14.4	0.0	0.2	2.0	11.5	21.2	7.6	9.0
FI.0.1	80.0	0.72	6.1	0.21	2.19	1.15	3.98	0.47	0.12	0.09	0.86	25.0	0.23	8.7	0.8	6.6	29.9	32.2	0.9	0.5	7.6	15.0	60.5	14.9	10.5
FI.0.2	80.0	0.70	6.1	0.21	2.16	1.08	3.93	0.51	0.20	0.09	0.87	24.4	0.23	8.0	0.8	6.1	30.0	29.1	0.3	0.6	5.1	14.8	63.0	11.8	10.1
FI.2.1	72.9	0.00	6.0	0.16	0.10	0.83	3.77	0.27	0.19	0.05	0.64	24.8	0.23	8.3	0.7	1.7	2.2	31.0	0.3	0.3	1.8	14.0	17.7	9.6	10.7
FI.2.2	72.8	0.01	6.0	0.17	0.09	0.88	3.80	0.26	0.14	0.04	0.77	24.7	0.23	7.2	0.7	1.5	2.3	33.1	0.4	0.4	7.1	14.2	18.3	14.0	11.3
FI.4.1	72.7	0.01	5.9	0.19	0.10	0.81	3.76	0.25	0.19	0.04	0.67	24.9	0.24	8.8	0.7	1.2	1.9	30.9	0.5	0.4	7.6	14.1	21.6	10.5	10.7
FI.4.2	73.1	0.01	6.1	0.17	0.05	0.83	3.77	0.21	0.10	0.01	0.71	25.2	0.23	6.1	0.7	1.0	1.3	37.6	0.2	0.1	2.0	14.4	18.1	12.2	11.6
FI.8.1	71.0	0.01	5.9	0.13	0.04	0.70	3.70	0.21	0.18	0.00	0.59	24.4	0.23	8.2	0.7	0.8	1.0	33.9	0.0	0.2	2.1	13.8	15.7	16.7	11.1
FI.8.2	71.7	0.01	5.8	0.14	0.04	0.72	3.70	0.22	0.17	0.00	0.71	24.5	0.23	9.0	0.7	1.1	1.1	27.0	0.4	0.4	14.3	14.3	16.6	9.1	11.6
GM.0.1	79.9	1.49	11.1	0.11	4.25	2.34	5.20	1.12	0.04	0.23	2.77	15.1	0.49	2.0	0.7	3.7	59.0	20.4	1.7	0.6	6.2	26.2	55.6	14.9	21.8
GM.0.2	80.0	1.50	10.9	0.11	4.30	2.41	5.20	1.20	0.00	0.22	2.85	15.1	0.48	1.7	0.7	2.6	53.3	19.8	1.8	0.5	5.4	25.5	54.3	14.0	21.8
GM.2.1	70.0	0.29	10.8	0.09	1.11	2.70	5.21	0.69	0.00	0.18	3.20	14.7	0.48	1.9	0.6	1.7	13.4	19.7	1.2	0.4	5.0	22.6	10.6	15.7	20.4
GM.2.2	71.2	0.51	10.6	0.09	1.66	2.33	5.15	0.75	0.01	0.17	2.73	14.7	0.47	2.1	0.6	1.8	20.3	21.1	1.4	0.4	15.0	25.6	17.8	22.7	21.4
GM.4.1	67.0	0.01	10.4	0.08	0.24	2.18	5.24	0.57	0.00	0.13	2.58	14.5	0.49	1.4	0.6	1.4	1.2	22.2	1.4	0.4	4.0	25.9	3.3	13.9	21.8
GM.4.2	67.8	0.09	10.6	0.10	0.54	2.23	5.13	0.63	0.00	0.15	2.54	14.6	0.48	1.2	0.6	2.0	6.4	20.4	1.1	0.5	4.2	26.2	7.1	12.8	23.0
GM.8.1	67.0	0.01	10.9	0.08	0.13	2.18	5.15	0.59	0.00	0.07	2.52	14.8	0.51	1.9	0.6	1.1	0.8	23.9	1.1	0.4	3.6	22.6	2.4	12.6	20.1
GM.8.2	66.0	0.00	10.7	0.08	0.03	2.15	5.09	0.55	0.01	0.00	2.37	14.6	0.50	1.1	0.5	0.8	0.7	18.4	1.3	0.5	1.9	22.4	1.7	12.5	20.2
