

**KUTCHO CREEK PROJECT:  
BLENDING AND SEGREGATION  
ACID GENERATION TESTWORK  
FINAL REPORT**

**MEND Project 2.32.1**

This project was funded by the Resource Management Branch of the British Columbia Ministry of Energy, Mines and Petroleum Resources under the Canada/British Columbia Mineral Development Agreement; and by Homestake Mineral Development CO.

**March 1992**

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**RESCAN ENVIRONMENTAL SERVICES LTD.  
Vancouver, British Columbia**

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## **Executive Summary**

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## **EXECUTIVE SUMMARY**

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Exploration at Kutcho Creek, located 110 kilometres east of Dease Lake, B.C., has delineated a polymetallic, massive sulphide deposit with possible mining reserves of 13.9 million tonnes. In 1979, then owner, Esso Minerals Inc., submitted a proposal to government in order to develop the Kutcho site. Upon review of the proposal by the B.C. Mine Development Steering Committee, several issues were raised including the management of certain rock assemblages that were capable of generating acid. Preliminary acid generation studies indicated that footwall waste rock would generate acid and that the hanging wall material would consume acid.

The potential for acid generation at the Kutcho Creek project has become a key environmental issue with respect to obtaining the Stage II Approval-in-Principle. To alleviate these concerns, the present owners, Sumac Mines Ltd. and Homestake Mineral Development Co., embarked upon a jointly funded research program to investigate the potential for acid rock drainage (ARD) at Kutcho Creek and the viability of blending waste rock to mitigate ARD.

Preliminary ARD studies suggested that blending potentially acid generating waste rock with potentially acid consuming waste rock in a carefully designed waste rock dump would mitigate acid generation. This was viewed as a unique opportunity to study the effectiveness of waste rock blending to control ARD. Because of its unique character the waste rock blending research has attracted the interest of the Mineral Opportunity Program of the Canada-British Columbia Mineral Development Agreement. Rescan Environmental Services Ltd. was selected as the consultant to assist with the development of this research program and to carry out the testwork.

Research conducted to date includes static tests (acid base accounting) and kinetic experiments (laboratory humidity cells and on-site pilot scale weathering tests). The rationale and objectives for each test were as follows:

- Acid base accounting tests examined the chemical and physical composition of representative waste rock types to determine the balance between acid producing minerals (sulphides) and acid consuming minerals (carbonates) and the consequent potential to generate acid.



- Laboratory humidity cell tests examined the rates and factors controlling acid generation and acid consumption in a controlled weathering environment for the various types of rock and for blended samples of waste rock. Results were used to confirm the potential for acid generation identified by previous acid base accounting tests, and to provide a comparison to the large scale tests being conducted on-site.
- Lastly, large scale weathering tests consisted of three blended waste rock pads (20 tonnes each) which were intended to simulate acid generation behaviour of blended waste rock piles under natural weathering conditions.

Acid base accounting test results confirmed that footwall rocks are potentially acid generating and that hanging wall rocks have the potential to neutralize acid.

Laboratory humidity cell tests composed of blended ratios of waste rock material demonstrated that the rate of acid generation was significantly reduced. For the blended test cells the rate of neutralization, at least over the short term, was sufficient to maintain a slightly alkaline pH in the leachate thereby greatly reducing metal leaching.

Results from the blended field test pads are not as conclusive. It was discovered that leachate quality was dependent upon flushing rates as opposed to the actual acid generation rate. During the second year of observation, leachate from two of the three pads was consistently neutral in pH. Conversely, the third pad produced an acidic pH. This has been attributed to a reduction in flushing of the waste rock due to the inclusion of a soil cap. As a consequence, acid products were allowed to accumulate, resulting in a lower pH. In other words, the low pH did not necessarily reflect increased acid generation rates.

Long term predictions for acid generation have been made and are based on the sulphate production rates from the humidity cell testwork which have been extrapolated employing mathematically derived "best-fit" curves. Predictions, based on these extrapolations, show that the neutralization potential could be consumed in as early as 100 weeks with acidic conditions continuing until all sulphides were oxidized. Ideally, in order to completely obviate acid generation in any sample, there should be sufficient neutralizing potential (NP) in the sample (assuming only half of it is available) that the NP and sulphide component are consumed concurrently. Therefore, based on our long

term extrapolations, blending of Kutcho waste rock, even at 1:1, would not be a viable ARD mitigation strategy.

The overall objective for this research program was to develop a management plan, utilizing information obtained during the study, to ensure acid generation would not cause environmental degradation. A separate analysis has determined that the costs associated with blending large amounts of waste material in a full scale waste dump would be excessive. An alternative ARD mitigation strategy, the disposal of reactive waste material in a flooded impoundment, is generally accepted as the most feasible method for long term disposal of reactive mine wastes for Kutcho Creek.

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## **1 - Introduction**

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## 1.0 INTRODUCTION

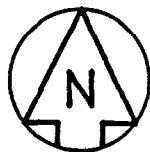
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### 1.1 Project History

During the early 1970s, exploration by Sumac Mines Ltd. and Esso Minerals Canada resulted in the discovery of the Kutcho Creek polymetallic massive sulphide deposit, located 110 km east of Dease Lake, B.C. (Figure 1-1). Subsequent exploration, particularly in the Kutcho lens delineated possible economic reserves of copper, zinc and silver mineralization. The initial mine plan, prepared in 1985, incorporated an open pit scheduled to mine 13.9 million tonnes of ore and 92.1 million tonnes of waste rock. It is anticipated that additional exploration and development will be completed prior to mine development. This supplemental exploration should provide a more accurate estimate of ore reserves.

The potential for acid rock drainage (ARD) at Kutcho Creek was identified during development of the mine plan as a key environmental issue. During 1983 and 1985, acid generation tests were carried out on samples of waste rock collected at the project site. The 1983 tests indicated that the footwall waste rock is potentially acid generating, while the hanging wall rock, low in sulphides, is capable of neutralizing acid. The 1985 testwork generally confirmed the results of the 1983 tests, and extended them via column leach tests performed to assess the possibility of blending potentially acid generating rock with potentially acid consuming rock in order to minimize ARD. The blended waste rock was inoculated with *Thiobacillus ferrooxidans* and distilled water was percolated through the culture. After the system equilibrated, there was no evidence of ARD.

In 1986, Sumac submitted a Stage II Environmental Impact Study Report to regulatory authorities. The British Columbia Mine Development Steering Committee (MDSC) reviewed the report and identified several key issues requiring further assessment, including the management of certain rock assemblages capable of generating acid. Results of the 1983 and 1985 testwork had indicated that the blending of acid generating rock with acid consuming rock on a stoichiometric basis would be an appropriate method to control ARD. However, the use of acid base accounting and column



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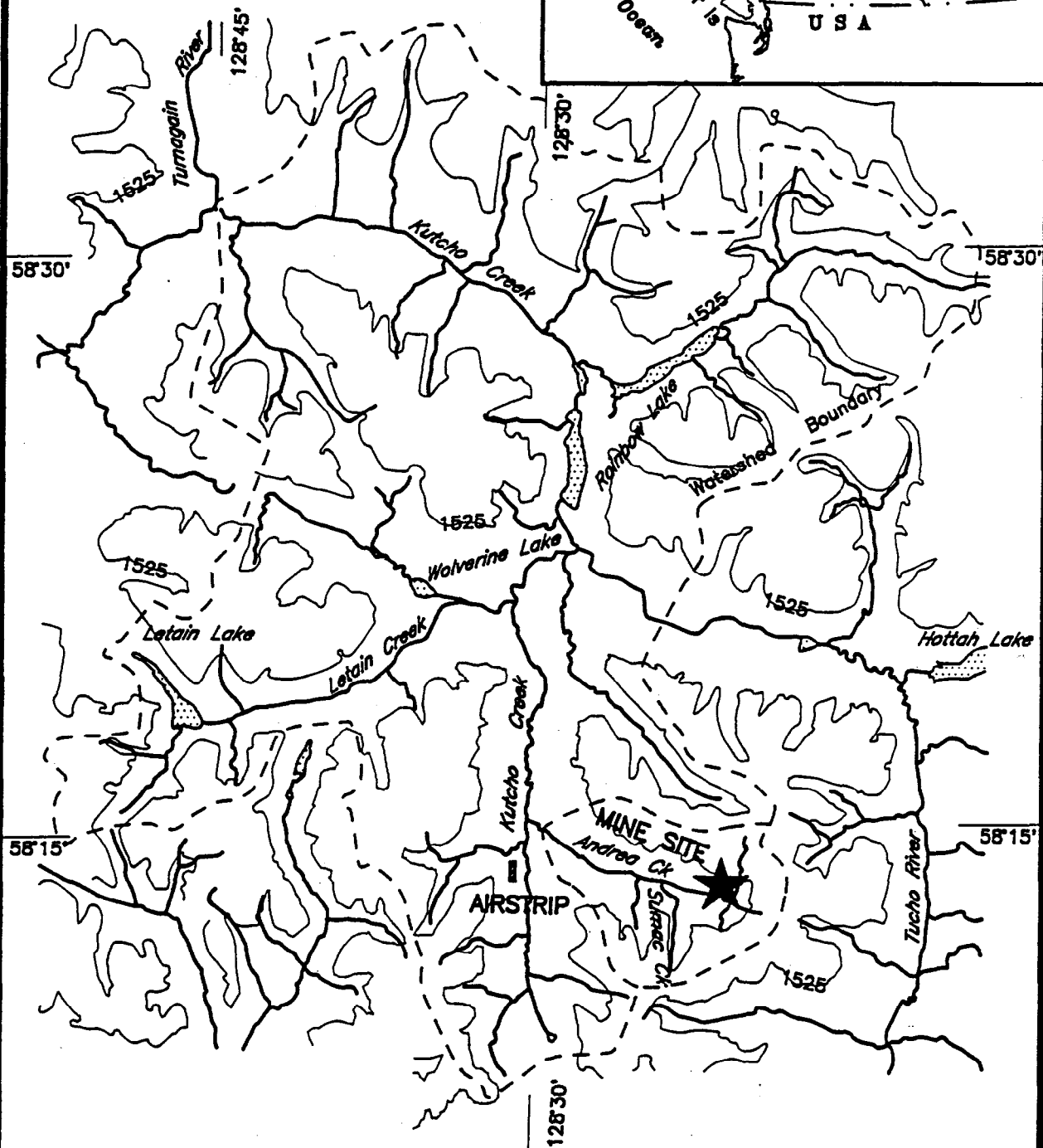
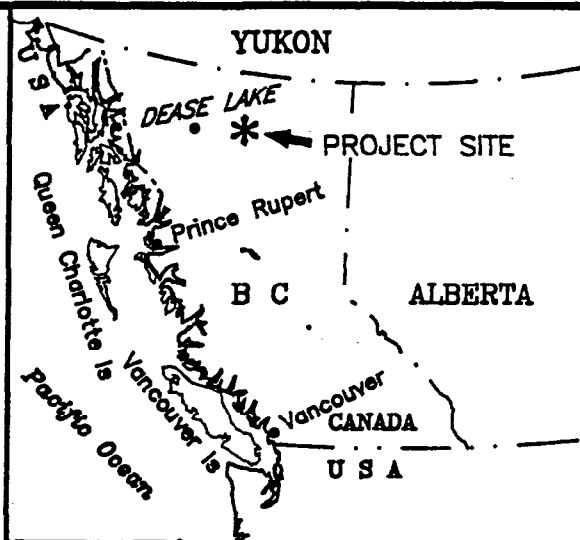


Figure 1-1 PROJECT LOCATION



experiments as a foundation for predicting ARD may be unreliable and misleading. Consequently, the joint venture partners initiated discussions with various consultants to design a research program to develop an effective ARD management strategy acceptable to the MDSC.

One of the objectives was to determine which waste rock assemblages associated with the Kutcho Creek project have the potential to generate acid, and which assemblages have the potential to consume acid. The program was also to determine, through the use of mineralogical analysis, the reactive minerals contributing to the possible generation of acid as well as the requirement of using segregation or blending as a method of controlling potential acid mine drainage.

Rescan Environmental Services Ltd. was selected as the consultant to assist with the development of a research program and to carry out the testwork. A number of experimental techniques were employed to study the potential for ARD and the effectiveness of blending waste rock to control ARD. These included:

- acid base accounting - a static test which employs a combination of laboratory procedures to determine the balance between acid producing materials (sulphides) and acid consuming materials (carbonates) in rock and consequently the potential to generate acid;
- humidity cells - a kinetic test which measures the rate of acid producing and consuming reactions in a laboratory environment; and
- field scale humidity cells - large scale humidity cells which measure the rate of acid producing and consuming reactions over an extended period of time under natural fluctuations of precipitation and temperature.

These tests have been completed and all research facilities at the Kutcho site have been decommissioned. Table 1-1 summarizes the Kutcho Creek acid generation research program.

**Table 1-1**  
**Acid Generation Research Program**

<b>Phase I</b>	<b>Sept 88 - Sept 89</b>	<p><b>Determine Acid Generation Characteristics</b></p> <p>Collect 22 rock samples representing the major rock types intersected in the Sumac adit. Perform tests including:</p> <ul style="list-style-type: none"> <li>• acid base accounting (ABA);</li> <li>• humidity cell testwork (20 weeks); and</li> <li>• petrographic analyses.</li> </ul>
<b>Phase II</b>	<b>Sept 89 - June 90</b>	<p><b>Segregation and Blending Testwork</b></p> <p>Select 50 samples from drill core for ABA analyses.</p> <p>Construct three 20 tonne field test plots to simulate the pre-production, 5-year and 5-year with soil cover blended waste dumps. Monitor for temperature, water quality and oxygen.</p> <p>Simulate field test plots with laboratory scale humidity cell tests (20 weeks).</p>
<b>Phase III</b>	<b>June 90 - October 91</b>	<p><b>Field Test Plot Monitoring</b></p> <p>Continue monitoring test piles for;</p> <ul style="list-style-type: none"> <li>• temperature;</li> <li>• oxygen; and</li> <li>• leachate quality including continuous pH monitoring, sulphate and heavy metals.</li> </ul>

This report was prepared to fulfill the following objectives:

- to outline the objectives and scope of the study;
- to discuss the results of each phase of the test program;
- to discuss the success of blending acid generating and acid consuming waste rock in order to reduce acid generation; and
- to outline design options for environmental management and protection plans to ensure that acid generation will not cause environmental degradation.

