



Characterization of four inactive hard rock mines in western Montana
by Jeffrey Harris Deckler

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE
in Land Rehabilitation

Montana State University

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Abstract:

This study involved an inventory and characterization of four abandoned hard rock mine sites in western Montana to ascertain the hazards to public health, safety, and general welfare, as well as other environmental impacts, associated with these mines.

The Alta mine in Jefferson County, Mt., was found to be discharging large quantities of dissolved solids including heavy metals, and particulate matter into the Spring Creek drainage. The mine was largely unvegetated due to the elevated heavy metal concentrations and low water holding capacity of the spoils, as well as wind scouring. The discharges from this site are potentially toxic to both aquatic life and humans, giving this site high priority for reclamation.

The Wasa mine in Granite County, Mt, produced discharges which were also toxic, impacting the entire length of North Fork Douglas Creek. Revegetation on the site was limited by active erosion and poor water holding capacity of the spoil materials.

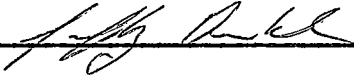
The Champion mine in Deer Lodge County, Mt. was a small disturbance which discharged acidic water laden with heavy metals into a tributary of Oro Fino Creek. However, the buffering capacity of the stream significantly ameliorated this impact. Vegetative growth on the site was limited by elevated heavy metal and salt contents, and restricted water movement in the tailings. Low water holding capacity was also a factor in the waste dumps.

The Bannack mill site in Beaverhead County, Mt. was the only one of the four study sites found not to create significant offsite impact. Revegetation of the tailings is limited by wind scouring and dessication.

A laboratory study was also conducted to ascertain the relationship between particle size and acid generation potential on spoils from the Alta site. It was found that although a weak inverse relationship existed between these two parameters, many other factors complicated this relationship. The "histories" of the materials was found to be the most important of these, as tailings and waste rock materials exhibited different behaviors. Water relationships were also thought to be a complicating factor in this experiment.

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CHARACTERIZATION OF FOUR INACTIVE HARD ROCK MINES
IN WESTERN MONTANA

by

Jeffrey Harris Deckler

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Land Rehabilitation

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ABSTRACT

This study involved an inventory and characterization of four abandoned hard rock mine sites in western Montana to ascertain the hazards to public health, safety, and general welfare, as well as other environmental impacts, associated with these mines.

The Alta mine in Jefferson County, Mt., was found to be discharging large quantities of dissolved solids including heavy metals, and particulate matter into the Spring Creek drainage. The mine was largely unvegetated due to the elevated heavy metal concentrations and low water holding capacity of the spoils, as well as wind scouring. The discharges from this site are potentially toxic to both aquatic life and humans, giving this site high priority for reclamation.

The Wasa mine in Granite County, Mt. produced discharges which were also toxic, impacting the entire length of North Fork Douglas Creek. Revegetation on the site was limited by active erosion and poor water holding capacity of the spoil materials.

The Champion mine in Deer Lodge County, Mt. was a small disturbance which discharged acidic water laden with heavy metals into a tributary of Oro Fino Creek. However, the buffering capacity of the stream significantly ameliorated this impact. Vegetative growth on the site was limited by elevated heavy metal and salt contents, and restricted water movement in the tailings. Low water holding capacity was also a factor in the waste dumps.

The Bannack mill site in Beaverhead County, Mt. was the only one of the four study sites found not to create significant offsite impact. Revegetation of the tailings is limited by wind scouring and dessication.

A laboratory study was also conducted to ascertain the relationship between particle size and acid generation potential on spoils from the Alta site. It was found that although a weak inverse relationship existed between these two parameters, many other factors complicated this relationship. The "histories" of the materials was found to be the most important of these, as tailings and waste rock materials exhibited different behaviors. Water relationships were also thought to be a complicating factor in this experiment.

INTRODUCTION

Gold was first discovered in Montana in 1852 by Francois Finlay in the Deer Lodge Valley (Young, 1970). However, it was the discovery of large placers at Grasshopper Creek in 1862, and at Alder Gulch in 1863 that signaled the beginning of the mining boom in what was later to be known as the Treasure State (Wolle, 1963). By 1865 Montana ranked second in the nation in gold production, with over 870,000 troy ounces refined (U.S. Bureau of Mines, 1956).

With vast acreages of unspoiled land before them, the miners of this period had no consideration of the environmental consequences of their actions. The philosophy of the day was to get as much as one could as fast as one could. The Encyclopedia of American Economic History (Porter, 1980) contains the following reflections on the attitudes of that time:

"During the half-century in which the quest for gold and silver was significant in the West, men from many countries and walks of life attempted to profit in mining camps. Many of them wanted to cash in on the availability of a free resource while enjoying the greatest possible personal freedom in the search for their fortune. The prospector, miner, and mining camp entourage of merchants, engineers, gamblers, and prostitutes readily abandoned one field for another at the first rumor of higher yields at a new strike. Eventually prospectors scanned the topography of every state west of the hundredth meridian in search of the mother lode."

Moreover, this philosophy remained prevalent well into the twentieth century. As a result, Montana has been left a legacy of thousands of

disturbed areas, ranging in size from less than one hectare to tens of hectares. Further, these disturbances often possess characteristics which create severe on-site and off-site environmental impacts. These include effects on: public health and safety, socioeconomic relationships, air and water quality, wildlife and aquatic life, hydrologic balances, and soil and vegetation relationships.

In response to an increasing awareness of the problems created by abandoned or inactive mine properties, the United States Congress included a section concerning the reclamation of these sites in the 1977 Surface Mining Control and Reclamation Act (Public Law 95-87). The provisions contained in Title IV of that act created a State Abandoned Mine Land Reclamation Fund, derived from a 35 cents per ton tax on mined coal. The tax is collected in each state by the federal government, with the state entitled to one-half the total revenue. To date the State of Montana's share of these monies is over 16 million dollars. The money is to be used by the state to evaluate proposed reclamation projects on abandoned mined lands, and to execute reclamation projects which are judged to be both necessary and feasible. Within this context, the Montana Department of State Lands is currently beginning an inventory of abandoned mine sites in the state for the purpose of evaluating possible reclamation projects. The criteria for evaluation are set forth in Section 26.4.1235 of the

Montana Strip and Underground Mine Reclamation Rules and Regulations (1980), and include:

- 1) The need for reclamation with respect to site quality objectives,
- 2) The feasibility of successful reclamation given existing technology,
- 3) The benefits which would be derived from successful reclamation, and
- 4) The cost of the reclamation project.

After evaluating the sites, the projects may then be prioritized, as set forth in Section 26.4.1234 (Montana Strip and Underground Mine Reclamation Rules and Regulations, 1980). Preference among projects competing for available resources in the State Abandoned Mine Land Reclamation Fund is given to the project of highest priority. Priorities include:

- 1) Protection of public health, safety, and general welfare from extreme danger resulting from the adverse impacts of mining,
- 2) Protection of public health, safety, and general welfare from adverse impacts of mining which do not constitute an extreme danger,
- 3) Restoration of environmental degradation associated with mining,
- 4) Research projects, and
- 5) Protection, repair, replacement, construction, or enhancement

of public facilities.

As part of the inventory process, the Montana Department of State Lands selected four abandoned hard rock mine sites to be evaluated for potential reclamation projects. These particular sites were chosen because the Department assumed that these mines may have constituted a significant environmental and public hazard. The sites were: 1) the Alta mine in Jefferson County, Montana; 2) the tailings dump directly south of the town of Bannack, Montana; 3) the Champion mine in Deer Lodge County, Montana; and 4) the Wasa mine in Granite County, Montana. The location of these sites is depicted in Figure 1.

In addition to characterization of the individual mine sites, a research project was implemented in order to predict the possible environmental degradation which might be expected as a result of acid mine drainage; a common problem on abandoned hard rock mine sites. The study attempted to ascertain whether a correlation existed between mine waste particle size and acid generation. If a correlation existed, then mechanical (grain-size) analysis would be a useful tool for predicting acid generation potential.

Specific project objectives included:

- 1) An investigation of hazards to public health, safety, and general welfare at each site.
- 2) Characterization of the physiographic and edaphic conditions

at each site.

3) Characterization of the physical and chemical properties of spoil and tailings materials present at each site.

4) Definition of the major reclamation problems at each site.

5) Execution of a research project which relates the rate of acid generation at a site to the particle size distribution of the materials present.

6) A qualitative estimation of reclamation potential at each site, based on items 1-5 above.

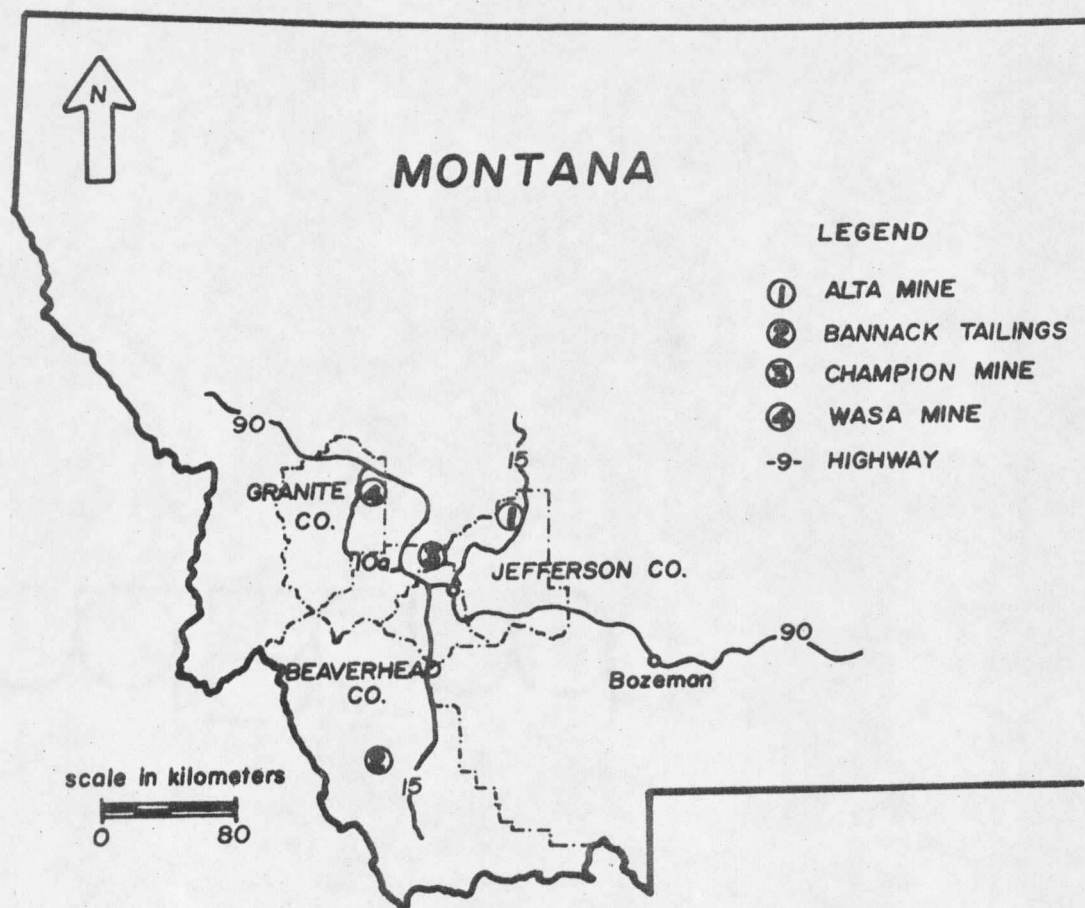


Figure 1. Location of hard rock mine study sites.

LITERATURE REVIEW

Site Characterization

The generation of acidity and potentially toxic levels of heavy metals are two of the most serious and well documented components of the environmental impact of mining. However, these factors rarely exist in isolation on mining disturbances (Down, 1974). Other factors of importance include:

1) Temperature extremes - as a function of spoil color, slope, and aspect may inhibit or preclude seedling establishment. Increased temperature may also increase chemical reaction rates and affect soil moisture relationships. Ameliorative measures include modified slope construction with respect to aspect and angle of incident radiation, and the use of mulches or other protective surface covers.

2) Wind erosion - contributes directly to air pollution. Wind scouring may also cause abrasion of plant stems and subsequent death. Excessive wind may lead to unfavorable soil and plant moisture relationships due to maintenance of a high vapor pressure gradient. Techniques to reduce wind erosion include the use of stubble, rock, or other mulches, chemical stabilization, tillage, and the planting of wind rows.

3) Drainage - may be excessive or inadequate, depending largely on particle size distribution and organic matter content. Other factors, such as proximity to water table, landscape position, compaction, and layering may also be involved. Excessive drainage

(low water holding capacity) may limit revegetation on the site. The addition of soil amendments such as manure, sewage sludge, or peat is often the course of treatment to increase water holding capacity. These measures may also increase drainage in soils with poor internal drainage by promoting soil structure. Incorporation of finer grained soil materials (where available) is another possibility, although it is seldom economically feasible.

4) Slope stability - steep slopes present a hazard to public health and safety and may contribute to water pollution with respect to slope failure and increased runoff. It can also be a severe limitation to vegetative establishment. Recontouring of slopes is a necessity in controlling slope failure. Both slope angle and configuration are important. Minimizing raindrop impact with mulches or vegetation, and minimizing water contact on the slope through the use of diversion ditches may also reduce the probability of slope failure.

5) Low nutrient status and slow or incomplete nutrient cycling - inhibits vegetative establishment. Low soil microbe levels are also involved. The use of fertilizers, and incorporation of organic soil amendments are the two most common ameliorative techniques employed to correct nutrient problems. Microbial inoculation may also be utilized in some cases.

It should be noted that the individual factors listed exhibit complex relationships and synergistic interactions which result in continuing, if not increasing environmental impact. Therefore when characterizing a disturbed area, a program must be implemented which considers several, if not all of these factors. Comparison of these factors on disturbed versus undisturbed areas may indicate which components demand particular attention in terms of site preparation and vegetative species selection (Jeffrey et al., 1974).

Characterization data on mine sites tend to conform with the relationships previously indicated. Farmer et al. (1976) found the major problems on the Blackbird mine (copper-cobalt) in Idaho to be low pH, high electrical conductivity, high erodability, and elevated heavy metal concentrations. Havens and Dean (1970) found wind erosion and scouring to be a major problem associated with uranium tailings in Arizona. Dean et al. (1969) working with copper mine tailings in Nevada found that the major problems included low nutrient status, wind erosion and scouring, extreme reflectivity of the tailings surface which resulted in high plant leaf temperatures, poor soil moisture and aeration relationships related to texture, and high salt and heavy metal concentrations. In two Colorado studies Boyles et al. (1974) and McWorter et al. (1974) discovered high acidity, elevated heavy metal and sulfate concentrations, and high total dissolved solids to be characteristic of mine drainages. Studies in the Coeur de

Alene mining district in Idaho (Mink et al., 1972; Norbeck et al., 1974) yielded similar data. In a comparison of mined versus unmined land in Ohio, Hanna (1964) found that the mined areas possessed decreased water quality due to acidity and heavy metals, increased sediment load, and increased runoff variability and flood potential as a function of a greater percentage of total flow being contributed by surface runoff. Blight and Steffen (1979) observed increased horizontal versus vertical permeability in tailings due to layering.

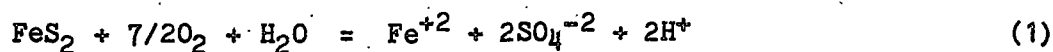
It is evident from these studies that mining disturbances throughout the United States exhibit many similar characteristics and problems. This may be important in predicting both the impacts of certain mines and the potential success of reclamation techniques which have been attempted elsewhere. Caution must be taken however to consider the site specific nature of the problem and the possible relationships therein.

Production Of Acidity On Mined Lands

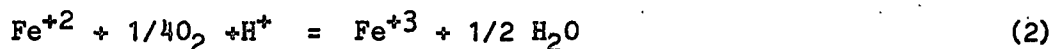
Acid mine drainage (and its associated manifestations) has long been considered one of the most serious of the environmental hazards associated with the mining industry (Limstrom, 1964). The problem is especially prevalent on abandoned mine sites due to the lack of corrective measures employed (Williams, 1975).

The formation of acid mine drainage (AMD) has been traced to the oxidation of iron disulfide minerals, primarily pyrite (Caruccio, 1968; Wentz, 1974; Williams, 1975). In the presence of oxygen and water the sulfides oxidize to form a series of soluble hydrous iron sulfates which commonly appear as white or yellow crusts on the weathered rock and sediment surfaces. Surface or groundwater flow over these crusts dissolves the salts which hydrolyze to form acidic drainages with high concentrations of sulfate and ferrous iron. The ferrous iron may subsequently be oxidized to the ferric state, complexing with ferrous and ferric oxyhydroxides to form additional acidity and the characteristic "yellowboy" precipitate which is associated with AMD (Caruccio et al., 1981). Ferric iron may also react to directly oxidize additional pyrite (reaction 4). However, since the oxidation of ferrous to ferric iron (reaction 2) does not take place at the pyrite surface, this oxidation by ferric iron is dependent on additional pyrite being present in the flow path of the ferrous oxidation products (Shumate et al., 1971). The stoichiometric chemical reactions explaining the oxidation of pyrite and the production of acidity are given by the following equations (Caruccio et al., 1981; Wentz, 1974):

Oxidation of pyrite by oxygen.



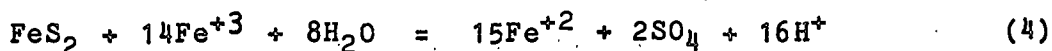
Oxidation of ferrous iron.



Precipitation of "yellowboy".



Oxidation of pyrite by ferric iron.



In addition to the spacial relationships involved in reaction (4), there are many other interactions involved in the production of acidity on mined lands. First, it has been shown that the reaction site of pyrite oxidation is different for oxygen than for ferric iron. This was demonstrated in experiments which showed that rates of reactions (1) and (4) were independent of ferric iron and oxygen concentrations, respectively, indicating that there was no competition for reaction sites between the two reactants. There were also indications that ferric iron oxidation of pyrite occurred at different sites under aerobic versus anaerobic conditions (Smith et al., 1968).

Although the chemical reactions presented do represent the stoichiometry of acid formation on mine sites, they are gross simplifications of the system. The formation of acidity is dependent on complex interactions, the full extent of which have yet to be determined.

Biological involvement in both pyrite and ferrous iron oxidation reactions by bacteria of the genera Thiobacillus and Ferrobacillus, is receiving increasing attention by investigators and is the focus of certain AMD abatement strategies. These bacteria have been found to be present in virtually all acid mine drainage water (Caruccio and Geidel, 1978; Galbraith et al. 1972). Also, clays and aluminum hydroxides may catalyze pyrite oxidation (Singer and Stumm, 1968), and oxygen adsorbed on pyrite surfaces may act as a catalyst in the oxidation of ferrous to ferric iron (Smith et al., 1968).

The ratio of ferric/ferrous ions in the system also appears to be an important factor in acid production on mined lands. Smith et al. (1968) stated that this ratio must be at least 0.3:1.0 for oxidation of pyrite by ferric iron to be significant, and that bacterial oxidation might be necessary to achieve this ratio. However this relationship may only be important under anaerobic conditions (Smith et al., 1968).

A column study conducted at West Virginia University (1971) determined that pyrite location on or in a rock fragment, position in the profile, and degree of encasement by weathering products were also important influences with respect to acid generation on mined lands. Other studies have shown that pyrite grain size and morphology are significant factors in the production of acidity on mined lands. Caruccio (1970) stated that acid generation was related to pyrite

grain size rather than the absolute quantity or mineralogy of the iron disulfide. One operative relationship was that decreased grain size increased the reactive surface area. Another factor which may have been involved is that with increased surface area, water films were less efficient barriers to oxygen diffusion (Shumate, et al., 1971). Additional study has shown that pyrite morphology may also exert significant influence in determining pyrite reactivity. Experiments by Caruccio (1970, 1972) and Caruccio et al. (1976) suggested that the reactive (framboidal) pyrite had a different composition than the stable (massive and tabular-euhedral) forms with respect to the presence of trace elements, and that these differences may have accounted for the relative reactivities.

Lastly, it must be noted that there are important factors in AMD production which are not directly associated with the reaction mechanics of acid production. Two of the most important are the alkalinity production potential of the system and the frequency of flushing of oxidation products from the system.

Studies by Caruccio (1968), Geidel (1979) and Caruccio et al. (1981) have shown that the production of AMD is dependent on the relative capabilities of the system to produce acidity and alkalinity. The production of alkalinity is dependent on and limited by the amount of calcareous rock present, the solubility of the specific mineral, the pH of infiltrating water, the partial pressure of carbon dioxide,

and the reactive surface area. Further, it has been found that due to differences in both reaction kinetics and solution equilibria of acid and alkalinity production, the frequency of flushing in the system may determine the pH of mine drainage. Equilibrium alkalinity levels are reached quickly due to a rapid reaction rate and low solubility product, while acid-producing systems have a slower reaction rate and higher solubility product. The alkalinity-generating system is quickly saturated with respect to free carbonates, whereas the acid-producing system allows for virtually continuous acid generation (Geidel, 1979; Good et al., 1970; Anderson et al., 1976). Thus more frequent flushing of mined lands should increase mine drainage quality by allowing for increased total alkalinity production in the presence of constant acid production.

An understanding of the complex relationships involved in the production of AMD is crucial to any reclamation effort dealing with pyritic minerals, especially considering the synergistic nature of acid production on these sites (Caruccio et al., 1981).

Acid Mine Drainage Abatement

The chemical and physical characteristics of a mining area may ameliorate some of the potential impacts of mining such as acid-production, heavy metal contamination, and increased sediment load. Factors influencing the ability of a system to mitigate these impacts

include: 1) the alkalinity production potential of associated strata and mine waste materials, 2) pH of inflowing ground and surface waters, 3) cation exchange capacity of mine spoils and stream channel materials, 4) flow dilution potential, 5) the precipitation of relatively stable heavy metal complexes, and 6) the reaction of streambed minerals with the associated release of basic cations (Crouse and Rose, 1976). Man-made abatement strategies attempt to emulate these factors.

Biological Control

As applied to AMD, biological control refers to inhibition of bacterial oxidation of ferrous to ferric iron (Starkey, 1945). It was found that without bacteria, this reaction proceeds slowly and is the rate limiting step in acid production (Singer and Stumm, 1968). Inhibition of this oxidation mechanism may be achieved either by pH adjustment or by killing the oxidizing bacteria with alpha-keto-acids or bacteriophages (Shumate et al., 1971). The use of reducing bacteria has also been suggested as an inhibitory agent (Shumate et al., 1971).

Exclusion of Water and Oxygen

The exclusion of water and/or oxygen from the reactive pyrite surface is, like biological control, a strategy of abatement through control of reaction kinetics. One method involves covering the pyrite

surface with an inhibiting substance to decrease the reactive surface area. However, Singer and Stumm (1968) believed this strategy to be ineffective since the oxidation of pyrite is not the rate limiting step in acid formation. Further, although this technique may have applications on shallow surface disturbances, the inaccessibility of underground mines (Shumate et al., 1971) and incorporation problems on many surface wastes makes this strategy infeasible.

Some of the more promising AMD abatement measures involve the exclusion of oxygen from and the curtailment of water flow through the reactive portions of the mine site. With underground mines this generally involves some type of costly sealing procedure (i.e. air, bulkhead, etc.). Sealing has been found to be effective in many cases, depending on the configuration of the mine workings, the ability of the strata to hold the seal, rock permeability, and other factors (Shumate et al., 1971). Similarly, the flooding of surface (Hamilton and Fraser, 1978) and underground (Shumate et al., 1971) mines has been used as a technique to exclude oxygen. The injection of inert gasses to exclude oxygen in underground mines has also been studied (Shumate et al., 1971).

Preclusion of water flow through surface wastes has been attempted by covering the wastes with impermeable chemical and/or physical coatings. This also stabilizes the surface and decreases

erosion, thus preventing the exposure of a fresh oxidizing surface; a major problem on these wastes (Dean et al., 1969). Once the surface is stabilized the increasing thickness of the oxidizing surface layer may act as an increasingly more efficient barrier to oxygen diffusion and thus inhibit additional acid production (Shumate et al., 1971). Good et al. (1970) evidenced this barrier layer phenomenon in field characterizations where it was found that the oxidized material in a tailings pond existed only in a surface layer a few centimeters deep.

Growth of vegetation on surface disturbances can also create a barrier to oxygen diffusion. Root respirational processes utilize oxygen in the upper soil profile, thus decreasing downward diffusion. Where topsoiling is used in conjunction with revegetation the added depth of inert material also acts as a diffusion barrier (Shumate et al., 1971). It must be noted however that vegetation may have the opposite effect; increasing oxygen diffusion by the removal of soil water and by root penetration (Brady, 1974). The removal of water by vegetation may also cause decreased leaching of wastes and decreased dilution potential. Vegetation does act to stabilize the surface and prevent erosion and the exposure of fresh oxidizing surfaces. It also contributes to nutrient cycling, soil formation, habitat development, and microclimate modification. Revegetation is considered the most permanent reclamation technique and is the only abatement strategy which ameliorates the aesthetic impacts of mining operations (Dean et

al., 1969).

Product Transport Control

There are two strategies of product transport control: 1) to prevent offsite passage of mine wastes, and 2) treatment of wastes before offsite discharge. The diversion of surface water around mined areas has been used to decrease recharge on both surface and underground disturbances. This decreases flow through mined sites and thus eliminates the transport of oxidation products. Care must be taken to completely stop flow, not simply reduce it, to eliminate product transport. Flow reduction may in effect create drainage with higher concentrations of acid and heavy metals due to reduced dilution (Shumate et al., 1971).

Historically, treatment of AMD upon discharge from the site has been employed to the greatest extent. Although this has been successful in many cases, the large cost and maintenance involved are often prohibitive. Also, there are indications that the relationships involved in treatment of AMD may be more complex, and necessitate a more flexible technology than is currently practiced. Traditionally, treatment has been to raise the pH of the mine drainage water with lime. At the higher pH the heavy metal contaminants as well as the "yellowboy" reaction products precipitate and can be allowed to settle out of suspension in sediment ponds. Other

treatment techniques, such as the use of microbial polymers to absorb heavy metal ions, flash distillation, and ion exchange are also being studied (Bhatt and Baker, 1974).

Many of the techniques mentioned affect more than one aspect of the acid generation system and take advantage of the synergistic nature of AMD relationships. However, it is reasonable to expect that the complexity of abandoned mine systems will necessitate the use of at least one and probably several of the abatement strategies discussed to control AMD problems on any given site.

METHODS AND PROCEDURES

Site Characterization

All sites were visited in August, 1981. During these visits a visual survey was performed to identify immediate hazards to public health, safety, and general welfare. The survey also provided a qualitative assessment of the site, including the general physiography, spacial relationships of mine wastes to streams and other features, and evidence of wind and water erosion. In addition, locations were chosen for the collection of water and soil samples and the description of soil profiles.

In general, water sampling locations were chosen in three areas: upstream of the disturbance, at the point of discharge from the disturbance, and downstream from the disturbance. In addition, discharge from all adits was sampled where possible. A more detailed description of the sampling locations may be found in the sections of this investigation pertaining to the individual mine sites.

Grab samples were manually obtained and preserved at each location in accordance with procedures described in Standard Methods for the Examination of Water and Wastewater (Rand, 1976). Four 500 ml. samples were collected at each location. Samples were filtered in the field using 0.45 micron nitrocellulose membrane filters in conjunction with a STERIFIL vacuum apparatus. Temperature, electrical conductivity (EC), and pH were measured at each location using the appropriate meter and probe. Samples were cooled on ice and

transported to the Montana State University Reclamation Research Laboratory at the earliest opportunity.

Soil sampling locations were selected by judgement to represent the typical materials in the area and to maximize the diversity of materials sampled. Peterson and Calvin (1965) indicated that with small sample sizes this method is satisfactory and may have a lower error than random sampling. In general, at least one sample pit was excavated in tailings areas and in waste rock piles at each site. One additional pit was excavated in an undisturbed area adjacent to each mine as a reference area. The number and locations of the sampling sites may be found in the sections of this investigation pertaining to the individual mine sites.

Profile descriptions were performed at each location in accordance with procedures outlined in the Soil Survey Manual (Soil Survey Staff, 1962). Samples of approximately 10 kg were collected from the diagnostic horizons of each soil profile for subsequent laboratory analysis. A bulk sample of approximately 25 kg was collected from one of the sampling pits (Alta upper tailings, site 13) for use in the acid generation study. Grab samples were also collected from several areas which appeared to exhibit atypical characteristics. These 1 kg samples were taken from the surface to a depth of 20 cm.

Laboratory Analysis of Field Samples

Water samples were analyzed by standard laboratory methods as outlined in Rand (1976), and U.S. E.P.A. Methods for Chemical Analysis of Water and Wastes (Kopp and McKee, 1979). The parameters analyzed and the methods of analysis are shown in Table 1.

Soil, spoil, and tailings samples were evaluated with respect to various physical and chemical characteristics. Field samples were air dried and rolled to obtain a representative sub-sample (Richards, 1969). Size distribution of dry aggregates was determined using flat sieves and a Ro-tap mechanical shaker (Cole, 1939). Jackson and Hellman (1945) demonstrated the Ro-tap to be among the best mechanical shakers. U.S. Standard square holed sieves were used in accordance with the recommendations of Tanner and Bourget (1951). The size fractions obtained are illustrated in Table 2.

Particle size analysis was performed using the pipette method developed by Robinson (1922) and Jennings et al. (1922). The method utilized incomplete dispersion (Olmstead et al., 1930) and a suspension density of 2.5 percent (%). Water holding capacity was measured using a pressure plate apparatus (Eilers, 1978). Measurements were taken at 1/3 and 15 bars tension. Soil pH and EC were determined in a saturated extract (Richards, 1969). The pH was also determined using a 1:2 paste dilution in 0.01M CaCl_2 (Peech, 1965).

Table 1. Analytical procedures and references for water quality determinations.

Parameter	Method of Analysis	References
pH	electronic	Rand, M.C. 1976. p.460. method 424.
EC	Wheatstone bridge	Ibid. p.71. method 205.
Dissolved calcium, magnesium, iron, manganese, zinc, lead, cadmium, nickel, aluminum, molybdenum, copper	Direct aspiration, atomic absorption analysis	Ibid. p.148. method 301A.
Dissolved sodium, potassium	Direct aspiration, atomic absorption analysis	Ibid. p.251. method 320A. p.234. method 317A.
Dissolved arsenic	Arsene generator, A.A.	Ibid. p.283. method 404A.
Dissolved mercury	Cold vapor generation, flameless A.A.	Ibid. p.156. method 301A.
Carbonate, Bicarbonate Alkalinity	titration	Ibid. p.280. method 403.
Sulfate	turbidimetric	Ibid. p.496. method 427C.
Chloride	Mercuric nitrate titration	Ibid. p.304. method 408B.

Table 1 (continued). Analytical procedures and references for water quality determinations.

Parameter	Method of Analysis	References
Nitrate nitrogen	Cd-Hg reduction colorimetric	Ibid. p.423. method 419C.
Flouride	electrode method	Ibid. p.391. method 414B.
Hardness	calculation	Ibid. p.201. method 309A.
SAR	calculation	
Total phosphorous	colorimetric	Kopp and McKee. 1979. method 365.1.

Table 2. Sieve sizes used in dry aggregate size determination and corresponding fractions obtained.

Sieve Size	Size Fraction	Size Class ¹
19.0 mm.	>19.0 mm.	rock fragment
4.0 mm.	4.0 - 19.0 mm.	-
2.0 mm.	2.0 - 4.0 mm.	gravel
1.0 mm.	1.0 - 2.0 mm.	v. coarse sand
0.5 mm.	0.5 - 1.0 mm.	coarse sand
0.25 mm.	0.25 - 0.5 mm.	medium sand
0.106 mm.	0.106 - 0.25 mm.	fine sand
0.053 mm.	0.053 - 0.106 mm.	very fine sand
	<0.053 mm.	silt and clay

1 - U.S.D.A. size classification (Brady, 1974).