Percent Decrease from Initial Weight																									
CF.0.1	100	-13	3	-5	-10	-10	1	-14	-2	0	-36	1	1	6	-1	12	-7	25	-100	15	-11	1	-5	-7	7
CF.0.2	100	13	-3	5	10	10	-1	14	2	0	36	-1	-1	-6	1	-12	7	-25	100	-15	11	-1	5	7	-7
CF.2.1	92	100	0	-88	94	-21	5	64	35	29	-220	3	1	7	17	21	99	37	-172	66	7	0	33	19	2
CF.2.2	93	100	4	-75	93	23	5	44	13	36	-3	-1	1	49	13	30	93	28	84	48	-25	18	44	3	12
CF.4.1	92	98	4	-7	95	26	0	44	-3	43	-62	2	6	2	9	74	94	-7	100	42	-660	14	47	-205	13
CF.4.2	91	98	2	-6	96	29	2	60	22	58	9	2	-2	3	14	80	94	11	-81	24	48	15	54	36	8
CF.8.1	92	99	-2	-14	98	17	5	66	27	86	-71	2	-1	9	10	51	98	17	-13	23	-338	3	50	26	-12
CF.8.2	91	98	-3	17	97	31	-1	59	21	72	28	3	-3	23	10	39	92	58	83	47	-4	-4	49	-112	-19
FI.0.1	100	-2	-1	0	-1	-3	-1	4	26	-3	1	-1	1	-4	-1	-4	0	-5	-48	9	-20	-1	2	-12	-2
FI.0.2	100	2	1	0	1	3	1	-4	-26	3	-1	1	-1	4	1	4	0	5	48	-9	20	1	-2	12	2
FI.2.1	91	100	1	24	95	26	5	45	-22	49	26	0	-2	1	8	74	92	-1	40	49	71	6	71	28	-4
FI.2.2	91	99	2	19	96	21	4	46	12	53	11	0	0	14	9	77	92	-8	24	23	-12	4	70	-5	-10
FI.4.1	91	99	4	7	95	27	5	49	-18	53	23	-1	-3	-6	9	81	94	-1	21	35	-21	5	65	21	-4
FI.4.2	91	99	0	17	98	25	5	57	39	86	18	-2	0	27	7	84	96	-23	72	90	68	3	71	8	-13
FI.8.1	89	99	3	38	98	37	6	56	-12	100	32	1	1	2	10	88	97	-11	95	57	67	8	75	-26	-8
FI.8.2	90	99	5	34	98	36	6	54	-6	95	18	1	-2	-8	9	83	96	12	35	22	-126	4	73	32	-13
GM.0.1	100	1	-1	-3	1	1	0	3	-100	-2	1	0	-1	-8	2	-17	-5	-2	3	-8	-7	-1	-1	-3	0
GM.0.2	100	-1	1	3	-1	-1	0	-3	100	2	-1	0	1	8	-2	17	5	2	-3	8	7	1	1	3	0
GM.2.1	88	78	2	16	74	-14	0	40	100	21	-14	2	1	-3	12	46	76	2	30	31	13	13	81	-9	6
GM.2.2	89	62	4	19	61	2	1	35	49	23	3	3	4	-12	11	42	64	-5	24	36	-157	1	68	-58	2
GM.4.1	84	99	5	22	94	8	-1	51	100	41	8	4	-1	27	16	55	98	-11	23	35	32	0	94	4	0
GM.4.2	85	93	4	12	87	6	1	45	100	34	10	3	2	36	17	35	89	-2	40	12	28	-1	87	12	-5
GM.8.1	84	99	1	23	97	8	1	49	100	70	10	2	-4	-1	16	67	99	-19	37	32	38	13	96	12	8
GM.8.2	82	100	3	30	99	9	2	53	29	98	15	3	-3	41	21	74	99	8	25	12	67	14	97	13	7

GM.8.2 : material.week.replicate

Table 10. Concentration of elements in soxhlet leachate.

