



Geochemical characteristics of a waste rock repository at a western gold mine
by Jason Dwayne Outlaw

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 was conducted to determine the extent of weathering in a large pyritic waste rock repository, characterize its geochemical variations, and correlate the extent of weathering with physical waste rock characteristics. Field sampling activities revealed a highly variable waste rock pile made up of distinct layers of material. Chemical characteristics of waste rock varied greatly between layers throughout the repository. To investigate the associations that may exist between waste rock chemical variables, a correlation analysis was performed on waste rock chemical data. Sample titratable acidity was correlated with soluble SO_4 ($r = 0.8299$), soluble Fe ($r = 0.7919$), soluble Al ($r = 0.9212$) and electrical conductivity ($r = 0.6720$).

The weathering of pyritic waste rock occurs when it comes into contact with air and water. This study revealed that regions of the waste rock dump where this interface occurs were more highly weathered. Samples of waste rock taken from the upper portions of the repository contained greater levels of acidity, electrical conductivity, and water soluble SO_4 , aluminum and iron. Though weathering may be significantly decreased deep within the repository, chemical data confirmed that weathering may still be occurring at any location within this waste rock pile. The oldest waste rock was found deeper in the interior of the waste rock repository, but it showed the highest degree of weathering. This was supported by data that showed the oldest samples contained greater levels of acidity, electrical conductivity and water soluble SO_4 , iron and aluminum. Finally, salt formations found within the waste rock repository were found to include copper, magnesium and zinc sulfates.

**GEOCHEMICAL CHARACTERISTICS OF A WASTE ROCK
REPOSITORY AT A WESTERN GOLD MINE**

by

Jason Dwayne Outlaw

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of the requirements for the degree

of

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in

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

This study was conducted to determine the extent of weathering in a large pyritic waste rock repository, characterize its geochemical variations, and correlate the extent of weathering with physical waste rock characteristics. Field sampling activities revealed a highly variable waste rock pile made up of distinct layers of material. Chemical characteristics of waste rock varied greatly between layers throughout the repository. To investigate the associations that may exist between waste rock chemical variables, a correlation analysis was performed on waste rock chemical data. Sample titratable acidity was correlated with soluble SO_4 ($r = 0.8299$), soluble Fe ($r = 0.7919$), soluble Al ($r = 0.9212$) and electrical conductivity ($r = 0.6720$).

The weathering of pyritic waste rock occurs when it comes into contact with air and water. This study revealed that regions of the waste rock dump where this interface occurs were more highly weathered. Samples of waste rock taken from the upper portions of the repository contained greater levels of acidity, electrical conductivity, and water soluble SO_4 , aluminum and iron. Though weathering may be significantly decreased deep within the repository, chemical data confirmed that weathering may still be occurring at any location within this waste rock pile. The oldest waste rock was found deeper in the interior of the waste rock repository, but it showed the highest degree of weathering. This was supported by data that showed the oldest samples contained greater levels of acidity, electrical conductivity and water soluble SO_4 , iron and aluminum. Finally, salt formations found within the waste rock repository were found to include copper, magnesium and zinc sulfates.

INTRODUCTION

Acidity, metal solubilization and salt generation resulting from the weathering of waste rock containing sulfide minerals are common occurrences at hardrock mining operations in western North America and throughout the world. Waste rock is that material that must be removed in order to mine an economically important ore. This waste rock often contains iron-sulfide minerals which, after removal from their oxygen deprived - chemically reduced geologic environment, are placed on site in large repositories. This material is then exposed to air and water, facilitating weathering reactions that can produce acidity, elevated levels of sulfate, and the solubilization of metals. If a sufficient amount of water comes into contact with the repository material, acid rock drainage can occur. Acid rock drainage occurs when the products of sulfide weathering are leached into the natural environment. This can be inhibitory to plant growth and negatively affect aquatic ecosystems.

Due to the large size of most waste rock repository facilities and difficulty of sampling, little is known of the geochemical processes that occur deep within a repository over long periods of time. This study to investigate the geochemical processes deep within a waste rock repository took advantage of waste rock excavation necessitated by an episode of ground movement that took place at the Golden Sunlight Mine located in southwest Montana during 1994. Due to this ground movement, approximately 15 million tons of waste rock were off-loaded from a large repository facility. This study

was conducted on the east waste rock complex that underwent excavation from July 1994 to March 1995. This provided a unique opportunity to observe materials and obtain samples from deep within a large waste rock pile.

The Golden Sunlight Mine is located in southwestern Montana approximately 8 km northeast of Whitehall along Interstate 90. (Figure 1) The mine is owned and operated by Placer Dome U.S. Inc. and has been operating since 1981, although historic mining occurred at this site beginning in the late 1800's. The site receives an average annual precipitation of 25.4 to 30.5 cm, mostly as rainfall from April to September (MAPS 1990).

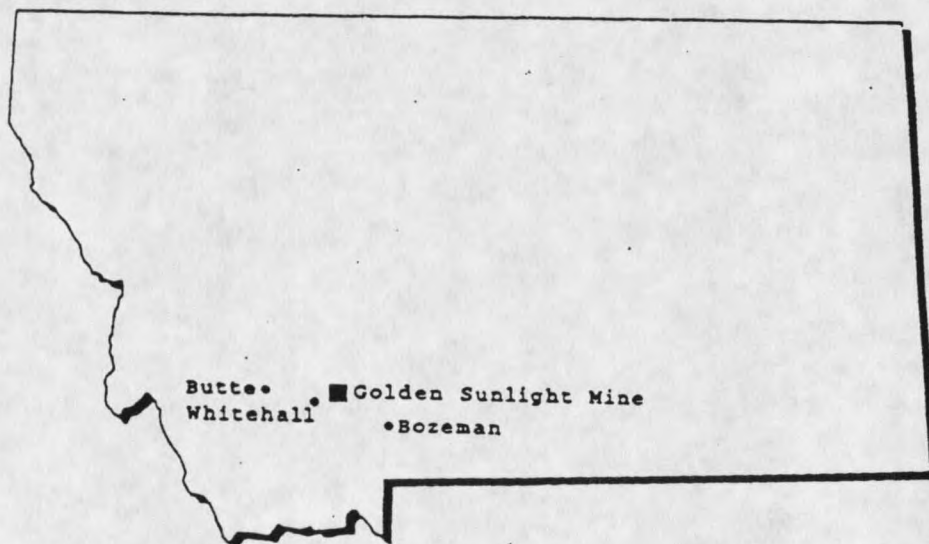


Figure 1. Location of the Golden Sunlight Mine, Whitehall, Montana.

Investigation Objectives

In order better to understand the geochemical weathering that occurs within a large waste rock repository, this investigation addressed the following research objectives:

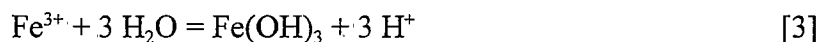
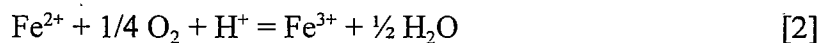
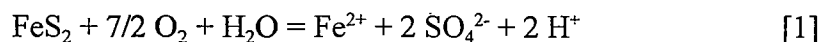
- determine the extent of weathering in the waste rock repository;
- characterize the geochemical variations in the waste rock repository; and
- correlate the extent of weathering with waste rock particle size distribution.

LITERATURE REVIEW

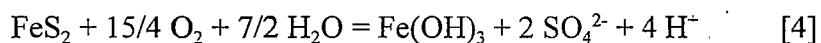
Pyrite Oxidation

The oxidation of pyrite takes place when the mineral is exposed to air and water. This process involves chemical and biological reactions and is dependent on environmental conditions such as the morphology of pyrite crystals and the presence of water and oxygen.

The oxidation of pyrite by oxygen and water can be expressed in the following widely accepted reactions.



These three reactions can be summarily expressed as Reaction 4.

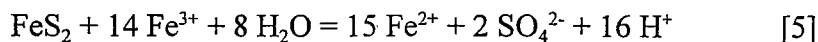


Reaction one indicates that the oxidation of pyrite produces ferrous iron (Fe^{2+}), sulfate (SO_4^{2-}) and hydrogen ions (H^+). Ferrous iron produced in Reaction 1 is then oxidized to yield ferric iron (Fe^{3+}) as shown in Reaction 2. Finally, the precipitate $\text{Fe}(\text{OH})_3$ is formed from the combination of Fe^{3+} and water (Reaction 3). This third step is a reversible dissolution/precipitation reaction and can serve as a source or sink of solution Fe^{3+} (Evangelou and Zhang, 1995).

While O_2 is the major oxidant of pyrite at neutral to alkaline pH, Singer and Stumm (1970) found Fe^{3+} to be the dominant pyrite oxidant at acidic pH levels (<3.5).

This reaction at $\text{pH} < 3.5$ produces 16 moles of acidity per mole of FeS_2 as shown in

Reaction 5.



Because Fe^{3+} is the dominant oxidant of FeS_2 , Reaction 2, which shows the production of Fe^{3+} from the oxidation of Fe^{2+} , is known as the rate-limiting step in abiotic pyrite oxidation (Singer and Stumm 1970).

When iron-oxidizing bacteria are present in the waste rock dump environment, the rate-limiting step in pyrite oxidation can be bypassed. One such iron-oxidizing bacterium is *Thiobacillus ferrooxidans*, an acidophilic iron-oxidizing bacterium that is ubiquitous in geologic environments containing pyrite (Ivarson et. al. 1982). Dugan (1975) and Singer and Stumm (1970) found that iron-oxidizing bacteria such as *T. ferrooxidans* can accelerate the rate of Fe^{2+} oxidation by a factor of 10^6 .

Other factors influencing the rate of pyrite oxidation are pyrite grain size and morphology. Shellhorn, Sobek and Rastogi (1985) used column leach testing to show an exponential increase in acidity with decreasing particle size (increased relative surface area) of pyritic sulfur refuse. Recent research has shown that pyrite particle morphology has an even greater influence on the rate of oxidation than particle size (Jennings and Dollhopf 1995).

Waste Dump Observations

Temperature profiles of a 20-year-old pyritic waste rock dump in the Northern Territory of Australia were measured by Harries and Ritchie (1980). They found that below 6m, temperatures in the dump remained essentially unchanged through their wet/dry season cycle. Since pyrite oxidation is exothermic, they concluded that this process primarily occurred in the top 5m of the dump with some regions showing oxidation down to 15m.