Soluble calcium, magnesium, sodium, potassium, zinc, copper, manganese, iron, lead, cadmium, nickel, silver, chromium, arsenic, and aluminum were determined in a saturated extract by atomic absorption analysis (Richards, 1969). The extractable concentrations of these elements were determined by atomic absorption using a 1N NH_4OAc (ammonium acetate) extracting solution (Fiskell, 1965; Viets and Boawn 1965; McLean, 1965; Olson, 1965). The NH_4OAc was buffered at pH 4.8 for all materials with pH <5.5 (as determined in a saturated paste extract), and at pH 7.0 for materials with pH >5.5, in order to more closely approximate field conditions. Exchangeable levels of these same elements were determined by difference, subtracting soluble from extractable concentrations.

Available phosphorous was determined using a 0.5 M NaHCO_3 extraction (Olsen and Dean, 1965). Nitrate nitrogen was determined colorimetrically using the phenoldisulfonic acid method (Richards, 1969). Acetate soluble sulfur was determined using the method of Bardsley and Lancaster (1965).

Soil organic matter was determined colorimetrically by the dichromate-wet digestion method (Sims and Haby, 1971). Cation exchange capacity (CEC) was determined by summation (Chapman, 1965) of exchange acidity using BaCl_2 (Peech, 1965) and the exchangeable cations which had previously been determined by difference. Cation exchange capacity was also determined by the neutral salt method

described by Osbourne (1978).

Acid Generation Study

Experimental Design

The objective of this study was to determine whether the particle sizes of waste rock and tailings materials were correlated to the acid generation rate and potential of inactive hard rock mine sites in western Montana. The hypotheses tested were:

- a. $H_0: g_1 = g_2 = g_3$ where g_x is the acid generation potential of a particular grain size.
- b. $H_0: t_{g1} = t_{g2} = t_{g3}$ where t_{gx} is the acid generation rate of a particular grain size.

In order to test these hypotheses, treatments were selected which included different grain sizes and different times of sampling. Three grain sizes were chosen for each waste material based on the quantities of material available after size fractionation. The size classes utilized are depicted in Table 3.

Four sampling times were chosen to facilitate acid generation rate determinations. The times were selected so that more measurements would be taken during the initial equilibration of the system, when rates of change should be greatest. The sampling times were: 1 hour, 1 day, 7 days, and 30 days.

Table 3. Particle size fractions utilized in acid generation study.

Spoils		Tailings	
Size Fraction	Size Class ¹	Size Fraction	Size Class ¹
2.0-4.0 mm.	gravel	.106-.25 mm.	fine sand
1.0-2.0 mm.	v.coarse sand	.053-.106 mm.	v.fine sand
0.5-1.0 mm.	coarse sand	<.053 mm.	silt & clay

1- U.S.D.A. size classification (Brady, 1974).

Two liming rates and a control were applied to each combination of sampling time and grain size. Measured pH levels in acid generating mine wastes decrease rapidly after exposure and then reach a relative equilibrium in which pH remains low and fairly constant (Nielson and Peterson, 1978). The addition of lime was designed to raise the pH from the equilibrium point, so that acid generation could then be measured as a function of the rate of pH decrease of the system. Rates of 2.2 and 22.0 metric tons/hectare (t/ha) were used in this study (measured as 1.0 and 10.0 tons/acre).

A modified split block design was used in this experiment, as this design provided for meaningful statistical analysis of both main effects and interactions (Little and Hills, 1978). All combinations of the main effects were represented in each block, therefore blocks represented replications of each treatment ($3 \times 3 \times 4 = 36$ treatment

combinations per block). Tailings and waste rock materials were treated as separate experiments, as the additional factor of "type of material" could not be meaningfully compared statistically with this experimental design (R. Lund, 1982). The experiment included three replications of each treatment, and thus six blocks in total. The experimental design is illustrated in Figure 2.

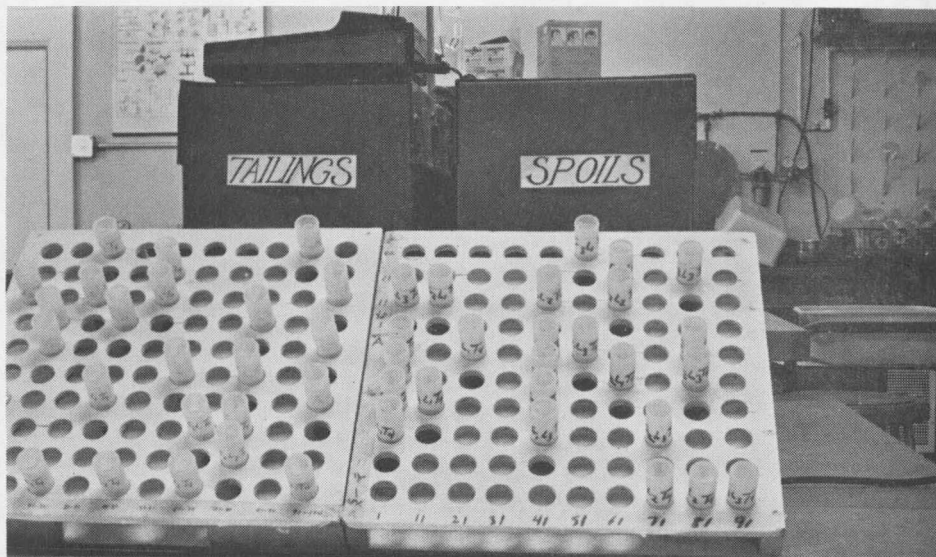


Figure 2. Tube rack at sampling time of 1 week, showing experimental materials and design.

Materials Collection and Analysis

Waste rock and tailings materials used in this study were collected from sample pits excavated at the Alta mine in Jefferson

County, Montana. Tailings material was collected as a bulk sample from one pit (site 13), while the waste rock material was collected as a composite from two profile pits (site 10 and site 08).

The materials were wet sieved to obtain a relatively accurate particle size fractionation (Allen, 1974) and air dried. No pretreatment or dispersion of the samples was performed prior to sieving as a precaution against possible chemical alteration of the material, although the materials were leached of soluble constituents during the wet sieving. Figure 3 shows the relative size of the fractions obtained.

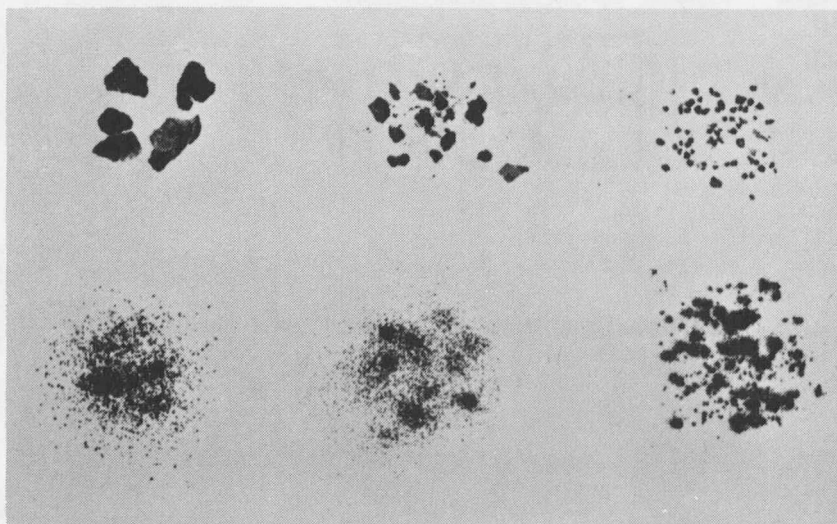


Figure 3. Particle size fractions obtained from wet sieving. Top row (l-r): gravel, very coarse sand, coarse sand. Bottom row (l-r): fine sand, very fine sand, silt and clay.

Reagent grade CaCO_3 (powder) was added to subsamples of each size fraction as prescribed. Ten grams of each grain size x lime rate combination was then placed in four separate plastic tubes, one for each sampling time. Each tube was maintained at 25% water content by weight through the addition of distilled water at four day intervals. At the appropriate sampling time pH was determined using a 1:2 soil to water ratio (Byers, 1978).

Total and pyritic sulfur analyses were performed by Energy Laboratories in Billings, Montana. Total sulfur was determined by titration of evolved sulfur dioxide with potassium iodate. Pyritic sulfur was calculated as the difference between HCl-extractable and HNO_3 -extractable sulfur (Sobek et al., 1978). Neutralization potential was determined by titration of the sample with sodium hydroxide after treatment with excess HCl (Sobek et al., 1978). These values were used to compute the acid-base account for the various size classes.

Lastly, linear regression analysis was performed to formulate predictive equations for lime rate as a function of grain size and desired pH. Grain size was coded using the phi scale developed by Krumbein for sedimentary particles. The scale is based on standard sieve sizes and thus varies as a function of $-\log_2$ of the particle diameter in millimeters (Folk, 1974).

RESULTS AND DISCUSSION OF ACID GENERATION STUDY

Results

Data obtained from the one month column study were graphed using combinations of the variables grain size, lime rate, and time. The relationships between these factors were most clearly shown graphing pH versus time for each grain size at each lime rate (Figures 4-9). Analyses of variance (ANOV) were performed and least significant differences (LSD) calculated to ascertain whether relationships illustrated in the graphical representation were statistically significant. All tables referenced in this chapter may be found in Appendix A.

Tailings - Analysis of Variance

The ANOV and LSD analyses for the tailings samples (108 samples) are shown in Table 5. The main effects of grain size (G), lime rate (L), and time (T) all exhibited significant differences at the 95% confidence level. Least significant difference analysis showed that: 1) the pH of the silt and clay fraction was significantly different from the fine and very fine sand fractions, which were statistically similar, 2) the effects of all three lime rates on measured pH were significantly different from one another, and 3) measurements taken at 1 hour were significantly different than those at 1 day, 7 days, and 30 days. The interactions of $G \times L$ and $G \times L \times T$ were also significant at the 95% confidence level.

Tailings - Silt and Clay Fraction

Analysis of variance was performed for each individual grain size to further investigate the effects of lime and time on tailings pH. Figures 4-6 illustrate the relationships between these variables.

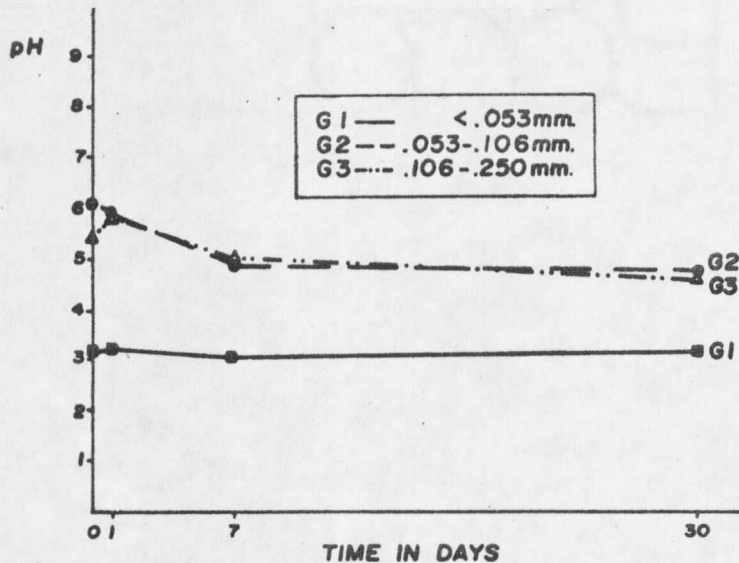


Figure 4. Measured pH versus time for the three tailings fractions at the lime control (0 t/ha).

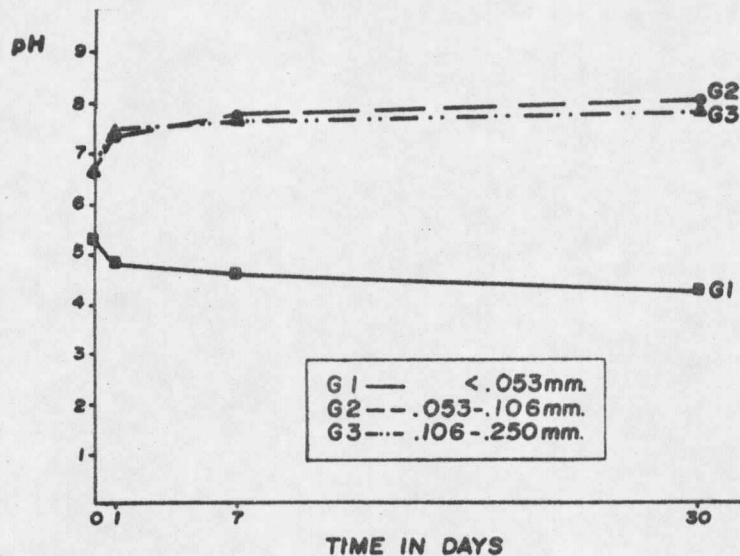


Figure 5. Measured pH versus time for the three tailings fractions at 2.2 t/ha lime.

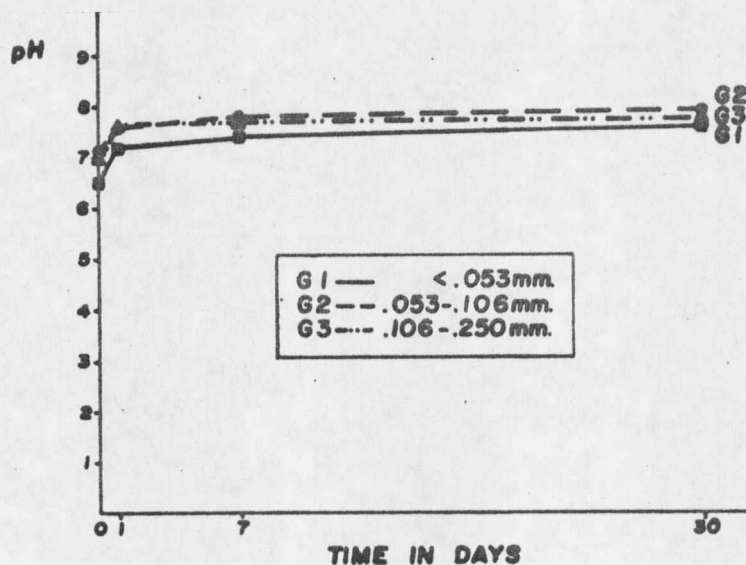


Figure 6. Measured pH versus time for the three tailings fractions at 22.0 t/ha lime.

The silt and clay fraction consistently displayed the lowest pH of all the tailings materials. These differences were statistically significant at all sampling times and all lime rates. Measured pH did not change with time for the lime control, decreased with time at 2.2 t/ha lime, and increased with time at 22.0 t/ha lime. Significant differences were demonstrated as a function of lime rate, with the pH increasing as the lime rate increased. The interaction of L X T was also significant, although the main effect of time was not. The analysis of variance and LSD analysis for the silt and clay fraction are shown in Table 6.

Tailings - Very Fine Sand Fraction

For all times and lime rates the pH of the very fine sand fraction was significantly higher than that of the silt and clay fraction but not significantly different from the pH of the fine sand fraction. Measured pH decreased with time for the lime control and increased with time at lime rates of 2.2 and 22.0 t/ha, however these differences were not significant over time. The pH of the tailings material was significantly lower for the control compared to either of the two lime application rates. Measured pH at both lime rates exhibited hydrogen ion concentrations which were statistically similar. Table 7 depicts the ANOV and LSD for this fraction.

Tailings - Fine Sand Fraction

The pH of the fine sand fraction was slightly lower although not significantly different from the very fine sand fraction. Again, pH decreased slightly with time for the control, and increased slightly with time for both lime application rates. The main effects of time and lime were significant, and were attributed to differences between the 1 hour versus 1 day, and control versus 2.2 t/ha per acre measurements, respectively. These relationships are illustrated by the ANOV and LSD analyses in Table 8.

Waste Rock - Analysis of Variance

The ANOV and LSD analyses for the waste rock samples (108 samples) are shown in Table 9. The main effects of grain size, lime rate, and time all exhibited significant differences at the 95% confidence level. This was similar to the results for the tailings material. However, the F-values for the waste rock indicated smaller differences between fractions than those exhibited by the tailings material. The pH of both the coarse sand and gravel fractions were statistically similar to the pH of the very coarse sand fraction but were statistically different from one another. No grain size exhibited consistently higher or lower pH's than the other sizes, as had occurred with the tailings. It was also noted that all three waste rock sizes displayed lower pH's than the two largest sizes of

the tailings material. The three lime rates exhibited hydrogen ion concentrations which were statistically different from one another, and pH measurements recorded at 1 hour were statistically different from the 1 day, 7 day, and 30 day values, all of which were statistically similar.

Waste Rock - Coarse Sand Fraction

Analysis of variance was again performed for each individual grain size to further investigate the effects of lime and time on waste rock pH. Graphic representations of the relationships between these factors are shown in Figures 7-9. Tables 10-12 show the ANOV and LSD analyses of the waste rock fractions.

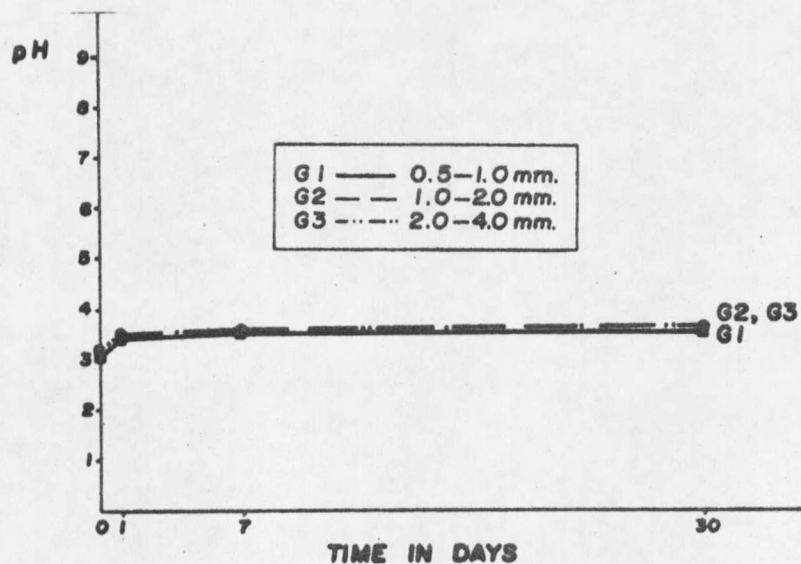


Figure 7. Measured pH versus time for the waste rock fractions at the lime control (0 t/ha).

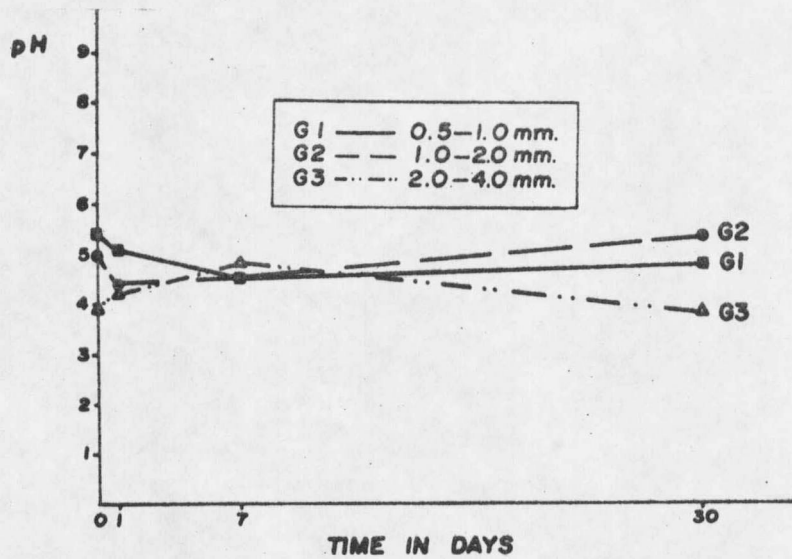


Figure 8. Measured pH versus time for the waste rock fractions at 2.2 t/ha lime.

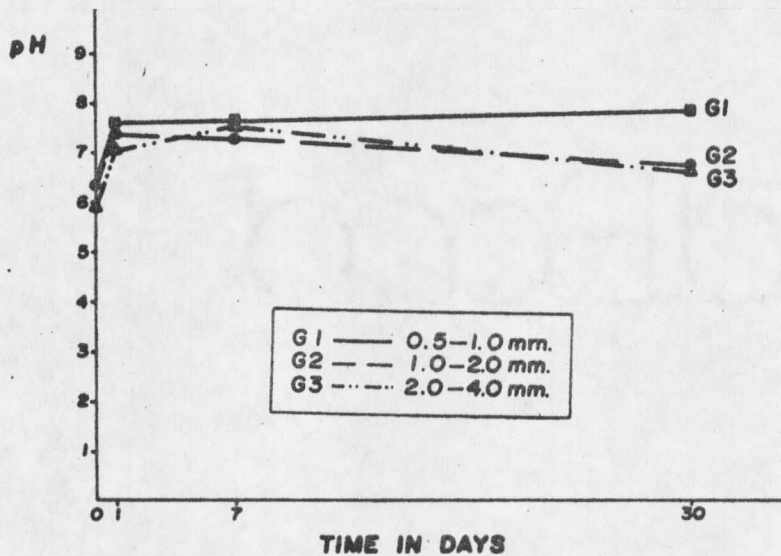


Figure 9. Measured pH versus time for the waste rock fractions at 22.0 t/ha lime.

Measured pH of the coarse sand fraction remained relatively constant over time in the lime control, decreased to day 7 and then increased at 2.2 t/ha applied lime, and increased to day 1 and then remained constant at 22.0 t/ha lime. The main effect of lime was significant at all levels, while pH did not significantly change with time during the experiment.

Waste Rock - Very Coarse Sand Fraction

Measured pH of the very coarse sand fraction remained relatively constant over time for the control, however at 2.2 t/ha lime pH decreased from 0 to 7 days and then increased slightly, while at 22.0 t/ha lime pH increased from 0 to 7 days and then decreased. The differences in pH were significant between all lime rates. The main effect of time, and the interaction between time and lime rate were not significant.

Waste Rock - Gravel Fraction

Recorded pH for the gravel fraction remained relatively constant over time in the lime control. At both lime application rates pH increased to day 7 and then decreased. The main effect of lime was significant at all levels. Measurements taken at 7 days were statistically different from measurements at 1 hour, 1 day, and 30 days. The hydrogen ion concentrations at the end of the experiment were not significantly different from the initial concentrations over

all lime rates.

Acid-Base Balance

Results of the acid-base balance are presented in Table 4. The data indicated that all six size fractions possessed net acid producing potential. The absolute levels of acid production potential based on pyritic sulfur content were surprisingly low considering the acid drainage problem at the Alta site. The unexpectedly large difference between total and pyritic sulfur may have been due to presence of other mineral sulfides.

Table 4. Acid-Base account for Alta tailings and waste rock.

Size class (mm.)	Alkalinity (t/ha CaCO ₃ equiv.)	Acidity ¹ ----- (t/ha CaCO ₃ equiv.) ---	Acidity ²
<u>Tailings</u>			
<.53	0.00	4.21	23.11
.053-.106	0.76	2.10	23.81
.106-.250	0.76	1.39	22.42
<u>Waste Rock</u>			
0.5-1.0	0.00	1.39	30.83
1.0-2.0	0.00	0.70	4.10
2.0-4.0	0.76	2.10	17.51

- 1) Acidity calculated by multiplying pyritic sulfur percentage by 70.06.
- 2) Maximum acidity calculated by multiplying total sulfur content by 70.06.

Regression Analysis

Using least squares multiple linear regression analysis, the following equations were computed to predict lime rate as a function of grain size and the desired pH of the material:

$$\text{Tailings: LR} = -11.06 + 0.65(G) + 2.17(\text{pH}) \quad (5)$$

$$R^2 = 0.47$$

$$\text{Waste rock: LR} = -9.74 + 1.45(G) + 2.39(\text{pH}) \quad (6)$$

$$R^2 = 0.76$$

where LR is the required lime rate in tons per acre, and G is the median grain size in phi units ($\text{phi} = -\log_2 \times \text{diameter in millimeters}$). Regression surfaces were plotted from these equations and are presented in Figures 10 and 11. Analysis of the R^2 values using F-ratios with two and six degrees of freedom indicated that the multiple coefficient of determination was highly significant ($p=.01$) for the waste rock regression, but not significant for the tailings regression.

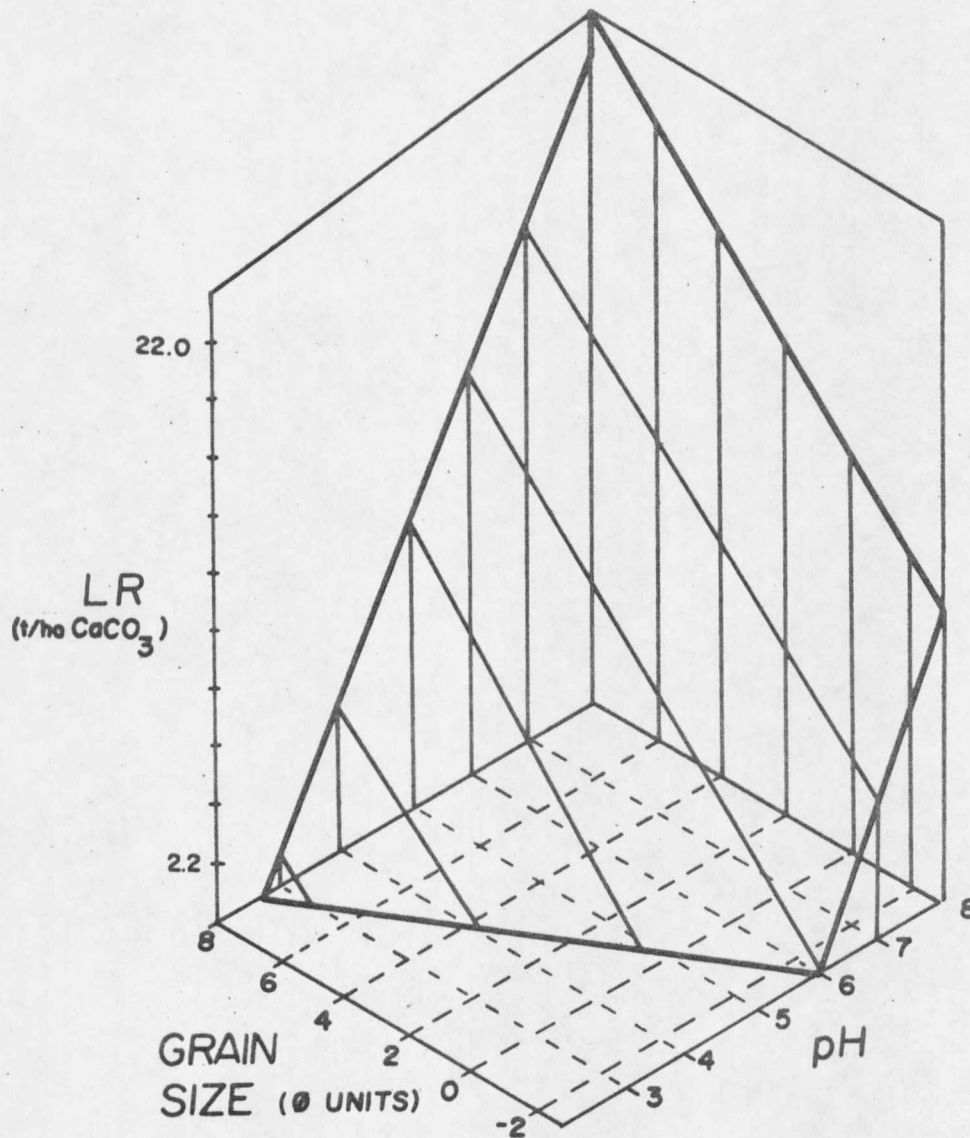


Figure 10. Regression surface for predicting lime rate from grain size and desired pH for Alta tailings.

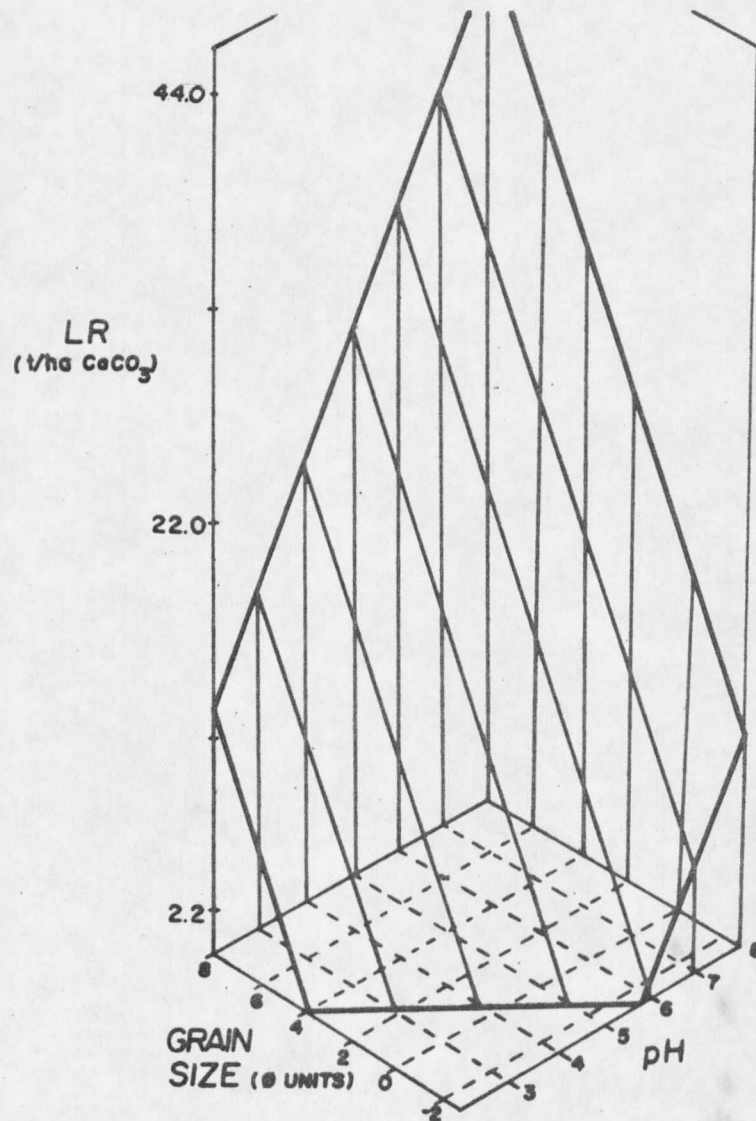


Figure 11. Regression surface for predicting lime rate from grain size and desired pH for Alta waste rock.

Discussion

Acid mine drainage is a manifestation of the balance between acid production and alkalinity production on a site (Caruccio et al., 1981). In this study alkalinity production was a function of lime rate and of the alkalinity levels of the materials. Measured pH was used as an indication of the instantaneous equilibrium of the acid-alkalinity balance. Thus we may estimate the relative acid mine drainage production potential of each grain size.

In general it is expected that: 1) if the acid production rate and potential are greater than the alkalinity production rate and potential, then pH should decrease. This decrease will be most rapid at the point where the total alkalinity potential is exhausted. 2) if the acid production rate is less than the alkalinity production rate, but the the total production potential for acidity exceeds that for alkalinity, pH will increase until the alkalinity potential is exhausted. This will be followed by a rapid decrease in pH as previously described, and 3) if acid production rate and potential are less than those for alkalinity pH will increase; this increase being most rapid at the point of exhaustion of the total acid production potential. Based on the work of Geidel (1979), and the data obtained from the acid-base accounting, it was expected that both the tailings and waste rock materials would exhibit net acid production in the control situation, as described in case 2 above (acid production rate

slower than alkalinity production rate, and higher acid production potential).

Differences in grain size were expected to affect both the acid production rate and potential as a function of differences in surface area. This would not only result in absolute pH differences, but also manifest itself as lags in the expressed pattern of pH change over time. The implied relationship was that a larger grain size would have a lower acid production potential and slower acid production rate than a smaller particle, and thus exhibit a higher pH for an extended time in the course of the experiment. Using this discussion as the basic premise, the relationships expressed in this study by the various size fractions may be examined.

In the tailings, the silt and clay fraction clearly exhibited a different behavioral pattern than either the very fine sand or fine sand fractions. This fraction ($<.053\text{mm}$) exhibited no change in pH over time in the control, which may have been a function of the lack of excess alkalinity as shown in the acid - base balance. Also, this fraction seemed to produce enough acidity to quickly neutralize 2.2 t/ha lime (Fig. 4 and 5).

The rapid initial decrease in pH exhibited by both the very fine sand and fine sand fractions in the control may be interpreted as a neutralization of the alkalinity indicated by the acid-base account.