Sample	Wt (g)	Al	Ba	Ca	Fe	K	Mg	Na	P	Si	Ti	As	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Se	Sr	Zn	Zr
		(Major Elements in mg/g)										(Trace Elements in ug/g)												
CF.1.1	4.88	0.9	0.1	31.8	0.4	12.4	2.7	0.0	0.0	0.1	0.00	7	1	3	-1	9	2823	3	4	32	31	2247	48	1
CF.1.2	4.73	0.5	0.2	32.6	0.6	13.7	2.4	0.1	0.1	0.3	0.00	7	0	6	-1	13	2870	3	2	72	32	2437	54	0
CF.2.1	0.95	2.6	0.6	28.4	1.9	13.7	4.1	-0.2	1.5	3.0	0.00	6	2	6	43	6	2825	7	18	144	39	2102	102	5
CF.2.2	0.82	1.2	0.7	26.9	2.9	12.4	3.4	0.3	1.1	4.0	0.01	5	2	12	20	33	2185	4	18	375	27	2443	165	1
CF.3.1	0.25	3.2	1.7	14.5	7.3	13.9	3.7	-1.4	5.4	7.2	0.01	-1	5	34	14	56	1385	10	41	617	46	2877	274	11
CF.3.2	0.24	5.1	1.0	12.5	5.5	13.2	3.8	-1.5	4.1	8.6	0.03	0	1	30	8	32	1325	16	21	593	39	2417	329	5
CF.4.1	0.17	1.4	1.8	9.6	6.4	15.8	3.6	-1.2	0.7	11.7	-0.01	-4	4	38	-2	19	1035	9	57	516	35	2982	247	9
CF.4.2	0.27	4.5	1.2	5.6	6.1	15.0	3.1	4.0	2.1	13.0	0.06	0	6	32	5	26	830	23	21	925	108	2039	494	12
CF.5.1	0.16	4.4	2.1	5.7	6.6	14.4	2.9	-1.6	1.6	12.4	0.03	-5	2	31	13	30	762	12	31	681	42	2715	257	12
CF.5.2	0.18	4.7	1.5	4.7	5.7	15.6	3.1	2.1	1.3	10.3	0.03	-3	2	31	7	13	754	21	24	947	71	1581	327	10
CF.6.1	0.11	3.5	0.3	5.2	6.5	20.7	3.4	0.3	0.3	6.9	-0.01	-10	-1	28	-2	181	800	11	28	383	49	2318	162	11
CF.6.2	0.13	3.8	0.1	2.3	4.3	17.4	2.3	2.2	0.2	14.3	0.00	-8	-1	29	-22	102	490	23	23	444	97	1046	714	8
CF.7.1	0.19	4.5	1.1	2.6	4.8	14.3	2.5	3.2	0.6	14.5	0.05	-3	4	28	1	96	524	12	29	689	71	1661	613	12
CF.7.2	0.26	5.1	0.7	2.2	3.4	10.0	2.0	4.8	0.3	16.5	0.02	0	4	14	-2	28	377	15	15	571	75	951	173	6
CF.8.1	0.13	7.3	1.3	4.3	5.3	19.5	2.8	-1.2	1.7	11.0	0.05	-7	6	32	-9	55	653	17	112	674	130	1952	550	21
CF.8.2	0.25	5.0	1.1	14.2	3.3	14.6	1.1	0.6	6.9	11.4	0.00	0	1	17	-7	77	354	14	32	1557	93	1260	166	12
FI.1.1	5.69	1.2	0.3	31.0	1.0	11.3	2.8	0.1	0.1	0.8	0.00	7	3	3	0	112	2935	3	2	82	33	4565	215	8
FI.1.2	5.51	1.0	0.7	32.4	1.0	14.9	2.7	0.4	0.1	1.0	0.00	7	2	5	0	120	2908	5	8	332	32	4879	264	2
FI.2.1	1.29	2.2	2.1	22.3	4.9	13.8	4.0	0.3	2.3	6.9	0.00	6	14	33	179	1118	2577	16	100	2063	54	2975	508	5
FI.2.2	1.31	2.7	1.4	24.1	3.0	13.4	3.5	0.1	1.7	6.0	0.00	7	6	17	35	614	2536	13	18	892	32	2164	410	4
FI.3.1	0.41	5.0	1.8	9.4	7.8	10.4	3.1	-0.2	5.0	12.1	0.01	3	3	31	78	348	872	27	50	1621	37	1622	478	9
FI.3.2	0.50	5.2	2.4	8.6	7.0	12.4	2.8	-0.1	4.8	13.2	0.01	3	3	36	65	416	790	25	36	1712	123	2042	377	6
FI.4.1	0.27	5.2	2.2	6.1	8.6	15.5	3.2	-1.1	2.6	13.2	0.01	0	7	41	38	312	812	26	26	1598	106	1789	368	19
FI.4.2	0.35	3.9	1.2	6.6	7.0	15.1	3.2	0.1	0.6	15.7	0.00	2	6	31	47	346	782	18	62	778	33	1906	393	8