Harries and Ritchie (1985) also studied the pore gas composition of this Australian waste rock dump. They found that in most regions of the dump, oxygen supply was the oxidation-rate-limiting mechanism. Oxygen levels in this dump were highly variable, ranging from <1% to approximately 20% of atmospheric conditions. In some areas of the dump, oxygen content was near 20% in the top 2m but declined rapidly to <1% as depth increased, leveling off at <1% for depths greater than 5m. In other areas, oxygen content was shown to decrease from near 20% to less than 10% as depth ranged from 0 to 5m, then increased to a maximum of 19% at a depth of 13m. It was determined that the main oxygen transport mechanisms in the dump were likely to be diffusion, due to concentration gradients, and advection, caused by thermal effects and atmospheric pressure changes.

Schafer et al. (1994) performed a monitoring study on a waste rock pile at the Golden Sunlight Mine to compare reclaimed and unreclaimed waste rock dumps. They found that rock particle size gradually increased with depth due to gravity sorting in the

end-dumping sequence. Freshly shot waste rock was determined to have a volumetric water content of less than 6 percent. Residual saturation was found to vary between 8 and 12 percent within the dump with residual saturation generally lower near the base of the dump where larger particles are deposited. Fine waste rock produced by vehicle compaction at the top of each bench was found to have a residual saturation level ranging from 15 to 20 percent.

Whitney, Esposito and Sweeney (1995) conducted a study to describe the distribution of secondary alteration minerals within an excavated pyritic mine dump near Central City, Colorado. They identified four mineralogical zones distributed vertically within the dump: a surficial, relatively unaltered zone; a leached zone; a cemented zone in which pore spaces are filled with the minerals copiapite ($\text{Fe}^{2+}\text{Fe}^{3+}_4(\text{SO}_4)_6(\text{OH})_2 \cdot 20 \text{H}_2\text{O}$) and coquimbite ($\text{Fe}^{3+}_2(\text{SO}_4)_3 \cdot 9 \text{H}_2\text{O}$); and an interior relatively unaltered zone.

Due to difficulty in sampling material found deep inside waste rock repositories, documentation concerning how waste rock weathers over long periods of time is nonexistent. This geochemical study, analyzing a range of samples collected throughout a large waste rock repository, is unique in this aspect.

MATERIALS AND METHODS

Waste Rock Sample Collection

The field sampling program was conducted simultaneously with excavation of the east waste rock complex. Excavation using electric shovels and 175 ton haul trucks began at the top of the waste rock pile at 1682 m (5520 ft) elevation and continued downward in approximately 12 to 18 m benches to the 1588 m (5210 ft) elevation level. Sampling occurred in 30 test pits that were located along two north-south and two east-west transect lines. The locations of these test pits with elevations are shown in Figure 2. Overall, 121 waste rock samples were collected for geochemical analysis.

Prior to the removal of each bench, transect lines were located by Golden Sunlight Mine survey staff and test pits were excavated to permit sampling. In this manner, sampling occurred along established transect lines at approximately 1.8 m vertical intervals throughout the portion of the east waste rock dump that was excavated.

Test pits were excavated to depths ranging from 3 to 4.6 m. One wall of each test pit was left vertical for logging and sampling while the other was sloped for safety concerns. Distinct layering of waste rock material was observed in the waste rock pile and was defined by changes in particle size and/or Munsell color. Each layer within a test pit was given a unique sample number (for example, TP10GS3 refers to test pit number 10 layer 3). The logs for each test pit are presented in Appendix B. A bulk sample was taken from each layer and transported to Montana State University for analysis. Sample

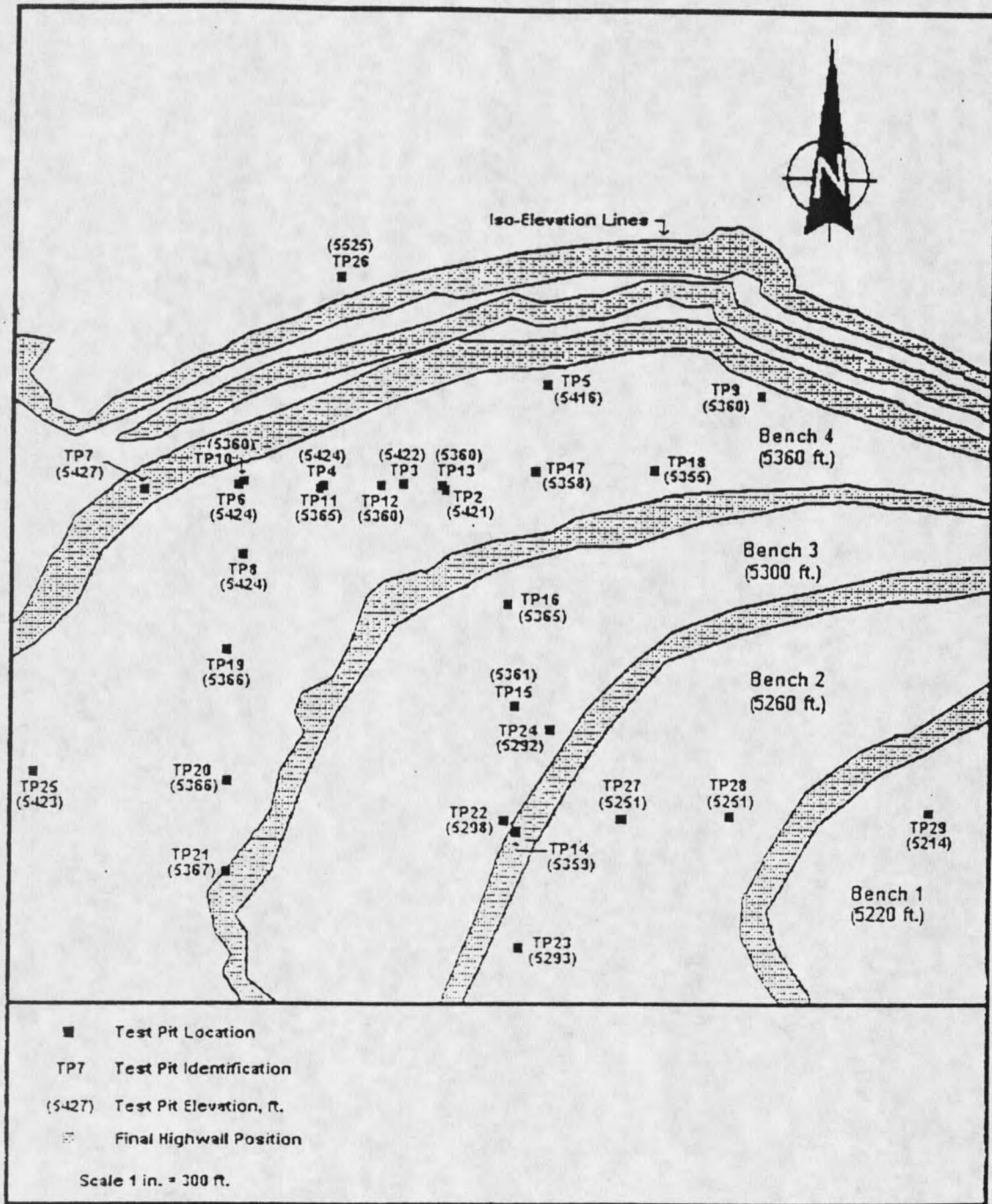


Figure 2. Overhead view of waste rock repository with test pit locations and elevations.

collection occurred concurrently with sample collection by researchers from the University of Saskatchewan who were performing a hydrogeologic study of this waste rock dump. Identical sample identification numbers were used by each university to facilitate data sharing and collaboration.

Analytical Procedures

Bulk samples were analyzed for particle size (ASTM D421-85). Aggregates were broken with a mortar and rubber-tipped pestle, then sieved by hand using metal sieves to obtain a <2mm diameter size fraction. It should be noted that while coarse layers were encountered in the waste rock pile, sampling of very coarse materials (>20 cm diameter) was prohibitive for practical reasons. A portion of the <2 mm diameter size fraction from each bulk sample was used for a 1:1 paste extraction (Methods of Soil Analysis, 1983, Method 10-2.3.2). Due to the low porosity of waste rock samples, a 1:1 paste extraction was chosen to ensure the collection of sufficient extract to analyze the entire suite of chemical variables. In addition, a 1:1 paste ensures that each sample is extracted at the same soil to water ratio, as opposed to the subjective variability involved in preparing a saturated paste. This water extract was analyzed for pH (Methods of Soil Analysis, 1965, Method 60-3.1.2), electrical conductivity (EC) (Methods of Soil Analysis, 1965, Method 62-2.2.3), soluble iron (Fe), aluminum (Al), manganese (Mn) and sulfate (SO₄) (Methods of Soil Analysis, 1965, Method 62-1.3.2.1) and titratable acidity (TA) to pH 7 (Standard Methods for the Examination of Water and Wastewater, p. 2-30). Waste rock of <2mm size was analyzed for potential acidity and sulfur fractionation, including total sulfur

(TS), hot water extractable sulfur (H_2O-S), HCl extractable sulfur (HCl-S), HNO_3 extractable sulfur (HNO_3-S), residual sulfur (Res-S) and neutralization potential (NP) (Modified Sobek et. al., 1978). The hot water extraction is intended to remove sulfur from the readily soluble calcium, magnesium and sodium sulfates. Sulfate sulfur existing in less soluble minerals such as Jarosite ($KFe_3(SO_4)_2(OH)_6$) is removed with the HCl extraction. The HNO_3 extraction serves to extract the sulfide sulfur that exists as pyrite and the residual sulfur is a measure of the organic sulfur in the sample.

The parameters pH, EC, titratable acidity and soluble Fe, Al, Mn and SO_4 were measured by the Soil Analytical Laboratory at Montana State University. To monitor the precision of analysis, laboratory replicates were entered into the sample set at a 10 percent rate. Replicate relative percent difference (RPD) averaged 2.2% pH, 9.1% EC, 5.6% titratable acidity, 8.2% soluble Al, 5.8% soluble Fe, 7.1% soluble Mn, and 4.1% soluble SO_4 .

Neutralization potential and the sulfur fractionation parameters were measured by Energy Laboratories, Inc. in Billings, MT. Laboratory replicates were entered into the sample set at a 10 percent rate. Replicate RPD averaged 11.3% neutralization potential, 1.8% total sulfur, 19.9% hot water extractable sulfur, 12.1% HCl extractable sulfur, 2.4% HNO_3 extractable sulfur, and 11.1% residual sulfur.