## **1.2 Acknowledgements**

Since the test program was viewed as a unique opportunity to study the effectiveness of waste rock blending to control ARD, it attracted the interest of the Mineral Opportunities Program of the Canada-British Columbia Mineral Development Agreement. Funding for the research program was provided by the Canada/British Columbia Mineral Development Agreement of B.C. Ministry of Energy, Mines and Petroleum Resources, the federal Department of Energy, Mines and Resources, Sumac Mines Ltd. and Homestake Mineral Development Company.

## **2 - Project Description**



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## **2.0 PROJECT DESCRIPTION**

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This chapter presents a summary description of the project setting, geology of the Kutcho Creek deposit and mining plan. Readers requiring more detail are referred to the Exploration Report for the Kutcho Creek Property (Holbeck and Heberlein, 1985) and the Environmental Assessment Stage II Report (Norecol, 1986).

### **2.1 Project Setting**

The Kutcho Creek site is located in a remote area of northern British Columbia, 110 kilometres east of Dease Lake. The property is accessible by fixed wing aircraft from Dease Lake to a 1,100 m long gravel strip which is connected to the project area by an eight kilometre unimproved dirt road.

Within the project area, three volcanogenic massive sulphide bodies have been delineated. The largest, the Kutcho Creek deposit, is the focus of this study. The Kutcho Creek deposit is a polymetallic, massive sulphide deposit that is held under separate but adjoining mineral claims by Sumac Mines Ltd. and Homestake Mine Development Co. Estimated reserves based on drill data are 13.9 million tonnes grading 1.75% copper, 2.47% zinc, 28.91 g/t silver and 0.34 g/t gold. A preliminary feasibility study conducted in 1985 by Wright Engineers Ltd. indicated that an open pit was the most feasible method of extracting the ore; however, underground methods are still being considered.

### **2.2 Property Geology**

The Kutcho Creek deposit is located within a volcanic island arc sequence composed of intercalated mafic and felsic volcanic and volcanoclastic rocks referred to as the Kutcho Creek formation. Rocks of the Kutcho Creek formation are limited to a narrow wedge of volcanic rock, truncated both to the north and south by north dipping thrust faults which crosscut the project area.

Three elongate, massive sulphide lenses have been delineated and appear to occur along a single time-stratigraphic horizon within the Kutcho Creek formation. The sulphide deposits are located in the thickest section of the formation which also appears to be

closest to the centre of volcanism. Each sulphide lense is a discrete, elliptical body consisting of layered massive sulphide and low sulphide intervals. The Kutcho lens, which is the focus of this study, is wedge-shaped in cross-section at its east end and dish-shaped in cross-section at its west end.

The ore sequence comprises three lithological units. There is a basinal lapilli tuff which hosts the massive sulphide horizons, a quartz feldspar crystal tuff which overlies, and may be transitional to, the lapilli tuff unit and a thick meta-gabbro unit, which overlies the quartz feldspar crystal tuff (Figure 2-1).

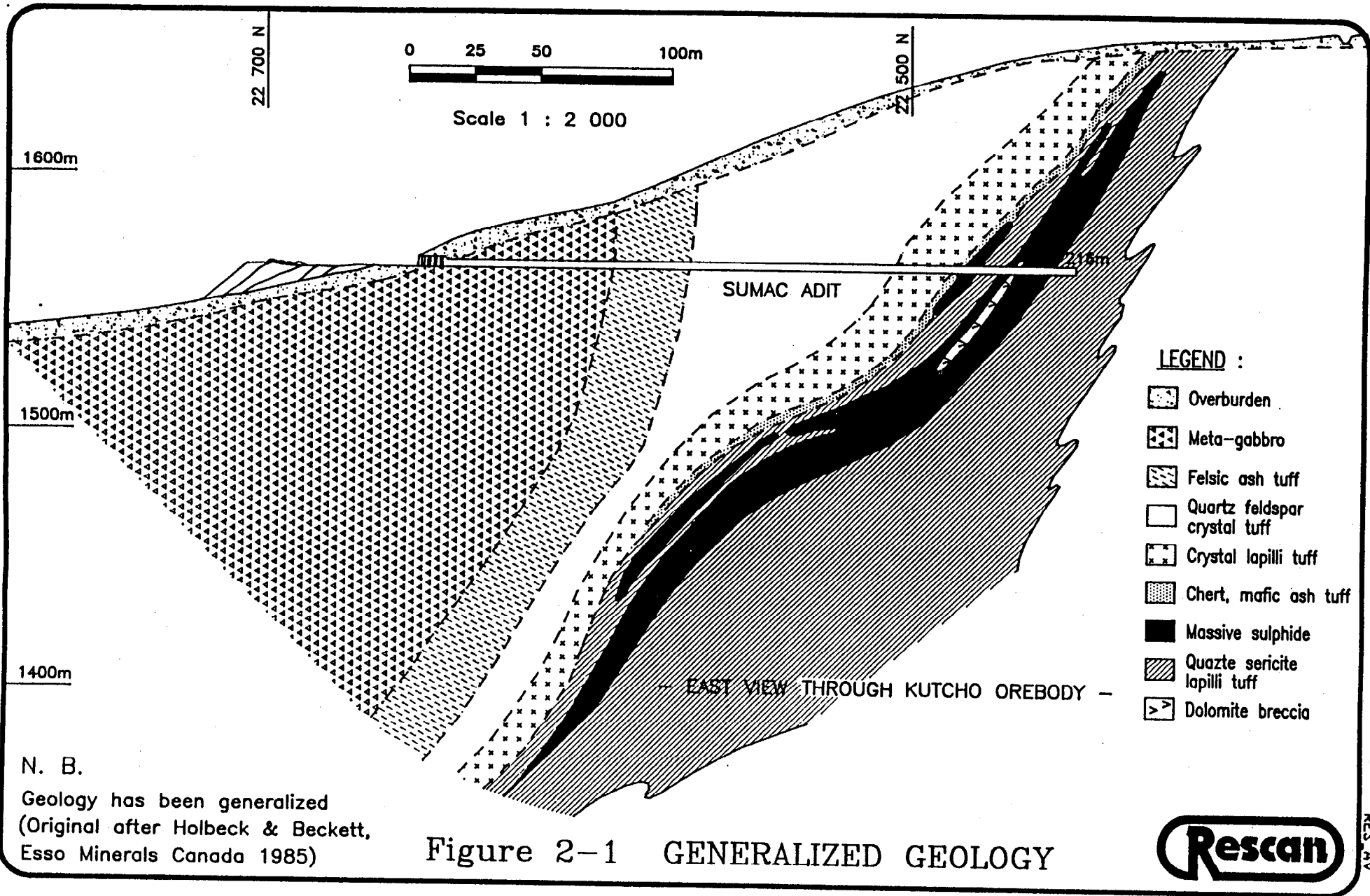
The lapilli tuff, composed of a quartz sericite lapilli tuff, and overlying crystal lapilli and mafic ash tuff, has within it zones which have been enriched either in carbonates, cherts or pyrite. Pyrite enrichment is pervasive primarily within the footwall, quartz-sericite lapilli tuffs, whereas carbonate or chert enrichment occurs mainly in the hanging wall crystal lapilli and mafic ash tuffs.

Mineralization consists primarily of chalcopyrite, sphalerite, bornite and pyrite with minor amounts of chalcocite, tetrahedrite, galena, digenite, electrum and silver tellurides. Metal zonation has not been well defined within the deposit but in general there is a copper rich sulphide layer which overlies a mainly pyritic sulphide layer.

### 2.3 Mining Plan

The Kutcho Creek project will involve the development of an open pit mine for the production of approximately 106 million tonnes of ore and waste rock over the proposed 10 year mine life. The mine will produce a total of 13.9 million tonnes of ore grading 1.75% copper, 2.47% zinc, 28.91 g/t silver and 0.34 g/t gold. The average stripping ratio will be 6.6:1.

The general site arrangements presented in this report were selected by Wright Engineers (1985) during preparation of their preliminary feasibility study. Figure 2-2 illustrates the general arrangement proposed for the development of the project. The site layout includes an open pit; a waste rock stockpile; a tailings disposal pond; a water storage facility and plant facilities which include a crushing-grinding-flotation concentrator, a diesel power generating plant, mine access roads and the accommodation camp.



N. B.  
 Geology has been generalized  
 (Original after Holbeck & Beckett,  
 Esso Minerals Canada 1985)

Figure 2-1 GENERALIZED GEOLOGY



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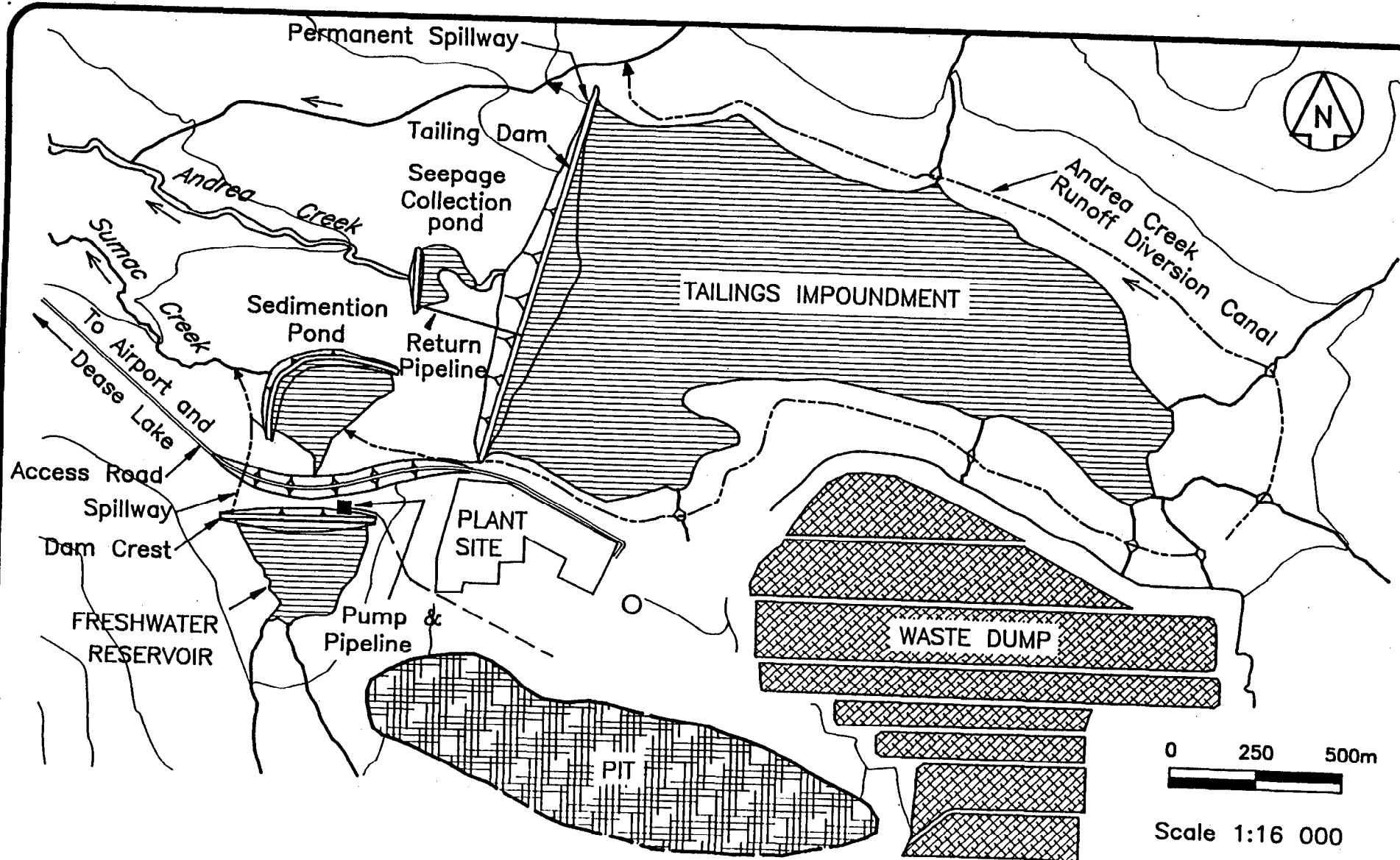


Figure 2-2 PROPOSED SITE LAYOUT

Source : Stage II Environmental Assessment Report, 1986.



The mine and related facilities will be located near the headwaters of Andrea Creek (Figure 2-2). The total area which will be disturbed by the proposed operations is approximately 500 hectares (5 km<sup>2</sup>).

### **2.3.1 Open Pit Mining Operations**

The oval shaped pit located at the headwaters of Andrea Creek will lie at an elevation of 1,600 m (Figure 2-2). The pit will ultimately be 1,500 m long and approximately 400 m wide. Due to the side-hill location of the deposit the final pit depth will result in a pit wall 230 m high on the footwall side and 120 m on the opposite hanging wall side.

The appropriate pit slope for the footwall was affected by the presence of schistose rocks at this location. Based on geotechnical studies (Piteau Associates in Wright Engineers, 1985), the pit wall slopes for pit designs were 45 degrees for the footwall and 53 degrees for the lower and more competent hanging wall. These slopes will result in stable pit walls based on a maximum desired pit depth of 250 m.

Mining will be carried out using conventional open pit methods and equipment. Typical equipment will include large rotary drills, 9.2 m<sup>3</sup> shovels, 80 tonne trucks, a hydraulic excavator for more selective mining, large bulldozers, graders and other ancillary equipment. It is proposed that mining will be carried out on 10 m benches with safety berms placed every 20 m. Permanent haul road and ramps have been designed with a 25 m side surface and a maximum grade of 10%.

### **2.3.2 Waste Dump**

The scheduled pit production amounts to approximately 92.1 million tonnes of waste rock which will require 41 million cubic meters of storage area. All waste rock from the mining operation will be disposed in an area east of, and adjacent to, the open pit. There will be two different varieties of waste rock. Of the 92.1 million tonnes produced, 9.1 million tonnes will contain sulphides and have been determined to be potentially acid generating; the remainder, 83.0 million tonnes, has been determined to be potentially acid consuming.