FI.5.1	0.27	6.3	2.2	3.8	7.4	14.6	2.8	-0.4	2.1	15.1	0.03	0	7	36	28	172	665	23	34	1244	114	1522	409	16
FI.5.2	0.32	6.0	1.2	2.7	6.9	11.8	2.7	0.2	0.9	17.9	0.01	1	5	30	21	241	592	19	12	569	83	1230	316	9
FI.6.1	0.11	5.3	0.0	2.8	7.4	19.5	3.7	-1.3	0.2	7.9	-0.01	-10	3	31	-7	87	759	19	35	477	79	1358	252	11
FI.6.2	0.16	6.6	0.4	0.9	4.5	12.3	2.2	-0.8	0.2	17.0	0.00	-5	3	21	9	111	414	15	32	460	79	819	176	5
FI.7.1	0.27	6.6	1.4	1.3	4.9	14.1	2.5	3.0	0.4	16.7	0.02	0	3	26	9	72	451	20	33	1100	104	998	284	12
FI.7.2	0.37	7.1	0.9	0.9	3.7	11.9	1.7	2.5	0.3	21.4	0.02	2	5	17	16	78	285	15	12	880	114	621	337	11
FI.8.1	0.25	8.1	1.1	0.9	4.4	10.6	2.0	0.2	0.4	19.8	0.02	0	7	24	-9	89	368	19	70	922	59	748	348	13
FI.8.2	0.33	8.4	1.2	0.8	4.0	14.3	1.8	2.2	0.2	21.0	0.01	1	5	24	22	139	285	17	93	890	151	637	316	10
GM.1.1	5.50	0.0	0.1	32.7	0.5	12.5	3.8	0.2	0.4	0.1	0.00	7	3	3	0	40	3163	3	10	161	32	3928	57	0
GM.1.2	5.50	0.0	0.1	32.5	0.4	13.5	3.5	0.2	0.2	0.6	0.00	7	1	4	0	37	3029	3	1	148	32	3853	53	4
GM.2.1	3.50	0.8	0.1	33.4	0.1	13.3	4.6	-0.1	0.4	0.3	0.00	7	1	3	2	8	2789	4	9	110	31	1922	30	2
GM.2.2	4.60	1.0	0.1	32.1	0.1	13.5	3.9	0.0	0.4	0.2	0.00	7	1	3	7	7	2695	4	6	37	31	1864	34	1
GM.3.1	1.59	0.4	0.1	32.6	0.3	13.6	4.4	-0.2	0.6	0.2	0.00	7	3	3	1	25	3319	3	21	161	30	1874	75	3
GM.3.2	2.43	1.5	0.1	32.0	0.1	13.4	3.9	-0.1	1.4	0.4	0.00	7	0	3	-2	-4	2744	3	2	23	30	1781	36	2
GM.4.1	1.22	0.5	0.1	30.4	0.3	9.5	3.9	-0.4	0.4	0.2	0.00	6	1	3	134	20	2795	3	108	108	30	1746	40	0
GM.4.2	1.10	2.1	0.3	30.2	0.7	11.9	3.4	0.0	3.4	1.4	0.00	6	1	2	-1	48	2407	6	3	243	28	1784	67	1
GM.5.1	0.65	0.3	0.1	30.7	0.5	10.0	4.1	-0.4	0.8	0.1	0.00	5	1	2	-12	49	3245	3	10	328	28	1940	26	1
GM.5.2	0.31	2.3	0.9	22.5	5.4	13.5	0.6	0.0	10.3	6.9	-0.01	1	2	17	-12	312	518	9	13	1927	36	1620	93	8
GM.6.1	0.29	1.2	0.1	28.7	0.6	10.2	3.5	-1.4	2.0	0.3	-0.01	2	-2	0	-28	-19	2646	2	-5	-52	18	1960	7	0
GM.6.2	0.10	0.7	0.0	21.7	5.8	14.6	0.4	-2.4	6.3	-0.3	-0.03	-11	-1	25	-71	466	341	2	28	232	-14	1302	274	-2
GM.7.1	0.22	1.5	0.5	18.9	5.0	10.7	0.9	2.3	6.9	4.9	-0.01	-2	2	20	439	319	634	7	260	2761	9	1363	175	13
GM.7.2	0.21	2.1	0.6	8.0	6.7	10.0	0.6	4.2	3.6	9.6	-0.01	-2	-1	15	-18	97	207	7	29	1711	22	785	36	8
GM.8.1	0.31	3.0	1.0	26.3	3.0	11.3	0.4	-0.4	12.5	2.2	-0.01	1	-1	10	-22	140	330	4	11	2137	15	1557	102	9
GM.8.2	0.16	4.3	0.8	6.9	8.8	15.8	0.9	3.8	3.1	7.5	-0.02	-5	0	27	-10	86	203	11	80	2005	71	706	178	19

GM.8.2 : material.week.replicate

Table 11. Cumulative weight gain in soxhlet leachate.

Sample	Wt (g)	Al	Ba	Ca	Fe	K	Mg	Na	P	Si	Ti	As	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Se	Sr	Zn	Zr
		(major elements in mg, trace elements in ug)																						