These two fractions exhibited similar increases in pH at both lime rates. This indicated that within the time frame of the experiment acid generation was insufficient to neutralize even 2.2 t/ha lime. Further, data from the acid-base account (based on pyrite content) indicated that of all the grain size x lime rate combinations, only the silt and clay fraction treated with 2.2 t/ha lime had sufficient acid production potential to depress pH over the long term.

The tailings data seemed to exhibit relationships which were quite similar to those anticipated. The smallest grain size showed a considerably greater capacity to neutralize alkalinity than either of the larger sizes. Data from the waste rock samples did not follow this pattern.

All three waste rock grain sizes exhibited little change in pH over time in the control, despite the indication of alkalinity production potential in the gravel fraction. A somewhat erratic pattern of pH change as a function of grain size emerged with the application of 2.2 t/ha lime. The pH of the coarse and very coarse sand fractions decreased initially, and then increased. The decrease was more prolonged for the smaller grain size, and indicated a greater neutralizing capacity. The subsequent increase in pH may be interpreted as either the point of acid potential depletion, or as a result of decreased acid production rate. This decrease in acid production rate could have been due to the formation of coatings on

the pyrite surface by oxidation products. The presence of excess calcium may also have been a factor (Caruccio et al., 1978). The gravel fraction exhibited a different reaction pattern. Measured pH showed a significant increase from days 0 to 7, and then decreased slightly to day 30. The high acid production potential of the gravel fraction as indicated by the acid-base account would explain this behavior when related to the kinetics of the system. At 22.0 t/ha lime, all three fractions exhibited decreasing rates of pH increase with time. This was similar to the patterns exhibited by the tailings material.

Two questions arise from the relationships displayed by the tailings and waste rock materials at the Alta mine. They are: 1) Why did the tailings but not the waste rock materials seem to exhibit the expected correlation of neutralization potential and surface area?, and 2) Why were the pH's of the waste rock material lower than those of the two largest tailings grain sizes?

Although the relationships expressed seemed to be quite complex, a hypothesis was postulated to explain these apparent anomalies which was consistent with the original hypothesis that acid generation is largely a surface area dependent phenomenon. Reactive pyrite, the acid producer of interest, is dispersed throughout the host rock with somewhat higher concentrations associated with the ore bodies

(Chadwick, 1982). Thus it can be envisioned that the extracted ore and waste rock is made up of rock fragments with small pyrite grains both totally encased within, and protruding from the surface of these fragments. The fragments are relatively large in the case of waste rock, and thus the surface area of exposed pyrite is probably both relatively small when compared to that in the tailings, and relatively constant as a function of the ratio of waste rock surface area : pyrite surface area. These relationships were evidenced in the acid-base accounting, where the waste rock material showed both lower total pyrite content and more uniform pyrite distribution as a function of grain size than the tailings. Further, due to the size of the waste rock fragments, there was a relatively small increase in surface area as a function of decreased particle size. This may explain why all three waste rock grain sizes exhibited similar reaction patterns and hydrogen ion concentrations. Also, since the waste rock had less exposed pyrite surface area, it is reasonable to expect that the potential for oxidation products to affect reactivity (decreasing acid production) might be relatively high. This may explain the anomalous behavior of the waste rock coarse and very coarse sand fractions at 2.2 t/ha lime. The effects on pyrite reactivity would be masked at the higher lime rate due to the extreme excess of alkalinity production potential.

Tailings material on the other hand might be expected to exhibit large differences in exposed pyrite surface as a function of the small fragment sizes created by crushing during the milling process and increased weathering of the grains. The greater surface area should increase the acid production potential and possibly decrease the importance of surface coating. Unfortunately, the behavior of the tailings very fine and fine sand fractions did not support this view. Also, the crushing and weathering may increase the separation of the pyrite grains from the host rock. Under these conditions the pyrites would be concentrated in the smallest size class rather than being disseminated throughout the various classes due to encasement in larger particles. The acid-base account confirmed this relative abundance of pyrite in the smallest tailings fraction.

Although this hypothesis seems somewhat reasonable for describing the relationships between grain sizes within each material, thus far it does not explain why the fine and very fine sand fractions of the tailings material seemed to exhibit less neutralizing potential than the waste rock despite the occurrence of similar pyrite contents and alkalinity potentials. One possibility is that the milling process had somehow altered the reactivity of the pyrite through the addition of certain chemicals or as a function of the high heavy metal concentrations in the tailings. The work by Caruccio (1972) on pyrite trace element content lends credence to this idea. A more tenable

explanation involves the "histories" of the two materials. Compared to waste rock, tailings material is considerably more weathered due to: 1) the finer grain sizes as a result of milling, and 2) deposition in a wetter environment, facilitating greater microbial activity and product transport. Although acid-base accounting indicated similar amounts of pyrite present in the two materials, the pyrite present in the tailings may be a remnant of much greater quantities which have been oxidized. This previous oxidation had likely reduced the reactivity of the tailings pyrite by forming coatings, and thus the acid production exhibited by the tailings in this study was less than expected. The silt and clay fraction exhibited high acid production despite this lowered reactivity due to the elevated amounts of pyrite present.

Although this hypothesis explains the questions raised by the experiment within the context of acid production being a surface area dependent phenomenon, these questions might also be partially explained by a manifestation of the experimental design with respect to water relationships. The tailings material with its smaller pore spaces retained water more uniformly throughout the tube length than the waste rock, which ponded water at the bottom of the tubes but held very little water in the upper two-thirds of the tube volume. With the majority of its pores filled to a greater extent than the waste

rock, the tailings material may have (relatively) acted as an oxygen diffusion barrier and allowed for less pyrite oxidation to take place. Also, the increased water content may have allowed for more CaCO_3 to be brought into solution, increasing the pH. Of course the interaction was not that simple, as the ponding in the waste rock tubes decreased oxidation in the ponded section and thus affected total oxidation. Also, it would be expected that this effect would be greatest in the tailings silt and clay fraction, which actually showed the greatest neutralization potential. The relatively large amounts of pyrite present in this size class may have been sufficient to negate this.

Lastly, the implications and value of the regression equations which were developed must be discussed. The equation for the Alta tailings indicated a greater buffering capacity for smaller grain sizes. However the R^2 value of 0.47 was not statistically significant, and indicated that less than one half of the influence in determining lime rate was due to the factors of grain size and desired pH. The previous discussion suggests that other factors which may have been important were: 1) mineralogy as it related to weathering, which in turn is related to grain size and reactivity, 2) pyrite morphology (Caruccio, 1970, 1972) and ore milling processes as they related to reactivity, and 3) water content and regime as they related to product transport and acid-base equilibria (Geidel, 1979). The R^2

value for the Alta waste rock was statistically significant and indicated that 0.76 of the influence in determining lime rate was accounted for by grain size and desired pH. The equation coefficients showed that buffering capacity increased with decreasing grain size in these materials. The regression surfaces indicated the waste rock had a higher neutralization potential at a given grain size and a steeper response surface compared to the tailings. Despite the significance of the multiple coefficient of determination for the Alta waste rock, the author believes that the relationships involved were more complex than indicated by the regression. This complexity was evidenced by the erratic variation in pH changes over time as previously described.

Summary and Conclusions

The relationships expressed in this experiment indicated that there were differences between grain sizes with respect to their acid-base equilibria, and that these differences may enable one to infer acid generation potential or lime application rates. The significant interactions between grain size and lime rate outlined the limits of buffering capacity for each grain size and the patterns of pH change over time may have indicated relationships with respect to differences and changes in pyrite reactivity. The length of the experiment may have limited the interpretation of the data such that inferences could

be made only as to the short term neutralization capacity of the materials, rather than the long term acid production potentials. Other laboratory studies have demonstrated continued pyrite oxidation for several years (Struthers, 1964). Also, the fact that the tubes were not flushed and/or held at equal water potentials may have significantly affected the results of the study.

Significant linear regression analysis showed that grain size and desired pH were important factors in predicting lime rates on minesoils. However, it was indicated that additional factors must also influence AMD production. This was especially evident with the tailings material. Minerology, trace element interactions, pyrite morphology, and water relationships may be some of the more important of these factors.

SITE CHARACTERIZATION RESULTS AND DISCUSSION

For each mine site, soil and water data were evaluated with respect to appropriate criteria. Water quality data were compared to U.S. E.P.A. standards pertaining to impact on aquatic life, use as drinking water, and long term irrigation use. These standards (Table 13), as well as the water quality data for the individual sites, may be found in Appendix B. Soil chemical data were compared to suspected phytotoxic levels presented in "Diagnostic Criteria for Plants and Soils" (Chapman, 1966) and the Montana Strip and Underground Mining Act (1979). Soils data were also related to guidelines developed by Schafer (1979) which rate soil materials for use as coversoil. These criteria are presented in Appendix C (Tables 18 and 19), along with soil physical and chemical data and pedon descriptions from each site. Parameters such as mode of deposition, history, and profile genesis were also considered. Three general groups of soil profiles were examined in this study: those in 1) natural (undisturbed) soil, 2) mill tailings, and 3) waste rock. These materials exhibited drastically different characteristics. The undisturbed soils showed profile development, which involves organic matter buildup near the surface, development of structure, and translocation of clays, cations, and other materials within the profile. These soil formation processes are important in terms of facilitating water movement and retention, and nutrient cycling. Figure 12 illustrates the profile of

an undisturbed soil.



Figure 12. Profile of an undisturbed soil, showing soil development and horizonation. This pit is located at the Alta mine (site 09).

The characteristics of tailings materials were influenced by the milling process, which physically and chemically accelerated weathering, and by fluvial deposition, which stratified the

tailings as a function of particle size. Such stratification often tends to impede vertical water movement through the tailings and creates seeps, perched water tables, and chemically reduced zones. This layering is depicted in the tailings profile in Figure 13.

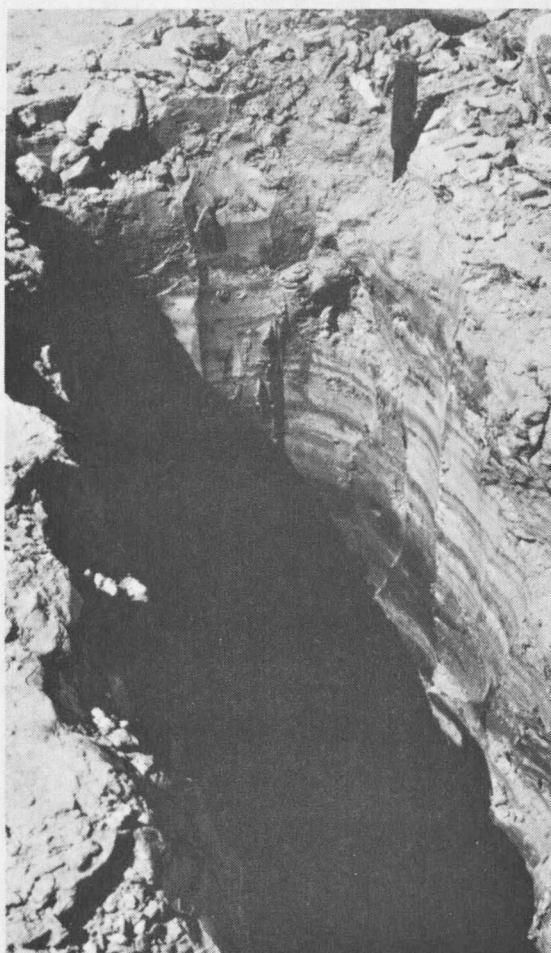


Figure 13. Profile of tailings pond illustrating layering and zone of reduction (dark). This profile is taken from the Bertha tailings lower pond (site 14).

Waste rock pits were characterized by relative homogeneity, lack of profile development, and low water holding capacity due to a high percentage of rock fragments. These characteristics are depicted in Figure 14.

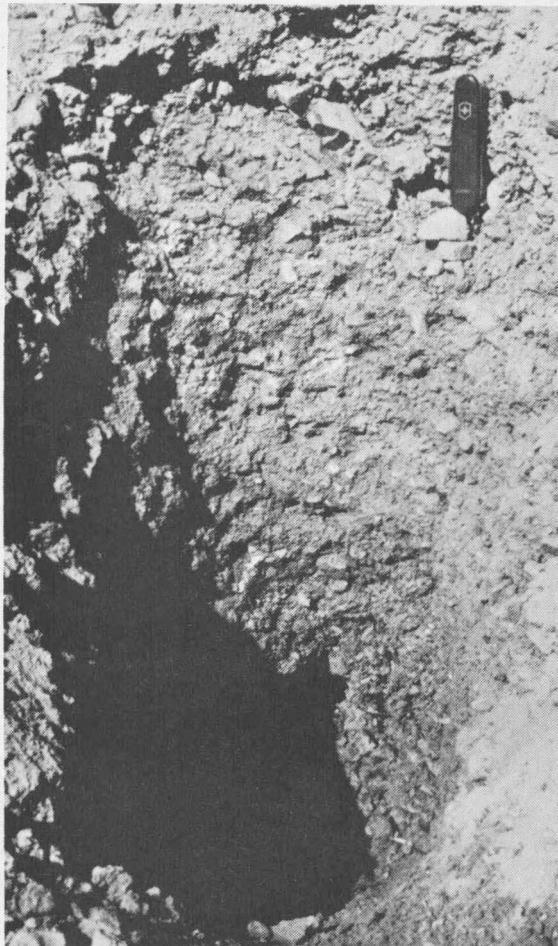


Figure 14. Waste rock profile pit taken from the Alta Mine (site 10) depicting rocky and homogeneous nature of this material.

In addition to soil and water parameters, this investigation evaluated general physiographic features at each site. These included slope lengths and gradients as they related to erosion potential; evidence of wind and water erosion, and physical hazards to public health and safety.

Characterization of the Alta Mine

Site Description

Location. The Alta Mine is located on Alta mountain in sections 9 and 10, T7N, R4W MPM, Jefferson County, Montana. It is approximately 3.6 kilometers (km) WSW of Jefferson City, situated on private claims adjacent to BLM property and near the Helena National Forest. Access to the mine is obtained via Interstate Highway 15.

Climate. The best available climatological data for the Alta site was obtained from the Helena AP weather station (elev. 1200 m). Yearly precipitation was variable and averaged 28.98 ± 10.40 cm (U.S. Weather Bureau, 1971-1981). Most of the precipitation fell as spring and fall rains, and snow. Summer precipitation occurred as a few thunder storms (Becraft et al., 1963). Approximately 65 - 75% of the annual precipitation fell during the growing season, which averaged 120 ± 7 frost free days. The average annual daily temperature was 6.4 ± 1.0 degrees centigrade ($^{\circ}\text{C}$), while maximum and

minimum temperatures reached 38.9 and -37.2° C, respectively (U.S. Weather Bureau, 1971-1981). Although similar data was obtained from the Basin 3W weather station (elev. 1685 m), it must be noted that local climate is variable in mountainous areas. Conditions at the Alta site may be somewhat wetter and cooler than is indicated by the data presented.

Geology and Mining History. The Alta study site lies on the northern boundary of the Boulder batholith. The mine itself was underlain by Elkhorn Mountain volcanics, and the ore body consisted of lenses, veins, and replacement bodies of the minerals sphalerite, argentiferous galena, tetrahedrite, and pyrite (Becraft et al., 1963). These minerals yielded silver and lead as the principle metals, along with copper, zinc, and gold. The deposit was in a well developed east-trending shear zone along which the volcanic host rock was fractured and intensely altered for widths of 45-60 meters (m). The vein dipped 30-60° N in the upper levels of the mine and 60-70° N in the lower levels. A quartz latite dike cut across the ore body in the open pit on the upper portion of the mountain. The ore in these upper sections had been leached and was of low grade (Becraft et al., 1963).

The Alta ore body was mined by a shaft 200 m deep with 13 levels through a vertical interval of 420 m. The main shaft was flooded and nearly all the workings were inaccessible (Becraft et al., 1963).

Mining was begun at Alta in 1869 by the Alta Montana Mining Company, which operated until 1882 when high transportation costs caused the mine to close. It was bought in 1883 by S.T. Hauser and D.C. Corbin, who organized the Helena Mining and Reduction Company, built new smelters to handle the ore, and induced the Northern Pacific Railroad to build a line from Wickes to East Helena to reduce transportation costs. The mine experienced peak production in the ten years that followed (1883 - 1893), yielding over 32 million dollars of ore to become the largest producer in the district. This era of prosperity ended in 1896 when the mine closed due to a drop in silver prices, high mining costs, and inefficient ore extraction at the concentrator. The mine was reopened at least twice to surface excavation, most recently by the Lahey Leasing Company from 1949 - 1957. The tailings from the concentrator were reworked three times and were ultimately trucked from their site on Corbin Flats to East Helena in the late 1930's.

The tailings materials which were included in this study were from the Bertha mine, which operated from 1906 - 1918 (Roby et al., 1960). The pond is located in section 3, T7N, R4W MPM, approximately 1.6 km NE of the Alta mine. The Bertha was mined utilizing a main shaft 275 m deep with 5 levels, some of which extended as much as 457 m along the vein. The ore body consisted of chalcopyrite and pyrite contained in the coarse white quartz gangue of the Boulder batholith.

The mineral cosalite was also present. The strike of the vein was N 40° E and the dip 80° S. It averaged 1.2 m in width, ranging from several centimeters (cm) to 3 m (Knopf, 1913). Copper was the main metal extracted from the Bertha mine, along with smaller amounts of silver and gold.

Physiography. The two sites included in this study lie within the Colorado mining district; an area of smooth rounded ridges and moderately sloping valleys. Relief in the area is approximately 300 m, with the mountain peaks ranging from 1800-2590 m in elevation (Becraft et al., 1963). The Alta mine site was carved into a drainage on the east face of Alta mountain from the summit at 1890 m to the base some 365 m below. The total area disturbed was approximately 10 ha.

The site may be divided into upper and lower segments. On the upper area a series of open cuts progressed down the slope and created four benches in the mountainside. The cuts were characterized by nearly vertical 18-30 m highwalls and steep sidewalls which consisted mainly of waste rock piled at the angle of repose. Waste rock was also piled at the mouths of the cuts, along the mining roads, and has been dumped over the slope burying the bases of small clumps of trees, thereby killing them. The physiographic features described are depicted in Figure 15. Two open adits existed at the uppermost open

cut and constitute a hazard to public health and safety. Other adits apparent on the upper portion of the mine were collapsed at the surface.

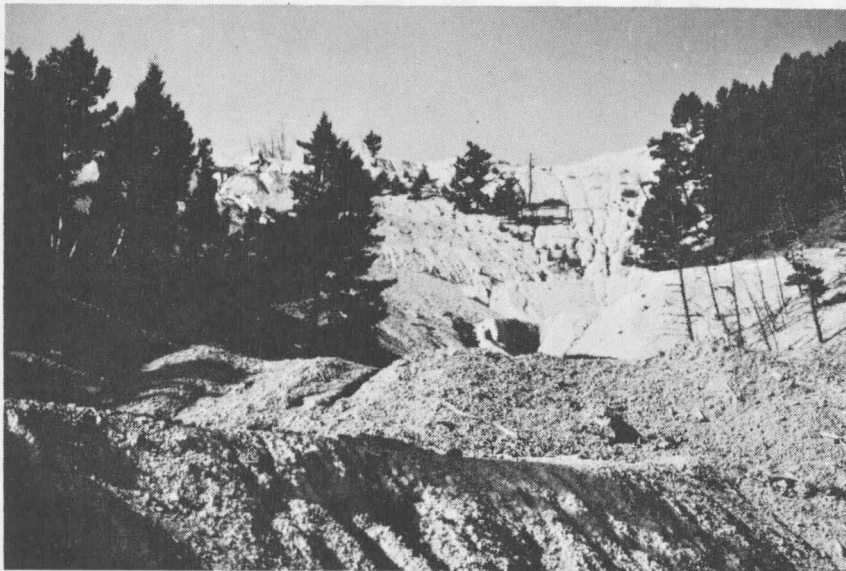


Figure 15. View of the Alta mine from the lower dump.

The lower portion of the mine consisted of a bench at the base of the mountain on which were situated several buildings and a headframe. These buildings, along with other structures on the property have been described in detail by Clark (1981). All structures on the property were in poor condition and should be considered potential hazards to public health and safety. Associated with this lower area was a large waste rock pile which had been dumped off the bench at the angle of

repose into the drainage below. The dump was 15-18 m in height.

The Bertha tailings were deposited along Corbin Creek in the northeastern footslopes of Alta mountain. The mill pond consisted of two levels. The lower level was at the eastern end of the pond, was approximately 1.5 m thick, and exhibited marked vertical layering of materials. The upper level was at the western end of the pond, was approximately 6 m thick, and displayed less vertical variation in the upper 100 cm. The upper level of the tailings occupied approximately 80% of the 1.5 ha pond. In addition, there existed a wooden drainageway constructed under the upper tailings which was open both at the western edge of the tailings and at the tailings dike. This drainageway may constitute a serious safety hazard.

The Bertha mill site disturbed an additional 1.5 ha a few hundred meters upstream (west) of the tailings pond. The site was characterized by the mill ruins, and waste rock piles both adjacent to the stream and scattered on the hill slopes. Figures 16 and 17 depict the Bertha tailings and mill sites.

Hydrology and Water Quality Analysis

The Alta mine occupies a large portion of a drainage on the eastern face of Alta Mountain. Thus nearly all precipitation falling on this drainage moves over and through the mine wastes. The only surface flows observed in late summer (08/18/81) were a seep at the



Figure 16. View of Bertha tailings looking south.



Figure 17. View of the Bertha mill site looking south.

base of the lower dump and a minor seep from a collapsed adit on the upper portion of the mine. A study by the Montana Water Quality Bureau (Ingman, 1981) postulated that the seep at the base of the mountain consisted of: 1) resurfaced water from the upper seep, 2) water contributed by other underground workings, and 3) precipitation leached through the waste rock.

The Alta mine drainage flowed into Corbin Creek below the Bertha tailings, which then flowed into Spring Creek and finally into Prickly Pear Creek approximately 5 km downstream. Although flow from the Alta seep was low (yearly mean=.06 cfs), a Montana Water Quality Bureau study found this drainage to unquestionably be the largest single source of pollutants to Spring Creek (Ingman, 1981). The study found the drainage to have low pH, high EC, and elevated sulfate and hardness levels. The drainage water exceeded applied water quality standards for every parameter tested, including turbidity, total dissolved solids, and several heavy metals. The pollution load was found to vary seasonally, being greatest during spring runoff due to increased leaching of the waste materials (Ingman, 1981). There was evidence of severe erosion during these high flow periods, as revealed by gullies approaching 5 m in depth and several mine structures near the headframe which were filled with sediment. The introduction of waste rock particles into the stream also contributes to the elevated pollution loads at these times. Data from this study, which are listed

in Table 14, corroborated those of Ingman. The Alta drainage exhibited a rust colored iron precipitate throughout its length. The drainage water was shown to increase the solubility of metals in Corbin Creek (Ingman, 1981).

The Bertha tailings were apparently deposited in the stream bottom of Corbin Creek, with a wooden drain pipe directing streamflow under the tailings. Since abandonment, the creek had migrated away from this diversion, and flowed around the northern edge of the tailings pond. Establishment of the new channel had eroded approximately 10% of the total tailings volume along the northern boundary. Severe gully erosion was also present on the southern side of the pond, and accounted for removal of an additional 5% of the tailings material. This erosion was probably due to stream flooding, although runoff from the small watershed above the ponds may also have contributed to the problem.

Water samples were obtained from Corbin Creek approximately 1.0 km upstream of the disturbance and at the point of discharge from the tailings. Data from these samples are listed in Table 14. A marked decrease in water quality occurred downstream of the disturbed area, indicated by an increase in sulfate and dissolved heavy metals, hardness, and EC. Of the heavy metals, the largest increases were exhibited by manganese, zinc, and copper. Measured pH remained

within an acceptable range. These findings were similar to those of Ingman (1981). A yellowish-green precipitate was evident on the stream bottom which was not noted in the previous study.

Ingman determined that the major problem of this segment of the drainage was a high metal-bearing sediment load derived from the tailings and the Bertha mill site 0.5 km upstream, both of which border Corbin Creek. He sited this segment of the creek as a significant source of copper, manganese, and zinc to the Prickly Pear drainage. The metal content here was in sediment complexes, in contrast to the Alta drainage where most of the metals were dissolved. This was probably due to greater erosional transport and higher pH at the Bertha site. Another study by the Montana Water Quality Bureau (Pederson, 1977) indicated that the entire Corbin Creek drainage was devoid of aquatic life. From the studies performed it is evident that both the Alta mine drainage and Corbin Creek below the Bertha tailings are significant sources of degradation to the Prickly Pear drainage and constitute a hazard to aquatic life and public health.

Minesoil Characterization

Natural Soils and Vegetation. A native soil at the Alta mine (site 09) was classified as a coarse-loamy mixed Argic Cryoboroll. This particle size class was somewhat coarser than soils in the area

described by Veseth and Montagne (1980) and Montagne et al. (1982). Physical and chemical data, as well as the pedon description for this soil are represented in Tables 25 and 26. The soil was moderately deep, well drained, and exhibited moderate permeability and erosion. Structure was weak fine granular. Chemical and physical data indicated low nutrient status and heavy metal content. There was evidence of possible enrichment of heavy metals in the A and B horizons due to wind deposition from the mine and subsequent leaching. Heavy metal levels were however well below suspected toxic limits (Chapman, 1966). Cation exchange capacity was 15 meq/100g, with calcium dominating the exchange complex. Exchange acidity was present, with measured pH ranging from 4.5-6.0. Electrical conductivity indicated non-saline conditions.

The Alta natural soil was a fair to good rangeland soil supporting vegetation which included bluebunch wheatgrass, Idaho fescue, and big sagebrush (Veseth and Montagne, 1980). Forested areas were also present on mountain slopes and consisted of lodgepole pine, Douglas fir, white pine, spruce, and fir. Aspen was also noted on the mine site. Although devoid of vegetation over most of its area, the mine disturbance supported over 40 species of vegetation. A list of these species may be found in Table 61 (Appendix D). The vegetative cover on the site was concentrated at the base of dumps and along roadsides. It was postulated that these areas supported vegetation

because they: 1) afforded protection from wind blown particles, 2) were relatively protected from excess evaporation, 3) may have had relatively greater moisture contents due to slope position, and 4) trapped fine particles and seed.

Alta Waste Rock (upper mountain). Alta waste rock was sampled at two locations; at the second open cut on the upper mountain (site 10), and on top of the lower dump (site 08). These sites are depicted in Figure 18.

Material from the upper mountain site was fairly homogeneous. It was coarse textured with a high rock fragment percentage, and exhibited moderate drainage and permeability and a low water holding capacity. The soil was classified as a sandy-skeletal mixed Typic Cryorthent. Erosion was severe due to excessive slope lengths and gradients, and the lack of protective vegetative cover. Soil structure was weak granular. Field pH was moderately acid (5.5), while the pH of laboratory samples was 6.2. Chemical data indicated low soluble and exchangeable levels of all heavy metals except lead, which was over 300 ppm (NH_4OAc extractable). Nutrient status, organic carbon, and EC were all low. A pedon description, and physical and chemical data from this site are presented in Tables 27 and 28.

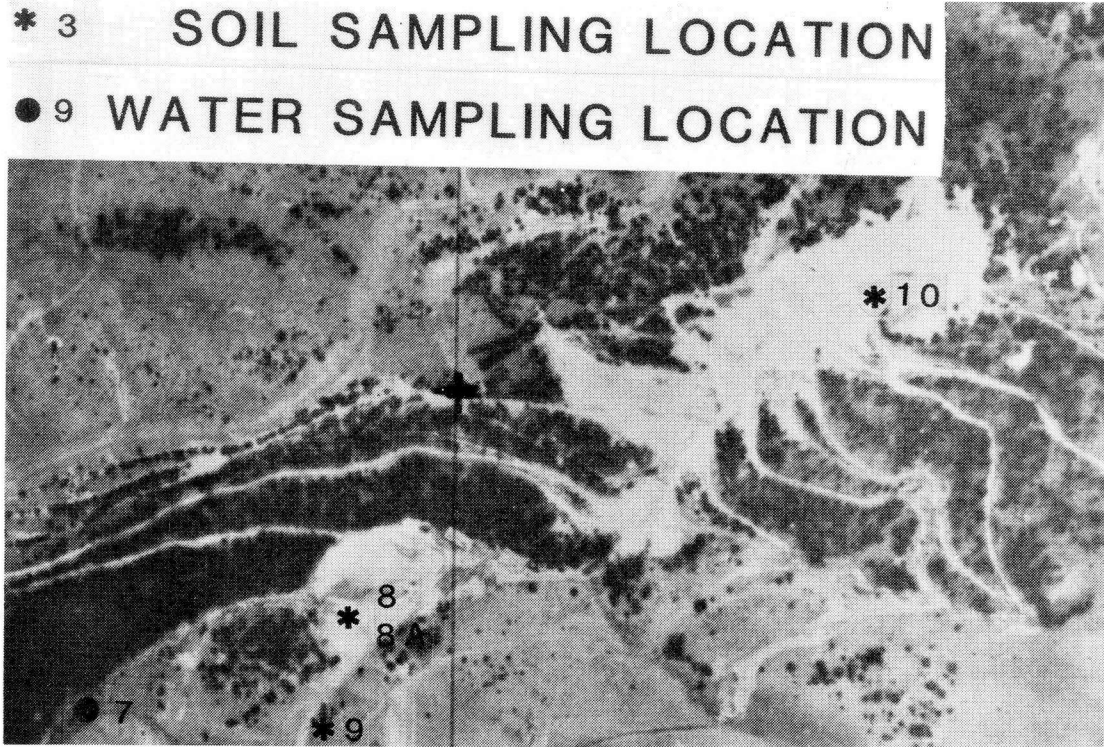


Figure 18. Aerial photo of the Alta mine, showing sampling locations for soil and water.

From these analyses it appeared that the upper Alta waste piles were not a major contributor to pollution emanating from the site. High pH and low sulfate levels indicated acid generation was not a problem here, and low heavy metal levels minimized concerns with respect to toxicity problems. The important considerations on the upper mountain were the lack of vegetative cover and the accelerated erosion; two problems which act synergistically. In addition to

active erosion, low nutrient status and low water availability probably have inhibited vegetative establishment on the upper mountain.

Alta Waste Rock (lower dump). The Alta mine lower dump exhibited characteristics which were quite different from those on the upper mountain. This was probably due to differences in the minerology of the ore body as a function of the depositional sequence of the various metals, and the leaching of the upper ore body as described by Becraft et al. (1963). The waste rock of the lower dump was finer in texture, had a lower rock fragment content, and a higher CEC (30 meq/100g) than the upper wastes, however its water holding capacity and available water content were not appreciably different. The soil was classified as a coarse-loamy mixed Typic Cryorthent. The most striking differences however were related to pH. In contrast to the upper wastes, the lower dump was extremely acid with pH measuring 3.0. This in conjunction with high sulfate levels (12860 ppm) indicated excessive pyrite oxidation and acid formation. Correspondingly, levels of soluble heavy metals were elevated. This was especially true of zinc and manganese, which measured 40.9 and 25.2 ppm (water soluble) respectively. These levels approach the tolerance limits stated by Chapman (1966). It was evident that the lower dump was a major contributing source of pollution to the Alta Mine drainage,

where the adverse effects of elevated heavy metal levels and low pH have been documented. Tables 29 and 30 show the pedon description and physical and chemical data from the lower dump.

Acid mine drainage was being produced in this area despite high levels of extractable calcium and the high pH of infiltrating water from the upper mountain. High sulfate levels indicated that much of the calcium may be in gypsum, which does not neutralize acidity. This gypsum may have been an end product of previous acid neutralization. The extent of groundwater pollution cannot be conclusively estimated using available data. However, it appeared that water from the underground workings must have been the dominant source of inflow to the lower dump (as postulated by Ingman, 1981), and that the pH of this water was low. Acid generation in the underground workings was apparently sufficient to significantly lower the pH of water from the upper mine with which it mixes. It was also interesting to note that the black material in the lower dump (sample 8A) maintained a high pH despite being embedded in acidic material. Thus although the extractable heavy metals contents of this material were extremely high, the soluble levels of these metals were low.