When the preliminary feasibility study was prepared, it was thought that blending of the two waste rock materials would effectively control acid drainage. The method proposed

was to encapsulate the acid generating waste rock within the acid consuming waste rock. This would minimize the infusion of oxygen to the dump centre, and isolate pyritic rock from surface run-off and contact with groundwater. Should acid generation occur, the acid consuming materials would provide sufficient neutralization capacity to consume the acid. The success of this method depends on, among other things, the properties of the neutralizing material, its reactivity and rate of dissolution.

### **2.3.3 Tailings Impoundment**

Mill tailings and minor quantities of other wastes, including runoff from the waste rock storage area, will be stored in a flooded tailings impoundment. Approximately 12.6 million tonnes of tailings, which have been determined to be acid generating, will be placed in the impoundment. In choosing a site for the tailing impoundment the primary concerns were for a competent, impervious base and a suitable foundation for the dam structure. The proposed site for the tailings impoundment area is behind a dam near the headwaters of Andrea Creek (Figure 2-2). Andrea Creek will be diverted around the tailings pond and back into the original stream channel below the dam.

Tailings slurry will consist of rock ground to silt and sand size, combined with water and chemicals used in the metallurgical process. The slurry will flow to the dam by pipeline and will be discharged into the pond from the crest of the dam. The tailings solids will be submerged permanently in order to prevent acid generation. A floating reclaim barge will be used to collect clarified supernatant from the tailings pond and recycle it back to the plant for treatment prior to discharge.

Upon mine abandonment, it is proposed to create a permanent, flooded pond with a minimum of 2 m of water covering the tailings. The water cover will prevent oxidation and acid generation in the tailing material.

Details concerning the mill and additional environmental protection and waste management plans, including sewage disposal and spill contingency planning, are beyond the scope of this report but are included in the Environmental Assessment Stage II Report (Norecol, 1986).

### **3 - Biophysical Setting**

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## **3.0 BIOPHYSICAL SETTING**

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The Kutcho Creek mine site lies within the Stikine Ranges of the Cassiar Mountains in an area drained by the tributaries of the Turnagain River. The surrounding mountains are glacier eroded with broad U-shaped valleys. The highest peaks in the immediate area of the mine site average about 2,050 m in elevation. The mean elevation along Kutcho Creek, a north flowing tributary of the Turnagain River, is approximately 1,300 m.

A brief description of the climate, surface and groundwater flow characteristics and surface water quality are presented in this chapter as background information relevant to the research program discussed in this report.

### **3.1 Climate**

The Kutcho Creek site has a continental climate characterized by long, cold winters and short, cool summers with relatively low annual precipitation. The climate is affected by the massive barrier of the Coast Mountains, with peaks over 3,000 m and narrow, tortuous valleys, which limit the incursion of moist Pacific air masses. The mean annual precipitation in the vicinity of Kutcho Creek is between 440 - 650 mm, of which 45 - 60% falls as snow. Heaviest precipitation usually occurs in the summer months when solar radiation promotes the development of daytime convective clouds leading to brief, intense rainstorms.

The buildup of Arctic high pressure areas in winter over northern Canada results in the penetration of cold, dry Arctic air through valleys in the Cassiar Mountains into the Stikine and Iskut basins. The drainage of cold air into valley bottoms allows winter overnight minimum temperatures throughout this region to occasionally reach -40 to -45°C under cloudless skies. Under these circumstances, temperatures on the higher slopes remain 5 to 15°C warmer, resulting in semi-permanent temperature inversions in the valleys.

In other seasons, daytime temperatures are relatively uniform over the region, with warmer temperatures in the valleys and cooler temperatures in higher elevations. Temperature inversions may develop overnight in valleys in response to cold air drainage.



### **3.1.1 Precipitation**

Precipitation data for Sumac camp and Kutcho Creek are not complete enough to provide monthly and annual summaries. However, the data collected does provide a cross reference for data collected at climatological stations in the general vicinity of the Kutcho Creek project. The mean annual precipitation in the vicinity of Kutcho Creek is between 440 - 650 mm, the majority of which falls as snow. A 24 hour rainfall of 43 mm has a recurrence interval of approximately 50 years at Dease Lake, but only about 5 years at Fort Nelson and Fort St. John. Based upon these observations, the precipitation intensity-duration-frequency curves for Fort Nelson and Fort St. John are more representative of the project area, certainly more representative than curves for Dease Lake. The two largest 24-hour rainfalls observed at Sumac camp during the limited period of record were 43 mm on July 23, 1980 and 43 mm on July 10, 1985.

### **3.2 Hydrology**

Surface water and groundwater hydrology are of prime concern for the Kutcho Creek project for a number of reasons. Firstly, there must be an adequate supply of water from Sumac Creek to provide process and potable water. Secondly, mine site runoff may require treatment prior to discharge. Finally, to avoid contamination of Andrea Creek, flood waters should be diverted around the tailings pond.

#### **3.2.1 Surface Water Hydrology**

The project area is in the headwaters of the Turnagain River, immediately north of the divide between the Stikine and Liard River basins. Elevations are greater than 1,250 m and this has a major effect on the study area's hydrologic regime, which is dominated by very low streamflow in winter and high streamflow in late spring during snowmelt.

Most mine-related activities would take place within the Andrea Creek basin (Figure 3-1). The downstream progression of flow from the study area is Andrea Creek, Kutcho Creek, Turnagain River, Liard River and then the MacKenzie River.

### *3.2.1.1 Mean Monthly Flows*

From the results of the studies carried out by Norecol and Sumac in the summers (June through September) of 1984 and 1985 runoff was consistently high from Dam Site and Sumac Creeks, with monthly averages of 5.4 to 9.1 mm/day, respectively for these summer months. This reflects an extended snowmelt season from the higher elevations and north facing slopes in those two tributary basins. The available data from Kutcho Creek suggest that July runoff from the Kutcho basin is much less than that from the area closer to the proposed mine site.

### *3.2.1.2 Daily and Instantaneous Flows*

From the 1984 and 1985 study, daily and instantaneous flows were calculated based upon daily manual stage readings and from a continuous water level record, which was installed on the lower Andrea Creek (Table 3-1).

For Andrea Creek the highest instantaneous peak flow occurred in July, 1985 in response to a rainstorm. That instantaneous storm peak was 19% greater than the mean daily discharge and the recurrence interval of that particular runoff event was in the order of a 5-year flood. Peak flows from the other gauged sites were estimated to be 5.4 m<sup>3</sup>/s, 25.4 m<sup>3</sup>/s and 40.7 m<sup>3</sup>/s for Andrea Creek above Sumac Creek, Sumac Creek and Kutcho Creek respectively. Figure 3-1 shows the locations of the gauged sites.

### *3.2.1.3 Flood Flows*

The 200-year floods in study area creeks were estimated by various methods. These results are reproduced in Table 3-1. Predicted 200-year flood peak discharges are in the order of 1 m<sup>3</sup>/sec/km<sup>2</sup> for drainage basins between 7 and 70 km<sup>2</sup>.

### *3.2.1.4 Regional Low Flows*

The lowest mean monthly flows recorded at the regional gauge stations of the Stikine above Grand Canyon, Turnagain and Kechika rivers, occur in late winter. March is the month with the lowest average flows when the runoff averages are 4.8, 4.7 and 6.0 mm per month respectively from the three basins.

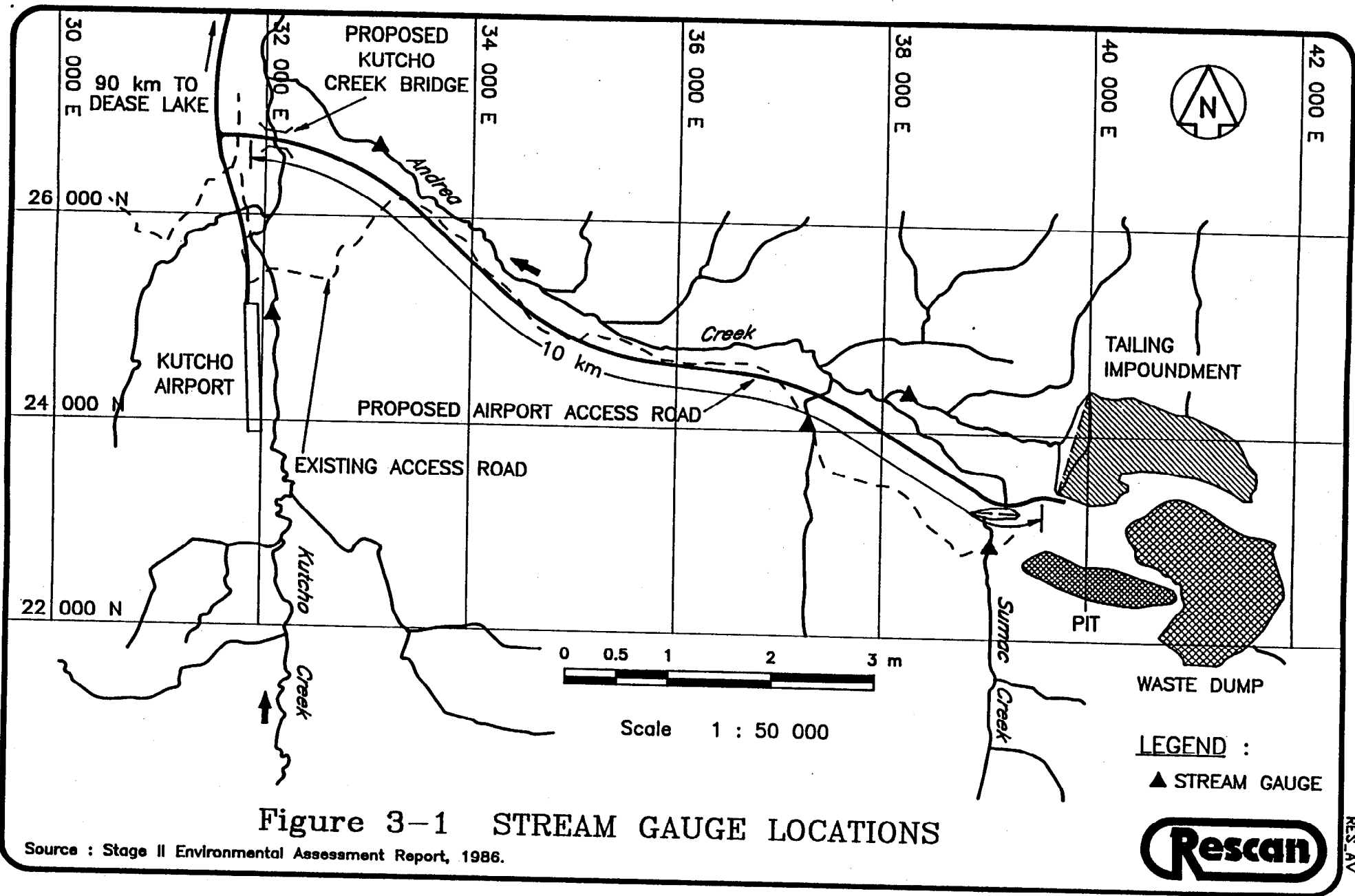


Figure 3-1 STREAM GAUGE LOCATIONS

Source : Stage II Environmental Assessment Report, 1986.

**Table 3-1**

**Summary of Estimated Floods In Kutcho Creek Basin  
with a 200-year Recurrence Interval**

Drainage	Area (km <sup>2</sup> )	N.W. Hydraulics*	Regional Analysis Q(m <sup>3</sup> /s)	BCH PMF Q(m <sup>3</sup> /s)	Rational Method Ql(m <sup>3</sup> /s)	SCS Method Ql(m <sup>3</sup> /s)	Recommended Design Flows	
							Minimum 200-year Design Flows Q(m <sup>3</sup> /s)	Minimum 200-year Instantaneous Flow Ql(m <sup>3</sup> /s)
Dam site Creek Into Andrea Creek	7.3	7-14	4.2-6.3	6.4	15	9-14	7	11
Sumac Creek Into Andrea Creek	9.3	9-17	4.6-6.9	7.0	17	9-13	8	12
Andrea Creek above Sumac Creek	24.6		10-16	18	37	25-38	15	25
Andrea Creek Into Kutcho Creek	70	40-75	26-39	51	52	41-60	40	60
Kutcho Creek upstream of Andrea Creek	105	50-105	39-57	78	N/A		60	90

\* Northwest Hydraulics Ltd. (1979) provide estimates of peak flows but no information is provided on the recurrence interval or whether estimates are mean daily or instantaneous discharge.

Note: Instantaneous peak discharge computed by the rational or SCS methods will be 1.5 - 2 times the mean daily discharge. Q = mean daily discharge; Ql = instantaneous discharge.

The mean annual 7-day low flow for the Turnagain River basin (6,580 km<sup>2</sup>) is 10.2 m<sup>3</sup>/s. This is equivalent to 0.94 mm of runoff in 7 days, or an average discharge of 1.55 litres/sec/km<sup>2</sup> for a 7 day period. If all parts of the Turnagain basin contributed equally at times of low flow, then the mean annual 7-day low flows in Kutcho, lower Andrea, upper Andrea, Sumac and Dam Site Creeks at the staff gauge locations would be 163, 104, 38, 12 and 11 litres/sec, respectively.

### **3.2.2 Groundwater Hydrology**

Groundwater flow and storage within the Kutcho deposit area appears to be primarily along structural weakness in the rock. The structural weaknesses have been identified as two orthogonal joint sets, one striking north-south with a near vertical dip, and the other striking east-west with a dip generally less than 20 degrees to the south.

The discontinuous nature and irregular spacing of these structural features hamper groundwater flow. However, the groundwater flow seems to have two components:

- a general flow direction to the north which originates as recharge on the ridge above the pit and flows northward toward the discharge zone associated with Andrea Creek, and
- a general flow direction to the west in which groundwater originating as recharge in the upper catchment area of Andrea Creek flows parallel to the creek along the strike of bedrock schistosity.

Hydraulic conductivity values determined from falling head tests carried out on the piezometers installed in the footwall rock of the ore body generally fall in the range of 10<sup>-10</sup> to 10<sup>-9</sup> m/s. Zones of higher permeability may exist, particularly within zones of weak altered rock.