CF.1.1	5	44	6	1552	21	604	131	1	2	3	0.1	35	6	15	-3	45	13784	15	22	158	152	10969	235	3
CF.1.2	5	22	8	1539	30	646	111	3	4	12	0.0	34	2	28	-3	62	13561	15	9	340	149	11516	255	2
CF.2.1	6	69	11	1821	39	734	169	0	16	31	0.1	40	8	20	37	51	16461	22	39	295	189	12961	332	8
CF.2.2	6	31	13	1759	54	747	139	5	13	45	0.1	38	4	38	13	89	15346	18	24	647	171	13512	389	3
CF.3.1	6	77	16	1857	57	769	179	-4	30	49	0.1	40	9	29	41	65	16805	25	49	448	201	13676	400	10
CF.3.2	6	44	15	1789	68	779	148	2	23	66	0.1	38	4	46	15	97	15666	22	29	790	181	14097	469	4
CF.4.1	6	79	19	1873	68	796	185	-6	31	69	0.1	39	10	35	40	68	16981	26	59	536	207	14183	442	12
CF.4.2	6	56	19	1804	84	819	156	13	28	101	0.3	38	6	54	16	104	15888	28	35	1038	210	14643	601	8
CF.5.1	6	87	22	1882	79	819	190	-9	33	89	0.1	38	10	40	43	73	17106	28	64	647	213	14626	483	14
CF.5.2	6	64	21	1813	94	848	162	16	31	120	0.3	38	6	60	17	106	16026	32	39	1211	222	14932	661	9
CF.6.1	7	91	22	1888	86	842	193	-8	34	97	0.1	37	10	44	42	93	17195	29	67	690	219	14884	501	15
CF.6.2	6	69	21	1816	100	870	165	19	31	138	0.3	37	6	64	14	120	16091	35	42	1269	235	15069	755	10
CF.7.1	7	99	24	1893	95	869	198	-2	35	124	0.2	37	10	49	43	111	17294	32	73	820	232	15199	618	17
CF.7.2	7	83	23	1821	109	897	170	32	32	182	0.4	37	7	68	14	127	16189	39	46	1419	255	15317	800	12
CF.8.1	7	109	26	1899	102	895	202	-4	37	139	0.3	36	11	53	41	119	17379	34	87	908	249	15454	690	20
CF.8.2	7	95	26	1858	117	934	173	33	49	210	0.4	37	7	72	12	147	16279	43	54	1816	278	15639	842	15
CF Orig	80	4281	202	1921	655	3404	335	261	59	28051	170	nd	nd	15758	807	1369	26101	34614	420	1891	nd	41565	3578	7561
FI.1.1	6	66	15	1763	57	646	157	4	4	44	0.0	42	19	18	-2	637	16706	19	9	467	185	25986	1222	19
FI.1.2	6	56	41	1784	53	823	149	22	8	53	0.0	41	11	30	-2	662	16023	27	42	1832	179	26884	1456	11
FI.2.1	7	95	42	2050	120	824	209	8	33	132	0.0	50	37	60	229	2075	20024	39	137	3124	254	29816	1875	25
FI.2.2	7	91	59	2101	92	998	195	24	30	132	0.0	50	20	52	43	1469	19355	44	66	3004	220	29726	1994	17
FI.3.1	7	115	49	2088	151	866	222	7	53	181	0.0	51	38	73	260	2217	20377	50	157	3781	269	30473	2069	29
FI.3.2	7	117	71	2144	127	1060	209	23	54	198	0.0	52	21	70	75	1676	19748	57	84	3854	281	30740	2181	19
FI.4.1	8	129	55	2105	174	908	230	4	60	217	0.0	51	40	84	270	2300	20595	57	164	4209	297	30953	2168	34
FI.4.2	8	131	75	2167	152	1113	221	23	56	253	0.0	52	23	81	92	1798	20024	63	106	4129	293	31413	2320	22
FI.5.1	8	146	61	2115	194	947	238	3	66	257	0.1	51	42	93	278	2346	20773	63	173	4543	328	31360	2277	38
FI.5.2	8	150	79	2176	174	1151	229	24	59	310	0.1	52	25	91	98	1875	20213	69	110	4311	320	31807	2421	25