There was evidence that the upper 17 cm of the profile had been leached of much of its heavy metal load, with some of the metals having been removed from the system, and some possibly having

accumulated lower in the profile. This leaching may have assisted in the establishment of the few plants which existed on the dump. There was one vegetated area on a flat near the headframe, where topsoil from unmined slopes above had been deposited by sedimentation. It is likely that this topsoil provided added nutrients and available water and also acted as a buffer with respect to root contact with potentially toxic materials.

Bertha Tailings (lower pond). Samples taken from the Bertha tailings illustrated the extreme horizontal and vertical variability of tailings materials. Site 14, located on the lower pond, exhibited marked vertical stratification in texture, color, and reaction. The soil was classified as a fine-silty over sandy mixed Typic Cryofluvent. The surface C1 horizon consisted of lenses of gray and rust material with a silty clay loam texture. The upper 10 cm formed a platy crust with a hard consistence when dry. The C2 horizon was also a silty clay loam, however it had a massive structure and an extremely hard consistence, dry. Although bulk density measurements were not obtained, it is believed that this layer may impede root penetration. Both the C1 and C2 materials had a high water holding capacity (44%), CEC (45 meq/100g), and available water content (25 %). Both horizons also exhibited extremely acid pH (3.0) and elevated levels of heavy metals. Further, despite the findings of Ingman

(1981), a high percentage of these metals were water soluble. This was especially true of copper (3388 ppm) and zinc (1479 ppm). These levels are ten times the suspected phytotoxic standards and exceed all soil and water quality criteria. Sulfates, and the metals manganese, iron, cadmium, and nickel were also present at potentially toxic levels. Tables 32 and 33 present the physical and chemical data as well as the pedon description for this site.

In contrast, the C3 horizon was quite sandy (93% sand) and exhibited markedly lower heavy metal levels and a higher pH (5.2) than the upper horizons. This extreme texture difference, which may have been due to changes in the milling process, must inhibit vertical water movement within the tailings. It is likely that a perched water table exists during some periods, with water then moving horizontally within the C2 horizon and seeping out the sides of the pond. Even in late August, at the time of sampling, the C2 horizon was noticeably wetter than the remainder of the profile. Although this created potentially favorable moisture relationships for plant growth, the elevated levels of heavy metals effectively had precluded vegetative establishment. Wind scouring may also have been an important factor explaining the lack of vegetation on the tailings, as evidence of wind erosion was prominent. Wind may conversely have aided plant establishment in some cases, as it was noted that the few areas of the tailings which did support vegetation were areas where wind and water

had deposited relatively innocuous materials on the tailings surface.

Bertha Tailings (upper pond). Data for the Bertha upper tailings are presented in Tables 34 and 35. The pond was characterized by a thick loamy fine sand surface layer which consisted of lenses of rust and gray material. The upper 7 cm had a platy crust, with the remainder of the profile being single grained. The soil was characterized as a coarse-silty mixed Typic Cryofluvent. An elevated sulfate level (12970 ppm) and low pH (3.2) indicated pyrite oxidation, however heavy metal levels were low. This may have been due to low total metal levels as a function of improved extraction processes and/or lower grade ore in the later years of production. There was also evidence of leaching of most of the heavy metals from the upper profile due to its sandy texture. The leachate had precipitated the metals as salts on the eroded faces of the tailings. A surface sample of these salts exhibited water soluble heavy metal levels of up to 1986 ppm (copper) and a sulfate level of 34000 ppm. Thus, although the data from upper tailings indicated that material from the soil profile pit was relatively non-toxic, data from the salt efflorescences suggested possible toxicity problems. It may be that this situation represented the later stages of tailings oxidation, where much of the heavy metals have been solubilized and transported from the body of the tailings.

Bertha Mill Waste Rock. A grab sample of the Bertha waste rock showed a sandy clay loam texture, low pH (2.7), and elevated levels of heavy metals. Copper, iron, and aluminum were present at potentially toxic levels ranging from 30-60 ppm (water soluble). Table 37 lists the data from this sample.

Discussion of Alta Mine and Bertha Tailings Results

The studies of the Alta mine and the Bertha tailings indicated that all the materials present on the sites, with the exception of the upper Alta waste rock, pose problems with respect to environmental pollution. Low pH and toxic heavy metal levels seemed to be the predominant hazards, along with sediment problems arising from the proximity of the Bertha materials to Corbin Creek. Slope failure does not appear to be an immediate danger, although erosion on the sites was severe and may accelerate future slope failure. Physical hazards in the form of open adits and failing mine structures were present on all sites. The areas were quite visible from a distance, and thus exerted a large negative aesthetic impact. This was especially true of the Alta mine, which may prove to be the most difficult of the sites to revegetate due to the extremely steep slopes and lack of suitable cover material. A specific listing of problems and recommendations is as follows:

1) All mine buildings and structures must be considered a potential hazard to human safety and thus should be removed from the site. These artifacts may be disposed of or donated to organizations such as museums and historical societies. At the Alta mine these structures consisted of several buildings and a headframe located on the lower two-thirds of the mountain. There was also a small structure located on the west side of the mountain top. The mill ruins were the only hazard of this type observed at the Bertha sites.

2) All open adits or tunnels of any type must be considered an extreme hazard to human safety and should be (minimally) sealed in such a way as prevent entry or access. At the Alta mine two adits would necessitate such treatment. Both were located on the southern rim of the uppermost open cut on the mountain. It did not appear that either of these adits require air or bulkhead seals to prevent seepage. The possibility of sealing the collapsed adit from which the Alta seep begins may be investigated, however it is believed that the extent of the underground workings may make this impractical due to a large hydraulic head. The extensive workings also pose the potential problem of a new seep developing upon sealing of this adit. It is recommended that a treatment facility be constructed to improve the quality of the Alta drainage at some location before entry into Spring Creek. Although locating the facility at the discharge point

would have the advantage of lower required capacity and would improve a longer section of stream, it is possible that Corbin Creek should be included in the treatment process. The treatment plant is believed to be necessary in order to treat seepage emanating from underground workings which would not be ameliorated by surficial treatments.

3) The lower Alta waste rock dump clearly represents an environmental hazard due to the discharge of toxic drainage water. Treatment for this problem should include the incorporation of lime to increase pH, decrease soluble levels of heavy metals, and improve the plant growth medium. It is also suggested that full advantage be made of the proximity of good coversoil from the adjacent hillslopes. Soil could be stripped to the maximum feasible depth (approximately 20 cm) and directly applied to the lower dump. Sufficient coversoil depth would have to be maintained on the stripped slopes to support revegetation. The stripping could incorporate slope recontouring to preclude the gully erosion which presently exists in some areas. Care should be taken during recontouring to maintain the function of the lower dump "bench" as a barrier to further transport of eroded material from the upper mountain. The use of diversion ditches might also be considered at this time. If additional coversoil depth is desired after topsoil volume calculations are made, coarse limestone could be used as a water movement barrier to prevent

upward flow of contaminated water from the spoils. Waste rock from the upper mountain might also prove to be a suitable cover material under the topsoil, and should strongly be considered. The author believes that topsoil application will be necessary to establish vegetation on this area.

4) The upper section of the Alta mine does not appear to pose a significant environmental hazard, although it is probably contributing sediment to the Alta drainage during high flow periods. The area does however create a severe aesthetic impact. Revegetation of the upper mountain may be severely limited by the lack of suitable cover material, and by restrictions on earth-moving operations created by steep slopes and very shallow depth to bedrock. This last constraint may limit the options available in the recontouring plan, and should be thoroughly investigated by an engineer. If possible, the recontouring plan should include: 1) benches or diversion ditches to channel water onto vegetated portions of the mountain, 2) shortened slope lengths and decreased gradients, and 3) incorporation of concave slope configurations to minimize runoff energy. Due to the rocky nature of the probable root growth medium (upper mountain waste rock), and the probable persistence of highwalls on the site, it is suggested that revegetation efforts concentrate on establishing tree species. In addition to being better suited to the waste rock texture, trees provide "vertical cover" and will greatly lessen the negative

aesthetic impact of the highwalls. The use of bare-root seedlings is advised. It is also possible that the light color of the upper mountain waste rock has inhibited vegetative establishment by reflecting solar radiation (this may also explain why the vegetation on the site was concentrated in "protected" areas, which receive less solar radiation). The use of mulches would help ameliorate this effect, and also add much needed nutrients to the system.

5) The Bertha tailings and mill waste both contribute sediment and toxic substances to Corbin Creek, and both must be moved away from the streambank. In the case of the tailings the possibility of removing them from the site to be processed should be investigated. It is the most assured method of preventing further problems created by the tailings materials, and has the added advantage of increasing the area which could be used for waste rock treatment and disposal. Recommendations for the tailings pond area are: a) strip as much suitable material from the hillside behind (south of) the ponds as possible and store in stockpiles, b) move tailings away from the streambank and back into the hillside, c) heavily lime the tailings material, d) apply stockpiled coversoil to the tailings surface, and e) rip-rap the streambank. The same type of approach is recommended for the mill site, although implementation will be much more difficult due to the greater volume of material and more restricted working

area. It is imperative however that the waste rock be moved and protected by rip-rap. The refuse which has been dumped in this area should also be removed during rehabilitation of the site.

Characterization of the Bannack Mill Tailings

Site Description

Location. The Bannack mill tailings site is located in sections 6 and 7, T8S, R11W MPM, Beaverhead County, Montana. The area is approximately 29 km WSW of Dillon and lies opposite the town of Bannack on the south side of Grasshopper Creek. Access to the site is obtained via Montana State Highway 278.

Climate. The best climatological data available for the Bannack mill site was from the Dillon WMCE weather station (elev. 1593 m). Yearly precipitation averaged 28.8 ± 7.1 cm, most of which fell as spring and fall rains and summer thunderstorms. Approximately 65-75% of the annual precipitation occurred during the growing season which averaged 92 ± 23 frost free days. The average annual daily temperature was 6.4 ± 0.5 °C, while maximum and minimum temperatures reached 37.2 and -36.1 °C respectively (U.S. Weather Bureau, 1971-1981). The local climate at Bannack may be slightly wetter than indicated by the presented data.

Mining History and Geology. The Bannack mill and tailings site was a part of the Hendricks (Graeter) mine, whose workings extended under the hillside to the south of the ponds. The ore deposit of the Hendricks mine was a replacement body in a north trending zone of overthrust Madison Limestone. The ore occurred in two bedding planes, in veins of oxidized gold-bearing red-brown iron oxides having a maximum thickness of 2.4 m (Geach, 1972). Gold and silver were the main metals produced, along with some lead and copper. Total production for the mine was estimated at 40 thousand dollars. The mine workings consisted of 450 m of underground tunnels and an open cut approximately 50 by 90 m in size (Geach, 1972).

The Hendricks mine was one of the earliest claims in the Bannack area, but did not produce substantially until the construction of the first mill in 1918, which was followed by construction of a larger mill in 1920. The mine operated until 1921 and later reopened from 1933-1941. Some minor excavation was performed in 1961. The Hendricks mill not only processed ore from the Hendricks mine, but also operated as a custom mill. Ore was brought in from as far away as Dillon (Herseth, 1981). Although the exact dates and mines involved in the custom milling operation are not known, a variety of materials were evident at the site.

Physiography. The tailings site is located south of the Pioneer

Mountains in an area of north-south trending, well rounded mountain ranges separated by broad intermountain troughs. The maximum relief in the (Bannack) district is approximately 550 m. Sharp cliffs and gulches are also present due to the outcropping of resistant limestone and quartz strata (Shenon, 1931). Bannack itself lies on the eastern edge of a large north-south trending alluvial valley and is adjacent to a flaring gap in a small mountain range to the east.

The disturbed area, which totaled approximately 2 ha, may be divided into upper and lower sections. The upper section consisted of the Hendricks mine excavations, and contained an open adit which should be considered a hazard to public health and safety. There were also hazardous areas of eroded, steep slopes associated with the open pit and areas of apparent hydraulic mining. The (lower) tailings pond area consisted of four diked levels of tailings which increased in thickness from 1.5 m at the eastern end of the ponds to 3.5 m at the western end. The dike of one of the ponds was breached. Adjacent to the northeastern perimeter of the ponds was an area with scattered piles of waste rock approximately 1.5 m high. These were probably remnants of former placer and hydraulic mining. The general features of the Bannack tailings site are illustrated in Figure 19. The lower portion of the mine also contained the remains of the old mill structure. Although the structure was in relatively good condition it was considered a potential safety hazard.



Figure 19. View of the Bannack tailings ponds looking NE from the Hendricks mine adit.

Hydrology and Water Quality Analysis. The Bannack tailings site is located on the edge of the Grasshopper Creek flood plain, in an area of alluvial and colluvial deposits at the base of rounded hills which extend to the south. The ponds appear to have been deposited in the position of an alluvial fan which had been removed by hydraulic mining, and thus it is reasonable to expect that a large portion of the surface runoff from the small watershed above may pass through the site. However, during field reconnaissance (08/11/81) little evidence of surface flow was apparent. The Hendricks mine adit was completely

dry, and there was only one area of gully erosion on the site. This was found in the western section of the tailings, where a dike had been breached. Piping was evident at the breach. It was concluded that surface flow through the tailings occurred only during spring runoff or during high-intensity precipitation events, and little material was removed from the site by this action. Further, sediment from the ponds probably does not directly enter Grasshopper Creek during these periods due to the wide vegetated flood plain which must be traversed. The tailings ponds were located some 75 m from the streambank. Tailings material was introduced into the stream during flood events, as evidenced by an area of reworked tailings on the northern border of the ponds. Due to the low lying position on the landscape occupied by the tailings, it is possible that the groundwater table or capillary fringe intercepted the base of the ponds during wet periods. Leachate from the ponds may have affected local groundwater quality.

Water samples were obtained from Grasshopper Creek above and below the disturbance. Data from these samples, presented in Table 15, indicated that the water quality was good, and unaffected by the Hendricks mine and mill site. All measured parameters were well within acceptable levels for aquatic life and human usage. This supported the findings of several studies performed from 1973-1976 which indicated that the Hendricks mine disturbance was not a major

contributor to the pollution of Grasshopper Creek (Anseth and Phippen, 1979).

Minesoil Characterization

Natural Soils and Vegetation. A native soil described at the Bannack site (site 03) was classified as a fine-loamy mixed Typic Cryoboralf. Physical and chemical data, along with the pedon description for this soil may be found in Tables 38 and 39. The soil was deep, well drained, and exhibited medium to rapid permeability and moderate erosion. Structure was weak coarse subangular blocky. Chemical and physical data indicated neutral pH, high organic matter content (4.3%), and high cation exchange capacity (40 meq/100g) with calcium dominating the exchange complex. Heavy metal content was low. Electrical conductivity, available water holding capacity, and textural class were all rated good with respect cover-soil quality to guidelines presented by Schafer (1979). This rangeland soil supported vegetation which included Idaho fescue, bluebunch wheatgrass, big sagebrush and rabbitbrush as the dominant species.

Large areas of the tailings were devoid of vegetation but for a few scattered shrubs and forbs. In contrast, certain area of the tailings were well covered with rabbitbrush. These vegetated areas: 1) appeared to be in low lying areas which were protected from wind

action, and 2) were often associated with a reddish-brown tailings material, rather than the gray material which comprised the majority of the tailings surface.

Bannack Tailings (near mill). Bannack tailings were sampled at five locations including two soil profiles and three grab samples. The profiles were located near the mill (site 01) and in the northwest (NW) quarter of the ponds (site 02). These locations are shown in Figure 20. Pedon descriptions and physical and chemical data are presented in Tables 41-46.

The profile at site 01 was characterized as a coarse-silty mixed Typic Cryofluvent. It exhibited a thin surface crust, and had an abrupt vertical textural change at a depth of 17 cm, with silty material overlying sandy material. This stratification may have been due to changes in milling procedures and certainly must impede vertical water movement in the tailings. The surface crust was not believed to be sufficiently strong to restrict seedling emergence, however it may have prevented good seed/soil contact which is important for germination. Available moisture in the silty layer was over 20%. Measurements of EC, organic matter content, and water soluble heavy metal levels were all low. Evidence of wind erosion was prominent.

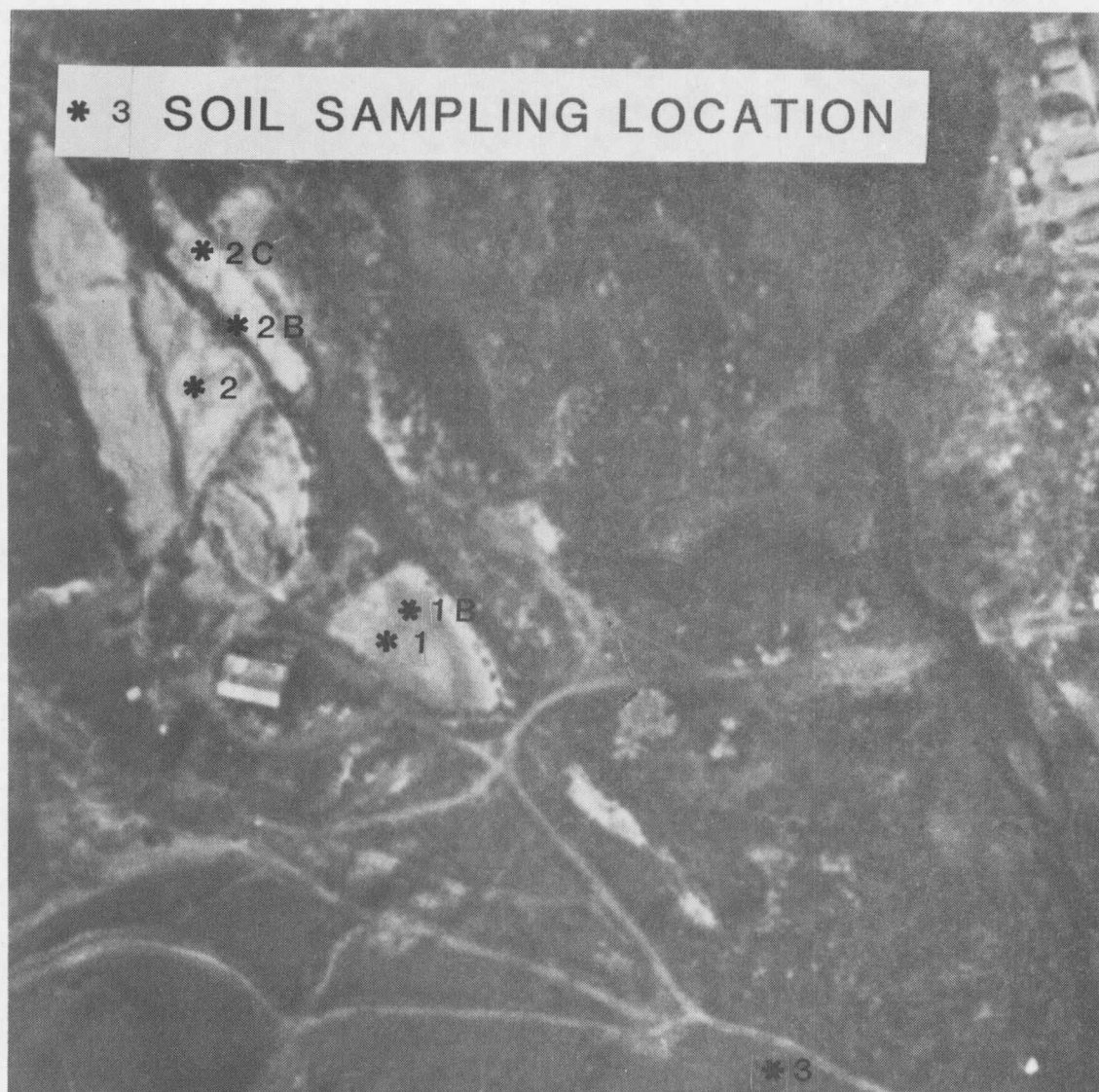


Figure 20. Aerial photograph of the Bannack mill and tailings site showing sampling locations.

A grab sample from a swale (site 01B) 5 m N of site 01 showed characteristics similar to the silt layer of site 01. However, the upper 2 cm exhibited a moderately alkaline pH (8.2), and EC levels which were inhibitory to plants as a result of a salt accumulation at the surface. Despite this elevated EC, the swale had greater vegetative establishment than the surrounding area. Chemical data indicated that these were largely magnesium and sodium salts.

Bannack Tailings - (northwest section of pond). Material from the northwest section of the ponds exhibited a coarser texture and lower water holding capacity than the material near the mill. In all other respects the characteristics of these two materials were similar. A surface sample from the reworked area north of the ponds (site 02B) also exhibited similar characteristics, as did the sample of reddish-brown material taken from a dike (site 02C).

Discussion of Bannack Tailings Results

The reddish-brown material on the site supported dense stands of rabbitbrush, which indicated that the material was non-toxic to this species. It was believed that this material was similar to the tailings at the Gold Creek mill 200 m downstream, which also supported vegetation. However, it was noted that the Gold Creek tailings were reported to be responsible for the pollution of Grasshopper Creek (Anseth and Phippen, 1979). Evidently, levels of

heavy metals in the tailings which were toxic to aquatic life did not restrict plant growth. It was also observed that the gray material at the Bannack site supported vegetation in the protected areas behind the dikes. Thus it was apparent that the lack of vegetation on the Bannack tailings was not due to physiochemical limitations of the rooting medium.

Evidence from the Bannack tailings site suggested that wind action may have been the major factor responsible for the lack of vegetative cover. Several effects of wind action were manifested on the site, including: 1) wind scouring of seedlings, 2) moisture deficiencies as a result of rapid evaporation by maintenance of steep water potential gradients at the surface of bare soils which had only moderate available water holding capacity, 3) removal of seeds from the flat, hard surface of the ponds, and 4) active erosion and deposition. The preponderance of vegetation on areas of the ponds protected from these effects substantiates this conclusion.

There is currently a proposal to reroute the road which goes through the town of Bannack across Grasshopper Creek and around the northern boundary of the tailings area in order to divert vehicular traffic away from this historic town site. Implementation of this proposal may also include reclamation of the tailings area. The following is a list of recommendations pertaining to this program:

1) The new road should be elevated as it passes the perimeter of the tailings, with the roadbed acting as a dike to prevent the removal of tailings materials from the site during flood events. The northern face of the road base should be covered with topsoil obtained from the adjacent floodplain, while maintaining sufficient soil depth on the stripped areas to support revegetation. Consideration should also be given to applying topsoil to any area north of the road which is unvegetated due to the presence of reworked tailings. Application of topsoil will insure rapid vegetative establishment. Revegetation may be further enhanced by the salvage and reapplication of vegetation "sod pads" on the floodplain surface.

2) The open adit of the Hendricks mine should (minimally) be sealed so as to prevent human access, as it is a hazard to public health and safety. This is imperative, as the new road will significantly increase the utilization of the mine site for tourism and/or recreation.

3) The mill structure itself presents a hazard to public safety, however it is also an important historical building. It is suggested that the structure be secured with fencing so that the flotation vats and inner workings may be seen from outside the structure.

4) Revegetation of the tailings pond surfaces should not be difficult. The chemical and physical properties of the tailings materials do not seem to necessitate the application of topsoil,

although use of topsoil would enhance the prospects for success. The most important aspect of the revegetation effort is amelioration of the effects of wind action. Several techniques may be utilized to do this. First, seedbed preparation and planting will in themselves mitigate the situation by increasing surface roughness, and providing good seed/soil contact. The use of mulches is a common technique which will further reduce wind effects. Application of either a mulch which lies flat on the surface or a hay mulch crimped into the surface will provide protection from wind scouring and moisture loss, and will greatly enhance the possibility for successful reclamation. The use of snow fences and the planting of windbreaks are other ameliorative measures which may be used. Nitrogen and phosphorous fertilization will be necessary to meet plant nutrient requirements.

One alternate plan should be considered; that is to simply chemically stabilize the tailings surface without planting. This will minimize offsite impacts while providing the benefit of (visually) maintaining the area as a historic site. Studies by Dean et al. (1969) and Havens and Dean (1970) have shown this to be an effective technique, and have indicated that natural revegetation is enhanced by the procedure.

5) Reduction and revegetation of slopes in the open pit and surface mined areas should also be considered as a part of the

reclamation effort. Concave slope configurations should be incorporated into slope design wherever possible to minimize runoff energy. Sufficient depths of coversoil materials appear to be readily available.

Characterization of the Champion Mine

Site Description.

Location. The Champion Mine is located in sections 28 and 33, T6N, R8W MPM, Deerlodge County, Montana. The privately owned property is within the Helena National Forest, just to the west of the Continental Divide. The site is approximately 24 km NNW of Butte, Montana and is accessed via Interstate 90.

Climate. The best climatological data available for the Champion mine was obtained from the Deer Lodge 3W weather station (elev. 1484). Yearly precipitation averaged 27.7 ± 9.9 cm, most of which fell as spring and fall rains and summer thunderstorms. Approximately 65-75% of the annual precipitation occurred during the growing season, which averaged 52 ± 32 frost free days. The average annual daily temperature was 5.2 ± 0.3 °C, while maximum and minimum temperatures reached 36.1 and -40.0 °C respectively (U.S. Weather Bureau, 1971-1981). It is likely that the local climate at the site is somewhat wetter and cooler than these data indicate due to its proximity to the

continental divide.

Geology and Mining History. The Champion mine was the leading producer in the Oro Fino Mining District, with a total yield of over 300 thousand dollars. The mine was first operated from 1886-1888, but closed due to the high cost of ore transportation to the mill near Deer Lodge. Champion was reopened in 1920 by the Butte-Jardine Metals Company, which built a flotation mill on site. The operations continued until 1926, when low silver prices forced closure of the mine (Pardee and Schrader, 1933). The property is currently owned by the Anaconda Company.

The ore body was a proustite/pyrargyrite-bearing quartz vein 0.3-2.4 m wide. It was characterized as a fissure deposit in the aplite phase of the Butte quartz monzonite mineralization (Billingsly and Grimes, 1918). The mine has been worked to the 275 m level (Anaconda Co., 1981).

Physiography. The Champion mine is located in an area of rounded mountains and moderately steep drainages on the east side of the Deer Lodge Valley. Local relief is approximately 400 m, with mountain peaks rising over 2225 m. The Champion mine site occupies the bottom and north slope of a small drainage, within an elevation range of 1950-1980 m.

The mine disturbance of approximately 2.5 ha may be divided into an upper waste rock area and a lower tailings area. On the upper area, waste rock from the operation was dumped off a bench artificially created for mine structures. It was apparent that material had been mechanically removed from the face of the western end of the dump. This had resulted in the formation of oversteepened, nearly vertical slopes approximately 9 m high. These slopes constitute a hazard to public safety. The Champion adit was also located on the upper portion of the mine. The adit was partially collapsed at the surface, however it appeared that access to the shaft was possible. In such condition this adit also poses a threat to public safety. A third feature of the upper area was the presence of several mine structures. These included two ore bins which must be considered serious safety hazards as their tops are open and at ground level. Other mine structures included two concrete foundations on the NW edge of the disturbance and the remnants of two cabins east of the mine site. A concrete foundation was also present on the upper bench near the Champion adit.

The lower area of the mine was associated with the Champion tailings which occupied a lowland area adjacent to a tributary of Oro Fino Creek. The tailings seemed to have been deposited in one pond, to a depth of approximately 1.5 m. The tailings dike and over 60% of the tailings materials had been removed from the site by water

erosion. The general physiology of the waste rock and tailings areas are shown in Figure 21.

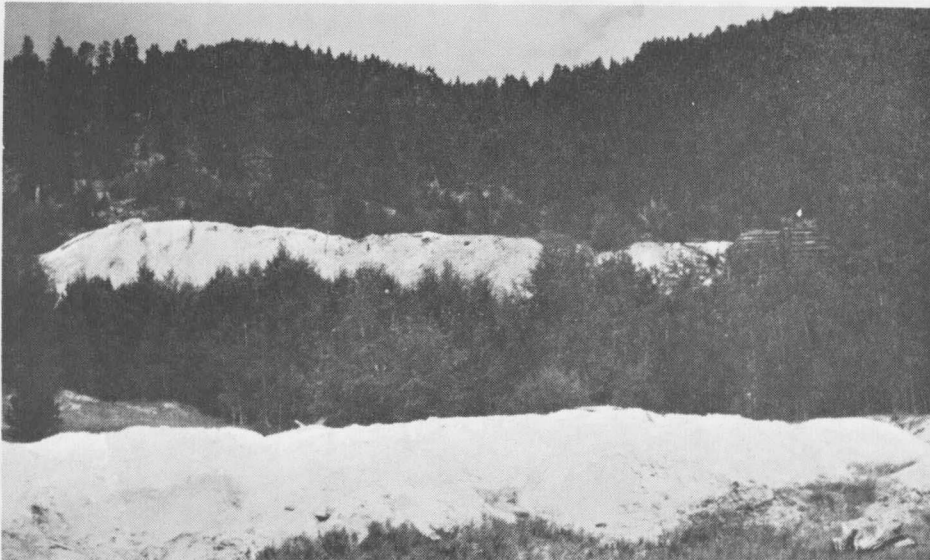


Figure 21. View of the Champion mine looking north from the center of the tailings pond.

Hydrology and Water Quality Analysis. The position of the Champion disturbance on the landscape indicated that water from approximately 10 ha of the watershed above the mine flows through the site. The tailings pond intercepted the groundwater table, as evidenced by shallow excavations that filled with water. Surface flow on the site originated from the tributary to Oro Fino Creek which skirts the southern edge of the tailings pond, and from discharge emanating from the Champion adit. Evidence indicated that the stream

overflowed its banks during spring runoff and/or severe storm events, and had caused large amounts of water to flow directly over the tailings. This flow was responsible for the extreme dissection of the tailings. Flow from the adit cascaded down the face of the waste rock dump and then traversed the tailings pond near its northern edge before entering the stream. A white precipitate was found where drainage from the adit flowed over the waste rock and a red precipitate was on the tailings. Chemical analysis indicated a significant amount of iron was removed from the water in these precipitates.

Water quality samples were obtained at four locations: 1) 100 m upstream of the disturbance, 2) at the adit discharge, 3) at the center of the tailings pond, and 4) 200 m below the mine. Quality of the upstream sample was good, as indicated by low heavy metal levels, low EC, and slightly alkaline pH (8.0). Samples obtained from the mine site however, exhibited degraded water quality. Measured pH was moderately to extremely acid (5.3-3.8), and levels several heavy metals including iron, manganese, copper, and zinc exceeded one or more of the applied federal standards. Water quality 200 m downstream had significantly improved. Measured pH was 7.5, and only copper and manganese exceeded water quality criteria. The presence of sediment from the tailings was noted downstream. Data indicated that although the Champion mine was responsible for degradation of Oro Fino

Creek, the natural buffering capacity of the stream significantly ameliorated this influence during low flow periods. It was expected that a longer portion of the stream was adversely impacted during spring runoff. Water quality data for the Champion mine are presented in Table 16.

Minesoil Characterization

Natural Soils and Vegetation. An undisturbed soil near the Champion mine was classified as a sandy mixed Typic Cryochrept. The soil was of fair cover-soil quality, and was characterized by low available water holding capacity, slightly acid pH (5.5), and high rock fragment content (5-40%). Electrical conductivity measured 0.2 mmhos/cm, organic carbon was 0.5%, and heavy metal levels were low. Soil structure was weak granular. The pedon description, and physical and chemical data for this soil are presented in Tables 47 and 48. Vegetation in the area was mixed coniferous forest. On the disturbance vegetation was present in the bottoms of channels eroded through the tailings, despite extremely acid pH's. A rush (Juncus spp.) was the dominant plant in these areas. Small amounts of vegetation also grew on the flat tops of some of the remaining tailings islands. Virtually no vegetation was supported on the waste rock dumps. A partial species list of the plants found on the site may be found in Table 62 (Appendix D).

Champion Tailings (vegetated flat). Two soil profiles were excavated in the Champion tailings: 1) at the eastern boundary of the pond adjacent to a grassed flat (site 05), and 2) on a remnant island (site 06) in the center of the pond. The locations of the Champion sampling sites are depicted in Figure 22.