Measured flow and trends of flow between 1982 and 1984, from the weirs located on creeks beside the adit, suggest that the hanging wall rocks are much more permeable and produce significantly greater flows than the footwall rocks.

Surface runoff will occur in the northerly direction towards the waste dump and tailings impoundment and in a northwest direction towards Sumac Creek.

### *3.2.2.1 Waste Dump*

Generally, topographic slopes across the dump area are less than 10 degrees to the north; hence surface runoff will occur in a northerly direction towards the tailings impoundment. Based upon existing hydrogeologic data within the Kutcho Creek area it would be expected that groundwater flow within the waste dump area would occur in northerly direction toward the discharge zone associated with Andrea Creek.

### *3.2.2.2 Tailings Pond*

Groundwater flow within the tailings area will be primarily controlled by local topography. Groundwater flow will originate as recharge at the topographic highs associated with the valley of Andrea Creek and maintain a flow path within the valley walls discharging into the broad valley floor associated with Andrea Creek.

## **3.3 Water Quality**

From 1976 to 1983 and from 1984 to 1985, water quality sampling programs were carried out in the area around the Kutcho Creek mine site. The data indicate that the pH of the surface waters is slightly alkaline; Andrea and Kutcho Creeks have an average pH of 7.9. Conductivity was moderate, averaging 104.5 micromhos/cm in Andrea Creek and 102.3 micromhos/cm in Kutcho Creek. Alkalinity was also moderate, averaging 58.1 mg/L in both streams, indicating a moderate buffering capacity. Kutcho Creek and Andrea Creek water is considered to be moderately hard, at between 75 and 80 mg/L as CaCO<sub>3</sub>. Suspended solids were generally less than 1 mg/L. The maximum suspended solids level of 15 mg/L was recorded on Sumac Creek during spring freshet.

Evaluation of results for total and dissolved metals for the 1984-1985 sampling program showed general agreement with earlier results. Most levels of metals were low and within the ranges expected in relatively undisturbed watersheds. Levels of arsenic, barium, cadmium, lead and mercury were all below detection limits. Iron and aluminum were seasonally elevated at all sites during spring freshet, mostly related to high sediment levels at this time.

Copper and zinc levels, both total and dissolved, were consistently elevated for Sumac Creek and Andrea Creek. Comparison with groundwater samples from the mine site shows that the ore body was probably the source of the copper and zinc that entered Sumac Creek and yielded elevated levels of these metals at sites on lower Sumac Creek and lower Andrea Creek.

## **4 - Overview of Acid Rock Drainage**

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## 4.0 OVERVIEW OF ACID ROCK DRAINAGE

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This chapter provides an overview of the physical, chemical and biological factors contributing to the formation of ARD. Following a description of the factors leading to ARD, a short explanation of the various management strategies that have been developed to minimize or prevent ARD in rock piles is provided.

Acid generation is caused by the exposure of certain sulphide minerals (mainly pyrite, FeS<sub>2</sub>) to air and water in the presence of microbial catalysts which mediate oxidation of the sulphide. The major end product of this oxidation is sulphuric acid, which may leach metals from the surrounding rock, resulting in drainage water high in metals and sulphate and low in pH. The potential effects of acid generation can be offset by the presence of acid consuming minerals such as calcite, which have the capability to neutralize the acid.

Acid drainage is a consequence of a complex and interdependent system of physical and geochemical processes operating within the waste rock pile (Morin *et al.* 1991). The physical aspects of acid drainage include hydrogeologic processes which transport the acidic water through the rock dump to the surrounding environment. Movement of the water into, through and out of a waste rock pile represents a primary pathway for contaminants to be released to the surrounding environment. The biogeochemical aspects of acid drainage include acid generation, bacterial acceleration of reaction rates, acid neutralization and metal leaching, which lead to the release of acidity, sulphate, alkalinity and metals from waste rock into the water contacting the rock surfaces.

The combination of physical and geochemical process interactions produces site-specific types of acid drainage. Several different types of acid drainage have been classified, however the classification system was based upon measured parameters at external discharge locations, and therefore did not reflect reactions occurring within the waste rock pile. To further complicate matters, one type of acid drainage may evolve into another in a rock dump. Rather than attempting to fit acid drainage into a classification system, the physical and geochemical processes operating within a particular waste rock pile should be delineated (Morin *et al.* 1991).

The chemical equation most often used to describe acid drainage is as follows:





In this equation pyrite,  $\text{FeS}_2$ , is oxidized by molecular oxygen and water to form ferric hydroxide, sulphate and hydronium ions or acidity. However, acid generation is much more complex than this equation suggests. Aqueous iron is affected by pH, redox conditions and other chemical and biological factors and thus may not precipitate from solution as indicated in the equation. Interpretation, prediction and analysis of acid generation in any particular waste rock pile rely upon even greater degrees of complexity which are a result of sulphur oxidation, types of sulphide minerals and bacterial participation in the reactions. Classification and interpretation of all of these factors are beyond the scope of this report.

A number of geochemical reactions known as "acid neutralization" reactions may minimize the impacts of acid generation by decreasing levels of acidity, increasing pH toward neutral values and causing aqueous metals to precipitate from the rock pile runoff water. Three possible scenarios exist for neutralization: (1) water passes over neutralizing minerals dissolving a portion of them and thereby accumulating aqueous alkalinity, then subsequently flows over the acid generating minerals; (2) the water contacts acid neutralizing and acid generating minerals simultaneously; and (3) water contacts acid generating minerals, accumulates aqueous acidity, and then contacts acid neutralizing minerals. With all three scenarios neutralizing minerals are progressively consumed over time. If the neutralizing minerals are consumed completely before the rate of acid generation subsides, the intensity of the acid drainage may increase. The principle carbonate minerals capable of acid neutralization are calcite, dolomite and ankerite. According to mineralogical studies, most rock types from the Kutcho adit contained carbonate minerals, principally calcite, with quantities ranging from 2-57% of the sample (Section 7.1.3).

In an acid generating waste rock pile, the initial contents of acid neutralizing and acid generating minerals and their rates of consumption will determine the geochemical composition of the rock pile runoff. Particulars of the aqueous based neutralization reactions and the types of neutralizing minerals affecting acid generation are complex and are not discussed in this report.

Since acid drainage is a consequence of many physical, geochemical and biological processes, computer modelling has been used to provide insights into the development of acid drainage. However, Morin *et al.* (1991) suggested that existing computer models

cannot simulate the most significant processes functioning in waste rock piles. Although acid drainage theory is sufficiently developed, and the existing computer models simulate one or more of the critical processes, none of the models closely approximates all of the processes involved in the formation of acid drainage.

Further breakdown of the internal reactions that determine the type and quantity of acid generation are beyond the scope of this report. Interested readers are directed to the *Critical Literature Review of Acid Drainage from Waste Rock* (Morin *et al.* 1991).

The following management strategies have been employed to prevent or control acid generation in rock piles:

- reduce permeability of the waste rock pile to oxygen;
- prevent oxidation and the affiliated exothermic reactions from significantly increasing dump temperature;
- minimize leachate production and movement; and
- inhibit seepage to the more reactive portions of the dump, especially the toe.

Specifically, the most recent research to control acid drainage has focused upon:

- use of surface covers and liners to prevent infiltration of water and oxygen into the waste rock;
- bactericidal control of the microbial population;
- use of metal precipitating agents to cloak waste rock surfaces;
- use of neutralizing compounds or alkaline recharging;
- underwater disposal;
- waste segregation and selective dump placements; and
- waste rock blending.

The presence of acid neutralizing and acid generating minerals in the Kutcho orebody inspired the project partners to examine the possibility of blending waste rock to mitigate ARD.

## **5 - Research Program**

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## 5.0 RESEARCH PROGRAM

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In 1983, B.C. Research conducted acid generation studies, on behalf of Sumac, on selected core and composite samples. These studies indicated that the footwall waste rock is potentially capable of generating acid and the hanging wall rock, low in sulphide, is potentially capable of neutralizing acid. Further testwork in 1985, which included column experiments and acid base accounting tests, confirmed the earlier results and suggested that blending of the various rock types on a stoichiometric basis would be an appropriate method to control acid generation. Results from this initial testwork are described in Section 7.1.1. What follows in this chapter is a discussion of the research program developed to further the initial work.

### 5.1 Objectives

In 1988, Sumac Mines Ltd. and then owner Esso Minerals Canada, proposed a jointly funded test program to provide an assessment of the potential for ARD on the property and to ascertain the viability of blending waste rock to control ARD. A three phase program was developed.

Phase I was initiated in 1988. The objective of the Phase I research program was to determine whether mine development would have the potential to generate ARD. The program was to employ mineralogical analysis to identify the reactive minerals contributing to acid generation, and to determine the effectiveness of using segregation or blending as a method of controlling potential acid mine drainage.

Phase I consisted of a general reconnaissance level survey of the site to look for evidence of acid rock drainage and to extensively sample rock from inside the Sumac exploration adit. Sampling encompassed the various lithologies of the hanging wall, footwall and massive sulphide ore zone rock units. A series of kinetic weathering tests using humidity cells charged with various individual rock types was initiated. These tests were carried out on 20 samples for a duration of 20 weeks. The testwork was completed in late 1989 and a final report for Phase I was issued in November 1989.

Phase II was initiated in 1989. Field scale (20 tonne) test piles were designed and built at the Kutcho Creek property in order to determine whether blending acid generating footwall wastes with acid consuming wastes would prevent acid generation from occurring in full-scale waste dumps. Humidity cell testwork was also completed under controlled laboratory conditions on six samples blended with the same net neutralization potential (NNP) weighted ratio of acid generating to acid consuming rock as those in the field. Acid base accounting (ABA) tests were performed on 50 additional core samples which were selected to represent the lithologies in the Kutcho project area. Results were reported in the Phase II Report published September 1990, and are summarized in Chapter 7 of this report.

Phase III of the program, completed October 1991, involved monitoring of the field test piles including sampling of leachate and collection of pertinent climatic data. Water quality monitoring was performed monthly starting in July and continuing until freeze-up in mid-October. Additionally, pH probes were installed to continuously monitor pH of leachate from each test pile. Results for Phase III of the research program are presented in Chapter 7. Table 5-1 summarizes the various test procedures according to the objectives. Figure 5-1 shows the scheme for test procedures.

**Table 5-1  
Summary of Test Procedures**

To Determine	Test Used	Samples
(1) Acid Generation Characteristics	• Acid Base Accounting	22 Samples from ADIT
		50 Samples from CORE
	• Humidity Cell Testwork	22 Samples from ADIT
	• Mineralogical Studies	22 Samples from ADIT
(2) Effectiveness of Blending	• Humidity Cell Testwork	3 Cells - 1.0 kg *
	• Field Test Pads	3 Pads - 20,000 kg *

\* (1) - "Preproduction" Blend - used 1:1.1 acid generating/acid consuming ratio  
 (2) - Five Year Blends - used 2:1 acid generating/acid consuming ratio

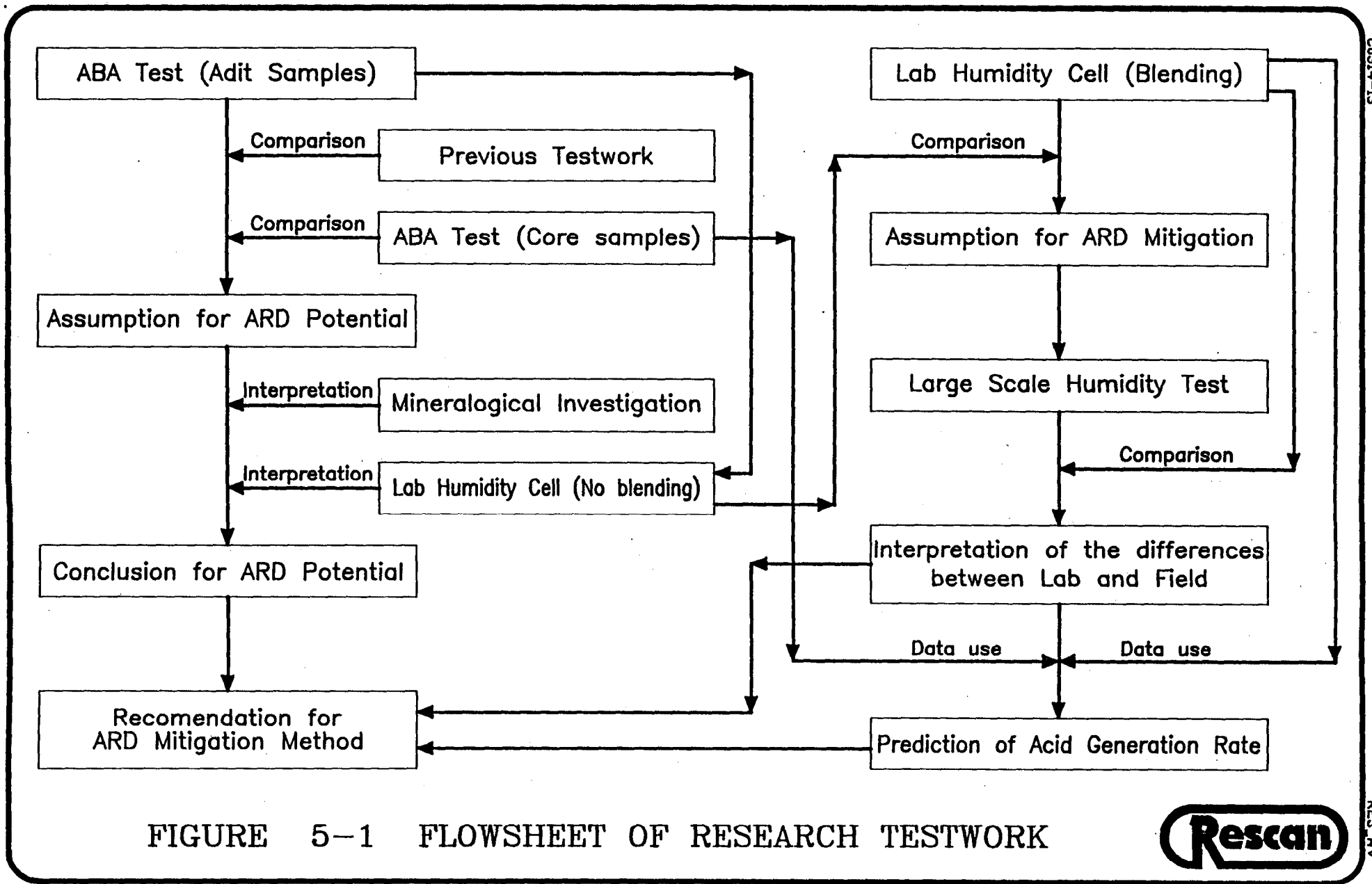


FIGURE 5-1 FLOWSHEET OF RESEARCH TESTWORK



## **5.2 Predictions Using Laboratory and Pilot Scale Studies**

Using information acquired during the three phases of the research program, the viability of waste rock blending to control ARD at Kutcho Creek on a full scale basis may be assessed. Mineralogical analysis, acid base accounting, kinetic weathering tests using humidity cells, and field scale test piles were all used to provide the necessary information to formulate an ARD mitigation strategy for the Kutcho Creek project. Specifically, the rate of sulphate production, measured in milligrams of sulphate per 100 grams per week for the laboratory humidity cells and field scale test plots was used to estimate the quantity of ARD that would likely be produced by a full scale waste rock pile.