In order to analyze the data based on age, position, and percent passing a 2mm sieve, the data were divided into three age categories, four elevation categories, and four

particle size separation categories. Achieving relatively uniform sample sizes was the basis for the delineation of categories. Measurements below analytical detection limits were adjusted for inclusion in the development of all categories. This adjustment multiplied respective analytical detection limits by a factor of 0.7 to obtain a numerical value (Severson 1979).

In cases where data populations were normal or where data transformations could be applied to normalize populations, a one-way analysis of variance (ANOVA) was conducted using a 95 percent confidence interval. Where the p-value for the observed F statistic was less than or equal to 0.05, the hypothesis of equality of means was rejected. Data sets with unequal means were then subjected to the Student-Newman-Keuls means separation procedure at the 0.05 level of significance.

In cases where data populations could not be normalized through transformation, a one-way ANOVA on ranks was performed using a 95 percent confidence interval. Where the p-value for the observed H statistic was less than or equal to 0.05, the hypothesis of equality of medians was rejected. Data sets with unequal medians were then subjected to the Dunn's separation procedure at the 0.05 level of significance. Results were reported with respect to sample means.

Determination of Sample Ages

Sample ages were determined using drawings supplied by Golden Sunlight Mines, Inc. Drawings for the years 1987, 1988, 1989, 1990, 1992 and 1993 were provided which document the crest and toe position of the repository for each year. Figure 3 shows the

waste rock dump study area areal view with the locations of cross-sections. Figures 4, 5, 6 and 7 show cross-sections A-A', B-B', C-C' and D-D', respectively. These cross-sections show the crest and toe positions of the repository for each year along with the locations of test pits. Test pit 29 was excavated in material placed in 1994. The location of test pit 29 in Figure 5 is shown outside the last toe and crest position due to the unavailability of toe and crest positions for 1994.

Since new material is placed on the repository by end-dumping from the edge, the oldest aged material is found not at the lowest elevations of the repository but farther toward the interior from the edge. This can be seen by examining Figures 4 through 7. Thus, sampling at higher elevations in the waste rock pile encountered not just new material, but materials of varying ages. To support this, a correlation analysis was performed on test pit elevations vs. material age. While the correlation was significant ($p = 0.007$), a low r-squared value of 0.24 hinders interpretation because only 24 percent of the variability in age can be attributed to elevation.

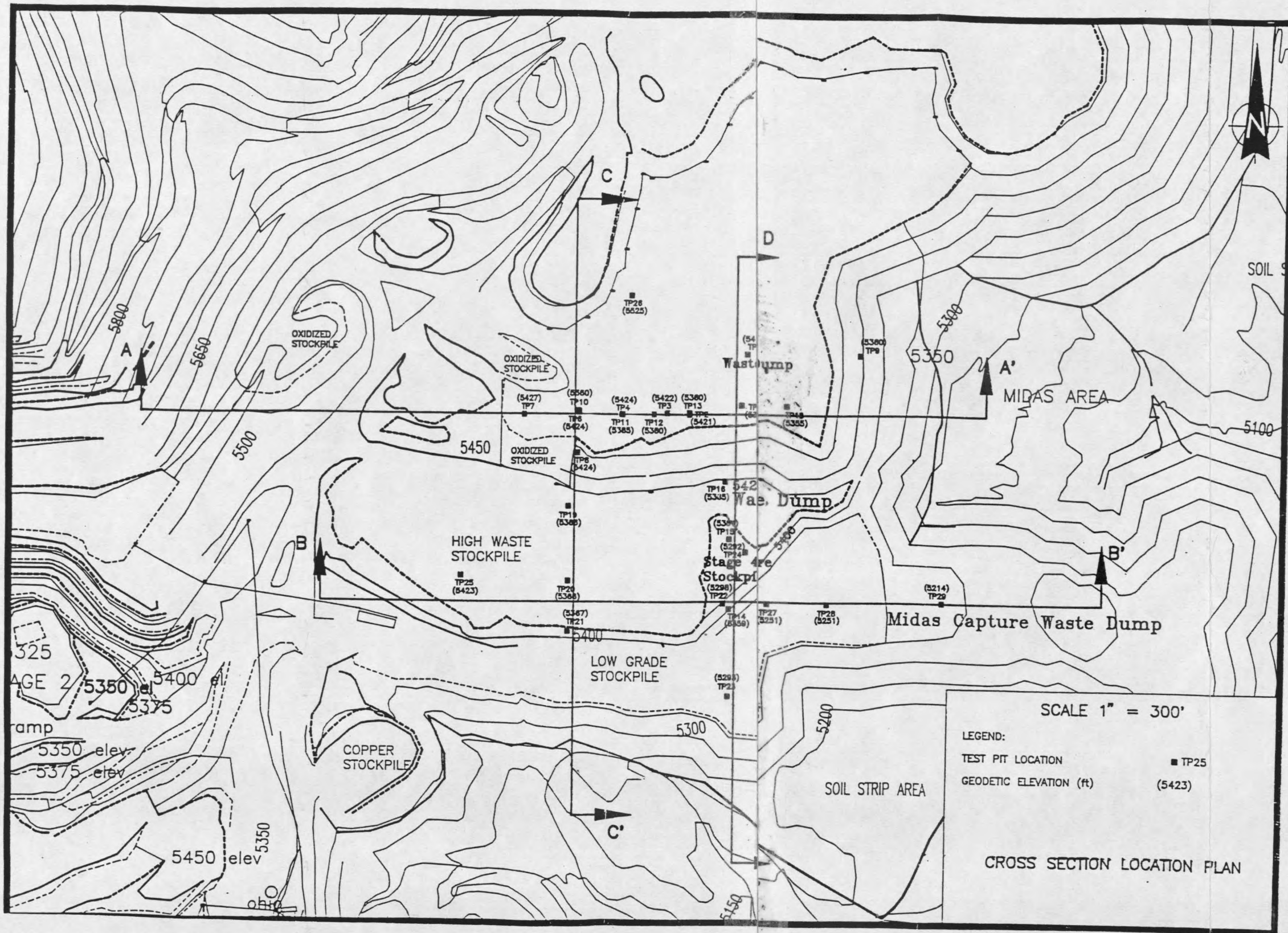


Figure 3. Aerial view of waste rock repository showing cross-sections A, B, C and D.

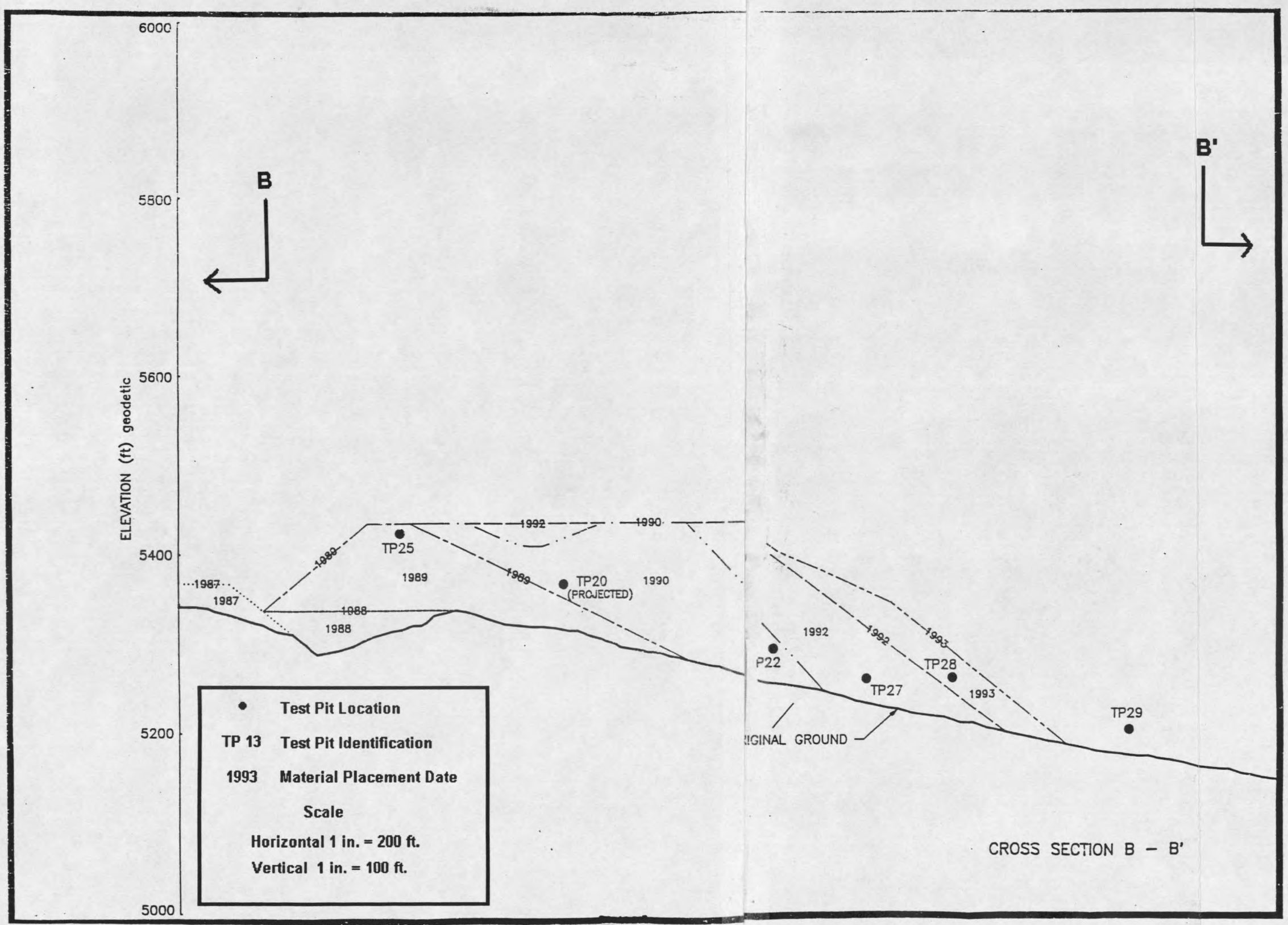


Figure 5. View of waste rock repository vertical plane through cross section B - B'.