Site 05 was classified as a fine-silty mixed Typic Cryofluvent. A distinct texture difference occurred at a depth of 12 cm, with sandy material overlying fine silt. Although this layering would not create a perched water table, inhibition of vertical water movement was likely. Available water holding capacity was rated as fair for use as cover-soil. Cation exchange capacity averaged 10 meq/100g in the profile, while EC measured 0.2 mmhos/cm in the upper 12 cm and 3.0 mmhos/cm in the lower profile. Data indicated heavy metal levels were low, with the exception of aluminum which was present in potentially toxic amounts. All measured cations exhibited markedly higher levels in the C2 horizon. Low pH (3.5), and high sulfate levels indicated extensive pyrite oxidation. Profile development was evidenced, probably due to the influence of the adjacent flat with respect to topsoil deposition and vegetative colonization. A surface sample (site 06A) taken from the vegetated top of a remnant island in the center of the tailings exhibited similar chemical properties.

Champion Tailings (remnant island). Tailings in this area (site

06) were classified as a fine-silty over sandy mixed Typic Cryofluvent. Physical and chemical data were similar to those of site 05. Horizontal variations in texture served to trap moisture in the middle of the profile, which was wet in late August. An extremely high percentage of the heavy metal content was in soluble forms, with aluminum and manganese present at potentially phytotoxic levels. Measured pH was extremely acid (3.0), and EC data indicated inhibitory salt concentrations (5mmhos/cm).

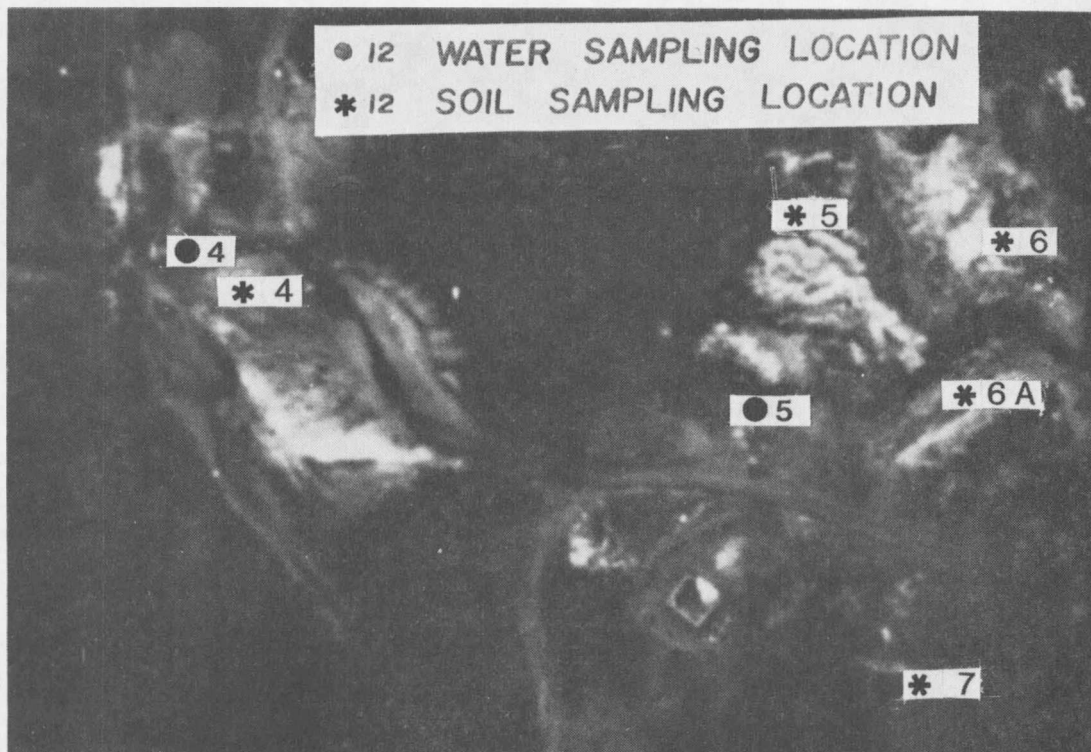


Figure 22. Aerial photograph of the Champion mine showing soil and water sampling locations.

Champion Waste Rock. A grab sample from the Champion waste dump (Site 04) exhibited low available water holding capacity (6%), a CEC of 20 meq/100g, extremely acid pH (3.5), and low organic matter content (<.5%). Electrical conductivity was slightly elevated although not inhibitory, and heavy metal levels were low. Aluminum was potentially phytotoxic (5 ppm water soluble), however it was present in amounts significantly lower than exhibited by the tailings. Pedon descriptions and physical and chemical data for the Champion spoil samples may be found in Tables 49-54.

Discussion of the Champion Mine Results

Study of the Champion mine indicated that degradation of stream quality had occurred as a result of the disturbance. However, the presence of aquatic life in the stream, as well as indicated levels of measured parameters suggested that this degradation was not extremely serious. The lack of vegetation on the site was considered a problem with respect to both aesthetics and offsite transport of mine waste materials. On the waste rock, available water seemed to be the most limiting factor for vegetative establishment. Somewhat elevated EC levels exacerbated this problem, and it was possible that the slightly elevated heavy metal levels synergistically affected plant growth under this moisture stress. It was evident that the tailings material was capable of supporting vegetation. The question remains

as to why some areas were vegetated, while others were not. The data suggested that EC and heavy metal levels are present in potentially inhibitory or toxic levels. Areas which supported vegetation had lower levels of these parameters, had been leached, or were in areas of surface water or ground water flow. These situations apparently provided a suitable plant growth environment.

It must be noted that areas of the tailings exhibited thixotropy. This may present problems with respect to machinery operation in the reclamation effort. The following are specific recommendations for the Champion mine disturbance:

- 1) The most immediate hazard associated with this site is the safety hazard posed by the old ore bins. These should be dismantled immediately and either removed from the site, or if possible used for raw materials in slope or streambank stabilization. Other structures on the site pose minimal safety hazards, but may be removed from the site if desired. The Champion adit should also be closely checked and sealed if necessary to insure (minimally) that access is not possible. Sealing to prevent further discharge should also be considered at this time.

- 2) The tailings materials present the greatest pollution hazard on the Champion site. An investigation should be initiated as to the cost effectiveness of backfilling the underground mine workings with a tailings slurry. This would be the most effective method of

preventing offsite transport of tailings material, and would also eliminate the flow of tailings leachate into the stream. Chemical testing of the remaining material which previously underlaid the tailings should be made to evaluate the need for fertilization, liming and topsoil application. Sufficient topsoil could be obtained from the adjacent grassy flat if necessary. Backfilling of waste rock into the adit and subsequent sealing to prevent discharge might also be considered.

If backfilling proves to be impractical an alternate strategy would be to attempt revegetation in place. Heavy liming would be necessary for successful plant reestablishment. Recontouring of the tailings would probably be beneficial in that it would disrupt textural layering and facilitate vertical water movement and leaching. However, the thixotropic characteristics of the tailings materials would have to be considered in this plan. Dewatering of the pond might be necessary for physical support of machinery during the earth moving and liming processes. It is suggested that diversion ditches be included in the reclamation plan to minimize surface flow. Control of the stream would be difficult and costly, however it is necessary that some provision be made either for assured stream diversion around the tailings during flood events or for complete revegetation before the next event. The grassed flat adjacent to the tailings should be

utilized as fully as possible for topsoil, sod pads, and dike material

3) The waste rock dumps do not constitute a chemical health hazard of consequence. The slopes on the western end of the dump do however present a safety hazard and should be recontoured. This recontouring could include repair of the roadbed which bisects the dump. Hydromulching of the dump surface might be a sound practice to enhance revegetation and aesthetic rehabilitation. It is recommended that the waste dumps and the slopes above them be disturbed as little as possible.

Characterization of the Wasa Mine

Site Description

Location. The Wasa mine is located in section 27, T9N, R12W MPM, Granite county, Montana. The site is situated on private land approximately 24 km NNE of Phillipsburg, in the Deerlodge National Forest. Access to the mine is obtained via U.S. Route 10a.

Climate. The best climatological data available for the Wasa mine was from the Phillipsburg RS weather station (elev. 1606 m). Yearly precipitation averaged 36.6 ± 12.9 cm, with most of the precipitation falling as snow and spring and fall rains. Summer precipitation occurred as a few thunderstorms. Only 55-65% of the

annual precipitation fell during the short and variable growing season which averaged 39 ± 27 frost free days. The average annual daily temperature was 4.8 ± 0.7 °C, while maximum and minimum temperatures reached 35.0 and -37.8 °C respectively (U.S. Weather Bureau, 1971-1981). Local climate at the Wasa mine may be somewhat cooler and wetter than is indicated by this data.

Geology and Mining History. The Wasa mine, discovered in 1910, was one among several mines known collectively as the Forest Rose group of the Dunkelberg mining district. Wasa was the major producer of zinc in the district, and also yielded small quantities of lead, copper, and silver. The mine operated almost continuously until 1947, shutting down only during the depression years.

The Wasa mine utilized four adits through a vertical interval of 55 m. These were: 1) Wasa 3 at 1871 m altitude, 2) Wasa 2 at 1859 m, 3) Zimmer Jack at 1862 m, and 4) Wasa 1 at 1835 m altitude. The adits were driven east from the NE side of Douglas Creek and total 460 m in length. Approximately 240 m of additional workings are present at the site (Popoff, 1953). A surface pit has also been opened on the property. The last known owner of the mine was the Butte and Western Mining Company (Krohn and Weist, 1977).

The Wasa ore body was in a structurally complex area on the west limb of the Dunkelberg anticline. The major geologic feature was the Wasa/Shamrock fault, which cut through and displaced the anticlinal

axis. This fault was accompanied by a wide zone of brecciated rocks that had been metamorphosed and mineralized. The ore body was classified as a hydrothermal replacement body in the lower limestone member of the Cretaceous Kootenai formation. The vein trended NE along the fault planes, dipped 75° E and averaged 4.5 m in thickness (Popoff, 1953; Gwinn, 1960). The major minerals were massive and fine grained sphalerite and pyrite. Chalcopyrite, galena, pyrrhotite, and siderite had also been identified. Parts of the ore body had been oxidized to depths of 15 m (Popoff, 1953).

Physiography. The Wasa mine is located high on the western side of Dunkelberg Ridge in the Flint Creek Range. It is situated in a narrow, steep-sided drainage in the headwaters of the North Fork of Douglas Creek. Altitudes in the area range from 1500-2400 m, with local relief of 450-1350 m.

The mine site occupies the bottom of the drainage through a vertical drop of 60 m. The size of the disturbance is approximately 4 ha. Waste rock from the operation was found as piles resting at the angle of repose on the drainage floor and side slopes, and as a blanket of debris covering the drainage bottom (Figure 23). The open pit was located on the SW side of the drainage. The highwall was approximately 12 m high and posed a threat to public health and safety due to its height and steepness. Waste rock and colluvial material

were found at the bottom of the pit. The Wasa 1, 2, and 3 adits also constitute a safety hazard as they were all open to the surface and filled with water. The Zimmer Jack adit was collapsed at the surface. The only mine structures remaining were a loading chute and remnants of a dumping ramp on the lower portions of the mine. Of these, only the chute was viewed as a potential hazard. There were no tailings materials on the Wasa site, as ore from the mine was trucked to and milled at the Forest Rose mine (Popoff, 1953).



Figure 23. View of the Wasa mine looking east from below the Zimmer Jack adit.

Hydrology and Water Quality Analysis. This Wasa mine is located in the headwaters of North Fork Douglas Creek, one of the two severely

impacted streams in the Flint Creek Range (Ingman and Bahls, 1979). Surface flow on the site originated from the small drainage area above the mine and from seeps which issued from all four mine adits. These seeps were major contributors to the total flow in the upper reaches of the stream during low flow periods. An erosion gully existed at the bottom of the draw, indicating the dominant surface flow path. The gully was present down much of the length of the disturbance and was most pronounced at the downstream edge of the site, where water from the Wasa 1 adit flowed over a waste dump.

A Montana Water Quality Bureau Study demonstrated stress on aquatic life along the entire length of North Fork Douglas Creek as a result of the Wasa mine. At the mine source, levels of cadmium, copper, iron, and zinc exceeded various water quality standards. The aquatic life present consisted only of the green algae Stigeoclonium and the diatom Achnanthes minutissima (Ingman and Bahls, 1979). This low species diversity was indicative of stressed conditions. At the mouth of North Fork Douglas Creek stream water still exhibited elevated levels of zinc, cadmium, and sulfates, and aquatic communities still indicated slight stress. Ingman and Bahls concluded from this data that the Wasa mine was the major contributor to the degraded water quality of the creek.

For the present study five water sampling locations were chosen:

1) 0.4 km. above the mouth of North Fork Douglas Creek (site 09), 2) North Fork Douglas Creek directly above the Wasa disturbance (site 12), 3) below the Wasa 1 adit (site 13), 4) below the confluence of the seeps emanating from the Wasa 2 and Wasa 3 adits (site 10), and 5) below the Zimmer Jack adit (site 11). Sampling locations are shown in Figure 24.

Data from these samples substantiated the findings of Ingman and Bahls (1979), and are listed in Table 16. The upstream sample exhibited moderately acid pH (5.0) and low EC (.06 mmhos/cm), hardness (46 ppm), sulfate (38 ppm), and heavy metal levels. All parameters were well within established water quality standards. Samples from the adit seeps however, all exhibited degraded quality. The samples from below Wasa 2 and 3 and Zimmer Jack were similar and were characterized by elevated EC (0.2 mmho/cm), hardness (150 ppm), and sulfate (100 ppm) levels, however these levels did not appear to be exceedingly high. Zinc and copper were present in the water at levels which slightly exceeded standards for human and aquatic life, respectively. Measured pH was 5.0. Drainage water from the Wasa 1 adit exhibited neutral pH, elevated bicarbonate (113 ppm), hardness (200 ppm), and sulfate (100 ppm) levels. Concentrations of zinc slightly exceeded quality standards for human consumption and levels of copper were slightly over recommended limits for aquatic life. Water sampled from the mouth of North Fork Douglas Creek was characterized by

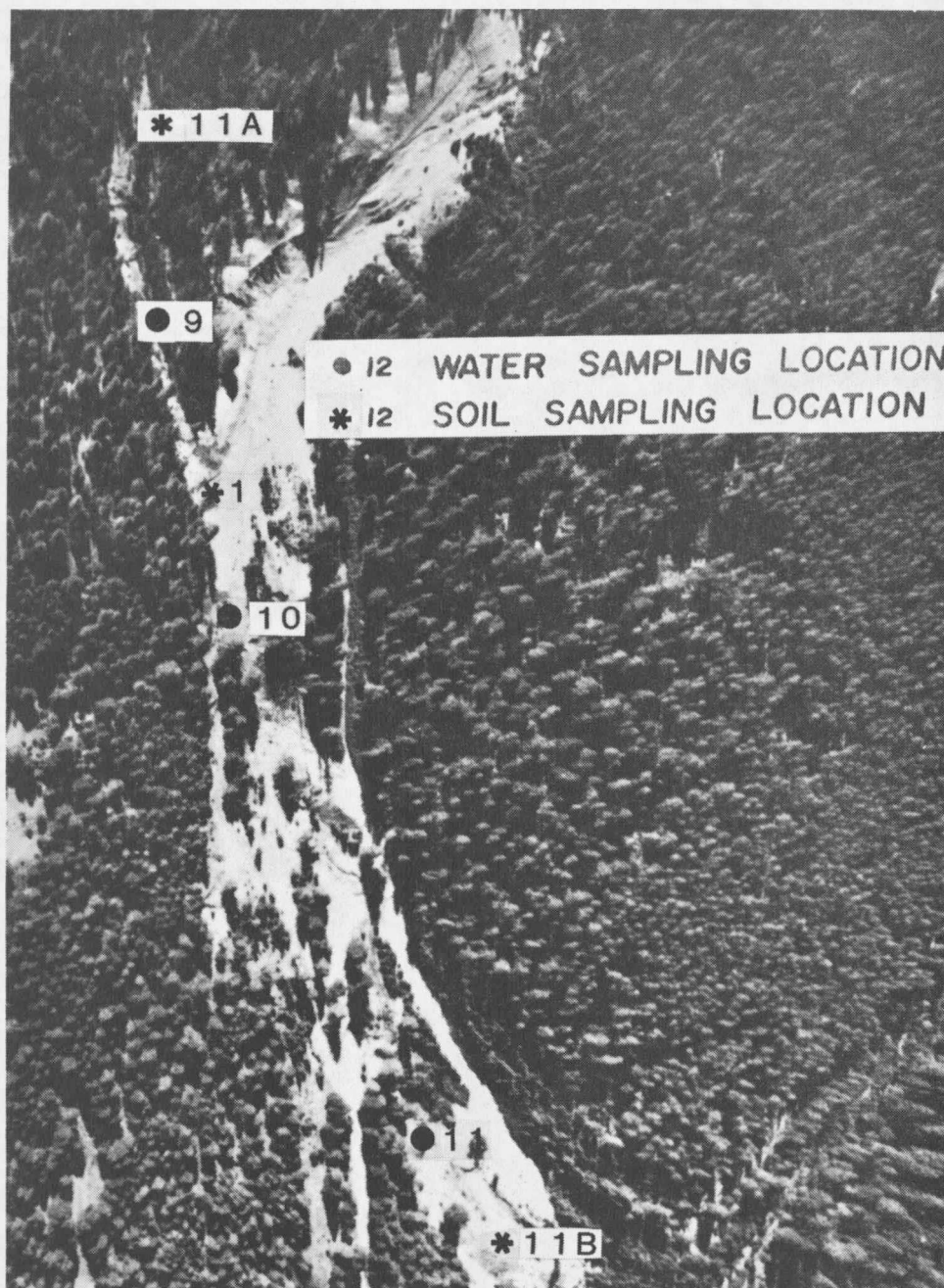


Figure 24. Aerial photograph of the Wasa Mine showing soil and water sampling sites.

neutral pH, and high bicarbonate (141 ppm) and hardness (137 ppm) levels. Measurements indicated low sulfate and heavy metal levels, although copper was present in quantities detrimental to aquatic life (.06 ppm). Data from the Wasa mine indicated water quality degradation due to drainage from the disturbed area. Although this degradation was not severe, it did affect the entire North Fork Douglas Creek and beyond.

Minesoil Characterization

Natural Soil and Vegetation. An undisturbed soil adjacent to the Wasa mine was characterized as a coarse-loamy mixed Typic Cryoboroll. The soil was deep, had moderate drainage, medium permeability, and exhibited severe rill erosion. Available water holding capacity was 10-15%. Soil structure was weak fine granular. Electrical conductivity (0.2 mmhos/cm) was low, and CEC measured 15 meq/100g with calcium dominating the exchange complex. Heavy metal levels and organic matter content were also low. Exchange acidity was present, and measured pH was moderately acid (5.5). Physical and chemical data, as well as the pedon description for this soil may be found in Tables 55 and 56. The natural vegetation in the area was mixed coniferous forest composed mainly of Douglas fir, lodgepole pine, and spruce.

The disturbance was largely unvegetated, however over 20 species

were found to be invading the site. These species are listed in Table 63 (Appendix D). Colonization was found both in protected microhabitats and on dump slope faces. Vegetative cover on this mine was by far the greatest of the four studied, and it was estimated that approximately 30 percent of the total disturbed area was revegetated.

Wasa Waste Rock. Wasa waste rock samples included one soil profile (site 11), and two grab samples (sites 11A and 11B). The location of these sites is depicted in Figure 24. The waste rock profile was classified as a sandy-skeletal mixed Typic Cryorthent. The soil exhibited moderate drainage, permeability, and an available water content of 13%. Measured pH was 3.0, and organic matter content 0.9%. Electrical conductivity did not suggest inhibition of plant growth, and although heavy metal levels were slightly elevated they did not exceed toxicity standards. A grab sample taken above the Wasa 3 adit (site 11A) exhibited similar characteristics, with measured parameters being somewhat less toxic and/or inhibitory than at site 11. The grab sample taken below the Wasa 1 adit also showed similar characteristics. Heavy metal levels were even further depressed due to the higher pH (neutral) of this material. Data from these samples are presented in Tables 57-60.

Data and reconnaissance observations suggested that available

moisture and active erosion are the two principle limiting factors for plant establishment and growth. Visual evidence indicated that plants are colonizing the site: 1) where erosion was less severe, 2) in depressions , and 3) in shaded areas where evaporative moisture loss was minimized. The long narrow shape of the disturbance and large seed source enhance the revegetation potential of this site.

Discussion of Wasa Mine Results

Study of the Wasa mine indicated that drainage from the site caused water quality degradation of North Fork Douglas Creek. Soil physical and chemical parameters indicated that they did not present a public health hazard, and suggested that plant available moisture and erosion were limiting revegetation of the site. Specific recommendations for the Wasa disturbance are as follows:

- 1) Due to the persistence downstream of the degradational effects of the Wasa drainage it is suggested that all four adits be sealed to prevent further discharge. Although this will be quite expensive, it appears to be the only way to deal with this problem, as the drainage is already alkaline and thus cannot effectively be treated by liming. The use of techniques such as flash distillation might be investigated, however they do not appear to be a practical alternative. Sealing of the adits provides the additional advantage of decreasing the erosion potential on the site. This is especially

critical with respect to the Wasa 1 adit, which has the largest discharge.

2) The highwall of the open out is a potential safety hazard. Further, it was apparent that much of the erosion on the site is associated with water flowing through this cut. It is suggested that the cut be recontoured, incorporating the following ideas (within allowable economic constraints) into the final plan. Minimization of slope gradient and use of concave slope configurations would allow for a smooth slope transition into the drainage bottom and central portion of the mine. This would also provide excess material which could be spread as coversoil over large unvegetated areas on the lower portion of the mine, as a continuation of the earth moving activity. Thus in one movement the safety hazard would be removed, erosional energy would be reduced, and the plant growth medium would be improved. Mulches and manure might be considered as supplements to the coversoil supply if necessary. It may be noted that nearly all of the unvegetated area on the site lies below the open cut, facilitating this plan. All recontouring would have to consider stream channel protection, as the existing stream does flow through the site in this area. Care should also be taken to minimize disturbance to the upper one-third of the site, on which natural revegetation has occurred.

3) The old loading chute presents a possible safety hazard and should be removed.

Summary and Conclusions

Data from the abandoned hard rock mines included in this study indicated that all four sites are responsible for environmental degradation of the surrounding area and/or contain various health and safety hazards. Although each disturbance possessed site specific problems, it was evident that elevated heavy metal levels, sediment transport both onsite, and offsite into streams, and physical safety hazards were the major negative characteristics which the four mines had in common. Vegetative establishment on the sites was most often limited by poor available water holding capacity of the soil material and wind action. Potentially phytotoxic or inhibitory levels of heavy metals and salts were often also involved. Low nutrient status on all four disturbances will necessitate fertilization with nitrogen and phosphorous to maximize revegetation potential.

It was interesting to note that the Wasa mine was causing degradation without the production of AMD, and that elevated heavy metal levels may emanate from an alkaline mine drainage. This suggests that the use of high sulfate/low pH drainages as an indicator of abandoned mine pollution may be limited in that it will not identify this type of site as a pollution source.

There is a need in future study for increased surface water and ground water modeling so that the pattern of water quality degradation

may be mapped in greater detail. This is especially true of sites with complex water flow systems, such as the Alta mine. Also, investigation should be initiated to ascertain whether plant establishment is inhibited by the crusts which tended to form on the surfaces of the tailings ponds.

The following outline provides a listing of priorities for each site, as well as a ranking of the sites for reclamation priority:

I) ALTA - This mine was ranked first due to the extreme environmental degradation associated with the site.

- 1) Treat acid drainage from the Alta seep and revegetate the lower dump.
- 2) Move both the Bertha tailings and the Bertha waste rock away from Corbin Creek. Stabilize and revegetate these spoils.
- 3) Revegetate the upper mountain.
- 4) Remove mine structures.

II) WASA - This mine was ranked second due to stream quality degradation, high discharge rates, and high usage of Douglas Creek water.

- 1) Seal all adits to prevent further discharge.
- 2) Revegetate waste rock. It should be noted that due to the high potential for natural revegetation on the site, this phase of the operation may be delayed in favor of more important projects. Erosion will remain a limiting factor without recontouring.
- 3) Remove chute.

III) CHAMPION - This mine was rated third due to its slight environmental hazard, and the high potential for reclamation success due to the small area involved.

- 1) Remove ore bins.
- 2) Remove or revegetate tailings.
- 3) Seal adit to prevent access and discharge.
- 4) Revegetate waste rock.

IV) BANNACK - This mine was rated fourth due to the low environmental hazard, and the road building project and value as an historic site, which by law have low priorities.

- 1) Build elevated roadway which will act as a dike.
- 2) Seal adit and secure mill.
- 3) Revegetate or chemically stabilize the tailings.
- 4) Reclaim surface excavations.

APPENDICES

APPENDIX A

ANOV AND LSD ANALYSES FOR ACID GENERATION STUDY

Table 5. Overall Analysis of Variance and Least Significant Difference of soil pH for the Alta tailings material.

SOURCE	DF	ANOV S.S.	M.S.	F-VALUE
BLOCKS	2	.1396	.6979E-01	
GRAIN SIZE	2	73.05	36.53	621.6*
LIME RATE	2	149.4	74.70	1271.*
GRAIN X LIME	4	23.06	5.765	98.11*
TIME	3	1.678	.5594	9.519*
GRAIN X TIME	6	.5660	.9433E-01	1.605
LIME X TIME	6	8.305	1.384	23.55*
G X L X T	12	7.518	.6265	10.66*
RESIDUAL	70	4.113	.5876E-01	

LSD ANALYSIS		
FACTOR	IDENT.	MEAN pH
GRAIN SIZE	<.053mm	5.0 a
	.053-.106	6.7 b
	.106-.250	6.8 b
LIME	CONTROL	4.6 A
	1.0 T/A	6.5 B
	10. T/A	7.4 C
TIME	1 HOUR	6.0 d
	1 DAY	6.2 e
	7 DAYS	6.2 e
	30 DAYS	6.3 e

Comments: Asterisk (*) indicates significance at $p=.05$. Same letter next to mean pH indicates no significant difference between means.

Table 6. Analysis of Variance and Least Significant Difference of soil pH for the Alta tailings silt and clay fraction.

SOURCE	DF	ANOV	M.S.	F-VALUE
		S.S.		
BLOCK	2	.4082E-01		
LIME	2	97.39	48.70	1151.*
TIME	3	.7187E-01	.2396E-01	.5664
LIME X TIME	6	3.372	.5620	13.39*
RESIDUAL	22	.9305	.4230E-01	

LSD ANALYSIS		
FACTOR	IDENT.	MEAN pH
LIME	CONTROL	3.2 a
	1.0 T/A	4.8 b
	10. T/A	7.2 c
TIME	1 HOUR	5.0 A
	7 DAYS	5.0 A
	30 DAYS	5.0 A
	1 DAY	5.1 A

Comments: Asterisk (*) indicates significance at $p=.05$. Same letter next to mean pH indicates no significant difference between means.

Table 7. Analysis of Variance and Least Significant Difference of soil pH for the Alta tailings very fine sand fraction.

SOURCE	DF	ANOV		
		S.S	M.S.	F-VALUE
BLOCK	2	.3190	.1595	
LIME	2	34.44	17.22	179.2 [*]
TIME	3	.6248	.2083	2.167
LIME X TIME	6	8.161	1.360	14.15 [*]
RESIDUAL	22	2.115	.9611E-01	

LSD ANALYSIS		
FACTOR	IDENT.	MEAN pH
LIME	CONTROL	5.4 a
	1.0 T/A	7.4 b
	10. T/A	7.6 b
TIME	1 HOUR	6.6 A
	7 DAYS	6.8 AB
	1 DAY	6.9 B
	30 DAYS	6.9 B

Comments: Asterisk (*) indicates significance at $p=.05$. Same letter next to mean pH indicates no significant difference between means.

Table 8. Analysis of Variance and Least Significant Difference of soil pH for Alta tailings fine sand fraction.

SOURCE	DF	ANOV S.S	M.S	F-VALUE
BLOCKS	2	.2427E-01	.1212E-01	
LIME	2	40.64	20.32	547.4*
TIME	3	1.547	.5158	13.90*
LIME X TIME	6	4.290	.7150	19.26
RESIDUAL	22	.8165	.3712E-01	

LSD ANALYSIS		
FACTOR	IDENT.	MEAN pH
LIME	CONTROL	5.2 a
	1.0 T/A	7.4 b
	10. T/A	7.5 b
TIME	1 HOUR	6.4 A
	30 DAYS	6.8 B
	7 DAYS	6.8 B
	1 DAY	6.9 B

Comments: Asterisk (*) indicates significance at $p=.05$. Same letter next to mean pH indicates no significant difference between means.

Table 9. Analysis of Variance and Least Significant Difference of soil pH for the Alta waste rock material.

SOURCE	DF	ANOVA S.S.	M.S	F-RATIO
BLOCKS	2	6.250	3.125	
GRAIN SIZE	2	3.262	1.631	5.732*
LIME	2	241.5	120.7	424.3*
GRAIN X LIME	4	2.798	.6995	2.458*
TIME	3	3.753	1.251	4.397*
GRAIN X TIME	6	2.227	.3712	1.304
LIME X TIME	6	6.165	1.028	3.611*
G X L X T	12	4.005	.3337	1.173
RESIDUAL	70	19.92	.2846	

LSD ANALYSIS		
FACTOR	IDENT.	MEAN PH
GRAIN SIZE	<.053mm	4.8 a
	.053-.106	5.1 ab
	.106-.250	5.3 b
LIME	CONTROL	3.4 A
	1.0 T/A	4.7 B
	10. T/A	7.0 C
TIME	1 HOUR	4.7 d
	1 DAY	5.1 e
	7 DAYS	5.1 e
	30 DAYS	5.2 e

Comments: Asterisk (*) indicates significance at $p=.05$. Same letter next to mean pH indicates no significant difference between means.

Table 10. Analysis of Variance and Least Significant Difference of soil pH for the Alta waste rock coarse sand fraction.

SOURCE	DF	ANOV S.S.	M.S.	F-VALUE
BLOCKS	2	1.149	.5747	
LIME	2	95.42	47.71	281.4*
TIME	3	.9720	.3240	1.911
LIME X TIME	6	4.545	.7575	4.467*
RESIDUAL	22	3.731	.1696	

LSD ANALYSIS		
FACTOR	IDENT.	MEAN pH
LIME	CONTROL	3.4 a
	1.0 T/A	5.0 b
	10. T/A	7.4 b
TIME	1 HOUR	5.0 A
	7 DAY	5.2 A
	1 DAYS	5.4 A
	30 DAYS	5.4 A

Comments: Asterisk (*) indicates significance at $p=.05$. Same letter next to mean pH indicates no significant difference between means.

Table 11. Analysis of Variance and Least Significant Difference of soil pH for the Alta waste rock very coarse sand fraction.

SOURCE	DF	ANOV		F-VALUE
		S.S.	M.S.	
BLOCKS	2	2.215	1.107	
LIME	2	75.22	37.61	108.6*
TIME	3	.7257	.2419	.6988
LIME X TIME	6	3.728	.6213	1.795
RESIDUAL	22	7.616	.3462	

LSD ANALYSIS		
FACTOR	IDENT.	MEAN pH
LIME	CONTROL	3.4 a
	1.0 T/A	4.8 b
	10. T/A	6.9 c
TIME	1 HOUR	4.8 A
	1 DAY	5.1 A
	7 DAYS	5.1 A
	30 DAYS	5.2 A

Comments: Asterisk (*) indicates significance at $p=.05$. Same letter next to mean pH indicates no significant difference between means.

Table 12. Analysis of Variance and Least Significant Difference of soil for the Alta waste rock gravel fraction.

SOURCE	DF	ANOV S.S.	M.S.	F-VALUE
BLOCKS	2	3.162	1.581	
LIME	2	73.62	36.81	97.62 ^a
TIME	3	4.283	1.428	3.786 ^a
LIME X TIME	6	1.897	.3162	.8386
RESIDUAL	22	8.296	.3771	

LSD ANALYSIS		
FACTOR	IDENT.	MEAN pH
LIME	CONTROL	3.5 a
	1.0 T/A	4.2 b
	10. T/A	6.8 c
TIME	1 HOUR	4.4 A
	30 DAYS	4.7 AB
	1 DAY	4.9 AB
	7 DAYS	5.3 B

Comments: Asterisk (*) indicates significance at $p=.05$. Same letter next to mean pH indicates no significant difference between means.

APPENDIX B
WATER QUALITY DATA AND CRITERIA

Table 13. Water quality standards.