## **6 - Methodology**

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## 6.0 METHODOLOGY

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A variety of test methodologies and analytical procedures were implemented to determine the acid generating and acid consuming properties of the different rock lithologies present in the Kutcho deposit. Results of the laboratory testwork were subsequently used to formulate laboratory and field waste rock blending programs to simulate on-site conditions which are likely to occur if waste rock blending is chosen as an environmental management tool to mitigate ARD. This chapter provides a description of the various experimental techniques which included:

- acid base accounting;
- petrographic examination;
- laboratory humidity cell testwork, and
- field scale humidity cell testwork.

### 6.1 Acid Base Accounting

Acid base accounting (ABA) attempts to determine the net neutralization potential (NNP) of a rock by examining the balance between acid producing components, primarily pyrite ( $\text{FeS}_2$ ), and acid consuming components such as carbonates or other rock types capable of neutralizing strong acids. The ABA test is designed to identify whether a rock type has the potential to generate acid. However, it provides no information on the rate of acid production nor does it describe the effects that the acid drainage will have on the receiving environment.

Net neutralization potential (NNP) is defined as the difference between neutralization potential (NP) and the maximum potential acidity (MPA). Neutralization potential (NP) is an estimate of the ability of the sample to consume acid. The NP is measured by adding excess acid to a sample which lowers its pH to less than 2, and then titrating with sodium hydroxide to pH 7 to 8. In this study MPA was determined by multiplying the total sulphide content by a conversion factor of 31.25. The conversion factor is based on the stoichiometric equation of pyrite oxidation assuming that oxygen alone is responsible for oxidizing pyrite and that acid is generated through both complete sulphide oxidation to sulphate and precipitation of iron as  $\text{Fe}(\text{OH})_3$ . Because MPA and NP are measured

independently, a proper interpretation of ABA test results may require separate examinations of the two. Particular attention should be drawn to samples with low (highly negative) NNP which are considered to be potential acid producers when exposed to oxygen and moisture in the natural environment.

Paste pH of a sample is usually determined as part of ABA testwork. A paste pH between 6.0 and 9.0 often indicates the presence of reactive carbonate minerals, such as calcite. A paste pH below 5.0 generally indicates that some acid generation has occurred in the sample prior to testing. It also indicates that the sample's NP is low or is not readily available. When carbonates are present in the sample they are usually reactive enough to show a correlation between paste pH and NP.

#### **6.1.1 Kutcho Creek Acid Base Accounting**

The acid generating potential of Kutcho Creek waste rock was investigated prior to the September 1988 start-up of the acid generation research program. Samples of Kutcho Creek waste rock were submitted to B.C. Research twice during 1983 (February and September) by Sumac Mines Ltd., and in 1985 after the project passed to Stage II Approval-in-Principal. Results from these investigations are summarized in Section 7.1.1 of this report.

Other than the 1985 studies, there was little ABA information available on the major rock lithologies in the Sumac adit prior to the completion of this testwork. During Phase I of the research program, 22 samples representing the major rock types intersected in the Sumac adit were examined prior to humidity cell testing (Figure 6-1). Composite channel samples were collected by chipping material from the wall of the adit. Several samples were taken from the larger rock units in order to detect any horizontal variation in ABA characteristics within these units. Furthermore, subsamples from selected humidity cells were submitted for post humidity cell ABA testing.

During Phase II of the research program, samples for ABA were collected from drill cores stored in open core racks located on site. The cores had been exposed to weathering conditions for up to five years; consequently, most samples exhibited evidence of prior acid generation. An attempt was made to collect a representative sample from all the major lithologies contained within the main deposit area. Sample

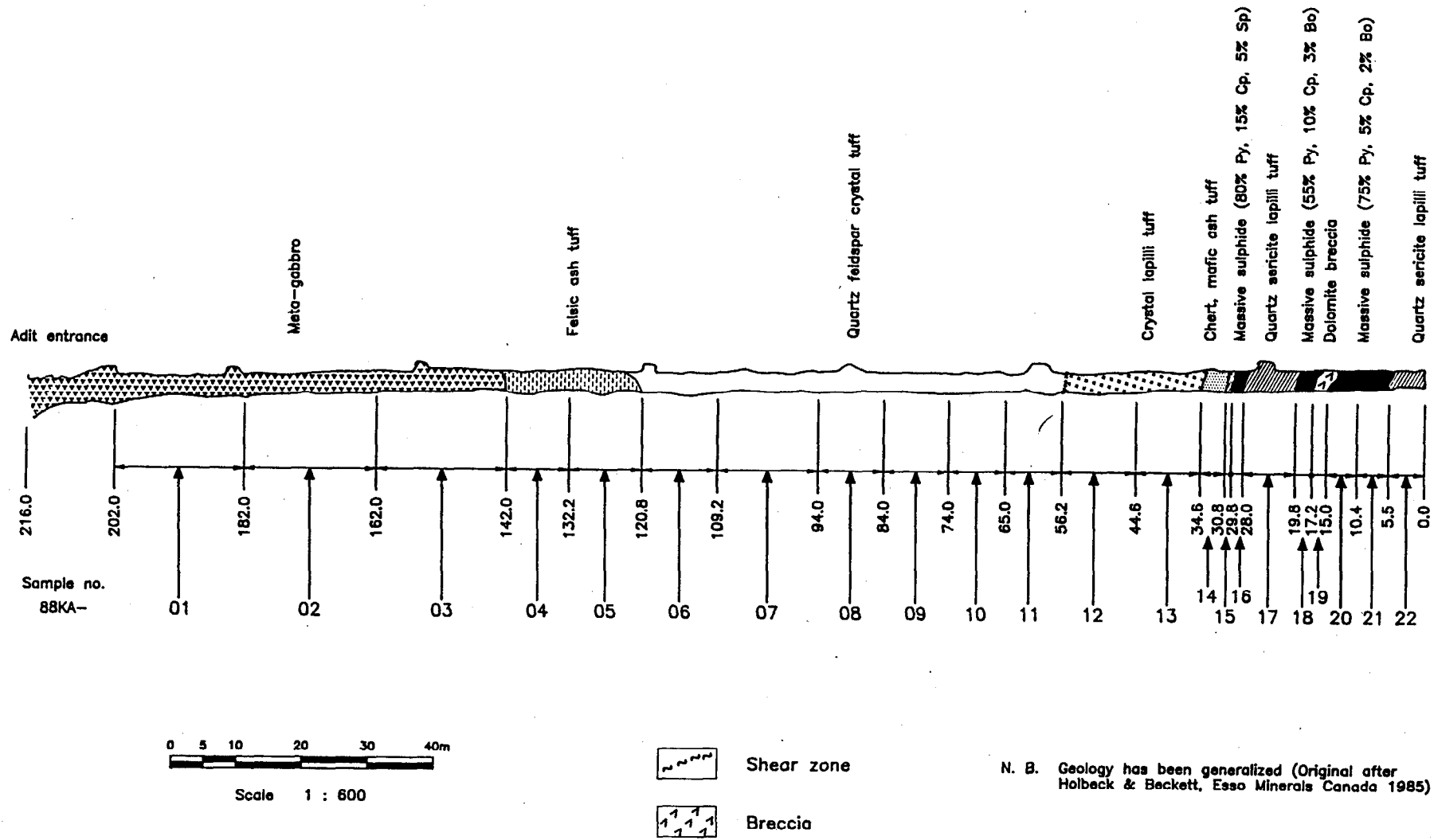


Figure 6-1 PLAN (SUMAC ADIT) GEOLOGY & SAMPLE LOCATIONS



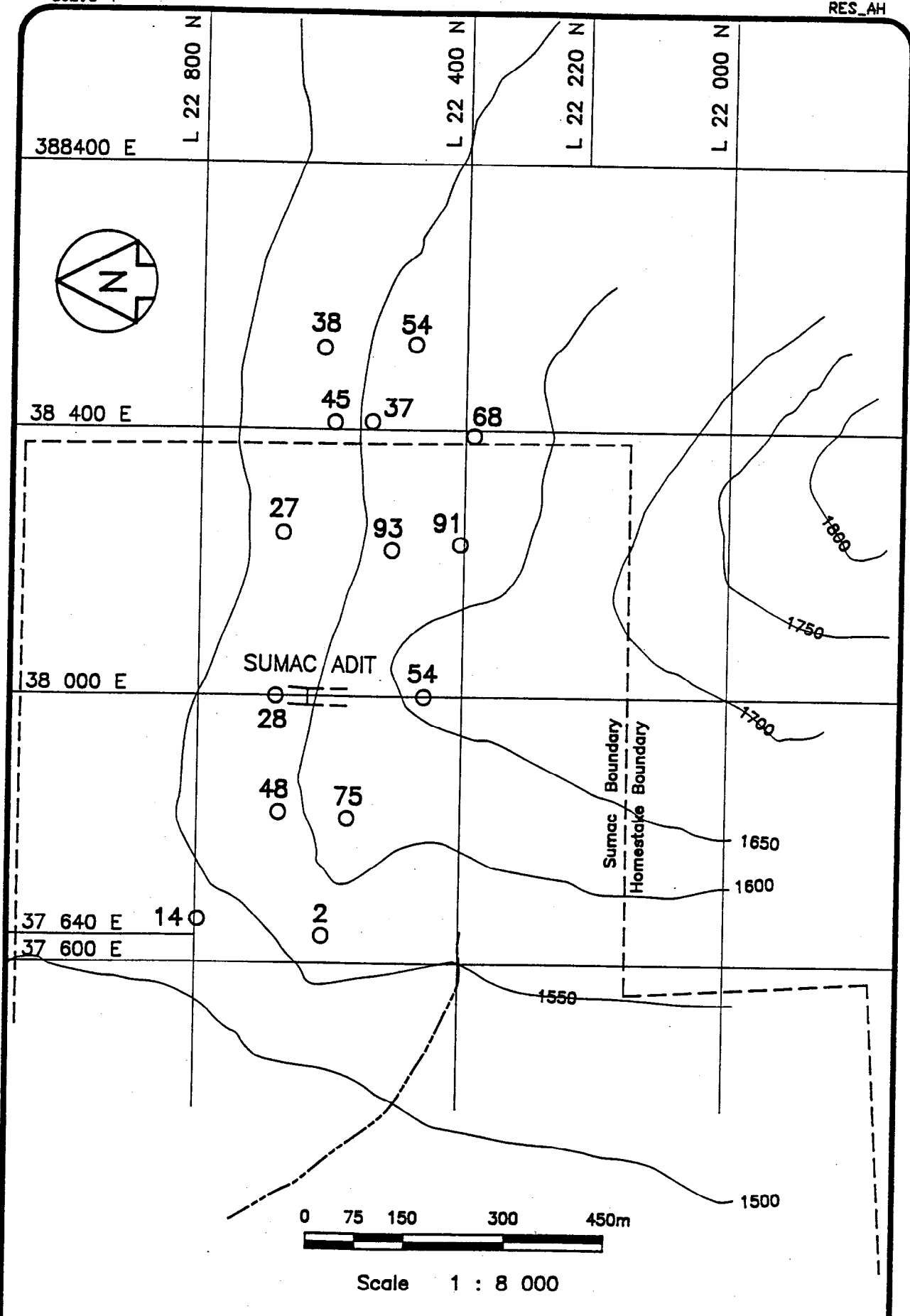


Figure 6-2 DRILL HOLE LOCATIONS



locations were determined using geological cross-sections and plan maps supplied by Sumac and Homestake (Figure 6-2). A total of 50 core samples representing the major rock types were examined in ABA tests. Results of the Phase II ABA study may be found in Section 7.1.2.

The general procedures recommended by the U.S. EPA were followed for ABA testwork (see Appendix A). Additionally, Kutcho Creek samples were predigested in an acid solution for 24 hours to rinse away previously produced acid products prior to the test. The ABA tests were carried out in the following manner.

All samples were dried, crushed and pulverized until they passed through a #140 mesh screen. Each sample was homogenized with distilled water into a paste, then its pH was measured. As discussed above, paste pH is a general indicator of any acid generation that has occurred prior to analysis.

Total sulphur analyses were also performed on the Kutcho Creek waste rock samples as an integral part of the ABA testwork. The use of total sulphur as an indicator of potential acid generation can be misleading because not all sulphur may be capable of generating acidity. For the purposes of this study, potentially acid generating reactive sulphur (sulphide) was determined by subtracting all forms of non-reactive sulphur from the total sulphur contained in a sample. Non-reactive forms of sulphur include gypsum, which can be leached with hydrochloric acid, and non-leachable sulphate such as barite. Total sulphur content was determined by LECO furnace. A split sample was reacted with hydrochloric acid (HCl) in order to remove the acid extractable sulphate prior to a similar LECO furnace total sulphur assay. The difference between total sulphur and sulphate yielded the quantity of reactive sulphide which was used to calculate maximum potential acidity.