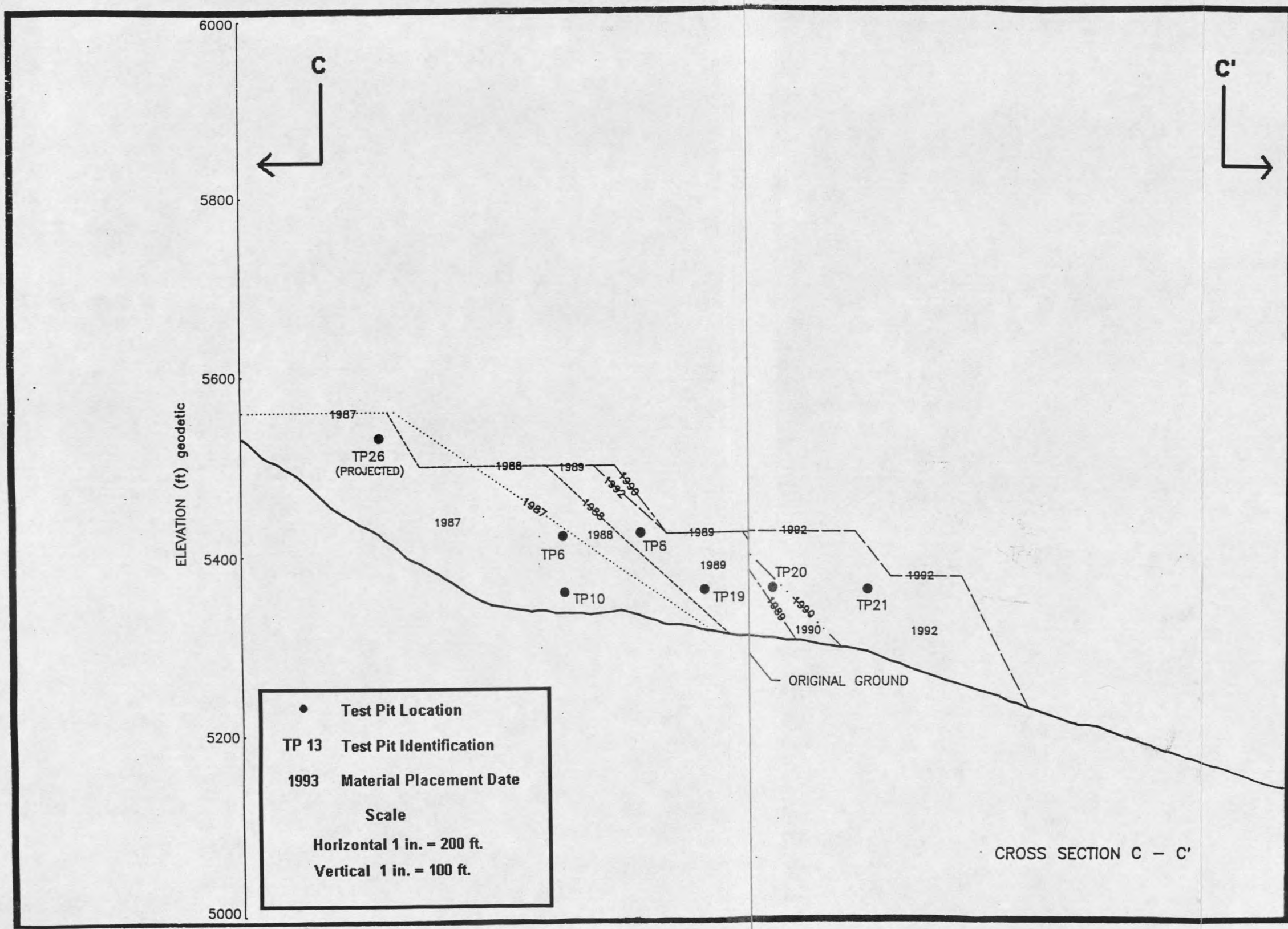


Figure 6. View of waste rock repository vertical plane through cross section C - C'.

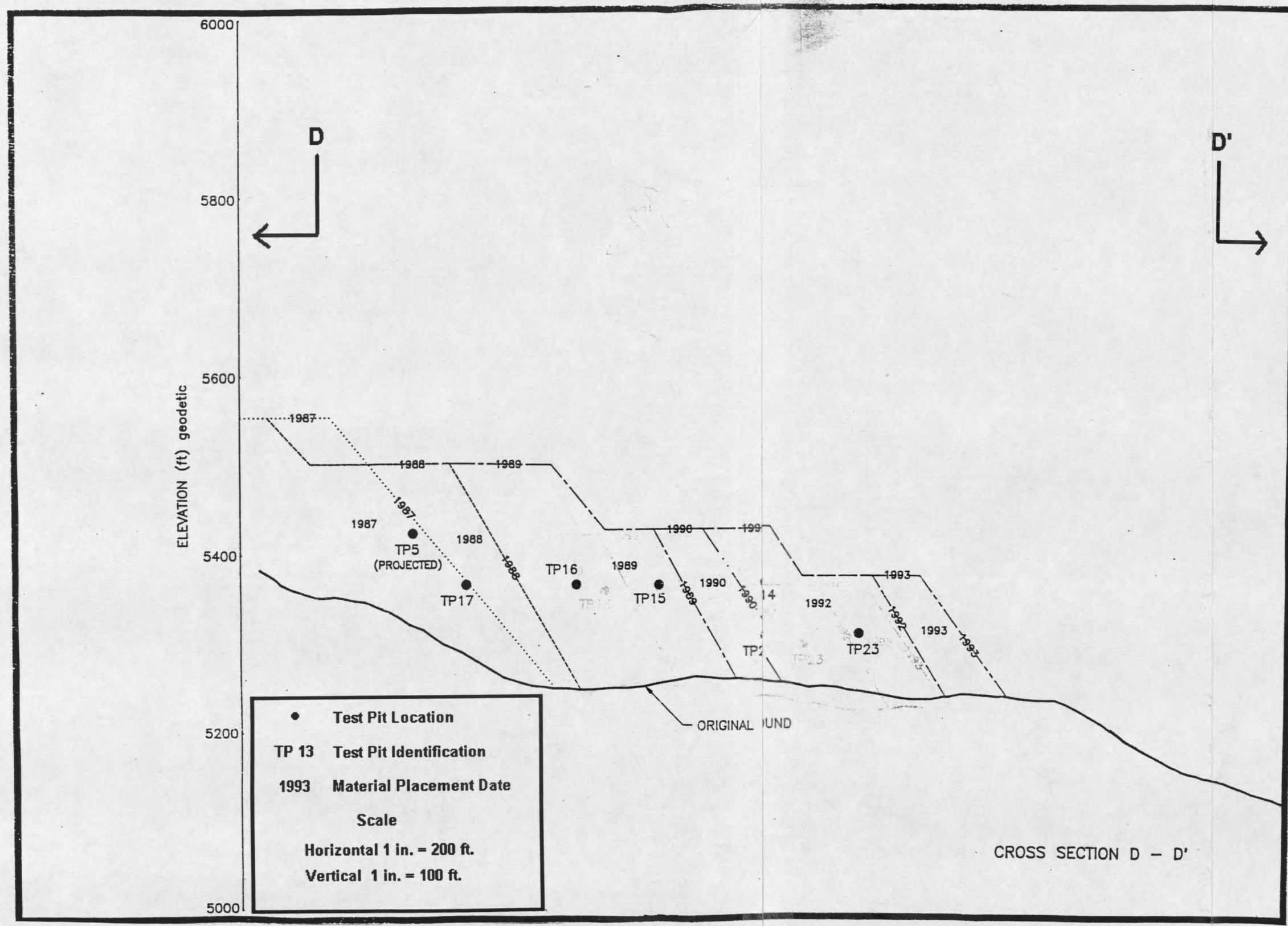


Figure 7. View of waste rock repository vertical plane through cross section D - D'.

RESULTS AND DISCUSSION

Waste Rock Physicochemical Characteristics

Field sampling activities revealed a highly variable waste rock pile made up of distinct layers of material. Layers of waste rock ranging from 10 cm to several meters in width were found to be dipping at an angle of approximately 40°. These layers of waste rock were comprised of either shale (sedimentary) or latite (igneous) rock types or a combination of the two. Both shale and latite rock types were found to contain massive and disseminated sulfide mineralization, with pyrite being the dominant sulfide mineral found. Often, color differences were sharply defined between layers. Munsell colors of waste rock ranged from red to reddish yellow to yellow - olive. Grain size differences between layers were observed, ranging from coarse "rubble layers" consisting of > 20 cm diameter particles with larger open interparticle voids to fine layers where voids between coarse particles were filled with silt and sand sized particles. A coarse rubble zone was found to exist at the base of the repository, most likely due to gravity sorting during pile construction.

Chemical characteristics of waste rock varied greatly between layers throughout the pile. A complete listing of chemical data can be found in Appendix A. A general overview of chemical data including means, standard deviations, minimum and maximum values are presented in Table 1. A mean value for neutralization potential is not presented because most layers had little or no neutralization potential. The 1:1 paste

Table 1. Chemical characteristics of waste rock materials.

Chemical Variable	n	Mean	Standard Deviation	Minimum	Maximum
Neutralization Potential (t CaCO ₃ /1000t)	121	-----	-----	<1	56.0
pH	121	3.6	1.4	2.0	7.6
EC (mmhos/cm)	121	8.09	3.89	0.85	17.73
SO ₄ (mg/L)	121	11466	7793	417	40335
Al (mg/L)	121	572	649	< 1	2925
Fe (mg/L)	121	1157	1979	< 1	10363
Mn (mg/L)	121	35	42	< 1	201
Titrateable Acidity (mg CaCO ₃ /L)	107	6806	6239	2.0	26615
Total Sulfur (%)	121	8.22	4.43	0.64	34.40
H ₂ O-S (%)	121	0.65	0.62	< 0.01	2.5
HCl-S (%)	121	0.47	0.74	< 0.01	5.3
HNO ₃ -S (%)	121	6.58	3.88	0.3	30.0
Residual-S (%)	121	0.52	0.44	.03	4.39

pH values ranged from 2.0 to 7.6 with a mean value of 3.6. Higher pH values (above 5.0) were associated with layers that contained a significant amount of neutralization potential due to the presence of chemical constituents capable of neutralizing acidity. The presence of neutralizing materials in some layers can also explain the wide range of titrateable acidity data - from 2 to 26615 mg CaCO₃/L. In turn, the wide ranges of soluble SO₄, Fe, Al and Mn data can be attributed to the variability of acidity in the waste rock dump because high acidity and associated low pH results in the solubilization of these metals

and SO_4 . Likewise, the high variability in electrical conductivity data can be attributed to varying levels of SO_4 solubilization due to varying levels of acidity. While the presence of neutralizing materials explains why the ranges of the chemical data are so great, it should be noted that only 22 out of the 121 samples contained a neutralization potential of 5 t CaCO_3 / 1000 t or greater. This explains why the means of the acidity influenced variables (EC, SO_4 , Fe, Al and Mn) are much greater than the minimum values. In summary, the presence of neutralizing materials in some layers of the dump can cause soluble metal levels to be quite low (below detection limit), but the overall effects of these layers are negligible as shown by the higher mean values of the soluble metals and other acidity influenced variables.