FI.6.1	8	152	61	2118	203	969	242	1	66	266	0.1	50	42	97	277	2356	20857	66	177	4596	337	31511	2305	39
FI.6.2	8	160	80	2177	181	1170	233	23	59	337	0.1	52	25	94	100	1892	20278	71	115	4383	332	31936	2449	26
FI.7.1	8	170	65	2121	216	1006	249	9	67	311	0.2	50	43	104	280	2375	20978	71	185	4891	365	31779	2381	43
FI.7.2	9	187	83	2180	195	1215	239	32	60	417	0.2	52	27	100	106	1922	20384	77	119	4711	375	32167	2574	30
FI.8.1	9	190	68	2124	227	1033	254	10	68	360	0.2	50	45	109	278	2397	21070	75	203	5120	379	31965	2468	46
FI.8.2	9	215	87	2183	208	1262	245	40	61	487	0.2	53	29	108	113	1968	20479	83	150	5008	425	32379	2680	33
FI Orig	80	6115	209	2175	1116	3953	487	160	88	24673	228	nd	nd	8380	787	6366	29957	30648	553	6314	nd	61752	13310	10278
GM.1.1	5	2	4	1795	25	685	207	9	20	3	0.0	40	18	17	-3	220	17387	18	54	887	175	21590	314	2
GM.1.2	5	2	5	1784	22	744	193	9	13	30	0.0	40	7	20	-3	204	16650	19	8	815	173	21178	291	23
GM.2.1	9	30	9	2964	30	1151	370	5	35	14	0.1	65	21	27	6	249	27139	32	84	1273	284	28310	420	9
GM.2.2	10	48	12	3259	26	1363	373	8	33	38	-0.1	72	10	34	30	236	29052	35	36	987	316	29755	447	28
GM.3.1	11	37	10	3483	34	1368	439	3	44	17	0.1	75	25	32	7	289	32432	37	117	1529	331	31299	539	14
GM.3.2	13	85	14	4036	28	1688	468	6	67	48	-0.1	89	11	41	24	227	35724	43	41	1042	390	34084	534	32
GM.4.1	12	43	11	3853	38	1484	486	-2	50	19	0.1	83	26	35	169	313	35830	41	249	1661	368	33421	588	14
GM.4.2	14	108	17	4368	36	1819	506	6	104	63	-0.1	95	12	44	23	279	38367	50	43	1308	421	36043	607	32
GM.5.1	12	45	12	4054	41	1549	513	-5	54	19	0.0	86	27	36	162	345	37951	43	256	1875	386	34689	605	14
GM.5.2	14	115	20	4437	52	1860	508	6	136	84	-0.1	95	13	49	20	375	38526	52	47	1900	432	36541	635	35
GM.6.1	13	48	12	4136	43	1578	523	-9	60	20	0.0	87	27	37	154	339	38712	43	254	1860	392	35253	606	14
GM.6.2	14	116	20	4460	58	1876	508	3	143	84	-0.2	94	12	51	12	424	38562	52	50	1925	430	36677	664	35
GM.7.1	13	52	13	4177	53	1601	525	-4	75	31	0.0	86	27	41	248	408	38849	45	310	2456	394	35547	644	17
GM.7.2	14	120	21	4476	72	1897	510	12	150	104	-0.2	94	12	55	8	444	38605	54	56	2282	435	36841	671	36
GM.8.1	13	61	16	4258	63	1636	526	-5	114	38	-0.1	87	27	44	242	451	38950	46	314	3112	398	36025	676	20
GM.8.2	14	127	23	4488	87	1922	511	18	155	116	-0.2	93	12	59	7	458	38638	56	69	2610	447	36957	700	39
GM Orig	80	11008	109	4275	2374	5198	1160	21	225	15098	489	nd	nd	1862	682	3174	56137	20062	594	5828	nd	54928	14417	21806

GM.8.2 : material.week.replicate Orig : weight initially in leachate

Table 12. Proportion of initial sample weight recovered in leachate.