### **6.2 Mineralogical Investigation**

Mineralogical investigation of the Kutcho Creek waste rock samples was performed in order to provide additional insight to the nature of the sulphide and carbonate minerals present in the waste rock. ABA procedures quantify both sulphate and carbonate minerals in static laboratory tests, however, they do not allow an accurate estimate of the rate of reaction which would be expected when the waste rock is exposed *in-situ* to oxygen and moisture. Petrographic analysis is commonly used as a supplemental investi-

gation technique for understanding why different neutralizing minerals exhibit variations in reactivity when exposed to acid.

During Phase I of the research program, 22 rock samples representing the major rock types intersected in the Sumac adit were collected. Split samples of 22 Kutcho Creek rock samples underwent petrographic thin and polished section examination prior to humidity cell testing. Samples representing major lithologies were reanalyzed following the 20 week humidity cell tests to determine whether the accelerated weathering and oxidation processes had induced any mineralogical changes.

After samples were crushed to a size between 5 mm and 0.02 mm, mineralogical analyses were performed by Vancouver Petrographics Ltd. . The fragments selected to prepare each thin/polish section, were chosen such that they represented all of the textural and mineralogical variations which were actually present in the sample. Results of the mineralogical investigation are presented in Section 7.1.3.

### **6.3 Laboratory Humidity Cells**

Humidity cells provide a carefully controlled weathering environment in order to estimate the kinetics of acid generation. Humidity cell testwork provides an indication of ARD characteristics of a waste material, however, it cannot be used to predict the kinetics and equilibria of the oxidation and neutralization reactions taking place in a natural environment. For example, coarser particles in a full scale rock dump will oxidize more slowly because of their smaller surface area available for reaction.

Humidity cells provide ideal conditions for naturally occurring sulphide-oxidizing bacteria which catalyze the break down of materials such as pyrite. Humidity cell test procedures involve subjecting one kilogram rock samples to alternating cycles of moist and dry air, followed by flushing with deionized/distilled water to remove accumulated acid products and leached metals. This rinse water is collected and analyzed for the byproducts of acid generation (Figures 6-3, 6-4; Plates 6-1, 6-2).

For the first three days of the seven-day cycle, moist air is blown through the one kilogram sample, followed by three days of dry air. On the seventh day of the test cycle, 500 mL of distilled water is poured into the cell, immersing the sample for a period of



**Plate 6-1: Phase I laboratory humidity cell tests. Twenty two humidity cells each contained one kilogram of rock representing the major rock types in the Sumac adit.**



**Plate 6-2: Phase II laboratory humidity cell tests. Acid producing and acid consuming waste rocks were blended and exposed to alternating cycles of moist and dry air. Leachate was collected and analyzed for by products of acid generation.**

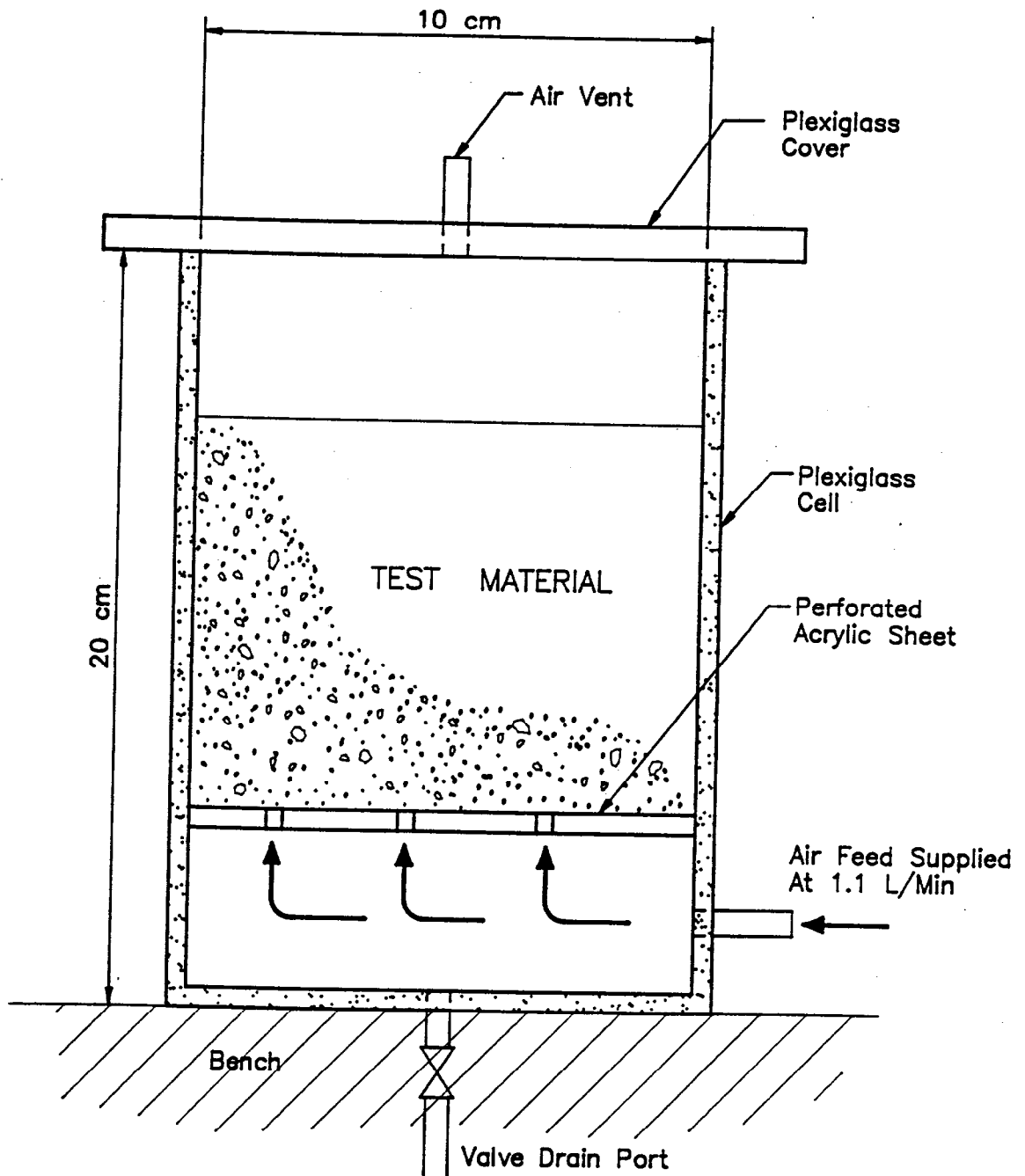


FIGURE 6-3 MODIFIED HUMIDITY CELL





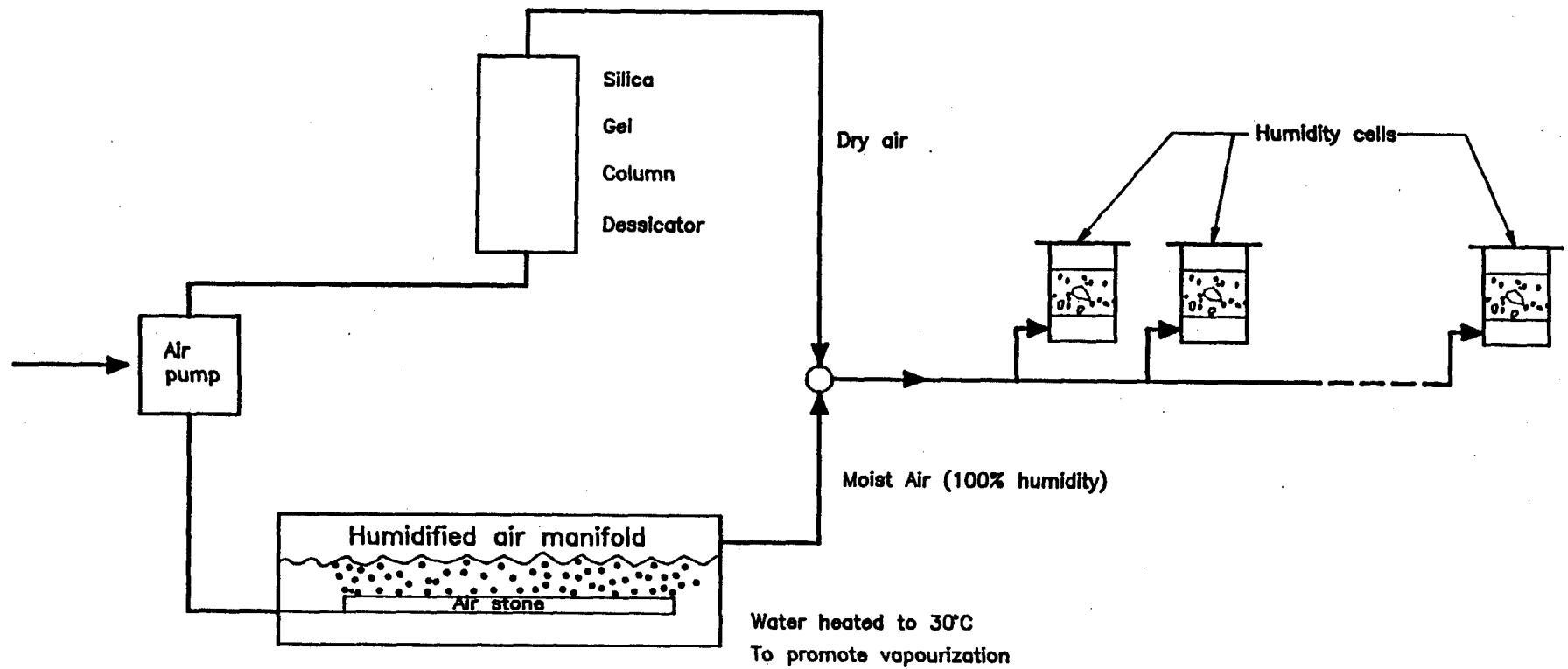


FIGURE 6-4 HUMIDITY CELL APPARATUS

one hour. The leachate is then collected and filtered through a 0.45  $\mu\text{m}$  filter. The liquid sample is analyzed for pH, acidity, alkalinity and sulphate. Metals are analyzed by inductively coupled plasma (ICP) and direct flame atomic absorption spectroscopy (AAS). Low concentration elements are determined by graphite furnace AAS. Detailed test procedures are outlined in Appendix A.

### **6.3.1 Non-Blended Humidity Cells**

Twenty-two samples representing the major rock types intersected in the Sumac adit were examined in the Phase I humidity cell tests. Particle size analyses were performed on all samples prior to charging the humidity cells in order to determine if surface area appreciably affected the rate of acid generation. Selected samples were also subject to post test ABA and mineralogical studies in order to provide additional insight into the reactivity of Kutcho Creek waste rock. Results of Phase I humidity cell tests and the associated particle size and post test analyses are presented in Section 7.1.4.

### **6.3.2 Blended Humidity Cells**

In Phase II, laboratory humidity cell tests were implemented to complement the larger, field scale tests. Procedures for the field scale tests are detailed below. Blending ratios used for the laboratory humidity cells were identical to those used in the field. Methodology for the blended humidity cell tests was identical to that employed for the non-blended humidity cells.

## **6.4 Field Scale Humidity Cell Tests**

To test the viability of blending waste rock which is potentially acid generating with that which is potentially acid consuming, large scale field test piles complimented with small-scale laboratory humidity tests (Section 6.3.2) were initiated in August 1989.

Three large scale field test piles were constructed on-site for Phase II of the Kutcho Creek research program. Each box was designed to hold 20 tonnes of waste rock blended to specific ratios of acid generating/acid consuming rock types thought to be representative of the preproduction and five year waste rock dumps. Two boxes were filled with the five year ratio. Sizing of the timber boxes was based upon the assumed bulk density of the crushed waste rock material stored adjacent to the adit. Based upon

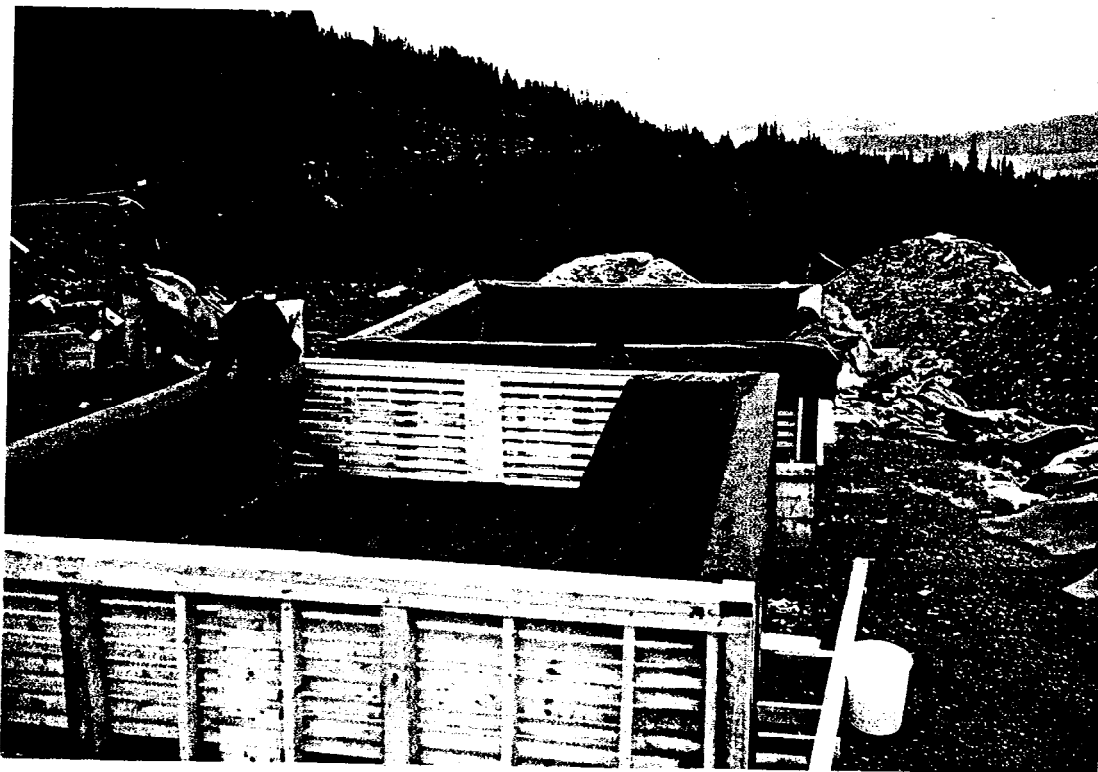
a rock density of 2.7 tonnes/m<sup>3</sup> and a swell factor of 1.5 the boxes were designed to hold 11.1 m<sup>3</sup> of waste rock.