Total sulfur values for waste rock samples ranged from 0.64 to 34.4% with a mean of 8.22%. Nitric acid (HNO_3) extractable sulfur exhibited the highest mean as compared to water and hydrochloric acid extractable sulfur. This suggests that a majority of the sulfur in this waste rock dump exists as sulfide sulfur, most likely in the form of pyrite (FeS_2).

Correlation Analysis of Waste Rock Chemical Data

In an effort to investigate the associations that exist between waste rock chemical variables, a Spearman Rank Order Correlation analysis was performed. Raw rank correlation results output including sample size are presented in Appendix C. A Spearman Rank Order Correlation is used to measure the strength of association between

pairs of variables without specifying which variable is dependent or independent. Results of this analysis are presented in Table 2. The Spearman correlation coefficient quantifies the strength of the association between the variables and varies between -1 and +1. A correlation coefficient near +1 indicates a strong positive relationship between the two variables, with both increasing together. A correlation coefficient near -1 indicates a strong negative relationship, with one variable decreasing as the other increases. A correlation coefficient near zero indicates no relationship between the two variables. A true association was assumed to exist if the p-value was less than 0.05.

Graphs illustrating the strongest relationships between waste rock variables are presented in Figures 8, 9 and 10. The production of hydrogen ions as shown previously in reactions one through three is greater for those samples that have undergone a higher degree of chemical weathering. Production of hydrogen ions causes a decrease in sample pH. In addition to hydrogen ions, weathering reaction products include Fe and SO_4 , as shown in reactions one through three. Since H^+ , Fe and SO_4 are all weathering reaction products, samples with a low pH (<4.0) also contain higher concentrations of water extractable Fe and SO_4 (Figure 8.) Increased acidity can also cause the solubilization of minerals found within a waste rock repository that may contain metals such as Al. These minerals become soluble at low pH levels, causing an increase in water extractable Al for those samples with a pH below 4.0 (Figure 8.) Since electrical conductivity (EC) is a measure of the amount of soluble salt in a sample, those samples with high EC measurements also have higher water extractable SO_4 values (Figure 8.)

Table 2. Correlation coefficients and associated p-values between various chemical characteristics in a waste rock repository.

Chemical Variable	pH	Electrical Conductivity (mmhos/cm)	Titrateable Acidity (mg CaCO ₃ /L)	Fe (mg/L)	Al (mg/L)	Mn (mg/L)	SO ₄ (mg/L)	Total Sulfur (%)	H ₂ O Sulfur (%)	HCL Sulfur (%)	HNO ₃ Sulfur (%)
pH	-----	-0.6702 <0.05	-0.8110 <0.05	-0.8342 <0.05	-0.8125 <0.05	-0.1376 0.1323	-0.7296 <0.05	-0.1486 0.1037	-0.1783 0.0504	-0.0064 0.9443	-0.1043 0.2543
Electical Conductivity	-0.6702 <0.05	-----	0.6720 <0.05	0.7314 <0.05	0.6257 <0.05	0.4977 <0.05	0.8437 <0.05	0.2670 <0.05	0.1647 0.0710	0.0194 0.8324	0.2349 <0.05
Titrateable Acidity	-0.8110 <0.05	0.6720 <0.05	-----	0.7919 <0.05	0.9212 <0.05	-0.0069 0.9434	0.8299 <0.05	0.2679 <0.05	0.0770 0.4298	0.1216 0.2119	0.2353 <0.05
Fe (mg/L)	-0.8342 <0.05	0.7314 <0.05	0.7919 <0.05	-----	0.7066 <0.05	0.3430 <0.05	0.7913 <0.05	0.3569 <0.05	0.2032 <0.05	0.0303 0.7408	0.3136 <0.05
Al (mg/L)	-0.8125 <0.05	0.6257 <0.05	0.9212 <0.05	0.7066 <0.05	-----	0.1865 <0.05	0.7814 <0.05	0.1185 0.1951	0.1106 0.2267	0.0583 0.5249	0.0854 0.3513
Mn (mg/L)	-0.1376 0.1323	0.4977 <0.05	-0.0069 0.9434	0.3430 <0.05	0.1865 <0.05	-----	0.5253 <0.05	0.1653 0.0700	0.1603 0.0790	-0.0266 0.7717	0.1628 0.0745
SO ₄ (mg/L)	-0.7296 <0.05	0.8437 <0.05	0.8299 <0.05	0.7913 <0.05	0.7814 <0.05	0.5253 <0.05	-----	0.2693 <0.05	0.2063 <0.05	0.0338 0.7123	0.2355 0.0094
Total Sulfur (%)	-0.1486 0.1037	0.2670 <0.05	0.2679 <0.05	0.3569 <0.05	0.1185 0.1951	0.1653 0.0700	0.2693 <0.05	-----	0.1131 0.2165	0.0892 0.3303	0.9797 <0.05
H ₂ O Sulfur (%)	-0.1783 0.0504	0.1647 0.0710	0.0770 0.4298	0.2032 <0.05	0.1106 0.2267	0.1603 0.0790	0.2063 <0.05	0.1131 0.2165	-----	-0.5509 <0.05	0.0360 0.6949
HCL Sulfur (%)	-0.0064 0.9443	0.0194 0.8324	0.1216 0.2119	0.0303 0.7408	0.0583 0.5249	-0.0266 0.7717	0.0338 0.7123	0.0892 0.3303	-0.5509 <0.05	-----	0.0359 0.6951
HNO ₃ Sulfur (%)	-0.1043 0.2543	0.2349 <0.05	0.2353 <0.05	0.3136 <0.05	0.0854 0.3513	0.1628 0.0745	0.2355 0.0094	0.9797 <0.05	0.0360 0.6949	0.0359 0.6951	-----
Residual Sulfur (%)	-0.0284 0.7568	0.1332 0.1451	0.1007 0.3013	0.2036 <0.05	0.0256 0.7800	0.0242 0.7921	0.1111 0.2247	0.7712 <0.05	-0.1144 0.2113	0.1365 0.1354	0.7562 <0.05

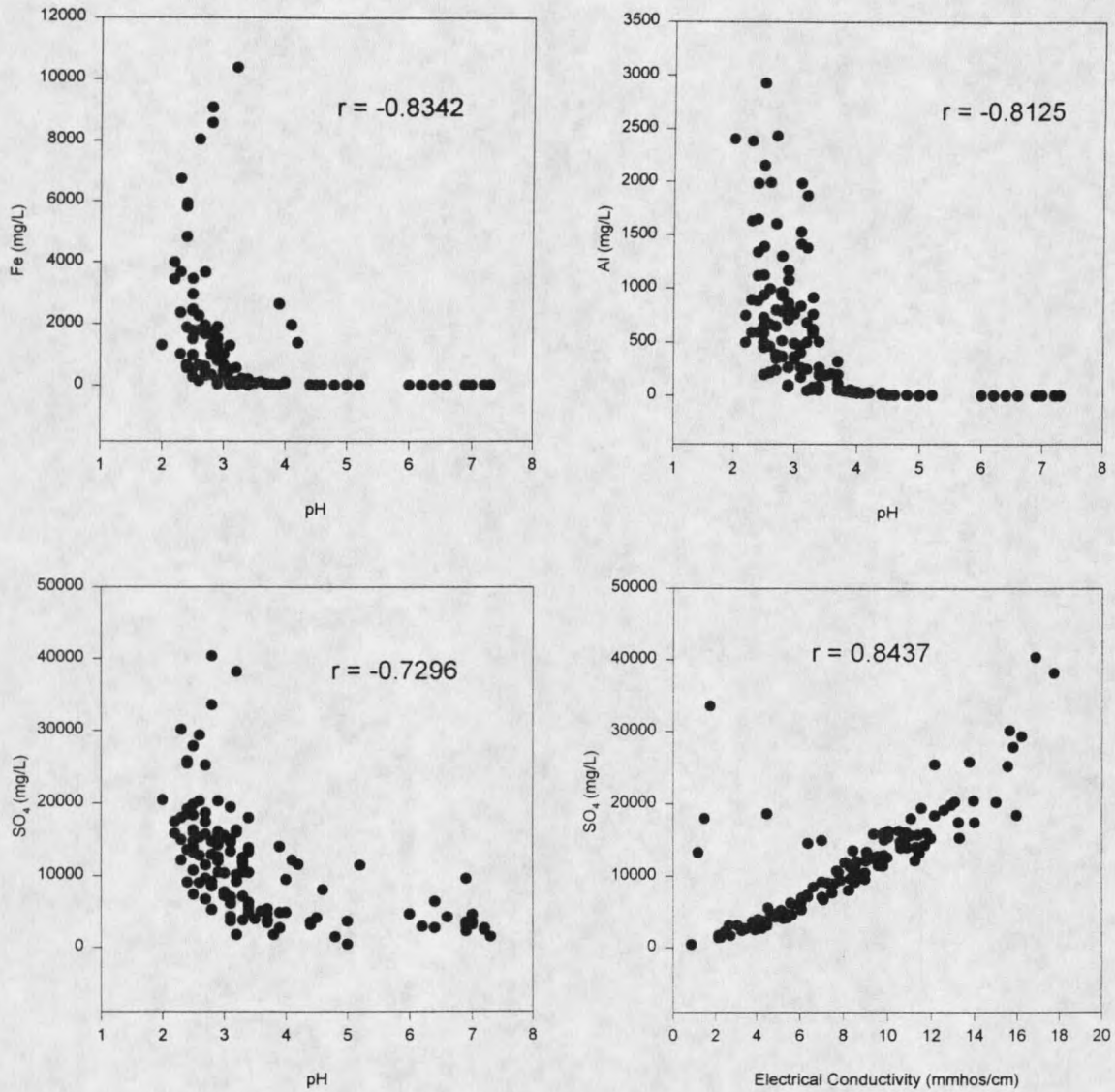


Figure 8. Relationships between waste rock repository pH, electrical conductivity and water extractable Fe, Al and SO₄.