Parameter	Suspect Levels (mg/l)		
	Detrimental effects on aquatic life	Recommended limits for drinking	Long term irrigation
pH	<6.5, >9.0	5.0-9.0	
arsenic	0.10	0.05	0.10
cadmium	0.012	0.010	0.01
copper	0.025	1.0	0.20
iron	1.0	0.30	5.0
lead	0.10	0.05	5.0
manganese	1.0	0.05	0.20
mercury	0.00005	0.02	
silver	0.003	0.05	0.05
zinc	0.01	5.0	2.0
nitrates		10.0	
TDS		250.0	

Comments: Standards are taken from U.S. E.P.A. Water Quality Criteria of 1972 and 1976. The later standards took precedent when available for the parameters listed.

Table 14. Water quality data for the Alta mine and Bertha Tailings sites.

Parameter	Alta Mine drainage	Corbin Creek above tailings	Corbin Creek below tailings
date sampled	8-18-81	8-19-81	8-19-81
pH (field)	2.8	7.2	6.8
pH (lab)	2.8	7.6	7.6
temp (field, °C)	13	13	22
EC(field, mmho/cm)	3.0	.2	.9
EC(lab, mmho/cm)	3.4	.3	.7
calcium (mg/l)	91.5	44.5	76.0
magnesium (mg/l)	94.4	8.4	47.6
sodium (mg/l)	19.75	16.0	18.0
potassium (mg/l)	1.55	1.15	4.40
iron (mg/l)	154.1	<0.01	<0.01
manganese (mg/l)	209.0	<0.01	1.33
copper (mg/l)	4.62	.029	0.230
zinc (mg/l)	9.35	.022	3.74
lead (mg/l)	0.107	.023	.028
cadmium	0.827	<.005	.038
nickel	0.167	<.01	.034
arsenic (mg/l)	.0404	.0038	.0038
molybdenum (mg/l)	.018	.009	.028
mercury (mg/l)	.0010	<.0004	<.0004
aluminum (mg/l)	87.8	<0.40	<0.40
bicarbonate (mg/)	0.0	173.2	107.7
carbonate (mg/l)	0.0	0.0	0.0
sulfate (mg/l)	12700.	36.0	335.0
chloride (mg/l)	4.3	2.8	2.36
nitrate (mg/l)	0.16	0.25	0.29
total phosphorous (mg/l)	0.01	0.05	0.01
flouride (mg/l)	0.16	0.12	0.50
hardness (mg/l)	1776.8	148.8	393.9
alkalinity(mg/l)	2194. *	142.1	88.3
SAR	0.35	0.58	0.40
Charge Mass Balance		0.37	1.31

Comments: asterisk (*) indicates acidity.

Table 15. Water quality data for the Bannack mill site.

Parameter	Grasshopper Creek above tailings	Grasshopper Creek below tailings
date sampled	8-10-81	8-10-81
pH (field)	7.3	7.6
pH (lab)	8.2	8.2
temp (field, °C)	22	22
EC (field, mmhos/cm)	0.20	0.24
EC (lab, mmhos/cm)	0.20	0.20
calcium (mg/l)	31.9	30.8
magnesium (mg/l)	6.5	7.0
sodium (mg/l)	21.9	14.9
potassium (mg/l)	-	-
iron (mg/l)	.055	.055
manganese (mg/l)	.011	.009
copper (mg/l)	.021	.005
zinc (mg/l)	<.005	<.005
lead (mg/l)	<.010	<.010
cadmium (mg/l)	<.005	<.005
nickel (mg/l)	<.010	<.010
arsenic (mg/l)	.002	.001
molybdenum (mg/l)	-	-
mercury (mg/l)	.0011	.0009
silver (mg/l)	<.010	<.010
bicarbonate (mg/l)	137.3	129.6
carbonate (mg/l)	0.0	0.0
sulfate (mg/l)	15.0	15.1
chloride (mg/l)	4.8	4.8
nitrate (mg/l)	0.01	0.01
Total phosphorous (mg/l)	0.016	0.011
fluoride (mg/l)	0.27	0.27
hardness (mg/l)	106.5	105.8
alkalinity (mg/l)	112.6	106.3
SAR	0.92	0.63
Charge Mass Balance	-2.57	-1.28

Table 16. Water quality data for the Champion Mine.

Parameter	Oro Fino Creek upstream	Adit discharge	Flow through tailings	Oro Fino Creek downstream
date sampled	8-12-81	7-7-81	7-7-81	8-12-81
pH (field)	7.9	5.3	3.8	7.6
pH (lab)	8.0			7.5
temp (field, °C)	8			14
EC(field, mmho/cm)	.125			.485
EC (lab, mmho/cm)	.210			.548
calcium (mg/l)	40.4	153.3	132.2	61.0
magnesium(mg/l)	10.2	93.33	71.00	30.2
sodium (mg/l)	4.41	6.00	7.07	6.50
potassium(mg/l)	3.05	2.92	3.84	3.25
iron (mg/l)	<.010	63.50	1.92	<.010
manganese(mg/l)	<.010	16.50	9.50	0.800
copper (mg/l)	0.054	0.027	0.047	0.049
zinc (mg/l)	<.005	0.216	0.196	<.005
lead (mg/l)	<.010	<.010	<.010	0.026
cadmium (mg/l)	<.005	<.005	<.005	<.005
nickel (mg/l)	<.010	0.216	0.136	0.031
arsenic (mg/l)	0.0060	0.011	0.003	0.0079
molybdenum(mg/l)	0.010	0.019	0.020	0.016
mercury (mg/l)	<.0004	0.0014	0.0014	<.0004
aluminum (mg/l)	<0.040			<0.40
bicarbonate (mg/l)	122.0			73.2
carbonate(mg/l)	0.0			0.0
sulfate (mg/l)	29.4			192.2
chloride(mg/l)	1.4			1.4
nitrate (mg/l)	0.13			0.11
Total (mg/l)				
phosphorous	0.03			0.02
fluoride (mg/l)	0.10			0.72
hardness (mg/l)	142.9	911.12	643.64	278.1
alkalinity (mg/l)	100.1			60.0
SAR	0.16	0.09	0.12	0.17
Charge Mass Balance	-2.68			-3.03

Table 17. Water quality data for the Wasa mine.

Parameter	N.F.Doug. Creek upstream	Wasa 2&3 seep	Zimmer Jack seep	Wasa 1 seep	N.F.Doug. Creek downstream
date sampled	8-20-81	8-20-81	8-20-81	8-20-81	8-20-81
pH (field)	5.0	5.0	4.6	7.0	7.2
pH (lab)	6.7	5.4	5.4	6.8	7.8
temp(°C)	10	8	15	8	14
EC(field, (mmho/cm)	.060	.160	.240	.280	.210
EC(lab,mmho/cm)	.076	.204	.246	.378	.212
calcium (mg/l)	13.4	32.1	39.3	60.1	45.6
magnesium(mg/l)	3.20	6.40	6.00	11.4	5.6
sodium (mg/l)	3.50	2.50	3.00	2.75	2.75
potassium(mg/l)	2.65	2.85	2.50	2.40	1.45
iron (mg/l)	<.010	1.107	<.010	0.097	<.010
mangasnese (mg/l)	<.010	0.330	0.240	0.320	0.050
copper (mg/l)	0.050	0.196	1.32	0.066	0.061
zinc (mg/l)	0.094	2.84	7.14	5.59	0.010
lead (mg/l)	0.018	0.015	0.012	0.025	0.012
cadmium (mg/l)	<.005	0.026	0.190	0.036	<.005
nickel (mg/l)	<.010	0.051	0.074	0.051	0.013
arsenic (mg/l)	0.0042	0.0076	0.0027	0.0034	0.0045
molybdenum(mg/l)	<.005	0.022	0.009	0.013	0.008
mercury (mg/l)	<.0004	<.0004	<.0004	<.0004	<.0004
aluminum(mg/l)	<0.40	<0.40	<0.40	<0.40	<0.40
bicarbonate (mg/l)	3.1	3.1	9.8	112.8	141.8
carbonate(mg/l)	0.0	0.0	0.0	0.0	0.0
sulfate (mg/l)	38.5	111.8	108.0	105.4	31.7
chloride (mg/l)	0.94	0.94	0.47	0.94	0.94
nitrate (mg/l)	0.13	0.13	0.19	0.22	0.24
tot.phos.(mg/l)	0.03	0.05	0.01	0.03	0.05
flouride (mg/l)	0.12	0.48	0.34	0.30	0.12
hardness (mg/l)	46.8	113.4	134.2	206.3	137.0
alkalinity(mg/l)	2.5	2.5	8.0	92.6	116.3
SAR	0.22	0.11	0.12	0.09	0.10
Charge Mass Balance	-1.71	1.18	-1.12	0.08	1.01

APPENDIX C

SOIL PROFILE DESCRIPTIONS AND ANALYTICAL DATA

Table 18. Soil quality criteria.

Parameter	Suspected Phytotoxic Level	
	Chapman ¹	Montana DSL ²
pH		8.8-9.0
EC (mmho/cm)		4-6
aluminum (ppm)	1-10	
arsenic (ppm)	2-30	
boron (ppm)		0.1-1.0
chromium (ppm)	5-150	
copper (ppm)	100 (exch.)	40
lead (ppm)	10-200	10-20
magnesium	>90% of exch complex	
manganese (ppm)		60
mercury (ppm)		0.4-0.6
nickel (ppm)	3-70 (exch.)	1.0
zinc (ppm)		40

Comments: (1) Values from Diagnostic Criteria for Plants and Soils (Chapman, 1966). Levels are water soluble unless otherwise noted. (2) Red flag values from the Montana Strip and Underground Mining Act (1979). Levels of aluminum, arsenic, chromium, copper, lead nickel, and zinc are DTPA extractable.

Table 19. Coversoil quality guidelines as excerpted from Schafer (1979).

Parameter	Good	Quality Rating Fair	Poor
Texture class	vfsl,fsl,sl, l,sil	lfs,ls,cl scl,sicl	s,c,sc, sic
EC	<4	4-8	>8
pH	5.6-7.8	4.5-5.6;7.8-8.4	<4.5;>8.4
Rock fragments	<15%	15-35%	>35%
Available water (% by volume)	>10	5-10	<5
Saturation water	25-80%	25-80%	<25;>80%
Trace elements	less than limits at right		<u>ppm</u>
			B > 8.
			Cd > 0.1-1.0
			Cu > 40.
			Pb > 10-20.
			Mn > 60
			Hg > 0.4-0.5
			Mo > 0.3
			Ni > 1.0
			Se > 2.0
			Zn > 40.0

Comments: Fair quality implies that mitigation of adverse properties will increase reclamation potential. Materials rated as poor may be suitable as coversoil only if adverse factors can be treated.

Table 20. Index for structure grade, size and kind used in soil profile descriptions.

Code	Structure grade	Code	Structure kind
01	massive	01	massive
02	weak: peds barely observable in place and when disturbed peds remain	02	platy
03	weak to moderate	03	granular
04	moderate: peds easily observable and when disturbed most of material consists of peds.	04	subangular blocky
05	moderate to strong	05	angular blocky
06	strong: peds distinctly visible, when disturbed entire soil mass is aggregated	06	prismatic
		07	columnar
		08	wedge

Code	Size Class	Diameter of granules	Thickness of plates (mm)	Diameter of blocks	Diameter of prisms
01	very fine	<1	<1	<5	<10
02	fine	1-2	1-2	5-10	10-20
03	medium	2-5	2-5	10-20	20-50
04	coarse	5-10	5-10	20-50	50-100
05	very coarse	>10	>10	>50	>100

Table 21. Index for effervescence in HCl, and horizon boundary used in profile descriptions.

Code	Effervescence	Code	Lower Horizon Distinctness	Code	Boundary Shape
01	noncalcareous	01	abrupt (<1in.)	01	smooth
02	slight	02	clear (1-2.5in.)	02	wavy
03	moderate	03	gradual (2.5-5in.)	03	irregular
04	violent	04	diffuse (>5in.)	04	broken
		05	arbitrary	05	arbitrary
		06	not reached	06	not reached

Table 22. Index for soil consistence used in soil profile descriptions.

Code	Dry consistence	Code	Moist consistence
01	loose	01	loose
02	soft: easily crushes to powder	02	very friable: crushes under gentle pressure
03	slightly hard: easily broken between thumb and finger	03	friable: crushes easily under moderate pressure between 0 and finger
04	hard: easily broken in hand	04	firm: crushes under moderate pressure between thumb and finger
05	very hard: broken in hands with difficulty	05	very firm: barely crushable between thumb and finger
06	extremely hard: cannot be broken in hands	06	extremely firm: crushes under strong pressure in hand
07	indurated	07	indurated
Code	Wet stickiness	Code	Wet plasticity
01	nonsticky: no adherence	01	nonplastic: no wire formed
02	slightly sticky: adheres to thumb and finger but comes off one cleanly	02	slightly plastic: wire forms but easily deformed
03	sticky: soil adheres and stretches before pulling apart	03	plastic: wire forms, moderate pressure required to deform
04	very sticky: soil adheres to both fingers	04	very plastic: wire forms, much pressure required to deform

Table 23. Index for pore abundance, size, and kind used in soil profile descriptions.

Code	Size	Code	Kind
01	none	01	none
02	micro and very fine	02	irregular and tubular
03	very fine (.1-.5mm)	03	tubular
04	fine and very fine	04	tubular continuous
05	fine (.5-2mm)	05	tubular discontinuous
06	medium and fine	06	vesicular
07	medium (2-5mm)	07	vesicular and tubular
08	coarse and medium	08	interstitial voids between peds
09	coarse (>5mm)	09	interstitial voids between rocks

Table 24. Index for root abundance, size, and kind used in soil profile descriptions.

Code	Size	Code	Location
01	none	01	none
02	very fine (0.1-1mm)	02	throughout horizon
03	fine and very fine	03	between peds
04	fine (1-2mm)	04	flattened in cracks
05	medium and fine	05	flattened around rocks
06	medium (2-5mm)	06	mat at top of horizon
07	coarse and medium		
08	coarse (>5mm)		
09	fine and coarse		

Code	Abundance CLASS	Very fine	Fine (NUMBER/DM**2)	Medium	Coarse
01	none				
02	trace				
03	few	<10	<10	<1	<1
04	few to common				
05	common	10-100	10-100	1-10	1-5
06	common to many				
07	many	>100	>100	>10	>5

Table 25. Pedon description for the Alta Natural Soil.

***** SITE DESCRIPTION *****

Soil Series: Site Number: 09 County: Jefferson
 Location: 1/4, NW1/4, NE1/4 Section 10 Township 7N , Range 4W
 Classification: coarse-loamy mixed Argic Cryoboroll
 Date Sampled: 08/18/81 Elevation: 5100ft, 1554m Precipitation: 11in, 279 mm
 Site Codes/Co:51/PM:12/Veg:21/LU:04/Drain:05/Perm:05/Erns:03/Postn:03/LP:01/
 Material: resid. crystalline Vegetation: perennial forage Land use: range
 Drainage: well Permeability: medium to rapid Erosion: moderate
 Slope: 25%, 13degrees Aspect: N Position: upper midslope
 Soil temp.(50cm) C, 32F Number of Horizons:03 Landform: sedimentary up

**** PROFILE DESCRIPTION ****

HOR.	NO.	DEPTH (cm)	COLOR		TEXT	STR CONS RT PR				pH	EFF	BND	*
			MOIST	DRY		CF	gsk	dmsp	asl	ask			
A1	801	0- 4	10YR 2/2	10YR 4/3 05 s1		10	213	11	722	748	6.5	1	32
B2	802	4- 25	10YR 2/2	10YR 3/3 05 s1		20	223	11	722	748	6.5	1	22
C1	803	25- 42	10YR 4/4	10YR 4/6 02 ls		30	123	2211	722	748	5.5	1	
R		42-60+	/	/							.		
		-	/	/							.		
		-	/	/							.		
		-	/	/							.		
		-	/	/							.		

CF=coarse fragment(%) STR=structure grade,size,kind
 CONS=moist,dry,sticky, plastic consistence RT=root amount, size, location
 PR=pore amount, size, kind EFF=effervesence BND=boundary
 COMMENTS (*):

Table 26. Soil physical and chemical data for the Alta Natural Soil.

Series: 02 Classification: coarse-loamy mixed Argic Cryoboroll
Site number: 09 County: Jefferson Location: Alta Natural Soil
Number horizons: 02 CoS: 51

Horizon Depth	Mechanical analysis								Water content			
(cm)	sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar	.3bar	0bar
	(%)								(%)			
Al/B2	0-25	48.0	41.0	11.0	8.4	10.9	8.6	11.5	8.6	17.0	8.9	17.6
C1	25-42+	46.0	40.0	14.0	6.8	7.8	7.9	13.5	10.0	20.0	9.2	13.7
-	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth	Dry Aggregate Analysis								CEC		Base	Exch	
(cm)	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.	Acidity
	(%)								(meq/100g)		(%)	(ppm)	
Al/B2	0-25	2.7	15.8	10.9	13.3	8.9	14.6	13.1	8.6	12.3	13.8	15.2	95.9
C1	25-42+	6.7	31.8	14.6	12.1	8.6	7.2	8.0	5.0	5.9	15.3	17.1	99.7
-	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth	Saturation Extract																
(cm)	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As
	(mmho/cm) ppm																
Al/B2	0-25	27.6	0.13	4.6	1.1	0.4	2.3	0.097	0.017	0.016	0.155	<.14	<.03	<.07	<.03	<.03	<.7 .001
C1	25-42+	23.2	0.11	3.6	1.2	0.5	1.0	0.027	0.016	0.004	0.165	<.12	<.02	<.06	<.02	<.02	<.6 0.0
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

**** **

Horizon Depth	NH4OAc Extract															
(cm)	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As	
	ppm															
Al/B2	0-25	2120.	224.	20.	260.	18.12	1.0	8.44	4.8	6.64	0.96	4.0	0.2	<0.2	39.2 <.02	
C1	25-42+	2478.	276.	26.	180.	2.44	2.16	2.24	0.36	1.5	0.4	3.2	<.08	<.02	<10. <.02	
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	

Horizon Depth	Org	pH	NO3			
(cm)	C	1:1	1:2	N	P	SO4
	(%)	H2O	CaCl2	-----	ppm	-----
Al/B2	0-25	1.6	4.4	5.4	<0.5	<0.1
C1	25-42+	0.6	6.0	6.1	.	18.4
-	.	.	.	.	.	.

Comments: Multiply values with stars (****) under column by 0.1.

Table 27. Pedon description for the Alta Waste Rock (upper mountain).

***** SITE DESCRIPTION *****

Soil Series: Site Number: 10 County: Jefferson
 Location: 1/4, NW1/4, SW1/4 Section 10 Township 7N , Range 4W
 Classification: sandy-skeletal mixed Typic Cryorthent

Date Sampled: 08/19/81 Elevation: 6000ft, 1828m Precipitation: 11in, 279 mm
 Site Codes/Co:51/PM:12/Veg: /LU:15/Drain:04/Perm:04/Erns:04/Postn:05/LF:17/
 Material: resid. crystalline Vegetation: unvegetated Land use: mine dump
 Drainage: moderate Permeability: medium Erosion: severe
 Slope: 40%, 20degrees Aspect: E Position: lower midslope
 Soil temp.(50cm) C, 32F Number of Horizons:02 Landform: disturbed land

**** PROFILE DESCRIPTION ****

HOR. NO.	DEPTH (cm)	COLOR		TEXT	STR CONS RT PR					pH	EFF	BND	*
		MOIST	DRY		CF	gsk	dmsp	asl	ask				
C1	0- 32	10YR 6/4	10YR 7/4 02 ls	60 223 3322 26 746	4.5	1	21						
C2	32-60+	10YR 5/4	10YR 7/3 01 s	60 223 2311 26 556	4.5	1	66						
	-	/	/										
	-	/	/										
	-	/	/										
	-	/	/										
	-	/	/										

CF=coarse fragment(t) STR=structure grade,size,kind
 CONS=moist,dry,sticky, plastic consistence RT=root amount, size, location
 PR=pore amount, size, kind EFF=effervesence BND=boundary
 COMMENTS (*):

Table 28. Soil physical and chemical data for the Alta Waste Rock (upper mountain).

Series:		Classification:sandy-skeletal mixed Typic Cryorthent													
Site number:10		County:Jefferson				Location:Alta Waste Rock (upper mountain)									
Number horizons:01		Co:51													
=====															
Horizon Depth		Mechanical analysis								Water content					
(cm)		sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar .3bar 0bar				
		(%)								----(2)----					
=====															
Cl/C2	0-60+	67.0	23.0	10.0	18.0	15.6	13.2	12.7	7.5	7.0	5.2 15.0 .				
-	-	.	.	.	.	.	.	.	.	.	.				
-	-	.	.	.	.	.	.	.	.	.	.				
=====															
Horizon Depth		Dry Aggregate Analysis								CEC	Base	Exch			
(cm)		>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum NaCl Satn. Acidity				
		(%)								(meq/100g)		(%) (ppm)			
=====															
Cl/C2	0-60+	9.2	35.6	15.5	15.7	9.9	6.0	3.8	1.7	2.8	6.0 6.3 94.2 6.0				
-	-	.	.	.	.	.	.	.	.	.	.				
-	-	.	.	.	.	.	.	.	.	.	.				
=====															
=====															
Horizon Depth		Saturation Extract													
(cm)		H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe Pb Cd Ni Ag Cr Al As				
		(mmho/cm)									ppm				
=====															
Cl/C2	0-60+	16.8	0.28	3.6	1.0	2.6	2.5	0.064	0.034	0.012	0.017 <.08 <.02 <.04 .002 <0.4				
-	-	.	.	.	.	.	.	.	.	.	.				
-	-	.	.	.	.	.	.	.	.	.	.				
=====															
=====															
Horizon Depth		NH4OAc Extract													
(cm)		Ca	Mg	Na	K	Zn	Cu	Mn	Fe Pb Cd Ni Ag Cr Al As						
		ppm													
=====															
Cl/C2	0-60+	994.	42.	20.	118.	2.24	7.16	2.04	0.36	324.	<0.2 <0.4 <.08 <0.2 <10. <0.2				
-	-	.	.	.	.	.	.	.	.	.	.				
-	-	.	.	.	.	.	.	.	.	.	.				
=====															
Horizon Depth		Org	pH	NO3											
(cm)		C	1:1	1:2	N	P	SO4								
		(%)	H2O	CaCl2	----	ppm	----								
=====															
Cl/C2	0 -60+	<.5	6.2	6.3	4.1	<0.1	18.9								
-	-	.	.	.	.	.	.								
-	-	.	.	.	.	.	.								
=====															

Table 29. Pedon description for the Alta Waste Rock (lower mountain).

***** SITE DESCRIPTION *****

Soil Series: Site Number: 08 County: Jefferson
 Location: 1/4, SE1/4, NW1/4 Section 10 Township 7N , Range 4W
 Classification: fine-loamy mixed Typic Cryorthent

Date Sampled: 08/18/81 Elevation: 5100ft, 1554m Precipitation: 11in, 279 mm
 Site Codes/Co:51/PM:12/Veg: /LU:15/Drain:03/Perm:03/Erns:04/Postn:04/LP:17/
 Material: resid. crystalline Vegetation: mixed, sparse Land use: mine dump
 Drainage: poor to moderate Permeability: slow to medium Erosion: severe
 Slope: 30%, 16degrees Aspect: S Position: midslope
 Soil temp.(50cm) C, 32F Number of Horizons:03 Landform: disturbed land

**** PROFILE DESCRIPTION ****

HOR.	NO.	DEPTH (cm)	COLOR		TEXT	CF	STR CONS RT PR				pH	EFF	BND	*
			MOIST	DRY			gsk	dmsp	asl	ask				
C1	801	0- 17	5Y 8/4	2.5Y 8/6	06 fsl	—	223	2232	111	748	4.0	1	22	
C2	802	1/- 49	7.5YR 6/8	5YR 6/8	02 ls	—	223	3311	111	111	4.0	1	22	1
C3	803	49-73+	2.5Y 8/6	7.5YR 8/0	06 fsl	—	223	2232	111	548	4.0	1	66	
		-	/	/							.			
		-	/	/							.			
		-	/	/							.			
		-	/	/							.			
		-	/	/							.			

CF=coarse fragment(%) STR=structure grade,size,kind
 CONS=moist,dry,sticky, plastic consistence RT=root amount, size, location
 PR=pore amount, size, kind EFF=effervescence BND=boundary
 COMMENTS (*): 1) Horizon contains pockets of dark (10YR 2/1), rocky material which has a pH of 6.0.

Table 30. Soil physical and chemical data for the Alta Waste Rock (lower mountain).

Series: Classification: fine-loamy mixed Typic Cryorthent
Site number: 08 County: Jefferson Location: Alta Waste Rock (lower dump)
Number horizons: 02 Co: 51

Horizon Depth (cm)	Mechanical analysis										Water content		
	sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar	.3bar	0bar	
	(%)										(%)		
C1	0- 17	41.0	37.0	22.0	7.7	9.0	8.1	9.0	7.4	13.0	8.7	17.2	
C2	17- 49	45.0	35.0	20.0	6.2	9.2	9.6	11.3	8.8	5.0	11.4	19.3	
-	-	.	.	.	.	.	.	.	.	.	.	.	

Horizon Depth (cm)	Dry Aggregate Analysis										CEC	Base	Exch
	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.	Acidity
	(%)										(meq/100g) (%) (ppm)		
C1	0- 17	21.8	15.5	16.6	17.6	13.3	7.9	3.0	4.3	15.4	30.9	93.3	27.0
C2	17- 49	5.7	24.3	15.8	18.7	14.3	9.0	6.3	2.7	3.2	55.1	32.4	96.1
-	-	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth (cm)	Saturation Extract																
	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As
	(mmho/cm) ppm																
C1	0- 17	27.4	2.24	131.4	1.8	0.7	4.6	1.288	1.667	0.554	0.312	.444	.007	.012	.004	<.03	6.2
C2	17- 49	29.2	2.73	125.2	32.7	1.7	7.1	40.85	5.515	25.21	0.093	.123	.212	.074	.004	<.03	9.5
-	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth (cm)	NH4OAc Extract																
	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As		
	ppm																
C1	0- 17	2818.	82.	18.	80.	5.92	7.52	2.76	58.4	122.	0.24	4.4	<.08	.032	56.	<.02	
C2	17- 49	10358	206.	22.	88.	156.8	33.8	74.4	129.6	50.2	1.16	7.6	<.08	0.7	18.6	<.02	
-	-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth (cm)	Org	pH		NO3							
		C	1:1	1:2	N	P	SO4				
	(%)	H2O		CaCl2	ppm						
C1	0 -17	<.5	3.2	2.7		1119					
C2	17 -49	<.5	3.3	2.9		1286					
-	-	.	.	.	.	8888					

Comments: Multiply values with dollar signs (\$\$\$\$) below column by 10.0.

Comments: Multiply values with dollar signs (\$\$\$\$) below column by 10.0.

Table 31. Soil physical and chemical data for the Alta Waste Rock (grab bag sample of dark material at site 08).

```

Series:                               Classification:
Site number:08A   County:Jefferson   Location:Alta Waste Rock Grab Bag (dark material in pit 08)
Number horizons: Co:51

=====
|Horizon Depth|                                     Mechanical analysis | Water content |
| (cm) | sand silt clay vcos cos ms fs vfs cos| 15bar .3bar 0bar | |
|---|---|---|---|
| 27- 42 | 55.0 30.0 15.0 7.2 | 13.6 12.3 12.3 19.6 11.0 | 6.7 13.9 |
| - | : : : : : : : : | : : : : : : : |
| - | : : : : : : : : | : : : : : : : |
=====

|Horizon Depth|                                     Dry Aggregate Analysis | CRC | Base | Exch |
| (cm) | >19um 19-4 4-2 vcos cos ms fs vfs si,c | Sum | NaCl | Satn. | Acidity |
|-----|-----|-----|-----|-----|-----|-----|-----|
| 27- 42 | 23.2 43.3 12.2 9.4 | 5.6 2.8 1.7 0.8 1.0 | 51.1 19.4 76.8 | 5.0 |
| - | : : : : : : : : | : : : : : : : |
| - | : : : : : : : : | : : : : : : : |
=====

|Horizon Depth|                                     Saturation Extract |
| (cm) | H2O EC Ca Mg Na K Zn Cu Mn Fe Pb Cd Ni Ag Cr Al As | |
|---|---|---|
| 27- 42 | 26.2 2.37 | 119.3 46.3 1.5 7.1 0.377 <.006 0.041 <.013 <.01 .018 .012 .005 <.03 <0.7 .001 |
| - | : : | : : : : : : : : : : : : : : : : : : : : : : : |
| - | : : | : : : : : : : : : : : : : : : : : : : : : : : |
=====

|Horizon Depth|                                     NH4OAc Extract |
| (cm) | Ca Mg Na K Zn Cu Mn Fe Pb Cd Ni Ag Cr Al As |
|-----|-----|-----|-----|-----|-----|-----|-----|
| 27- 42 | 6776. 702. 26. 172. 1804. 175.2 536. 391.6 97.8 12.8 15.6 <.08 0.32 140. <.02 |
| - | : : : : : : : : : : : : : : : : : : : : : : : |
| - | : : : : : : : : : : : : : : : : : : : : : : : |
=====

|Horizon Depth| Org | pH | NO3 |
| (cm) | C | 1:1 1:2 | N P SO4 |
|-----|-----|-----|-----|
| 17 -42 | <.5 6.8 6.7 | 6690 |
| - | : : : : : : : : |
| - | : : : : : : : : |
=====

Comments:

```

Table 32. Pedon description for the Bertha Tailings (lower pond).

***** SITE DESCRIPTION *****

Soil Series: Site Number: 14 County: Jefferson
 Location: 1/4, SE1/4, SE1/4 Section 03 Township 7N , Range 4W
 Classification: fine-silty over sandy mixed Typic Cryofluvent

Date Sampled: 08/26/81 Elevation: 5000ft, 1524m Precipitation: 11in, 279 mm
 Site Codes/Co:51/PM:12/Veg: /LU:14/Drain:02/Perm:02/Ersn:04/Postn:07/LF:17/
 Material: resid. crystalline Vegetation: unvegetated Land use: mill tailings
 Drainage: poor Permeability: slow Erosion: severe
 Slope: 3%, 2degrees Aspect: E Position: level slope
 Soil temp.(50cm) C, 32F Number of Horizons:03 Landform: disturbed land

**** PROFILE DESCRIPTION ****

HOR. NO.	DEPTH (cm)	COLOR		TEXT	STR CONS RT PR					pH	EFF	BND	*
		MOIST	DRY		CF	gsk	dmsp	asl	ask				
C1	0- 41	10YR 8/1	2.5Y 8/0 11 cl	00 111 4223 111 111	4.0	1	11						
C2	41- 56	7.5YR 3/0	2.5Y 6/0 09 sil	00 132 4232 111 111	4.0	1	11						
IIC3	56-90+	2.5Y 5/4	10YR 8/2 01 s	00 132 1111 111 111	5.5	1	66						
-	-	/	/										
-	-	/	/										
-	-	/	/										
-	-	/	/										

CF=coarse fragment(%) STR=structure grade,size,kind
 CONS=moist,dry,sticky, plastic consistence RT=root amount, size, location
 PR=pore amount, size, kind EFF=effervesence BND=boundary
 COMMENTS (*):

Table 33. Soil physical and chemical data for the Bertha Tailings (lower pond).