Final dimensions of the boxes were 3.28 m X 3.28 m with a side wall height of 1.35 m. The waste rock was placed to form a pyramid whose apex height at the centre of the heap was 1.67 m with a 30 degree slope angle.

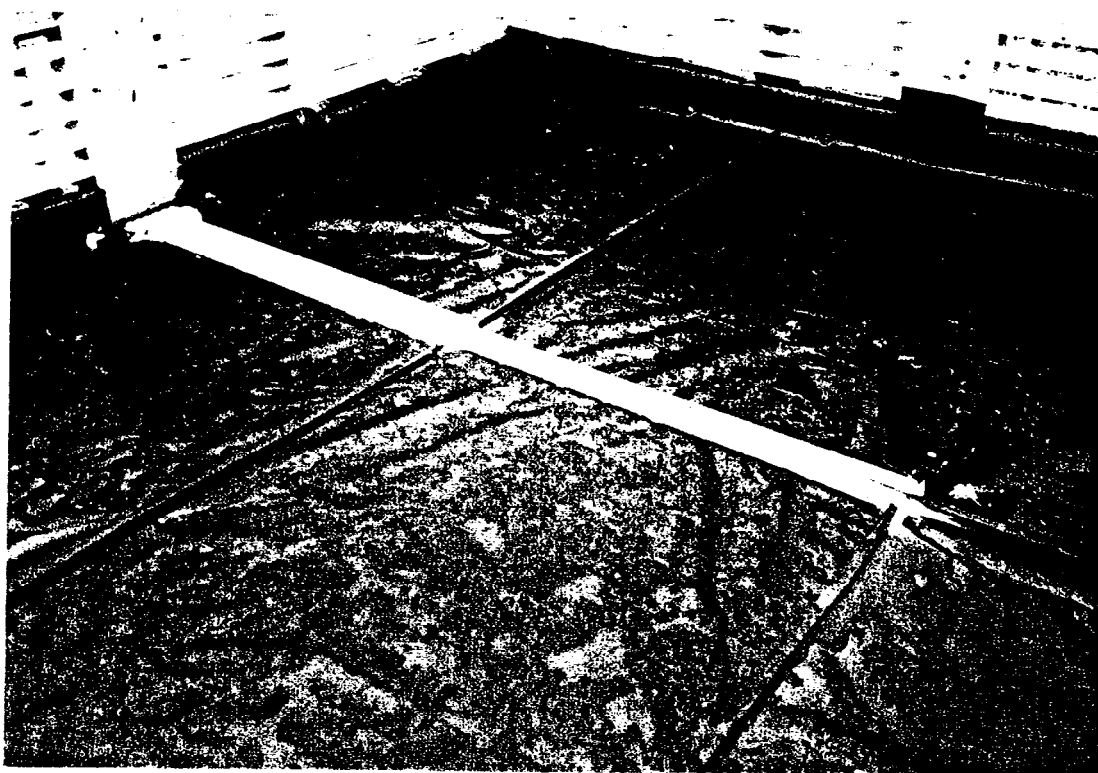
The walls of the test boxes were designed to permit the natural circulation of air into the sides of the waste pile (Plate 6-3). The floor of the wooden box was covered with a polyethylene liner and was sloped so that the runoff was channelled to a final collection point (Plate 6-4). Six separate drainage areas (lysimeters) were created by gluing baffle strips into the liner (Plate 6-5). Each lysimeter drained into the sample collection system through its own one inch (inside diameter) conduit. The function of the lysimeters was to determine whether or not precipitation falling on the waste heap was percolating uniformly through it. Wooden covers were installed over the conduits to prevent them from being crushed by rock. The plastic liner was protected by a layer of nonwoven geotextile. The test boxes were loaded with waste rock according to the anticipated waste rock production at the end of preproduction and after five years of mining (Plate 6-6).

Boxes were filled with blended waste rock by sequentially layering acid generating and acid consuming rock. A cubic metre bucket (i.e. 1.8 tonnes) of each waste rock was added, in turn, to the box, where it was spread uniformly throughout and mixed with the material beneath it. This construction method was thought to be representative of the degree of blending that could be achieved by full scale dump operations (Figure 6-5). A weighted NNP ratio of 1:1.1 acid generating to acid consuming for preproduction and 2:1 for each of the five year blends was achieved utilizing this method (Table 6-1). The ratios were determined by multiplying tonnes of each rock type by their corresponding NNP value given in Table 6-1.

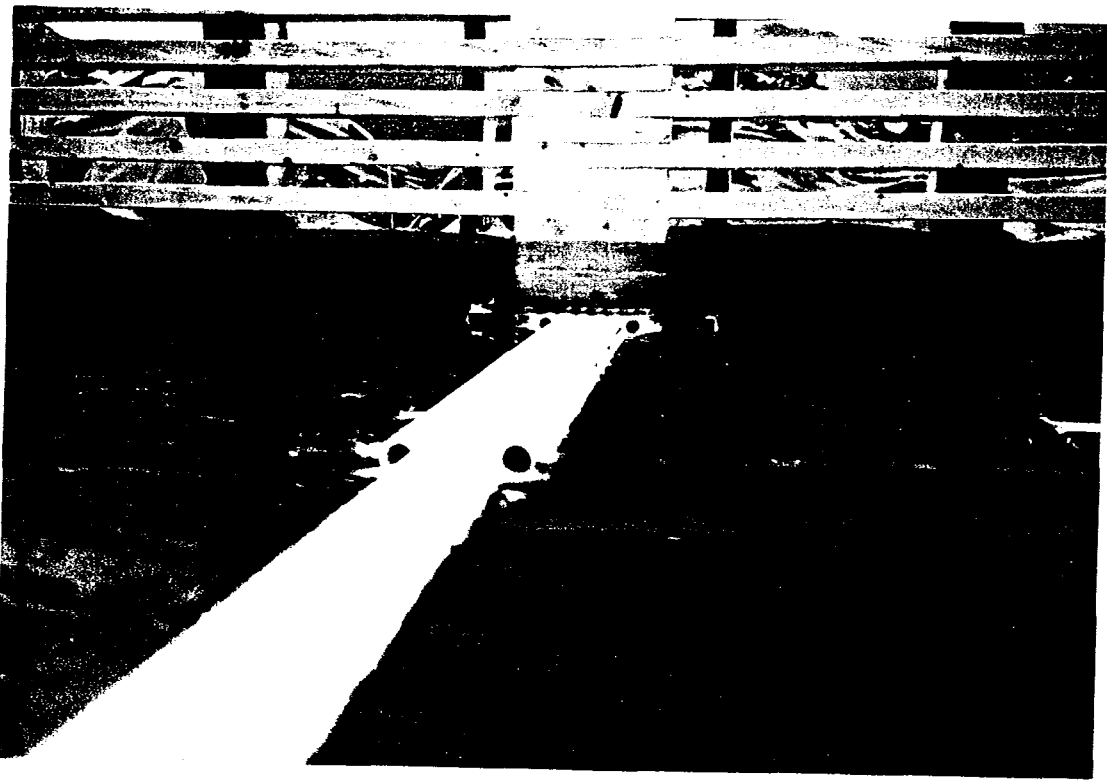
One of the two five year test heaps was covered with a six inch layer of till collected from an area adjacent to the adit. The till was used to intercept precipitation thereby reducing the amount of water percolating through the rock piles. Comparisons between the two five year test dumps should provide information on potential benefits of covering the dumps to control acid drainage.



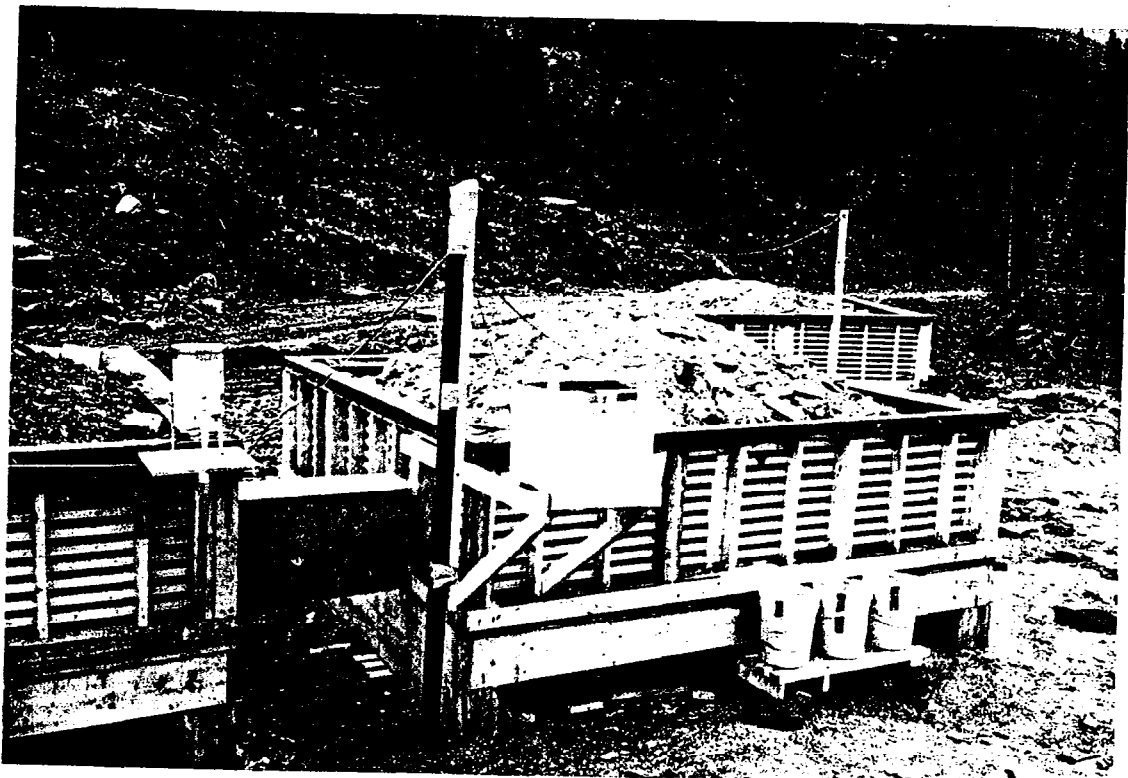
**Plate 6-3: Walls of the boxes were designed to permit natural circulation of air into the waste pile.**



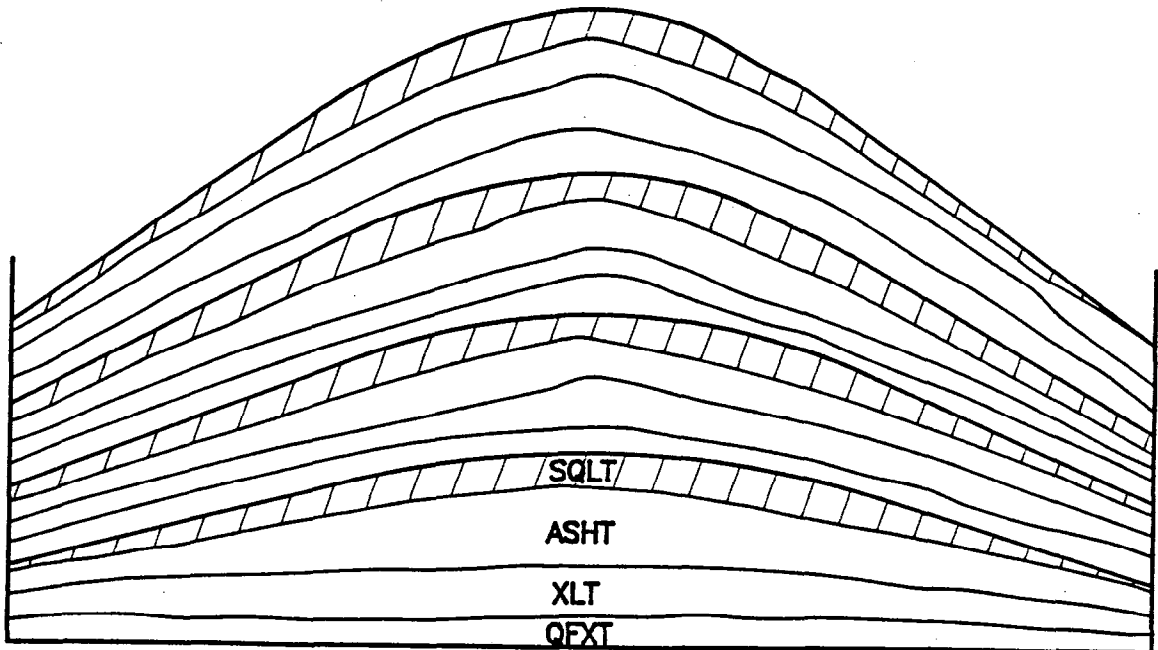
**Plate 6-4: The floor of each box was covered with a polyethylene liner, and was sloped to facilitate the collection of runoff.**



**Plate 6-5: Water collection system for sampling leachate from each lysimeter area.**



**Plate 6-6: Field scale humidity cells loaded with waste rock according to the anticipated waste rock production at the end of pre-production and after five years of mining. One of the five year test piles (left side of photo) was covered with a six inch layer of till to intercept precipitation.**



Each layer = one bucket lift = 1.8 tonnes

### Lithology

#### Footwall

SQLT- Sericite quartz lapilli tuff

#### Hanging wall

QFXT- Quartz feldspar crystal tuff

XLT- Crystal lapilli tuff

ASHT- Chert mafic ash tuff

Figure 6-5  
Schematic of Test Pile Showing Layered Blends

**Table 6-1**  
**Acid Generating/Acid Consuming Ratios of**  
**Preproduction and Five Year Blends**

Rock Type	# of Bucket Lifts	Tonnes <sup>1</sup>	NNP <sup>2</sup>	Weighted NNP (Tonnes X NNP)	Ratio (Acid Gen: Acid Consume)
<b>PREPRODUCTION</b>					<b>1:1.1</b>
<b>Acid Consuming</b>					
Crystal Lapilli Tuff	1	1.4	128.8	+180.3	
Quartz Feldspar Crystal Tuff	1	1.4	79.4	+111.16	
Chert, Mafic Ash Tuff	1	1.4	63.6	+ 89.04	
<b>Acid Generating</b>					
Sericite Quartz Lapilli Tuff	1/2	0.7	-473.4	-331.4	
<b>FIVE YEAR BLENDS</b>					<b>2:1</b>
<b>Acid Consuming</b>					
Crystal Lapilli Tuff	1	1.4	128.8	+180.3	
Quartz Feldspar Crystal Tuff	1	1.4	79.4	+111.16	
Chert, Mafic Ash Tuff	1/2	0.7	63.6	+44.52	
<b>Acid Generating</b>					
Sericite Quartz Lapilli Tuff	1	1.4	-473.4	-662.8	

<sup>1</sup> One bucket lift calculated to 2.7 tonnes/m<sup>3</sup> x 0.5m<sup>3</sup> = 1.4 tonnes.