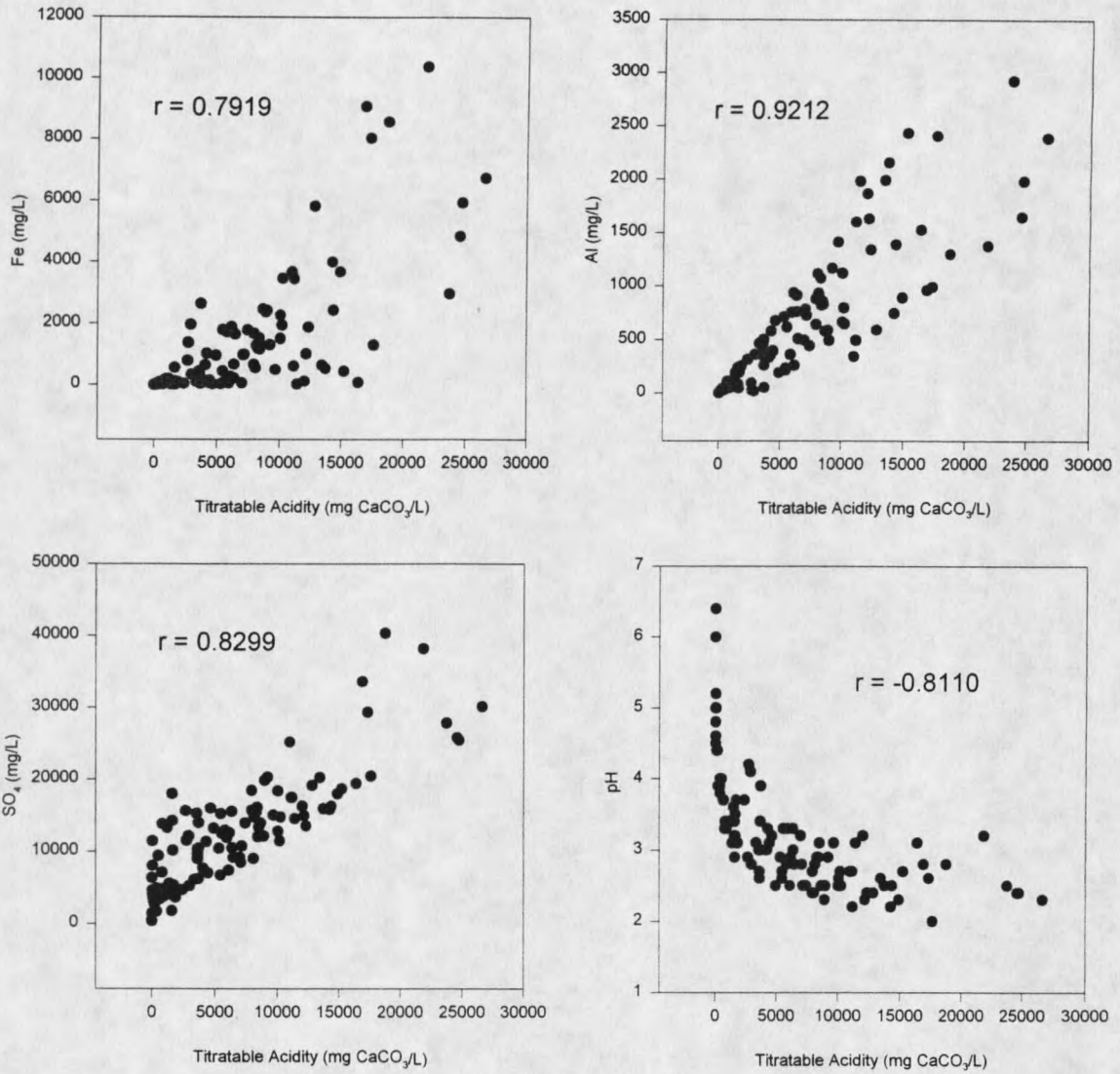


Figure 9. Relationships between waste rock repository titratable acidity and water extractable Fe, Al, SO₄ and pH.

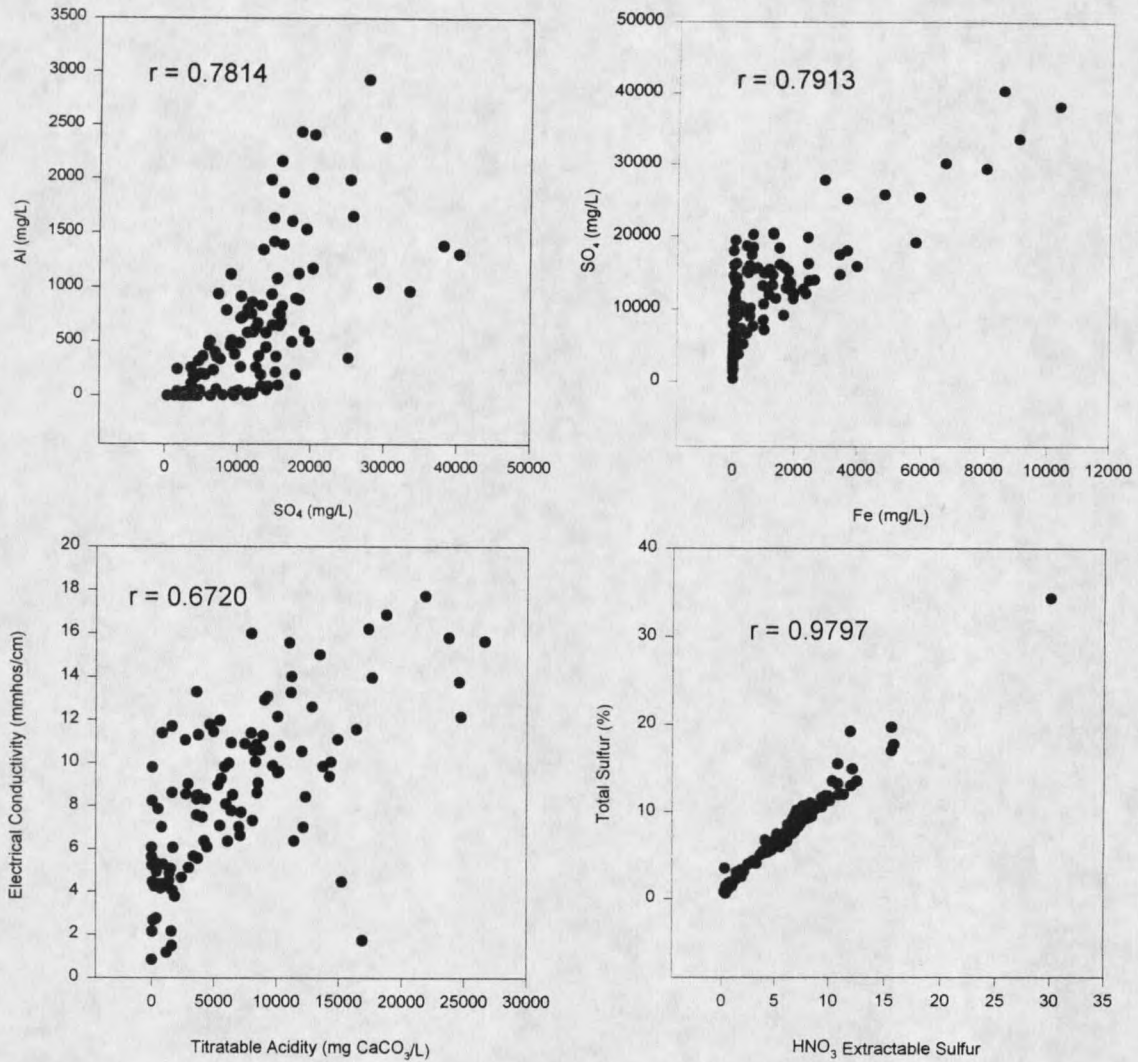


Figure 10. Relationships between HNO_3 extractable and total sulfur, electrical conductivity and titratable acidity, and water extractable SO_4 and Al and Fe.

Low pH values are correlated with high titratable acidity values as shown in Figure 9 due to increased acidity requiring the addition of more base to raise the sample pH to 7.0. This relationship appears to be exponential. For the same reasons as discussed for pH above, water extractable Fe, Al and SO₄ increase with titratable acidity (Figure 9.)

Because samples that contain high acidity have been shown to possess high concentrations of water extractable Fe, Al and SO₄, water extractable SO₄ is correlated with water extractable Fe ($r = 0.7913$) and Al ($r = 0.7814$) as shown in Figure 10. Due to SO₄ concentration being strongly correlated with titratable acidity ($r = 0.8299$), titratable acidity is also correlated with EC ($r = 0.6720$) as shown in Figure 10. The fourth graph contained in Figure 10 shows the strongly positive relationship between total sulfur and HNO₃ extractable sulfur. Total sulfur is more strongly related to HNO₃ extractable sulfur than any of the other extractable sulfur data ($r = 0.9797$). This graph illustrates that as total sulfur increases, so does HNO₃ extractable sulfur in a co-linear relationship. Since HNO₃ extractable sulfur is an indicator of sulfide-sulfur in a sample and sulfide-sulfur generally yields the most acid production, total sulfur contents can be used as a good predictor of the amount of acid a sample will produce.

Chemical Variability as a Function of Repository Age

In order to investigate how waste rock material undergoes weathering over time, one-way ANOVA analysis of waste rock chemical data was conducted based on sample

age. Table 3 summarizes the type of ANOVA used to analyze these data based on sample age.

Table 3. Type of ANOVA performed for analysis based on sample age.

Chemical Variable	One-way ANOVA	One-way ANOVA on transformed data ¹	One-way ANOVA on ranks
pH			X
Titrateable Acidity		X (square root)	
EC	X		
SO ₄		X (square root)	
Fe			X
Al		X (square root)	
Mn			X
Total Sulfur			X
H ₂ O Extractable S			X
HCL Extractable S			X
HNO ₃ Extractable S			X
Residual Sulfur			X

¹ Transformations applied.

Table 4 contains the one-way ANOVA results for chemical data based on sample age. Samples were grouped in three age classes for this analysis. The first group contains the oldest samples, placed on the pile prior to or during 1988. The second grouping contains data from samples placed on the pile during the years 1989 and 1990. The third grouping contains data from the youngest samples, placed on the pile during 1992, 1993 or 1994.

Table 4. One-way ANOVA results based on sample age.