Sample	Wt	Al	Ba	Ca	Fe	K	Mg	Na	P	Si	Ti	As	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	Se	Sr	Zn	Zr
CF.1.1	6	1	3	81	3	18	39	1	4	0	0	nd	nd	0	0	3	53	0	5	8	nd	26	7	0
CF.1.2	6	1	4	80	5	19	33	1	7	0	0	nd	nd	0	0	5	52	0	2	18	nd	28	7	0
CF.2.1	7	2	6	95	6	22	51	0	28	0	0	nd	nd	0	5	4	63	0	9	16	nd	31	9	0
CF.2.2	7	1	6	92	8	22	42	2	22	0	0	nd	nd	0	2	7	59	0	6	34	nd	33	11	0
CF.3.1	8	2	8	97	9	23	53	-2	50	0	0	nd	nd	0	5	5	64	0	12	24	nd	33	11	0
CF.3.2	7	1	8	93	10	23	44	1	39	0	0	nd	nd	0	2	7	60	0	7	42	nd	34	13	0
CF.4.1	8	2	9	97	10	23	55	-2	52	0	0	nd	nd	0	5	5	65	0	14	28	nd	34	12	0
CF.4.2	8	1	9	94	13	24	47	5	48	0	0	nd	nd	0	2	8	61	0	8	55	nd	35	17	0
CF.5.1	8	2	11	98	12	24	57	-3	57	0	0	nd	nd	0	5	5	66	0	15	34	nd	35	14	0
CF.5.2	8	2	11	94	14	25	48	6	52	0	0	nd	nd	0	2	8	61	0	9	64	nd	36	18	0
CF.6.1	8	2	11	98	13	25	58	-3	58	0	0	nd	nd	0	5	7	66	0	16	36	nd	36	14	0
CF.6.2	8	2	11	94	15	26	49	7	53	0	0	nd	nd	0	2	9	62	0	10	67	nd	36	21	0
CF.7.1	8	2	12	99	14	26	59	-1	59	0	0	nd	nd	0	5	8	66	0	17	43	nd	37	17	0
CF.7.2	8	2	11	95	17	26	51	12	54	1	0	nd	nd	0	2	9	62	0	11	75	nd	37	22	0
CF.8.1	9	3	13	99	16	26	60	-1	63	0	0	nd	nd	0	5	9	67	0	21	48	nd	37	19	0
CF.8.2	9	2	13	97	18	27	52	13	84	1	0	nd	nd	0	1	11	62	0	13	96	nd	38	24	0
Fl.1.1	7	1	7	81	5	16	32	3	5	0	0	nd	nd	0	0	10	56	0	2	7	nd	42	9	0
Fl.1.2	7	1	20	82	5	21	31	14	9	0	0	nd	nd	0	0	10	53	0	8	29	nd	44	11	0
Fl.2.1	9	2	20	94	11	21	43	5	38	1	0	nd	nd	1	29	33	67	0	25	49	nd	48	14	0
Fl.2.2	9	1	28	97	8	25	40	15	34	1	0	nd	nd	1	5	23	65	0	12	48	nd	48	15	0
Fl.3.1	9	2	24	96	14	22	46	4	61	1	0	nd	nd	1	33	35	68	0	28	60	nd	49	16	0
Fl.3.2	9	2	34	99	11	27	43	14	61	1	0	nd	nd	1	10	26	66	0	15	61	nd	50	16	0
Fl.4.1	10	2	27	97	16	23	47	2	69	1	0	nd	nd	1	34	36	69	0	30	67	nd	50	16	0
Fl.4.2	10	2	36	100	14	28	45	15	64	1	0	nd	nd	1	12	28	67	0	19	65	nd	51	17	0