Series:		Classification: fine-silty over sandy Typic Cryofluventluvent																
Site number: 14		County: Jefferson				Location: Bertha Tailings (lower level)												
Number horizons: 03		Co: 51																
=====																		
Horizon	Depth	Mechanical analysis								Water content								
	(cm)	sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar, 3bar, 0bar							
		(%)								----- (%)								
=====																		
C1	0- 41	9.0	52.0	39.0	1.5	2.8	1.8	1.5	1.4	5.0	16.3 41.1 .							
C2	41- 56	12.0	60.0	28.0	1.2	2.9	2.4	2.5	3.0	8.0	16.9 42.5 .							
IIC3	56- 90	93.0	5.0	2.0	8.8	18.1	22.4	30.3	13.4	3.0	1.3 1.7 .							
	-									.								
=====																		
Horizon	Depth	Dry Aggregate Analysis								CEC	Base	Exch						
	(cm)	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl Satn.	Acidity					
		(%)								(meq/100g)		(%)	(ppm)					
=====																		
C1	0- 41	4.2	20.3	14.5	21.8	13.3	7.8	5.4	7.7	10.0	32.4 46.0	52.1	105.					
C2	41- 56										42.7 46.9	55.2	95.0					
IIC3	56- 90										18.3 19.3	64.1	3.0					
	-																	
=====																		
=====																		
Horizon	Depth	Saturation Extract																
	(cm)	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As
		(%)	(mmho/cm)	----- ppm														
=====																		
C1	0- 41	44.7	23.5	186.1	608.2	1.5	0.8	679.7	1628.	102.0	469.6	.662	4.85	.917	.035	.313	282.	>.02
C2	41- 56	44.8	15.3	154.4	1591.	3.8	9.68	1479.	3338.	319.9	117.6	.802	14.7	1.93	.035	.029	258.	.002
IIC3	56- 90	20.1	4.82	75.2	188.6	0.8	3.1	19.28	0.784	21.17	0.044	.044	.373	.043	.006	<.02	<0.5	0.0
	-																	
=====																		
Horizon	Depth	NH4OAc Extract																
	(cm)	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As		
		----- ppm																
=====																		
C1	0- 41	4934.	1070.	28.	70.	1184.	3264.	191.6	1464.	70.6	8.54	14.8	<.08	0.24	558.	0.28		
C2	41- 56	3382.	2442.	36.	88.	2912.	5640.	580.	422.	192.	24.2	21.2	<.08	0.34	673.	0.36		
IIC3	56- 90	1966.	442.	24.	30.	200.4	1020.	115.6	390.	197.	4.44	3.6	<.08	<.20	14.4	.08		
	-																	
=====																		
Horizon	Depth	Org	pH	NO3		P		SO4										
	(cm)	C	1:1	1:2	N	ppm		-----										
		(%)	H2O	CaCl2														
=====																		
C1	0- 41	0.6	2.7	2.0			3600											
C2	41- 56	3.4	2.6	3.0			5964											
IIC3	56- 90	<.5	5.3	5.2			615											
	-	####																

Table 34. Pedon description for the Bertha Tailings (upper pond).

***** SITE DESCRIPTION *****

Soil Series: Site Number: 13 County: Jefferson
 Location: 1/4, SE1/4, SE1/4 Section 03 Township 7N , Range 4W
 Classification: coarse-silty mixed Typic Cryofluvent

Date Sampled: 08/26/81 Elevation: 5000ft, 1524m Precipitation: 11in, 279 mm
 Site Codes/Co:51/PM:12/Veg: /LU:14/Drain:04/Perm:04/Erns:04/Postn:07/LF:17/
 Material: resid. crystalline Vegetation: unvegetated Land use: mill tailings
 Drainage: moderate Permeability: medium Erosion: severe
 Slope: 7%, 4degrees Aspect: W Position: level slope
 Soil temp.(50cm) C, 32F Number of Horizons:1 Landform: disturbed land

**** PROFILE DESCRIPTION ****

HOR.	NO.	DEPTH (cm)	COLOR		TEXT	STR CONS RT PR				pH	EFF	BND	*	
			MOIST	DRY		CF	gsk	dmsp	asl					ask
C1		0-110	10YR 6/8	10YR 8/6	03 lfs	00	111	1121	226	111	4.5	1	66	1
		-	/	/							.			
		-	/	/							.			
		-	/	/							.			
		-	/	/							.			
		-	/	/							.			

CF=coarse fragment(%) STR=structure grade,size,kind
 CONS=moist,dry,sticky, plastic consistence RT=root amount, size, location
 PR=pore amount, size, kind EFF=effervescence BND=boundary
 COMMENTS (*): The upper 7 cm. of the profile has blocky structure, with blocks up to 5 cm. thick and 10 cm. in diameter. The remainder of the profile is sandy, rust colored material with thin lenses of gray (2.5Y 8/2) sandy and silty materials which comprise approximately 5 per cent of the total volume.

Table 35. Soil physical and chemical data for the Bertha Tailings (upper pond).

Series: Classification:coarse-silty mixed Typic Cryofluvent
 Site number:13 County:Jefferson Location:Bertha Tailings (upper level)
 Number horizons:01 Co:51

Horizon Depth	Mechanical analysis									Water content			
	(cm)	sand	silt	clay	vcos	cos	ms	fs	vfs	cos1	15bar	.3bar	0bar
		(%)									(%)		
Cl	0-110	47.0	45.0	8.0	0.5	0.6	1.8	12.2	31.9	18.0	3.5	15.0	.
-	-	.	.	.	.	.	.	.	.	.	.	.	.
-	-	.	.	.	.	.	.	.	.	.	.	.	.
-	-	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth (cm)	Dry Aggregate Analysis								CEC			
	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	sl,c	Sum	NaCl	Satn.
	(g)									(meq/100g)	(%)	Acidity
Cl	0-110			1.2	2.4	5.1	20.4	32.1	38.8	23.2	29.5	97.8
-	-											16.0
-	-											

Horizon Depth (cm)	Saturation Extract													
	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag
	(%)	(mmho/cm)	ppm											
Cl	0-110	30.2	1.99	149.7	10.3	1.3	3.7	1.313	6.310	0.990	0.175	<.01	.011	.015
-	-	.	.	.	.	.	.	.	.	.	.	.	.	.
-	-	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth (cm)	NH4OAc Extract													
	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al
	ppm													
Cl	0-110	4542.	82.	20.	32.	3.64	30.6	3.24	37.6	1.82	<0.2	4.4	<.08	<0.2
-	-	.	.	.	.	.	.	.	.	.	.	.	.	.
-	-	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth (cm)	Org	pH		NO3				
		C	1:1	1:2	N	P	SO4	
		(%)	H2O	CaCl2	----	ppm	----	
Cl/C2	0	-110	<.5	3.4	3.2	3.4	6.6	1297

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Comments: Multiply values with dollar signs (\$\$\$\$) below column by 10.0.

Table 36. Soil physical and chemical data for the Bertha Tailings (grab bag of salt efflorescences and crusts on upper pond).

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Series:
Site number:13B      County:Jefferson      Location:Bertha Tailings Grab Bag (salt efflorescences and crust)
Number horizons:      Co:51

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Horizon Depth (cm)	Mechanical analysis										Water content	
	sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar	.3bar	0bar
	(%)										(%)	
0- 20	48.0	40.0	12.0	5.3	9.3	8.9	11.0	13.5	17.0	6.3	20.3	.
-	.	.	.	.	.	.	.	.	.	.	.	.
-	.	.	.	.	.	.	.	.	.	.	.	.
-	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth (cm)	Dry Aggregate Analysis										CEC				Base	Exch
	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.	Acidity			
	(g)										(meq/100g)				(%)	(ppm)
0- 20	1.5	4.5	4.0	14.7	16.0	13.9	15.9	12.3	17.3	31.1	56.7	68.2	95.0			
-	.	.	.	.	.	.	.	.	.	.	.	.	.			
-	.	.	.	.	.	.	.	.	.	.	.	.	.			
-	.	.	.	.	.	.	.	.	.	.	.	.	.			

Horizon Depth (cm)	H2O	EC	Saturation Extract														
			Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As
	(g) (mmho/cm)		ppm														
0- 20	27.4	22.3	83.6	1058	1.0	0.12	452.1	1986	219.5	386.3	.230	3.40	.921	.026	0.53	321.	>.01
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth (cm)	NH4OAc Extract														
	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As
	ppm														
0- 20	3416	1578	28.	32.	664.	2816	304.8	1448	1.98	4.56	12.0	<.08	0.28	593.	<.02
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth (cm)	Org	pH	NO3	N	P	SO4
	C	1:1	1:2	---	---	---
	(%)	H2O	CaCl2	---	ppm	---
0 -20	0.9	3.0	2.2			3400
-	.	.	.	.	.	.
-	.	.	.	.	.	.
-	.	.	.	.	.	.

SSSS

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Comments: Multiply values with dollar signs ($$$$) below column by 10.0

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Table 37. Soil physical and chemical data for the Bertha Waste Rock (grab bag below mill at streambank).

Series:		Classification:		Location:Bertha Waste Rock Grab Bag (below mill at streambank)														
Site number:15		County:Jefferson																
Number horizons:		Co:51																
=====																		
Horizon Depth		Mechanical analysis									Water content							
(cm)		sand	silt	clay	voos	cos	ms	fs	vfs	cosi	15bar	.3bar	0bar					
		(%)									(%)							
0- 20		51.0	27.0	22.0	9.2	16.4	9.7	9.3	6.4	7.0	9.3	18.2	.					
-		.	.	.	.	.	.	.	.	.	.	.	.					
-		.	.	.	.	.	.	.	.	.	.	.	.					
=====																		
Horizon Depth		Dry Aggregate Analysis									CEC		Base	Exch				
(cm)		>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.	Acidity				
		(%)									(meq/100g)		(%)		(ppm)			
0- 20		4.9	15.9	9.7	26.3	19.4	10.6	7.0	3.2	3.1	43.9	36.5	91.8	44.0				
-		.	.	.	.	.	.	.	.	.	.	.	.	.				
-		.	.	.	.	.	.	.	.	.	.	.	.	.				
=====																		
=====																		
Horizon Depth		Saturation Extract																
(cm)		H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As
		(%)	(mmho/cm)										ppm					
0- 20		26.2	5.91	122.9	33.0	1.1	0.5	3.726	33.99	1.674	67.99	.063	.027	.102	.006	.131	46.4	.003
-		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
-		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
=====																		
Horizon Depth		NH4OAc Extract																
(cm)		Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As		
		ppm																
0- 20		7988	124.	28.	40.	8.04	79.6	5.16	524.	4.06	0.36	7.2	<.08	0.26	129.	0.04		
-		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.		
-		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.		
=====																		
Horizon Depth		Org	pH	NO3														
(cm)		C	1:1	1:2	N	P	SO4											
		(%)	H2O	CaCl2	---	ppm	---											
0- 20		<.5	2.7	2.1			1223											
-		.	.	.	.	.	.											
-		.	.	.	.	.	.											
=====																		
=====																		

\$\$\$

Comments: Multiply values with dollar signs (\$\$\$\$) below column by 10.0.

Table 38. Pedon description for the Bannack Natural Soil.

***** SITE DESCRIPTION *****

Soil Series: Site Number: 03 County: Beaverhead
 Location: 1/4, NW1/4, SE1/4 Section 07 Township 8S , Range 11W
 Classification: fine-loamy mixed Typic Cryoborall
 Date Sampled: 08/11/81 Elevation: 5800ft, 1767m Precipitation: 11in, 279 mm
 Site Codes/Co:18/PM:15/Veg:18/LU:04/Drain:05/Perm:05/Erns:03/Postn:03/LF:04/
 Material: colluvial Vegetation: shrubs & grasses Land use: range
 Drainage: well Permeability: medium to rapid Erosion: moderate
 Slope: 34%, 17degrees Aspect: N38W Position: upper midslope
 Soil temp.(50cm) C, 32F Number of Horizons:03 Landform: alluvial fan

**** PROFILE DESCRIPTION ****

HOR.	NO.	DEPTH (cm)	COLOR		TEXT	STR CONS RT PR				pH	EFF	BND	*
			MOIST	DRY		CF	gsk	dmsh	asl	ask			
A1	301	0- 14	10YR 3/3	10YR 5/3 08 1	20 244 3312 742 111	8.0	3	31					
B2	302	14- 36	10YR 4/3	10YR 6/3 08 1	20 244 3312 742 111	8.0	3	21					
Clk	302	36-92+	/	10YR 7/3 11 cl	40 111 4422 344 754	8.0	4	66					
		-	/	/									
		-	/	/									
		-	/	/									
		-	/	/									

CF=coarse fragment(%) STR=structure grade,size,kind
 CONS=moist,dry,sticky, plastic consistence RT=root amount, size, location
 PR=pore amount, size, kind EFF=effervesence BND=boundary
 COMMENTS (*):

Table 39. Soil physical and chemical data for the Bannack Natural Soil.

Series: Classification: fine-loamy mixed Typic Cryoboralf
 Site number: 03 County: Beaverhead Location: Bannack Natural Soil (0.5 Km. east of mine)
 Number horizons: 02 Cor: 18

Horizon Depth (cm)	Mechanical analysis										Water content		
	sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar	.3bar	0bar	
	(%)										%		
Al/B2	0-36	30.0	55.0	15.0	3.9	4.3	4.4	7.1	10.3	22.0	16.2	33.2	.
Clk	36-92	35.0	44.0	21.0	3.7	5.5	5.2	8.3	12.3	20.0	11.9	27.6	.

Horizon Depth (cm)	Dry Aggregate Analysis										CBC			Base	Exch
	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c		Sum	NaCl	Satn.	Acidity	
	(%)										(meq/100g)			(%)	(ppm)
Al/B2	0-36	4.2	29.0	7.4	5.6	6.6	6.4	10.1	15.9	15.2	46.8	37.9	99.9	0.0	
Clk	36-92	6.9	31.2	6.3	8.4	9.7	8.1	10.0	12.3	7.0	43.3	21.3	99.9	0.0	

Horizon Depth (cm)	Saturation Extract															
	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al
	(mmho/cm)		ppm													
Al/B2	0-36	40.0	0.52	49.4	3.8	1.7	11.1	0.031	0.022	<.004	<.020	<.20	<.04	<.10	<.04	<1.0
Clk	36-92	31.6	0.25	10.6	3.8	4.5	1.7	0.025	0.022	<.003	<.016	<.16	<.03	<.08	<.03	<0.8

Horizon Depth (cm)	NH4OAc Extract															
	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As	
	ppm															
Al/B2	0-36	8568.	232.	32.	610.	0.72	8.0	1.52	1.18	1.56	0.32	5.0	<.08	0.50	<10.	0.04
Clk	36-92	7408.	694.	52.	164.	0.36	1.44	1.68	1.10	1.76	<.02	5.2	<.08	0.54	<10.	0.08

Horizon Depth (cm)	pH						NO3					
	C	1:1	1:2	N	P	SO4	H2O	CaCl2				
	(%)						ppm					
Al/B2	0-36	4.3	7.5	7.3	5.9	<.01	22.0					
Clk	36-92	<.5	7.3	7.5			22.0					

Comments: Multiply values with stars (****) below column by 0.1.

Table 40. Pedon description for the Bannack Tailings (near mill).

***** SITE DESCRIPTION *****

Soil Series: Site Number: 01 County: Beaverhead
 Location: 1/4, NW1/4, SE1/4 Section 07 Township 8S , Range 11W
 Classification: coarse-silty mixed Typic Cryofluvent

Date Sampled: 08/11/81 Elevation: 5800ft, 1767m Precipitation: 11in, 279 mm
 Site Codes/Co:18/PM:11/Veg:09/LU:14/Drain:05/Perm:05/Ersn:06/Postn:07/LF:17/
 Material: resid. limestone Vegetation: sagebrush/grass Land use: mill tailings
 Drainage: well Permeability: medium to rapid Erosion: moderate-wind
 Slope: 4%, 2degrees Aspect: N60E Position: level slope
 Soil temp.(50cm) C, 32F Number of Horizons:03 Landform: disturbed land

**** PROFILE DESCRIPTION ****

HOR.	NO.	DEPTH		COLOR		TEXT	STR CONS RT PR				pH	EFF	BND	*
		(cm)	MOIST	DRY			CF	gsk	dmsh	asl	ask			
C1	101	0- 4	2.5Y 5/2	10YR 7/1	09 sil		00	442	3322	111	756	8.0	4	11
C2	102	4- 17	2.5Y 4/3	10YR 6/3	09 sil		00	332	3322	111	758	8.0	4	11 1
IIC3	103	1/- 76	5Y 4/1	5Y 6/1	02 ls		00	232	2211	111	748	8.0	4	66 2
		-	/	/	/							.		
		-	/	/	/							.		
		-	/	/	/							.		
		-	/	/	/							.		
		-	/	/	/							.		

CF=coarse fragment(%) STR=structure grade,size,kind
 CONS=moist,dry,sticky, plastic consistence RT=root amount, size, location
 PR=pore amount, size, kind EFF=effervesence BND=boundary
 COMMENTS (*): Durable crust present, 1-2cm. thick with plates 10cm.in diameter. Swales
 have surface salt accumulations and greater vegetative cover. Wind erosion is evident.
 1) Layers of C1 material interspersed 2) Horizon consists of stratified layers of
 darker more sandy material and smaller amounts of lighter more silty material.

Table 41. Soil physical and chemical data for the Bannack Tailings (near mill).

Series: Classification:coarse-silty mixed Typic Cryofluvent
 Site number:01 County:Beaverhead Location:Bannack Tailings (near mill)
 Number horizons:03 Co:18

Horizon Depth (cm)	Mechanical analysis										Water content		
	sand	silt	clay	vcos	cos	ms	fs	vfs	cos1		15bar	.3bar	0bar
	(%)										%		
C1	0-4	8.0	76.0	16.0	0.1	0.1	2.4	5.4	19.0	4.9	26.9	.	.
C2	4-17	8.0	74.0	18.0	0.0	0.1	1.2	6.7	15.0	5.7	28.8	.	.
IIC3	17-76+	71.0	26.0	0.3	.	0.5	22.0	48.5	17.0	1.3	6.2	.	.

Horizon Depth (cm)	Dry Aggregate Analysis										CSC				Base		Exch	
	>19um	19-4	4-2	vcos	cos	ms	fs	vfs	si,c		Sum	NaCl	Satn.	Acidity	(%)	(%)	(ppm)	
	(%)										(meq/100g)							
C1	0-4		0.2	4.6	15.7	22.0	14.5	5.1	37.9		43.4	10.4	99.0	0.0				
C2	4-17		1.5	10.7	19.4	16.9	9.6	6.6	35.2		42.7	10.6	98.4	0.0				
IIC3	17-76+		0.5	8.7	0.9	56.4	20.8	20.7			30.1	3.7	98.9	0.0				

Horizon Depth (cm)	Saturation Extract																	
	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As	
	(%)	(mmho/cm)	ppm															
C1	0-4	29.6	2.02	58.3	31.4	61.5	19.0	0.018	<.007	0.003	<.015	<.15	<.03	<.07	<.03	<.03	<.07	.004
C2	4-17	31.8	0.80	15.6	9.4	28.0	9.9	0.015	<.008	<.003	<.016	<.16	<.03	<.08	<.03	<.03	<.08	.009
IIC3	17-76+	23.1	0.61	9.0	4.7	8.6	2.9	0.015	<.006	0.003	<.012	<.12	<.02	<.06	<.02	<.02	<.06	.004

Horizon Depth (cm)	NH4OAc Extract															
	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As	
	ppm															
C1	0- 4	7664	480	202	248	46	15.16	36.4	0.36	102	1.68	5.2	0.36	0.32	<10	0.62
C2	4- 17	7152	670	116	188	96	40.4	36.2	0.4	112	1.96	5.6	0.32	0.34	<10	0.52
IIC2	17-76+	5428	290	40	62	39.6	16.72	26.0	0.58	66	1.28	4.8	0.16	0.24	<10	0.22

Horizon Depth (cm)	pH										NO3				SO4			
	Org	1:1	1:2	1:5	1:10	1:20	1:50	1:100	1:200	1:500	N	P	S	SO4	N	P	S	SO4
	(%)										ppm				ppm			
C1	0-4	<.5	7.4	7.6	9.2	<.01	1160											
C2	4-17	<.5	6.8	7.4			320											
IIC3	17-76+	<.5	6.9	7.5	3.3	<.01	236											

Comments: multiply figures in columns with stars (*) below by 0.1.

Table 42. Soil physical and chemical data for the Bannack Tailings (grab bag of salt efflorescence near site 01).

Series: Classification:
 Site number: 01B County: Beaverhead Location: Bannack Tailings Grab Bag (salt efflorescence near 01)
 Number horizons: 1 Co: 18

Horizon Depth (cm)	Mechanical analysis								Water content		
	sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar	3bar
0- 2	9.0	69.0	22.0		0.0	0.2	2.9	5.9	11.0	6.7	24.9
2- 15	1.0	80.0	19.0		0.0	0.1	0.3	0.6	15.0	5.8	30.8

Horizon Depth (cm)	Dry Aggregate Analysis								CSC			Base	Exch
	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.	Acidity
0- 2					0.0	8.7	23.5	30.4	18.1	7.9	11.5	53.4	39.2
2- 15					22.0	29.3	18.5	9.6	3.4	17.1	38.4	8.7	98.9

Horizon Depth (cm)	Saturation Extract															
	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al
0- 2	33.7	21.9	128.3	1109.	1629	146.1	0.047	0.045	0.028	0.094	2.09	0.22	1.11	0.21	3.03	<0.8
2- 15	32.7	1.30	19.5	26.	49.4	14.2	0.084	0.015	<0.003	<0.016	<.16	<.03	<.16	<.03	<.03	<0.8

Horizon Depth (cm)	NH4OAc Extract															
	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As	
	ppm															
0- 2	7344.	2334.	3016	432.	40.4	17.64	26.4	0.66	67.2	1.2	6.4	<.08	0.54	<10.	0.38	
2- 15	6606.	528.	148	202.	58.	23.92	28.	0.58	50.8	1.56	7.2	<.08	0.38	<10	0.46	

Horizon Depth (cm)	Org								pH				NO3			
	C	1:1	1:2	N	P	SO4										
0- 2	<.5	8.1	8.4			1086										
2- 15	<.5	7.0	6.9			43.										

Comments: Multiply figures in columns with asterisks (****) below by 0.1. Multiply figures in columns with dollar signs below by 10.0.

Table 43. Pedon description for the Bannack Tailings (northeast section).

***** SITE DESCRIPTION *****

Soil Series: Site Number: 02 County: Beaverhead
 Location: 1/4, NW1/4, SE1/4 Section 07 Township 8S , Range 11W
 Classification: mixed fine-sandy Typic Cryofluvent

Date Sampled: 08/11/81 Elevation: 5800ft, 1767m Precipitation: 11in, 279 mm
 Site Codes/Co:18/PM:11/Veg: /LU:14/Drain:04/Perm:03/Erns:04/Postn:07/LF:17/
 Material: resid. limestone Vegetation: unvegetated Land use: mill tailings
 Drainage: moderate Permeability: slow to medium Erosion: severe
 Slope: 2%, 1degrees Aspect: S42W Position: level slope
 Soil temp.(50cm) C, 32F Number of Horizons:03 Landform: disturbed land

**** PROFILE DESCRIPTION ****

HOR.	NO.	DEPTH (cm)	COLOR		TEXT	STR CONS RT PR				pH	EFF	BND	*	
			MOIST	DRY		CF	gsk	dmsp	asl					ask
C1	201	0- 13	10YR 5/3	10YR 7/1	02 ls	00	362	3311	643	757	8.0	4	11	1
C2	202	13- 46	10YR 5/2	10YR 7/1	04 lvts	00	111	2212	342	757	8.0	4	55	2
C3	203	46-66+	5Y 5/1	5Y 7/1	08 l	00	111	3422	111	111	8.0	4	66	
		-	/	/	/						.			
		-	/	/	/						.			
		-	/	/	/						.			
		-	/	/	/						.			

CF=coarse fragment(%) STR=structure grade,size,kind
 CONS=moist,dry,sticky, plastic consistence RT=root amount, size, location
 PR=pore amount, size, kind EFF=effervesence BND=boundary
 COMMENTS (*): 1) Lower part of C1 has band of reddish ls matereial (7.5YR 6/6) with more roots and pores than upper C1. 2) Stratification 3mm. thick of dark gray material similar to C3 and thin bands of 7.5YR 6/6. C2 horizon is thixotropic. Roots follow reddish colored vertical cracks in C2 and C3.

Table 44. Soil physical and chemical data for the Bannack Tailings (northeast section).

Series: Classification: fine-sandy mixed Typic Cryofluvent
 Site number: 02 County: Beaverhead Location: Bannack Tailings (upper pond)
 Number horizons: 03 Co: 18

Horizon Depth (cm)	Mechanical analysis										Water content	
	sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar	.3bar	0bar
	(%)										(%)	
C1	0-13	42.0	53.0	5.0		6.3	8.5	33.2	30.0	1.8	15.0	
C2	13-46	39.0	52.0	0.0		0.1	9.1	29.8	24.0	2.1	14.5	
C3	46-66+	33.0	61.0	6.0		0.0	6.8	26.2	31.0	1.9	16.3	

Horizon Depth (cm)	Dry Aggregate Analysis										CBC	Base	Exch
	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.	Acidity
	(%)										(meq/100g)	(%)	(ppm)
C1	0-13			0.9	1.7	2.1	23.8	27.8	43.8	31.8	4.2	98.6	0.0
C2	13-46			6.3	6.6	4.0	33.0	23.0	27.0	35.2	4.5	98.7	0.0
C3	46-66+			5.3	5.5	3.7	19.0	28.5	38.0	32.9	4.5	98.3	0.0

Horizon Depth (cm)	Saturation Extract																
	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As
	(mmho/cm)																
C1	0-13	23.4	0.27	5.4	3.3	4.5	2.3	0.011	0.011	<.002	<.012	<.12	<.02	<.06	<.02	<.02	<.6 .008
C2	13-46	23.5	0.80	14.2	9.3	21.3	4.14	0.033	<.006	0.002	<.012	<.12	<.02	<.06	<.02	<.2	<.6 .003
C3	46-66+	22.9	0.93	19.9	13.1	17.1	4.79	0.031	<.006	<.002	<.011	<.11	<.02	<.06	<.02	<.2	<.6 .003

Horizon Depth (cm)	NH4OAc Extract																
	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As		
	ppm																
C1	0-13	6042.	108.	36.	58.	42.2	16.4	43.6	0.46	71.2	1.68	5.2	<.08	0.24	<10.	0.32	
C2	13-46	6794.	70.	64.	44.	46.2	19.92	59.2	0.4	32.6	0.88	4.8	<.08	0.24	<10.	0.42	
C3	46-66+	6248	116.	68.	50.	60.4	24.56	58.	0.28	63.	0.96	4.0	0.44	0.20	<10.	0.42	

Horizon Depth (cm)	Org		pH		NO3		SO4	
	C	1:1	1:2	N	P			
	(%)		H2O CaCl2		ppm		ppm	
C1	0-13	<.5	6.7	7.1			63.5	
C2	13-46	<.5	7.2	7.3				
C3	46-66+	<.5	7.3	7.0				

Comments: Multiply figures in columns with asterisks (****) below by 0.1.

Table 45. Soil physical and chemical data for the Bannack Tailings (red material in dike).

Series:
Site number: 02B
Number horizons:
Classification:
County: Beaverhead
Co: 18
Location: Bannack Tailings Grab Bag
(red material in dike)

Horizon Depth
(cm)
Mechanical analysis
sand silt clay vcos cos ms fs vfs cosi
15bar .3bar 0bar
(%) (%)
50-60 50.0 42.0 8.0 23.0 4.1 15.2

Horizon Depth
(cm)
Dry Aggregate Analysis
>19mm 19-4 4-2 vcos cos ms fs vfs si,c
(%) (meq/100g) (%) (ppm)
50-60 1.6 4.8 10.3 35.6 18.0 29.7 22.7 5.8 99.7 0.0

Horizon Depth
(cm)
Saturation Extract
H2O EC Ca Mg Na K Zn Cu Mn Fe Pb Cd Ni Ag Cr Al As
(%) (mmho/cm) ppm
50-60 22.4 0.28 2.1 1.2 14.4 1.4 0.17 0.11 <.002 0.067 <.11 <.02 <.06 <.02 <.02 <.5 .003

Horizon Depth
(cm)
NH4OAc Extract
Ca Mg Na K Zn Cu Mn Fe Pb Cd Ni Ag Cr Al As
ppm
50-60 4184. 152. 96. 54. 7.4 3.12 4.36 0.24 14.0 <0.2 4.0 <.08 0.24 <10. 0.64

Horizon Depth
(cm)
Org pH NO3
C 1:1 1:2 N P SO4
(%) H2O CaCl2 ppm
50-60 <.5 7.2 7.3 3.1 <0.1 70.3

Comments: Multiply figures with stars (****) at the bottom of column by 0.1.

Comments: Multiply figures with stars (****) at the bottom of column by 0.1.

Table 46. Soil physical and chemical data for the Bannack Tailings
(grab bag of reworked tailings on N edge of ponds).

Series: Classification:
Site number:02C County:Beaverhead Location:Bannack Tailings Grab Bag (reworked tails on N edge)
Number horizons: Co:18

Horizon Depth	Mechanical analysis										Water content		
(cm)	sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar	.3bar	0bar	
	(%)										(%)		
0- 10	37.0	58.0	5.0	.	1.8	7.6	27.6	35.0	1.6	18.4	.	.	
10- 30	14.0	63.0	23.0	0.1	0.5	4.1	9.3	13.0	6.4	23.5	.	.	
-	.	.	.	.	.	.	.	.	.	.	.	.	

Horizon Depth	Dry Aggregate Analysis										CEC			Base	Exch
(cm)	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.	Acidity		
	(%)										(meq/100g)			(%)	(ppm)
0- 10	.	0.4	2.0	3.2	17.1	22.9	54.4	29.1	3.9	98.9	0.0	0.0			
10- 30	.	21.4	17.9	13.3	13.9	10.4	23.2	40.5	7.7	98.6	0.0	0.0			
-	.	.	.	.	.	.	.	.	.	.	.	.			

Horizon Depth	Saturation Extract																
(cm)	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As
	(mmho/cm) ----- ppm -----																
0- 10	21.4	1.65	20.7	13.5	56.0	7.7	0.021	<.005	0.006	<.011	<.01	<.02	<.05	<.02	<.02	<.05	.003
10- 30	31.0	1.66	35.4	27.7	79.0	10.1	0.030	<.007	0.003	<.016	<.16	<.03	<.08	<.03	<.03	<.08	.008
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**** **																	

Horizon Depth	NH4OAc Extract														
(cm)	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As
	----- ppm -----														
0- 10	5548.	96.	142.	60.	26.	10.32	35.2	0.32	60.4	1.28	4.0	0.72	0.2	<10.	0.34
10- 30	7186	454.	240.	114.	70.4	29.48	51.0	0.62	39.4	1.12	5.4	1.68	0.28	<10.	0.5
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth	Org	pH	NO3				
(cm)	C	1:1	1:2	N	P	SO4	
	(%)	H2O	CaCl2	-----	ppm	-----	
0- 10	<.5	6.7	7.5	.	392.	.	
10- 30	<.5	6.8	7.4	.	558.	.	
-	.	.	.	.	.	.	

Comments: Multiply figures in columns with asterisks (****) below by 0.1.

Table 47. Pedon description for the Champion Natural Soil.

***** SITE DESCRIPTION *****

Soil Series: Site Number: 07 County: Deer Lodge
 Location: 1/4, NW1/4, NW1/4 Section 33 Township 6N , Range 8W
 Classification: sandy mixed Typic Cryochrept
 Date Sampled: 08/13/81 Elevation: 6400ft, 1950m Precipitation: 11in, 279 mm
 Site Codes/Co:30/PM:15/Veg:01/LO:03/Drain:04/Perm:04/Erns:03/Postn:06/LP:02/
 Material: colluvial Vegetation: Mixed coniferous Land use: forest
 Drainage: moderate Permeability: medium Erosion: moderate
 Slope: 15%, 8degrees Aspect: S Position: footslope
 Soil temp.(50cm) C, 32F Number of Horizons:03 Landform: mountains

**** PROFILE DESCRIPTION ****

HOR.	NO.	DEPTH (cm)	COLOR		TEXT	STR CONS RT PR				pH	EFF	BND	*
			MOIST	DRY		CF	gsk	dmsp	asl	ask			
O2		+3- 0	/	/									
A1	701	0- 9	10YR 3/2	10YR 5/4 02 1s		05	113	1111	542	111	5.5	1	31
B2	702	9- 44	10YR 4/6	2.5Y 5/4 02 1s		15	123	3211	442	111	5.5	1	31
C	703	44-65+	10YR 4/6	2.5Y 5/4 02 1s		40	113	3211	242	111	5.5	1	66
		-	/	/							.		
		-	/	/							.		
		-	/	/							.		
		-	/	/							.		

CF=coarse fragment(%) STR=structure grade,size,kind
 CONS=moist,dry,sticky, plastic consistence RT=root amount, size, location
 PR=pore amount, size, kind EFF=effervesence BND=boundary
 COMMENTS (*):

Table 48. Soil physical and chemical data for the Champion Natural Soil.