Depository Placement	N	Mean pH	Mean Titratable Acidity (mg CaCO ₃ /L)	Mean EC (mmhos/cm)	Mean SO ₄ (mg/L)	Mean Fe (mg/L)	Mean Al (mg/L)	Mean Mn (mg/L)
≤ 1988	39	3.05 ± 0.89a ¹	9912 ± 6876 a	9.92 ± 4.44 a	15648 ± 9646 a	2197 ± 2839 a	901 ± 703 a	37 ± 40 a
1989 - 1990	52	3.45 ± 1.33 a	6054 ± 5561 b	7.40 ± 3.42 b	9915 ± 6350 b	821 ± 1269 a b	524 ± 585 b	28 ± 37 a
1992 - 1994	28	4.65 ± 1.68 b	3047 ± 3623 c	7.04 ± 3.14 b	8954 ± 4862 b	414 ± 759 b	216 ± 484 c	47 ± 52 a

Depository Placement	N	Mean Total Sulfur (%)	Mean H ₂ O Extractable Sulfur (%)	Mean HCl Extractable Sulfur (%)	Mean HNO ₃ Extractable Sulfur (%)	Mean Residual Sulfur (%)
≤ 1988	39	8.81 ± 5.79 a	0.68 ± 0.59 a	0.32 ± 0.54 a	7.22 ± 5.18 a	0.60 ± 0.68 a
1989 - 1990	52	7.47 ± 3.93 a	0.76 ± 0.68 a	0.53 ± 0.94 a	5.73 ± 3.20 a	0.45 ± 0.26 a
1992 - 1994	28	8.84 ± 2.99 a	0.46 ± 0.51 a	0.53 ± 0.50 a	7.30 ± 2.72 a	0.56 ± 0.26 a

¹ Means in the same column followed by the same letter are not significantly different (p ≤ 0.05)

Because acidity, Fe and SO_4 are waste rock weathering products, waste rock that is highly weathered will contain greater concentrations of these products. Each is significantly greater for samples taken from waste rock that has resided in the repository for longer periods of time and thus has been exposed to environmental conditions for longer periods of time. Due to increased acidity in the older aged samples, the solubilization of Al bearing minerals is increased. This results in higher water extractable Al concentrations in older portions of the repository. Mean water soluble Mn concentrations were not shown to vary significantly with respect to sample age. As previously mentioned, low Mn concentrations may point to random variability as a reason for uniform Mn distribution and the non-dependence on acidity. Mean total sulfur, residual sulfur and the extractable sulfur data do not vary significantly with respect to sample age. This suggests that sulfur content of waste rock material does not vary significantly from year to year due to uniformity of sulfur in the waste rock.

Chemical Variability as a Function of Position within Repository

In order to investigate the influence of geographical position within the waste rock pile on the extent of weathering, a one-way analysis of variance (ANOVA) analysis of waste rock chemical data was conducted based on sample elevation. Table 5 summarizes the type of ANOVA used to analyze these data based on sample depth.

Table 5. Type of ANOVA performed for analysis based on sample position.

Chemical Variable	One-way ANOVA	One-way ANOVA on transformed data ¹	One-way ANOVA on ranks
pH			X
Titrateable Acidity		X (square root)	
EC	X		
SO ₄		X (square root)	
Fe			X
Al			X
Mn			X
Total Sulfur			X
H ₂ O Extractable S		X (square root)	
HCL Extractable S			X
HNO ₃ Extractable S			X
Residual Sulfur			X

¹ Transformations applied.

Table 6 contains the one-way ANOVA results for chemical data based on sample elevations. Depth class 1 refers to the uppermost portions of the dump, greater than 1661m (5450 ft) in elevation. Depth classes 2 and 3 contain those samples located on the 1634 m (5360 ft) and 1615 m (5300 ft) bench elevations, respectively. Depth class 4 contains those samples located nearest the bottom of the dump facility, at elevation 1603 m (5260 ft) and below.

From this analysis, it can easily be seen that the samples taken from the upper portions of the repository have significantly higher concentrations of waste rock

Table 6. One-way ANOVA results based on sample elevation.

Depth Class ¹	N	Mean pH	Mean Titratable Acidity (mg CaCO ₃ /L)	Mean EC (mmhos/cm)	Mean SO ₄ (mg/L)	Mean Fe (mg/L)	Mean Al (mg/L)	Mean Mn (mg/L)
1	14	2.75 ± 1.03a ²	12360 ± 4752 a	11.07 ± 3.78 a	16091 ± 5621 a	1602 ± 1425 a	1242 ± 851 a	24 ± 21 a b
2	35	3.23 ± 1.35 a	9870 ± 7446 a	8.98 ± 3.95 a b	13973 ± 9301 a	2048 ± 2875 a	810 ± 688 a	38 ± 48 a b
3	52	3.68 ± 1.12 b	4138 ± 4004 b	7.83 ± 3.59 b	10478 ± 6843 b	822 ± 1431 a b	331 ± 354 b	44 ± 47 b
4	20	4.62 ± 1.83 b	3767 ± 4048 b	5.13 ± 2.40 c	6413 ± 4954 c	159 ± 297 b	314 ± 563 b	16 ± 13 a

Depth Class	N	Mean Total Sulfur (%)	Mean H ₂ O Extractable Sulfur (%)	Mean HCl Extractable Sulfur (%)	Mean HNO ₃ Extractable Sulfur (%)	Mean Residual Sulfur (%)
1	14	9.26 ± 8.41 a	0.34 ± 0.39 a	0.87 ± 0.81 a	7.33 ± 7.47 a	0.73 ± 1.09 a
2	35	8.78 ± 4.32 a	0.80 ± 0.53 b	0.38 ± 1.00 b	7.08 ± 3.65 a	0.52 ± 0.28 a
3	52	8.06 ± 2.75 a	0.83 ± 0.70 b	0.32 ± 0.40 b	6.44 ± 2.33 a	0.47 ± 0.20 a
4	20	6.94 ± 4.30 a	0.16 ± 0.25 a	0.71 ± 0.70 a	5.56 ± 4.08 a	0.52 ± 0.35 a

¹ Depth Class 1 = uppermost depths, 4 = lowest depth.

² Means in the same column followed by the same letter are not significantly different ($p \leq 0.05$)

weathering products. This may be because the upper portions of the dump are more likely to come into contact with air and precipitation, both of which are needed to drive the waste rock weathering reactions. For example, mean sample pH values are significantly lower and mean titratable acidity values are significantly higher in the upper portions of the dump. Since more oxidation is occurring in the upper portions of the repository, water extractable Fe and SO_4 , both weathering reaction products, are significantly higher in these regions. Because increased acidity is generated in these areas that are more exposed to air and precipitation, conditions are more favorable for the dissolution of Al bearing minerals resulting in significantly higher concentrations of water extractable Al. EC is also higher in the upper portions of the repository because SO_4 is a weathering reaction product and EC and SO_4 are strongly correlated as shown previously. Mean soluble Mn concentrations were not found to follow the same trend as the other soluble metals. Since Mn concentrations were at lower levels than the other metals, its infrequent occurrence at detectable levels in the repository may point to random variability in the overburden materials as a reason for its non-dependence on acidity. For instance, certain portions of the waste rock repository may contain more or less Mn primarily due to overburden variability. Mean total sulfur, residual sulfur and HNO_3 extractable sulfur values did not vary significantly throughout the waste rock pile. This supports the fact that the waste rock pile is homogeneous with respect to sulfur content. Mean H_2O and HCl extractable sulfur values were found to vary within the waste rock repository with respect to position,

but this variation can be attributed to random variability in sulfide mineral solubility and composition.

Chemical Variability as a Function of Sample Particle Size

In an attempt to associate waste rock particle size with waste rock chemical data, one-way ANOVA analysis of waste rock chemical data was performed based on percent passing a 2mm sieve by weight. Table 7 summarizes the type of ANOVA used to analyze this data based on sample particle size.

Table 7. Type of ANOVA performed for analysis based on sample particle size.

Chemical Variable	One-way ANOVA	One-way ANOVA on transformed data ¹	One-way ANOVA on ranks
pH			X
Titrateable Acidity		X (square root)	
EC	X		
SO ₄		X (square root)	
Fe			X
Al		X (square root)	
Mn		X (natural log)	

¹ Transformation applied

Table 8 contains the one-way ANOVA results for chemical data based on percent passing a 2mm sieve by weight. Particle size data were obtained from Greg Herasymuik at the University of Saskatchewan. Waste rock samples were divided into groups based on percent passing a 2 mm sieve. No samples were determined to have greater than 40

Table 8. One-way ANOVA results based on sample percent passing a 2mm sieve.

% Passing 2mm Sieve	N	Mean pH	Mean Titratable Acidity (mg CaCO ₃ /L)	Mean EC (mmhos/cm)	Mean SO ₄ (mg/L)	Mean Fe (mg/L)	Mean Al (mg/L)	Mean Mn (mg/L)
≤ 10	31	4.02 ± 1.65a ¹	5347 ± 5860 a	7.34 ± 3.99 a	8870 ± 6996 a	705 ± 1329 a	428 ± 571 a	24 ± 23 a
11 - 20	30	3.22 ± 1.20 a	9211 ± 7342 a	9.52 ± 3.66 a	14670 ± 7948 b c	1674 ± 2067 a	785 ± 759 a	36 ± 37 a
21 - 30	20	3.30 ± 1.16 a	8657 ± 6284 a	9.46 ± 4.35 a	14640 ± 8845 b c	1836 ± 2805 a	781 ± 706 a	53 ± 63 a
31 - 40	12	3.44 ± 1.26 a	5585 ± 5496 a	6.80 ± 3.55 a	12083 ± 7909 a c	1109 ± 2597 a	501 ± 605 a	57 ± 64 a

¹ Means in the same column followed by the same letter are not significantly different ($p \leq 0.05$)

percent passing a 2 mm sieve. Data presented in Table 8 shows no significant differences in waste rock chemical variables based on sample particle size. These data do not show a trend as anticipated. Observations were made while sampling this waste rock repository of some large waste rock particles that would crumble easily when agitated with hand pressure. This indicates that increased physical breakdown of waste rock particles could be associated with a high degree of chemical weathering. This would result in samples with finer particle sizes containing more waste rock weathering products. Data presented in Table 8 do not support this association, but do indicate that sample particle size is independent of sample chemistry. For example, a sample with < 10% of its mass passing a 2 mm sieve might contain more acidity (indicating a higher degree of weathering) than a sample with 31 - 40% of its mass passing a 2 mm sieve. One possible explanation of these data is that sample chemistry depends more on mineralogy than the degree of physical weathering. For example, a sample might be broken down into fine particles which would indicate a high degree of weathering, yet this sample would contain less waste rock weathering products than a sample made up of larger particle sizes because the larger particle-sized sample contained minerals that were more likely to produce acidity, Fe and SO₄.