Fl.5.1	10	2	29	97	17	24	49	2	75	1	0	nd	nd	1	35	37	69	0	31	72	nd	51	17	0
Fl.5.2	10	2	38	100	16	29	47	15	67	1	0	nd	nd	1	13	29	67	0	20	68	nd	52	18	0
Fl.6.1	10	2	29	97	18	25	50	1	75	1	0	nd	nd	1	35	37	70	0	32	73	nd	51	17	0
Fl.6.2	10	3	38	100	16	30	48	14	67	1	0	nd	nd	1	13	30	68	0	21	69	nd	52	18	0
Fl.7.1	10	3	31	98	19	25	51	6	76	1	0	nd	nd	1	36	37	70	0	34	77	nd	51	18	0
Fl.7.2	11	3	40	100	17	31	49	20	68	2	0	nd	nd	1	13	30	68	0	22	75	nd	52	19	0
Fl.8.1	11	3	32	98	20	26	52	6	78	1	0	nd	nd	1	35	38	70	0	37	81	nd	52	19	0
Fl.8.2	11	4	42	100	19	32	50	25	69	2	0	nd	nd	1	14	31	68	0	27	79	nd	52	20	0
GM.1.1	7	0	4	42	1	13	18	43	9	0	0	nd	nd	1	0	7	31	0	9	15	nd	39	2	0
GM.1.2	7	0	5	42	1	14	17	42	6	0	0	nd	nd	1	0	6	30	0	1	14	nd	39	2	0
GM.2.1	11	0	8	69	1	22	32	26	16	0	0	nd	nd	1	1	8	48	0	14	22	nd	52	3	0
GM.2.2	13	0	11	76	1	26	32	38	15	0	0	nd	nd	2	4	7	52	0	6	17	nd	54	3	0
GM.3.1	13	0	9	81	1	26	38	14	20	0	0	nd	nd	2	1	9	58	0	20	26	nd	57	4	0
GM.3.2	16	1	13	94	1	32	40	29	30	0	0	nd	nd	2	4	7	64	0	7	18	nd	62	4	0
GM.4.1	15	0	10	90	2	29	42	-9	22	0	0	nd	nd	2	25	10	64	0	42	28	nd	61	4	0
GM.4.2	17	1	16	102	2	35	44	28	46	0	0	nd	nd	2	3	9	68	0	7	22	nd	66	4	0
GM.5.1	16	0	11	95	2	30	44	-22	24	0	0	nd	nd	2	24	11	68	0	43	32	nd	63	4	0
GM.5.2	17	1	18	104	2	36	44	28	60	1	0	nd	nd	3	3	12	69	0	8	33	nd	67	4	0
GM.6.1	16	0	11	97	2	30	45	-41	27	0	0	nd	nd	2	23	11	69	0	43	32	nd	64	4	0
GM.6.2	18	1	18	104	2	36	44	16	63	1	0	nd	nd	3	2	13	69	0	8	33	nd	67	5	0
GM.7.1	16	0	12	98	2	31	45	-17	33	0	0	nd	nd	2	36	13	69	0	52	42	nd	65	4	0
GM.7.2	18	1	20	105	3	36	44	58	67	1	0	nd	nd	3	1	14	69	0	9	39	nd	67	5	0
GM.8.1	17	1	15	100	3	31	45	-23	50	0	0	nd	nd	2	35	14	69	0	53	53	nd	66	5	0
GM.8.2	18	1	21	105	4	37	44	88	69	1	0	nd	nd	3	1	14	69	0	12	45	nd	67	5	0

GM.8.2 : sample.week.replicate