Series: Classification:sandy mixed Typic Cryochrept

Site number:07 County:Deer Lodge Location:Champion Natural Soil

Number horizons:01 Co:30

Horizon Depth	Mechanical analysis										Water content		
(cm)	sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar	.3bar	0bar	
	(%)										(%)		
Al/B2	0- 44	78.0	17.0	5.0	20.0	23.4	15.2	12.5	6.9	6.0			
-													
-													

Horizon Depth	Dry Aggregate Analysis										CEC	Base	Exch	
(cm)	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.	Acidity	
	(%)										(meq/100g)	(%)	(ppm)	
Al/B2	0- 44	0.7	5.4	7.5	24.8	20.5	13.5	12.6	6.3	7.9	12.9	12.7	70.7	12.0
-														
-														

Horizon Depth	Saturation Extract																	
(cm)	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As	
	(mmho/cm)		ppm															
Al/B2	0- 44	18.0	0.17	4.3	0.8	0.4	1.4	0.025	0.013	0.019	0.095	<.09	<.02	<.04	.002	<.18	0.4	.001
-																		
-																		

**** **** **** ****

Horizon Depth	NH4OAc Extract															
(cm)	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As	
	ppm															
Al/B2	0- 44	1386.	194.	32.	172.	2.52	1.76	9.68	19.6	0.6	<0.2	4.0	<0.8	0.58	18.4	<.02
-																
-																

Horizon Depth	Org	pH	NO3				
(cm)	C	1:1	1:2	N	P	SO4	
	(%)	H2O	CaCl2	ppm			
Al/B2	0- 44	0.5	6.0	5.2	3.2	6.0	32.3
-							
-							

Comments: Multiply figures with stars (****) below column by 0.1.

Comments: Multiply figures with stars (****) below column by 0.1.

Table 49. Soil physical and chemical data for the Champion Waste Rock (grab bag).

Series:
Site number:04
Number horizons:
Classification:
County:Deer Lodge
Co:30
Location:Champion Waste Rock Grab Bag

Horizon Depth	Mechanical analysis										Water content		
(cm)	sand	silt	clay	vcos	cos	ms	fs	vfs	cos1	15bar	.3bar	0bar	
	(%)										(%)		
0- 20	62.0	25.0	13.0	6.3	14.7	15.0	15.7	10.3	9.0	8.2	14.8	.	
20- 65	64.0	25.0	11.0	9.9	17.1	15.6	14.0	7.4	9.0	7.3	14.8	.	
-	.	.	.	.	.	.	.	.	.	.	.	.	

Horizon Depth	Dry Aggregate Analysis										CEC	Base	Exch
(cm)	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.	Acidity
	(%)										(meq/100g)	(%)	(ppm)
0- 20	6.1	24.8	11.6	16.2	16.1	11.2	7.6	3.2	3.1	19.1	27.5	94.3	14.0
20- 65	6.6	31.4	9.4	19.2	14.6	8.1	5.0	2.5	3.2	14.4	22.4	78.0	22.0
-	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth	Saturation Extract																	
(cm)	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As	
	(mmho/cm)		ppm															
0- 20	23.5	1.83	117.5	7.2	0.7	6.6	0.284	0.141	0.884	0.023	<.12	<.02	<.26	<.02	<.2	1.2	0.0	
20- 65	23.5	2.27	111.3	15.2	2.0	6.6	0.82	2.35	0.58	0.263	0.23	0.04	0.39	<.02	0.23	7.0	.001	
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	

Horizon Depth	NH4OAc Extract															
(cm)	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As	
	ppm															
0- 20	3146.	128.	24.	112.	3.08	8.32	8.72	111.2	1.44	0.24	3.2	0.36	0.38	38.2	0.04	
20- 65	2136.	112.	28.	84.	4.4	16.52	3.28	316.0	1.86	0.2	3.6	0.08	0.7	137.	0.04	
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	

Horizon Depth	Org	pH	NO3	P	SO4
(cm)	C	1:1	1:2	N	
	(%)	H2O	CaCl2	ppm	
0- 20	<.5	3.8	3.8	2.7	2.3
20- 65	<.5	3.1	3.1		
-	.	.	.	.	.

####

Comments: Multiply figures with stars (****) below column by 0.1. Multiply figures with dollar signs (\$\$\$\$) below column by 10.0.

Table 50. Pedon description for the Champion Tailings (vegetated eastern boundary).

***** SITE DESCRIPTION *****

Soil Series: Site Number: 05 County: Deer Lodge
 Location: 1/4, NE1/4, NW1/4 Section 33 Township 6N , Range 8W
 Classification: fine-silty mixed Typic Cryofluvent

Date Sampled: 08/13/81 Elevation: 6400ft, 1950m Precipitation: 11in, 279 mm
 Site Codes/Co:30/PM:12/Veg:16/LU:14/Drain:02/Perm:02/Erns:04/Postn:07/LF:17/
 Material: resid. crystalline Vegetation: mixed shortgrass Land use: mill tailings
 Drainage: poor Permeability: slow Erosion: severe
 Slope: 5%, 3degrees Aspect: NW Position: level slope
 Soil temp.(50cm) C, 32F Number of Horizons:03 Landform: disturbed land

**** PROFILE DESCRIPTION ****

HOR.	NO.	DEPTH (cm)	COLOR		TEXT	STR CONS RT PR				pH	EFF	BND	*
			MOIST	DRY		CF	gsk	dmsp	asl	ask			
A1	501	0- 3	10YR 5/8	10YR 5/7	02 ls	00	223	1122	722	111	4.5	1	14
B2	502	3- 12	10YR 6/8	7.5YR 6/8	01 s	00	111	1111	542	111	4.5	1	11
IIC2	503	12-60+	5Y 8/1	2.5Y 8/0	09 sil	00	132	4225	425	484	.0	1	66 1
		-	/	/							.		
		-	/	/							.		
		-	/	/							.		
		-	/	/							.		
		-	/	/							.		

CF=coarse fragment(%) STR=structure grade,size,kind
 CONS=moist,dry,sticky, plastic consistence RT=root amount, size, location
 PR=pore amount, size, kind EFF=effervesence BND=boundary
 COMMENTS (*): 1) Rust colored (7YR 5/8) material present in bands 5mm. thick. Same
 material present in vertical bands either filling cracks or as a byproduct of leaching.

Table 51. Soil physical and chemical data for the Champion Tailings (vegetated eastern boundary).

Series: Classification:mixed Typic Cryofluvent

Site number:05 County:Deer Lodge Location:Champion Tailings (vegetated eastern boundary)

Number horizons:02 Co:30

Horizon Depth	Mechanical analysis										Water content		
(cm)	sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar	3bar	0bar	
	(%)										(%)		
Al/B2	0-12	72.0	22.0	6.0	0.3	1.1	38.2	32.4	12.0	4.1	10.0	.	
IIC2	12-60+	12.0	59.0	29.0	0.3	0.4	1.5	9.8	19.0	12.4	32.8	.	
-	.	.	.	.	.	.	.	.	.	.	.	.	

Horizon Depth	Dry Aggregate Analysis										CEC	Base	Exch	
(cm)	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.	Acidity	
	(g)										(meq/100g)	(%)	(ppm)	
Al/B2	0-12	.	.	1.2	8.8	4.2	2.9	19.6	18.1	15.3	7.8	3.5	80.8	6.0
IIC2	12-60+	1.0	4.1	7.9	22.4	16.4	10.3	8.3	9.1	20.5	15.2	.	19.0	.
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As	
(cm)	(mmho/cm)		ppm															
Al/B2	0-12	27.9	0.24	4.9	1.7	0.3	4.4	0.111	0.39	8.82	<.014	<.14	<.03	.039	<.03	<.3	1.3	.001
IIC2	12-60+	45.4	2.96	177.2	117.0	1.1	19.1	2.08	3.326	17.86	0.600	0.36	0.13	.818	0.09	<.45	44.3	.005
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As	
(cm)	ppm															
Al/B2	0-12	772.	166.	22.	74.	4.32	4.48	32.64	33.4	3.14	<0.2	7.6	<0.8	0.32	104.	0.02
IIC1	12-60+	1078.	400.	22.	132.	5.28	11.72	47.8	276.	1.04	<0.2	12.8	0.44	1.12	278.	0.26
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth	Org	pH	NO3															
(cm)	C	1:1	1:2	N	P	SO4												
	(%)	H2O	CaCl2	ppm														
Al/B2	0-12	<.5	3.6	3.5	222.													
IIC1	12-60+	<.5	3.2	2.6	3827													
-	.	.	.	.	.													

Comments: Multiply figures with asterisks (****) below column by 0.1.

Table 52. Pedon description for the Champion Tailings
(eroded face in center of pond).

***** SITE DESCRIPTION *****

Soil Series: Site Number: 06 County: Deer Lodge
Location: 1/4, NE1/4, NW1/4 Section 33 Township 6N , Range 8W
Classification: fine-silty over sandy mixed Typic Cryofluvent
Date Sampled: 08/13/81 Elevation: 6400ft, 1950m Precipitation: 11in, 279 mm
Site Codes/Co:30/PM:12/Veg: /LU:14/Drain:02/Perm:02/Erns:04/Postn:04/LP:17/
Material: resid. crystalline Vegetation: unvegetated Land use: mill tailings
Drainage: poor Permeability: slow Erosion: severe
Slope: 40%, 20degrees Aspect: W Position: midslope
Soil temp.(50cm) C, 32F Number of Horizons:04 Landform: disturbed land

**** PROFILE DESCRIPTION ****

HOR.	NO.	DEPTH (cm)	COLOR		TEXT	STR CONS RT PR					pH	EFF	BND	*
			MOIST	DRY		CF	gsk	dmep	asl	ask				
C1	601	0- 10	5Y 8/3	5Y 8/1	03 lfs	00	223	2121	111	766	4.5	1	11	
C2	602	10- 71	5Y 7/4	5Y 8/1	06 fs1	00	324	3322	111	553	4.0	1	11	1
C3	603	71- 97	2.5Y 7/0	5Y 8/1	09 sil	00	111	4432	111	111	4.0	1	11	2
IIC4	604	97-120	7.5YR 6/8	/	03 lfs	00	111	1111	111	111	4.0	1	66	
		-	/	/	/						.			
		-	/	/	/						.			
		-	/	/	/						.			
		-	/	/	/						.			

CF=coarse fragment(%) STR=structure grade,size,kind
CONS=moist,dry,sticky, plastic consistence RT=root amount, size, location
PR=pore amount, size, kind EFF=effervescence BND=boundary
COMMENTS (*): 1) Horizon interlayered with coarser, rust colored (10YR 7/8) material;
approx 35 percent by volume.2) Rust colored material (10YR 4/6) in upper part of C3 and
lower part of C2 has formed hardened layers or plates.

Table 53. Soil physical and chemical data for the Champion Tailings (eroded face in center of pond).

Series:		Classification:mixed Typic Cryofluvent																
Site number:06		County:Deer Lodge				Location:Champion Tailings (eroded face in center of pond)												
Number horizons:04		Co:30																
=====																		
Horizon Depth		Mechanical analysis								Water content								
(cm)		sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar	.3bar	0bar					
		(%)								(%)								
=====																		
C1	0- 10	40.0	49.0	11.0		0.1	0.3	15.9	23.7	21.0	4.9	22.4	.					
C2	10- 71	9.0	64.0	27.0	0.5	1.0	0.7	1.0	5.8	20.0	13.6	37.1	.					
C3	71- 97	7.0	65.0	28.0	0.1	0.4	0.5	1.0	5.0	19.0	14.4	38.1	.					
C4	97-120	86.0	12.0	2.0		0.1	4.8	52.8	28.3	8.0	2.1	6.2	.					
=====																		
Horizon Depth		Dry Aggregate Analysis								CEC		Base	Exch					
(cm)		>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.	Acidity				
		(%)								(meq/100g)		(%)	(ppm)					
=====																		
C1	0- 10				7.1	9.6	6.2	31.1	19.7	26.3	8.5	3.5	61.2	13.0				
C2	10- 71			0.3	26.3	19.6	12.0	9.1	7.6	25.1	10.4	15.2	58.0	39.0				
C3	71- 97	3.5	14.6	6.0	19.9	14.5	9.3	6.6	4.9	20.8	25.1	29.7	46.1	72.0				
C4	97-120			0.1	0.3	0.6	16.1	56.2	17.0	9.8	7.7	7.9	67.5	22.0				
=====																		
Horizon Depth		Saturation Extract																
(cm)		H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As
		(mmho/cm)																
C1	0- 10	30.3	0.71	11.5	8.9	0.5	3.5	0.473	0.958	0.327	0.619	<.01	<.01	.026	.005	<.01	5.3	.003
C2	10- 71	43.6	3.47	184.2	137.8	0.5	7.4	2.276	3.331	42.73	6.278	.052	.011	.037	.007	.632	65.4	.005
C3	71- 97	45.6	7.68	152.4	366.8	7.2	3.0	5.854	7.927	82.01	67.88	.141	.026	3.14	.018	4.74	197.	.018
C4	97-120	25.2	5.69	95.6	63.7	1.1	0.9	1.365	1.884	12.47	262.0	.050	.009	.312	.016	.768	34.0	.01
=====																		
Horizon Depth		NH4OAc Extract																
(cm)		Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As		
		ppm																
C1	0- 10	618.	140.	26.	40.	2.88	4.96	2.36	432.	0.56	<0.2	3.6	0.32	0.62	92.4	0.5		
C2	10- 71	942.	376.	24.	72.	4.48	6.12	96.4	484.	0.64	<0.2	11.2	0.36	1.94	214.	0.1		
C3	71- 97	1452.	860.	22.	80.	11.4	13.68	184.8	2100.	1.04	<0.2	35.2	0.36	8.14	468.	0.56		
C4	97-120	1044.	100.	28.	24.	2.84	2.84	28.4	648.	0.6	<0.2	6.4	0.40	1.04	69.8	0.12		
=====																		
Horizon Depth		Org	pH		NO3													
(cm)		C	1:1	1:2	N	P	SO4											
		(%)	H2O	CaCl2	-----	ppm	-----											
C1	0 -10	<.5	3.1	2.9	2.8	17.5	87.2											
C2	10 -71	<.5	3.0	2.9		555.												
C3	71 -97	<.5	2.8	2.5	2.5	12.9	2723											
C4	97 -120	<.5	2.7	2.1		565												
=====																		
Comments: Multiply values for SO4 by 10.0																		

Comments: Multiply values for SO4 by 10.0

Table 54. Soil physical and chemical data for the Champion Tailings (grab bag on vegetated flat ridge top).

Series:
Site number:06A
Number horizons:
County:Deer Lodge
Co:30
Classification:
Location:Champion Tailings Grab Bag (veg. flat in center of tail)

Horizon Depth (cm)	Mechanical analysis									Water content		
	sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar	.3bar	0bar
	(%)									(%)		
0- 15	60.0	29.0	11.0	0.1	19.6	10.5	16.8	13.0	13.0			
-												
-												
-												

Horizon Depth (cm)	Dry Aggregate Analysis									CEC	Base	Exch
	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.
	(%)									(meq/100g)	(%)	(ppm)
0- 15	1.5	5.4	7.5	24.8	20.5	13.5	12.6	6.3	7.9	13.2	15.5	59.5
-												
-												
-												

Horizon Depth (cm)	Saturation Extract													
	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag
	(%)	(mmho/cm)	ppm											
0- 15	26.0	2.88	119.6	55.5	2.5	3.9	0.990	0.379	12.53	0.231	.021	.010	.340	.005
-														
-														
-														

Horizon Depth (cm)	NH4OAc Extract													
	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al
	ppm													
0- 15	1318.	248.	20.	64.	5.08	7.72	48.4	332.	1.0	<0.2	9.6	<0.8	0.78	324.
-														
-														
-														

Horizon Depth (cm)	Org	pH	NO3
	C	1:1	1:2
	(%)	H2O	CaCl2
0 -15	0.8	3.2	3.4
-			
-			
-			

Horizon Depth (cm)	P				SO4
	ppm				----
0 -15	3420				
-					
-					
-					

Comments:

Comments:

Table 55. Pedon description for the Wasa Natural Soil.

***** SITE DESCRIPTION *****

Soil Series: Site Number: 12 County: Granite
 Location: 1/4, 1/4, SW1/4 Section 27 Township 9N , Range 12W
 Classification: coarse-loamy mixed Typic Cryoboroll

Date Sampled: 08/25/81 Elevation: 6100ft, 1859m Precipitation: 14in, 355 mm
 Site Codes/Co:46/PM:11/Veg:01/LU:01/Drain:04/Perm:04/Eran:04/Postn:05/LP:02/
 Material: resid. limestone Vegetation: Mixed coniferous Land use: commercial forest
 Drainage: moderate Permeability: medium Erosion: severe
 Slope: 30%, 16degrees Aspect: WSW Position: lower midslope
 Soil temp.(50cm) C, 32F Number of Horizons:03 Landform: mountains

**** PROFILE DESCRIPTION ****

HOR.	NO.	DEPTH (cm)	COLOR		TEXT	STR CONS RT PR					pH	EFF	BND	*
			MOIST	DRY		CF	gsk	dmsp	asl	ask				
A1		0- 8	10YR 2/1	2.5Y 3/2	05 s1	10	223	1121	732	748	5.0	1	23	
B2		8- 40	7.5YR 4/4	7.5YR 5/4	05 s1	30	223	1121	732	748	5.5	1	22	
C1		40-75+	10YR 5/8	10YR 5/8	05 s1	40	223	1121	642	748	5.5	1	66	
		-	/	/							.			
		-	/	/							.			
		-	/	/							.			
		-	/	/							.			
		-	/	/							.			

CF=coarse fragment(%) STR=structure grade,size,kind
 CONS=moist,dry,sticky, plastic consistence RT=root amount, size, location
 PR=pore amount, size, kind EFF=effervesence BND=boundary
 COMMENTS (*):

Table 56. Soil physical and chemical data for the Wasa Natural Soil.

Series: Classification:coarse-loamy mixed Typic Cryoboroll
Site number:12 County:Granite Location:Wasa Natural Soil
Number horizons:02 Co:46

Horizon Depth		Mechanical analysis										Water content		
(cm)		sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar	.3bar	0bar	
		(%)										(%)		
AL/B2	0- 40	52.0	38.0	10.0	15.0	10.6	8.7	10.5	7.2	11.0	8.7	23.1	.	
C1	40-75+	57.0	34.0	9.0	10.3	10.5	11.2	14.7	10.3	10.0	8.3	19.2	.	
-	.	.	.	.	.	.	.	.	.	.	.	.	.	

Horizon Depth		Dry Aggregate Analysis										CEC			Base	Exch
(cm)		>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.	Acidity		
		(%)										(meq/100g)			(%)	(ppm)
AL/B2	0- 40	11.3	35.9	10.2	10.8	9.3	7.2	6.1	3.2	6.0	11.7	15.3	99.3	31.0		
C1	40-75+	11.5	30.3	11.8	12.0	9.5	8.2	7.4	3.6	5.7	14.2	14.1	94.5	17.0		
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.		

Horizon Depth		Saturation Extract																
(cm)		H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As
		(%) (mmho/cm)																
AL/B2	0- 40	42.1	0.22	9.2	2.1	7.2	6.3	0.085	0.019	0.044	0.244	<.21	<.04	<.11	.005	<.42	<1.0	.003
C1	40-75m	35.9	0.12	4.6	1.6	1.0	1.6	0.076	0.032	0.008	0.919	.18	<.04	<.09	.006	<.36	<.90	.002
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
**** **** **** ****																		

Horizon Depth		NH4OAc Extract														
(cm)		Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As
		ppm														
AL/B2	0- 40	2152.	28.	28.	232.	10.32	1.92	5.68	1.32	1.34	1.24	3.6	<.08	<.02	<10.	.002
C1	40-75+	2392.	128.	26.	142.	52.8	14.72	10.40	24.2	9.82	2.08	5.6	0.16	<.20	34.2	<.02
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth		Org	pH	NO3												
(cm)		C	1:1	1:2	N	P	SO4									
		(%)	H2O	CaCl2	ppm											
AL/B2	0- 40	1.7	6.0	5.6	2.7	22.1	42.4									
C1	40-75+	0.8	5.3	5.7			<10.									
-	.	.	.	.	.	.	.									

Comments: Multiply values with stars (****) below column by 0.1.

Table 57. Pedon description for the Wasa Waste Rock.

***** SITE DESCRIPTION *****

Soil Series: Site Number: 11 County: Granite
 Location: 1/4, 1/4, SW1/4 Section 27 Township 9N, Range 12W
 Classification: sandy-skeletal mixed Typic Cryorthent

Date Sampled: 08/25/81 Elevation: 6100ft, 1859m Precipitation: 14.in, 355 mm
 Site Codes/Co:46/PM:11/Veg:01/LU:15/Drain:04/Perm:04/Ersn:04/Postn:03/LF:17/
 Material: resid. limestone Vegetation: Mixed coniferous Land use: mine dump
 Drainage: moderate Permeability: medium Erosion: severe
 Slope: 35%, 18degrees Aspect: Position: upper midslope
 Soil temp.(50cm) C, 32F Number of Horizons:02 Landform: disturbed land

**** PROFILE DESCRIPTION ****

HOR.	NO.	DEPTH (cm)	COLOR		TEXT	STR CONS RT PR					pH	EFF	BND	*
			MOIST	DRY		CF	gsk	clasp	asl	ask				
C1		0- 54	7.5YR 5/8	7.5YR 5/8	02 ls	40	223	1121	325	748	4.5	1	31	
C2		54-75+	10YR 5/8	10YR 6/4	02 ls	50	223	1111	325	758	4.5	1	66	
		-	/	/	/									
		-	/	/	/									
		-	/	/	/									
		-	/	/	/									
		-	/	/	/									

CF=coarse fragment(%) STR=structure grade,size,kind
 CONS=moist,dry,sticky, plastic consistence RT=root amount, size, location
 PR=pore amount, size, kind EFF=effervesence BND=boundary
 COMMENTS (*):

Table 58. Soil physical and chemical data for the Wasa Waste Rock.

Series: Classification:sandy-skeletal mixed Typic Cryorthent
Site number:11 County:Granite Location:Wasa Waste Rock
Number horizons:01 Co:46

Horizon Depth (cm)	Mechanical analysis										Water content		
	sand	silt	clay	veos	cos	ms	fs	vfs	cosi	15bar	3bar	0bar	
	(%)										-----		
Cl/C2	0-75	59.0	31.0	10.0	14.8	12.2	11.1	12.3	8.6	10.0	9.5	22.8	
-	.	.	.	.	.	.	.	.	.	.	.	.	
-	.	.	.	.	.	.	.	.	.	.	.	.	

Horizon Depth (cm)	Dry Aggregate Analysis										CBC	Base	Exch
	>19mm	19-4	4-2	veos	cos	ms	fs	vfs	sl,c	Sum	NaCl	Satn.	
	(%)										(meq/100g)	(%)	(ppm)
Cl/C2	0-75	12.4	41.3	10.4	9.0	8.0	6.5	5.4	2.6	4.4	8.4	9.8	51.1
-	.	.	.	.	.	.	.	.	.	.	.	.	.
-	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth (cm)	Saturation Extract															
	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al
	(%)	(mmho/cm)	ppm													
Cl/C2	0-75	37.1	2.25	137.2	13.7	3.2	2.3	33.42	8.540	12.33	0.587	.067	.447	.221	.007	<.04
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth (cm)	NH4OAc Extract															
	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As	
	ppm															
Cl/C2	0-75	840.	82.	28.	38.	84.6	42.4	21.68	316.	4.4	1.18	4.8	<.08	<.20	235.	<.02
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Horizon Depth (cm)	Org	pH		NO3		SO4	
	C	1:1	1:2	N	P		
	(%) <td>H2O<td>CaCl2</td><td>-----</td><td>ppm</td><td>-----</td></td>	H2O <td>CaCl2</td> <td>-----</td> <td>ppm</td> <td>-----</td>	CaCl2	-----	ppm	-----	
Cl/C2	0-75	0.9	3.1	3.0	2.9	6.9	5757
-	.	.	.	.	.	.	.
-	.	.	.	.	.	.	.

Comments:

Comments:

Table 59. Soil physical and chemical data for the Wasa Waste Rock (grab bag from dump above Wasa 3 adit).

```

Series:                               Classification:
Site number:11A      County:Granite    Location:Wasa Waste Rock Grab Bag (dump above Wasa 3)
Number horizons:     Cor:46

=====
|Horizon Depth| |-----| |Mechanical analysis| |Water content| | |
|   (cm)      | |sand silt clay vcos cos ms fs vfs cosi| |15bar .3bar 0bar|
|              | |-----| |-----| |-----| |-----|
|              | |      (%)      | |      (%)      | |      (%)      |
|0- 40 52.0 35.0 13.0 12.4 11.2 9.1 10.7 8.6 11.0 6.6 17.9 .
|-          -   .       .       .       .       .       .
|-          -   .       .       .       .       .       .
=====
|Horizon Depth| |-----| |Dry Aggregate Analysis| |CEC| |Base| |Exch| | |
|   (cm)      | |>19mm 19-4 4-2 vcos cos ms fs vfs si,o| |Sum| |NaCl| |Satn.| |Acidity|
|              | |-----| |-----| |-----| |-----| |-----| |-----|
|              | |      (%)      | |      (%)      | |      (%)      | |      (%)      |
|0- 40 9.6 32.6 10.4 10.6 10.4 8.6 8.0 3.6 6.2 8.3 5.5 77.5 23.0
|-          -   .       .       .       .       .       .
|-          -   .       .       .       .       .       .
=====
|Horizon Depth| |-----| |Saturation Extract| | |
|   (cm)      | |H2O EC Ca Mg Na K Zn Cu Mn Fe Pb Cd Ni Ag Cr Al As|
|              | |(mmho/cm)| |-----| |-----|
|              | |      ppm      | |-----| |-----|
|0- 40 27.2 0.07 1.9 0.7 0.3 1.2 0.045 0.012 0.008 0.030 <.14 <.03 <.07 .005 <.27 <0.7 .002
|-          -   .
|-          -   .
=====
|Horizon Depth| |-----| |NH4OAc Extract| | |
|   (cm)      | |Ca Mg Na K Zn Cu Mn Fe Pb Cd Ni Ag Cr Al As|
|              | |-----| |-----|
|              | |      ppm      | |-----| |-----|
|0- 40 1044. 112. 24. 82. 5.56 15.84 4.88 41. 0.52 0.36 4.0 0.44 <0.2 140. <.02
|-          -
|-          -
=====
|Horizon Depth| |Org| |pH| |NO3|
|   (cm)      | |C| |1:1 1:2| |N P SO4|
|              | |(%) | H2O CaCl2| |---- ppm ----|
|0- 40 0.6 4.4 4.1 116.
|-          -

```

```
Comments: Multiply values with stars (****) below column by 0.1.
```

Table 60. Soil physical and chemical data for the Wasa Waste Rock (grab bag from dump below Wasa 1 adit).

Series:	Classification:										Location:Wasa Waste Rock Grab Bag (dump below Wasa 1)									
Site number:11B	County:Granite																			
Number horizons:	Co:46																			
Horizon Depth	Mechanical analysis										Water content									
(cm)	sand	silt	clay	vcos	cos	ms	fs	vfs	cosi	15bar	.3bar	0bar								
	(%)										(%)									
0- 30	71.0	23.0	6.0	19.4	16.9	13.4	12.9	8.4	9.0	3.6	11.3	.								
-	.	.	.	.	.	.	.	.	.	.	.	.								
-	.	.	.	.	.	.	.	.	.	.	.	.								
Horizon Depth	Dry Aggregate Analysis										CBC		Base	Exch						
(cm)	>19mm	19-4	4-2	vcos	cos	ms	fs	vfs	si,c	Sum	NaCl	Satn.	Acidity							
	(%)										(meq/100g)		(%)	(ppm)						
0- 30	10.8	37.3	13.3	10.0	8.2	6.5	5.5	3.0	5.3	24.7	11.3	98.7	2.0							
-	.	.	.	.	.	.	.	.	.	.	.	.	.							
-	.	.	.	.	.	.	.	.	.	.	.	.	.							
Horizon Depth	Saturation Extract																			
(cm)	H2O	EC	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As			
	(%)	(mmho/cm)																		
0- 30	23.2	1.4	74.5	2.1	7.6	3.6	0.004	<.006	0.008	<.012	<.12	<.02	.013	.005	<.23	<0.6	0.0			
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.			
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.			
Horizon Depth	NH4OAc Extract																			
(cm)	Ca	Mg	Na	K	Zn	Cu	Mn	Fe	Pb	Cd	Ni	Ag	Cr	Al	As					
	ppm																			
0- 30	4798.	46.	32.	120.	66.6	7.92	19.68	0.78	1.76	2.84	4.4	<.08	<.02	<10.	<.02					
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.					
-	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.					
Horizon Depth	Org	pH	NO3																	
(cm)	C	1:1	1:2	N	P	SO4														
	(%)	H2O	CaCl2	ppm																
0- 30	0.6	6.5	6.8			457.														
-	.	.	.	.	.	.														
-	.	.	.	.	.	.														

Comments: Multiply values with stars (****) below column by 0.1.

APPENDIX D
PLANT SPECIES LISTS

Table 60. Partial species list for the Alta mine.

Scientific name	Common name
<u>Achillea</u> spp.	Yarrow
<u>Agropyron</u> spp.	Wheatgrass
<u>Agropyron trachycaulum</u>	Slender wheatgrass
<u>Agrostis</u> spp.	Bentgrass
<u>Antennaria</u> spp.	Pussytoes
<u>Arenaria</u> spp.	Sandwort
<u>Artemesia cana</u>	Silver sage
<u>Artemesia dracunculus</u>	Terragon sagewort
<u>Artemesia fridgida</u>	Fringed sagewort
<u>Bromus inermis</u>	Smooth brome
<u>Bromus tectorum</u>	Cheatgrass brome
<u>Carex</u> spp.	Sedge
<u>Chrysothamnus nauseosus</u>	Rubber rabbitbrush
<u>Deschampsia cespitosa</u>	Tufted hairgrass
<u>Festuca idahoensis</u>	Idaho fescue
<u>Festuca scabrella</u>	Rough fescue
<u>Fragraria virginiana</u>	Strawberry
<u>Hordeum jubatum</u>	Foxtail barley
<u>Juncus</u> spp.	Rush
<u>Koeleria cristata</u>	Prairie junegrass
<u>Pinus contorta</u>	Lodgepole pine
<u>Pinus flexilis</u>	Limber pine
<u>Poa</u> spp.	Bluegrass
<u>Potentilla</u> spp.	Cinquefoil
<u>Populus tremuloides</u>	Quaking aspen
<u>Pseudotsuga menziesii</u>	Douglas fir
<u>Rosa</u> spp.	Rose
<u>Salix</u> spp.	Willow
<u>Sitanion hystrix</u>	Bottlebrush squirreltail
<u>Stipa viridula</u>	Green needlegrass
<u>Symphoricarpos</u> spp.	Snowberry
<u>Verbascum thapsus</u>	Common mullein

Table 62. Partial species list for the Champion mine.

Scientific name	Common name
<u>Abies</u> spp.	Fir
<u>Agrostis</u> spp.	Bentgrass
<u>Carex</u> spp.	Sedge
<u>Fragraria virginiana</u>	Strawberry
<u>Juncus</u> spp.	Rush
<u>Pinus contorta</u>	Lodgepole pine
<u>Poa</u> spp.	Bluegrass
<u>Populus tremuloides</u>	Quaking aspen
<u>Rumex</u> spp.	Sorrel
<u>Salix</u> spp.	Willow
<u>Solidago missouriensis</u>	Goldenrod

Table 63. Partial species list for the Wasa mine.

Scientific name	Common name
<u>Abies</u> spp.	Fir
<u>Achillea</u> spp.	Yarrow
<u>Agropyron</u> spp.	Wheatgrass
<u>Agrostis</u> spp.	Bentgrass
<u>Carex</u> spp.	Sedge
<u>Dactylis glomerata</u>	Orchardgrass
<u>Deschampsia</u> spp.	Hairgrass
<u>Equisetum</u> spp.	Horsetail
<u>Fragraria virginiana</u>	Strawberry
<u>Phleum</u> spp.	Timothy
<u>Picea</u> spp.	Spruce
<u>Pinus contorta</u>	Lodgepole pine
<u>Poa</u> spp.	Bluegrass
<u>Pseudotsuga menziesii</u>	Douglas fir
<u>Salix</u> spp.	Willow
<u>Taraxacum</u> spp.	Dandelion
<u>Verbascum thapsus</u>	Common mullein

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