Scanning Electron Microscopy Analysis

While sampling in the waste rock pile, occasionally salt formations and other secondary mineral formation were noticed. These often occurred in areas of the dump where steam venting was evident. Salts were often crystalline in structure and were collected for scanning electron microscopy analysis. This analysis was performed to determine the chemical makeup of these substances. A summary of this analysis can be found in Table 9.

Table 9. Summary of SEM Analysis.

Sample Location	Sample Appearance	Possible Chemical Makeup
Test Pit 3 GS4	turquoise blue, crystalline	copper sulfate
Test Pit 6 GS1	white salt precipitates	magnesium, zinc sulfates
Test Pit 15, near moist venting	crystalline	magnesium sulfate
Test Pit 15 GS2, near vent	clay-like deposits	aluminum compound
Test Pit 20 GS1	black hard deposits	copper sulfate
Test Pit 21 GS1	yellow salt deposits	magnesium sulfate

SUMMARY AND CONCLUSIONS

This study was conducted to document and understand chemical weathering within a large pyritic waste rock repository. Thirty test pits were excavated and 121 waste rock samples were collected for geochemical and physical analysis, including particle size, pH, titratable acidity, electrical conductivity, soluble iron, aluminum, manganese and sulfate, sulfur fractionation and neutralization potential. Data from waste rock samples were compiled and analyzed to determine the extent of weathering in the waste rock repository, characterize the geochemical variations in the waste rock repository and correlate the extent of weathering with physical waste rock characteristics.

Field sampling activities showed a highly variable waste rock pile made up of distinct layers of material. Chemical characteristics of waste rock varied greatly within layers throughout the repository. Mean pH was 3.6 with a mean titratable acidity of 6806 mg CaCO₃/L. Mean electrical conductivity was 8.09 mmhos/cm and mean soluble SO₄ was 11466 mg/L. Mean soluble Fe was 1157 mg/L, soluble Al was 572 mg/L and soluble Mn was 35 mg/L. Mean total sulfur content was 8.22 % with most (6.58 %) existing as HNO₃ extractable sulfur. This suggests that a majority of the sulfur in this repository exists as sulfide sulfur, most likely in the form of pyrite (FeS₂).

In an effort to investigate the associations that exist between waste rock chemical variables, a correlation analysis was performed on waste rock chemical data. Low sample pH and high sample titratable acidity were shown to be correlated with high levels of soluble SO₄, Fe and Al. Additionally, soluble SO₄ was shown to be correlated with both

soluble Fe ($r = 0.7913$) and Al ($r = 0.7814$). Finally, increased sample titratable acidity was shown to be correlated with an increased sample electrical conductivity ($r = 0.6720$). These correlations exist because acidity, SO_4 and Fe are all waste rock weathering products and increase together. In the case of Al, it is released when conditions are acidic enough to cause the solubilization of minerals containing Al.

The weathering of pyritic waste rock occurs when it comes into contact with air and water. This study revealed that regions of the waste rock dump where this interface occurred was more highly weathered. For instance, samples of waste rock taken from the upper portions of the dump contained greater levels of acidity, electrical conductivity, and water soluble SO_4 , aluminum and iron. These data support the interpretation that this waste rock pile was undergoing chemical weathering where it was exposed to atmospheric conditions, but that weathering may be significantly decreased at locations where the influx of air and water into the dump were impeded.

Though weathering may be significantly decreased deep within the dump, data support that weathering may still be occurring at all locations within this waste rock pile. The oldest aged samples (placed on the repository in 1988 or earlier) found deep in the interior of the waste rock dump showed the highest degree of weathering. This was supported by data that show the oldest aged samples contain greater levels of acidity, electrical conductivity and water soluble SO_4 , iron and aluminum. Possibly, waste rock was exposed to conditions favorable to weathering when it was first placed on the

repository, then overlain by subsequent additions to the pile. Even though the oldest samples were farther away from the interface of oxygen and water, some degree of weathering must still be occurring in order for these samples to show a significantly higher degree of weathering than the younger aged samples (placed in 1992 or later).

Some confusion may result by the fact that samples taken from the upper portions of the repository and the oldest aged samples (which inherently reside deeper within the repository) both contained greater levels of waste rock weathering products. This apparent contradiction can be explained by examining the way in which the waste rock repository was constructed. Since new material is placed on the repository by end-dumping from the edge, the oldest aged samples reside not only at the deepest vertical positions but also deeper toward the interior of the repository from the edge. Thus, these two conclusions are not inconsistent. Samples taken from the upper portions of the repository, where the interface with the environment is greater, are shown to contain more weathering products as compared with those samples taken from the lower portions of the repository. Additionally, that material which has resided in the repository for longer periods of time contains more weathering products than the younger aged material, irrespective of its vertical position in the repository.

Sample chemistry was not shown to vary significantly with sample particle size. It was thought that a highly weathered sample would contain smaller particle sizes and higher concentrations of weathering products. This was shown to be false, possibly due

to sample mineralogy having more influence on chemistry than the amount of physical breakdown the waste rock has undergone.

Scanning electron microscopy analysis was used to estimate the chemical makeup of secondary minerals found within the waste rock repository. Since secondary mineral formation was noticed in areas where water vapor movement was evident, the chemical composition of these minerals may give an indication of the types of substances contained in and transported by these moisture migration pathways. Secondary minerals identified include copper, magnesium and zinc sulfates.

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APPENDIX A
Waste Rock Chemical Data

Table 10. Waste rock chemical data.

Sample ID	NP t/1000t	Total Sulfur %	Hot H2O S %	HCL S %	HNO3 S %	Residual S %	EC mhos/c	SO4 mg/L	Acidity mg CaCO3/	Al mg/L	Fe mg/L	Mn mg/L	pH
TP1GS1	35.0	6.050	1.420	<0.01	4.340	0.290	5.63	4620.0	15.0	<1	6.0	25.0	6.0
TP2GS1	6.0	5.620	0.640	<0.01	4.720	0.260	6.07	5319.0	1717.0	197.0	17.0	23.0	3.7
TP3GS1	<1	2.580	0.300	<0.01	1.940	0.340	2.15	1764.0	1584.0	244.0	10.0	1.0	3.2
TP3GS2	1.0	5.380	0.760	<0.01	4.390	0.230	7.08	6702.0	5452.0	237.0	452.0	9.0	2.7
TP3GS3	<1	5.290	1.000	<0.01	3.990	0.300	11.70	14256.0	1624.0	83.0	123.0	158.0	2.9
TP3GS4	<1	6.560	1.220	0.040	4.900	0.400	11.55	19416.0	16395.0	1528.0	70.0	14.0	3.1
TP4GS1	<1	19.200	0.900	5.300	11.900	1.090	15.64	30135.0	26615.0	2385.0	6733.0	5.0	2.3
TP4GS2	<1	4.120	0.270	<0.01	3.330	0.520	5.12	5241.0	2981.0	363.0	342.0	8.0	2.8
TP4GS3	<1	2.880	0.570	<0.01	2.010	0.300	3.78	3645.0	1867.0	259.0	102.0	7.0	3.1
TP4GS4	<1	8.820	1.570	<0.01	6.750	0.500	6.37	7164.0	4218.0	359.0	1031.0	16.0	3.0
TP4GS5	<1	7.250	1.200	<0.01	5.720	0.330	11.46	13209.0	4924.0	194.0	965.0	61.0	2.5
TP5GS1	<1	10.400	1.670	0.370	7.800	0.560	1.74	33564.0	16900.0	962.0	9069.0	142.0	2.8
TP5GS2	<1	9.740	1.430	<0.01	8.010	0.300	16.20	29346.0	17331.0	991.0	8030.0	181.0	2.6
TP5GS3	<1	9.460	0.580	<0.01	8.240	0.640	12.58	19161.0	12828.0	592.0	5815.0	103.0	2.4
TP5GS4	<1	10.600	0.300	0.410	9.400	0.490	10.76	14766.0	10256.0	650.0	3453.0	80.0	2.5
TP5GS5	<1	11.000	2.180	<0.01	8.340	0.480	11.39	15711.0	7967.0	646.0	1678.0	77.0	2.7
TP5GS6	<1	9.560	0.670	<0.01	8.330	0.560	17.73	38163.0	21842.0	1376.0	10363.0	102.0	3.2
TP6GS1	<1	12.000	<0.01	<0.01	11.300	0.690	12.15	18375.0	10069.0	1120.0	1511.0	36.0	2.5
TP6GS2	<1	6.740	0.910	<0.01	5.410	0.420	11.97	15237.0	5465.0	216.0	1799.0	25.0	2.6
TP6GS3	<1	11.300	0.600	<0.01	10.100	0.620	10.58	14712.0	8162.0	932.0	1294.0	35.0	2.8
TP6GS4	<1	9.380	0.520	<0.01	8.250	0.610	9.86	15021.0	9688.0	1412.0	502.0	63.0	3.1
TP6GS5	<1	4.220	0.910	<0.01	2.950	0.360	6.63	8493.0	7091.0	786.0	992.0	9.0	2.8
TP7GS1	<1	17.000	0.500	<0.01	15.600	0.930	13.76	25782.0	24588.0	1647.0	4828.0	2.0	2.4
TP7GS2	<1	6.780	0.740	0.600	5.090	0.350	6.36	7368.0	6103.0	936.0	268.0	2.0	2.5
TP7GS3	<1	2.510	0.720	0.060	1.550	0.180	9.83	15939.0	13737.0	2155.0	537.0	6.0	2.5
TP7GS4	<1	9.000	1.550	<0.01	6.860	0.590	8.43	13545.0	12329.0	1339.0	1878.0	<1	2.4
TP7GS5	<1	3.150	0.740	<0.01	2.160	0.250	7.32	9045.0	8080.0	1114.0	561.0	1.0	2.4
TP7GS6	<1	19.700	<0.01	2.500	15.600	1.600	12.15	25425.0	24743.0	1983.0	5928.0	2.0	2.4
TP7GS7	<1	10.600	1.300	<0.01	8.650	0.650	10.04	16257.0	14357.0	1387.0	2437.0	18.0	2.5