<sup>2</sup> Phase II ABA results.

Pile temperatures were continually monitored with thermistors placed in the centre of the waste heaps. Ambient temperature was also monitored. A comparison of internal and external pile temperatures should give an indication of the presence of the exothermic acid generation reactions taking place. Tygon tubing was inserted into the center of each test pile to permit withdrawal of air samples. A portable gas analyzer was used during two site visits to measure the percent oxygen within the waste piles.

Rainfall at the Sumac adit site was monitored in 1990 by a tipping-bucket rain gauge.

### 6.4.1 Monitoring of Waste Rock Dumps

Phase III of the acid generation research program was designed to monitor the effects of blending potentially acid generating waste rock with potentially acid consuming waste rock in field scale test piles and to compare the results to those of the laboratory scale test of Phase II.

The effort in 1990 was directed toward the installation of pH probes which would continuously monitor pH of discharge from each of the test piles as well as a reference probe to monitor pH of rainwater. The pH data was collected over an 82 day period between July 18 and October 8, 1990. During each site visit, water samples were collected from a series of three vessels which were installed to collect leachate from each pile over a 30-day period.

In 1991, Phase III of the research program continued with further data collection followed by decommissioning of all on-site instrumentation. Data collected during 1991 included internal temperatures of each test pile, pH and water quality of leachate. Temperature data were continuously accumulated over a two year period beginning in late September 1989. Collection of pH data was limited to the summer-fall months of 1990 and 1991.

Water quality sampling was performed during site visits on seven separate occasions between September 1989 and October 1991.

Composite one litre water samples, containing water from each of the three water vessels installed at each test pile, were analyzed for indicators of acid generation such as pH, sulphate and metals.



Where discrepancies exist between field and laboratory pH values, the field value is used because laboratory pH often reflects disturbances such as degassing, iron oxidation/precipitation, and biological transformations during shipping and storage. Water quality sampling results are summarized in Section 7.2.2.2.

## **7 - Results**

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## 7.0 RESULTS

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Results of the various test procedures used in the Kutcho Creek research program and the outcome of investigations initiated prior to the beginning of research program are now presented, including results from acid base accounting, mineralogical analyses, laboratory humidity cells and field scale humidity cells.

### 7.1 Determination of The Potential For ARD

#### 7.1.1 Previous Testwork

Samples of Kutcho Creek waste rock were submitted to B.C. Research on two occasions during 1983 (February and September), for the evaluation of acid generation potential. In February, four composite samples, two of ore, one of waste rock and one of tailings, were sent to B.C. Research for an initial titration and acid confirmation test. Results of this test are discussed in a report prepared by B.C. Research for Sumac, February 1983. The test methodologies are included in Appendix A.

These tests showed the footwall waste rock was classified as the only acid producer (NNP-252.9; Table 7-1). Test samples of ore and the tailings composite, with high % sulphur, were classified as non-acid generators by biological confirmation tests.

The objective of the biological confirmation test is to determine if the sulphide-oxidizing bacteria can generate enough sulphuric acid from the sulphides present to satisfy the acid demand of the samples. As outlined in Appendix A, a known volume of sample is preconditioned with acid and inoculated with sulphide oxidizing bacteria (*Thiobacillus ferrooxidans*). Experience has shown that not all sulfide minerals are amenable to microbiological attack nor do they all oxidize completely, thus the acid production potential indicated by the sulphur assay may be excessive. If the bacteria generate acid, microbiological action will continue on a self-sustaining basis once it becomes established, and acidic mine water will result. However, because it is a fixed volume of sample, acid production will slow down or cease, at which time additional sample material is added. If there has not been sufficient acid production, the pH will approach the natural pH of the sample (i.e. above pH 3.5) and the sample is reported as not being a potential source of acid mine water. If the pH remains at 3.5 or below, the remainder

of the sample is added and it is shaken for up to 72 h before measuring the final pH. If the final pH remains at or below 3.5 there is a strong possibility that acid mine drainage will be produced.

**Table 7-1**  
**Previous Acid Generation Testwork (February 1983)**

Initial Acid Production Test					
Sample	Total %S	Paste pH	kg H <sub>2</sub> SO <sub>4</sub> /tonne		Potential Acid Producer
			Acid Production	Acid Consumption	
Drill Core (ore)	32.5	7.43	994.5	54.4	Yes
Test Feed	29.9	7.74	914.9	78.9	Yes
W-2 Footwall	8.6	7.22	263.2	10.3	Yes
Tailings	26.8	7.51	820.1	116.1	Yes
Confirmation Test					
Sample	Initial pH	pH after 0.5 x original weight	pH after 1.0 x original weight	Confirmed Acid Producer	
Drill Core (ore)	1.57	4.03	5.90	No	
Test Feed	1.79	5.63	-	No	
W-2 Footwall	1.63	1.76	1.48	Yes	
Tailings	1.72	5.42	-	No	

Tests conducted by B.C. Research February 1983.

For both the ore and tailings composites, the addition of sample resulted in a rapid pH rise which likely caused a "shock" effect on the bacteria. This is thought to have resulted from the substantial amount of carbonate minerals contained in the samples. In both cases, because of the high sulphur content, it was felt that over an extended period of time the bacteria may be able to adapt to these conditions and commence acid production (B.C. Research, February 1983).

In September 1983, seven split core waste rock samples were submitted to B.C. Research, only one of which, the footwall sample, was classified as a potential acid producer (Table 7-2). All the other samples, mainly rocks of the hanging wall, were classified as non-acid producers. Results of these tests are detailed in a report by B.C. Research, September 1983.

In 1985, after passing to Stage II Approval-in-Principle, further acid generation potential studies were completed, including detailed acid base accounting on 47 samples from three drill cores and two column leach tests on composite samples from the hanging wall and footwall. One column was established to represent the "sandwiched" footwall rock with hanging wall rock and the other column was set up as a control with just footwall rock.

This work generally confirmed the 1983 conclusions by B.C. Research concerning the acid consumption potential of the hanging wall and the acid generating potential of the footwall rocks. It was shown that there is a great deal of variability in the rock types, more than previously identified and this indicated generally lower potential acid generation and consumption values (Table 7-3).

### **7.1.2 Acid Base Accounting**

Acid base accounting (ABA) testwork was performed on two separate occasions over the course of the 1989-1991 research program. During Phase I, 22 rock samples representing the dominant rock types contained in the Sumac adit were collected and submitted for ABA analysis. Following completion of humidity cell tests, eight samples were selected for further ABA testwork. The eight samples selected were judged to be the most representative of their respective lithologies, based on pH and sulphate releases observed during humidity cell testing.

During Phase II, 50 rock samples were obtained for ABA testing from drill cores stored in open racks located on-site.

For ease of discussion, results of Phase I and II are presented together. Results of ABA test work are summarized in Tables 7-4 and 7-5.

**Table 7-2**  
**Previous Acid Generation Testwork**  
**(September 1983)**

Initial Acid Production Test					
Sample	Total %S	Paste pH	kg H <sub>2</sub> SO <sub>4</sub> /tonne		Potential Acid Producer
			Acid Production	Acid Consumption	
Quartz Eye Schist	0.011	9.39	0.34	64.2	No
Footwall	11.92	8.50	364.8	47.5	Yes
Mixed Hanging Wall	0.37	9.23	11.3	94.5	No
Amphibolitic Schist	0.045	9.29	1.4	85.3	No
Chlorite Sericite Schist	0.39	9.09	11.9	115.2	No
Mixed Hanging Wall and Footwall	1.97	9.10	60.3	93.6	No
Sericite Quartz Schist	0.99	9.09	30.3	78.9	No
Confirmation Test					
Sample	Initial pH	pH after 0.5 x original weight	pH after 1.0 x original weight	Confirmed Acid Producer	
Footwall	1.59	1.67	1.79	Yes	

Tests Conducted by B.C. Research, September 1983.

**Table 7-3**  
**Previous Testwork (1985)**  
**Acid Generation and Neutralization Potentials**  
**Based Upon Drill Cores KT55, KT85 and KT100**

Rock Type	n	Total S(%)			MPA kg CaCO <sub>3</sub> /tonne			NP kg CaCO <sub>3</sub> /tonne			NNP kg CaCO <sub>3</sub> /tonne		
		min	max	mean	min	max	mean	min	max	mean	min	max	mean
<b>Hanging Wall:</b>													
Meta-gabbro (AMP)	8	0.02	1.32	0.29	0.63	41.3	9.15	1.81	238	91.4	-39.1	235	82.3
Quartz crystal tuff (QES)	18	0.01	1.28	0.18	0.31	40.0	5.71	15.3	330	91.0	-16.1	326	85.3
Sericite quartz lapilli tuff (SQS)	5	0.03	4.76	2.12	0.94	149	66.4	4.51	729	191	-98.3	729	124.5
<b>Ore Zone:</b>													
Low grade ore (LGO)	2	12.8	19.7	16.2	400	616	508	9.25	178	93.8	-437	-391	-414
<b>Footwall:</b>													
Sericite quartz lapilli tuff (SQS)	12	0.50	14.0	6.82	15.6	437	213	1.58	252	64.0	-434	237	-149
Pale green schist (PGS)	1	2.11	2.11	-	65.9	65.9	-	93.5	93	-	27.6	27.6	-

MPA = Maximum Potential Acidity  
 NP = Neutralization Potential  
 NNP = Net Neutralization Potential

Work Performed by B.C. Research and reported in Norecol, 1985

**Table 7-4**  
**Results of Acid Base Accounting Tests**  
**(Phase I 1989)**

Sample	Sulphide (%)	Total Sulphur by LECO (%)	Paste pH	Acid* Potential	Neut.* Potential	Net* NP
<b>Hanging Wall:</b>						
<b>Meta-gabbro</b>						
88KA - 1	0.042	0.062	9.52	1.3	121.3	120.0
88KA - 2	0.032	0.045	9.72	1.0	66.5	65.5
88KA - 3	0.017	0.034	9.26	0.5	78.3	77.8
<b>Felsic ash tuff</b>						
88KA - 4	0.313	0.336	8.83	9.8	96.7	+86.9
88KA - 5	Negl.	0.010	8.68	0.0	160.9	+160.9
<b>Quartz feldspar crystal tuff</b>						
88KA - 6	0.111	0.114	9.17	3.5	10.2	+6.7
88KA - 7	0.051	0.058	9.29	1.6	7.4	+5.8
88KA - 8	0.023	0.060	9.38	0.7	22.7	+21.7
88KA - 9	0.028	0.028	9.51	0.9	9.9	+9.0
88KA - 10	Negl.	0.006	9.32	0.0	21.7	+21.7
88KA - 11	0.278	0.288	9.11	8.7	105.2	+96.5
<b>Crystal lapilli tuff</b>						
88KA - 12	0.012	0.019	9.27	0.4	242.5	+242.2
88KA - 13	0.449	0.456	9.01	14.0	241.1	+227.1
<b>Chert, mafic ash tuff</b>						
88KA - 14	3.85	3.86	7.96	120.2	164.8	+44.6
<b>Sulphide ore zone:</b>						
88KA - 16	34.0	34.0	7.78	1061.8	200.0	-861.8
88KA - 18	33.8	33.8	6.39	1054.3	85.3	-969.0
88KA - 19	22.1	22.1	8.01	689.2	292.0	-397.2
88KA - 20	37.2	37.2	7.69	1160.5	186.0	-974.5
88KA - 21	34.8	34.8	7.22	1085.3	124.0	-961.3
<b>Footwall:</b>						
<b>Quartz sericite lapilli tuff</b>						
88KA - 15	8.59	8.62	8.12	268.3	531.8	+263.5
88KA - 17	8.06	8.20	5.35	251.7	13.5	-238.2
88KA - 22	15.4	15.5	6.00	480.3	18.3	-462.0

\*Potentials expressed in kg CaCO<sub>3</sub> equivalent per tonne of rock.

Note: A negative NET NEUTRALIZATION POTENTIAL (NNP) indicates that the sample is a potential source of acid mine drainage.



**Table 7-5**

**Summary of Acid Base Accounting Testwork (Phase II 1990)**

Rock Type	n	Paste pH			Total S(%)			MPA kg CaCO <sub>3</sub> /tonne			NP kg CaCO <sub>3</sub> /tonne			NNP kg CaCO <sub>3</sub> /tonne		
		min	max	mean	min	max	mean	min	max	mean	min	max	mean	min	max	mean
<b>Hanging Wall:</b>																
Meta-gabbro	7	8.5	9.5	8.9	0	0.55	0.15	0	17	4.7	99	300	187	94	294	182
Quartz feldspar crystal tuff	15	5.7	9.6	8.85	0	16.5	1.33	0	516	41.6	3	566	121.1	-513	553	79.4
Crystal lapilli tuff	8	7.4	9.4	8.8	0	6.84	1.73	0	214	54.4	22	422	183	-145	421	129
Chert mafic ash tuff	5	8.8	9.4	9.12	0	0.186	0.08	0	6	2.8	42	141	66.4	38	138	63.6
<b>Ore Zone:</b>	8	6.5	9.0	7.73	0.07	46.9	17.4	2	1,470	629	2	311	93.9	-1,385	309	-482
<b>Footwall:</b>																
Sericite quartz lapilli tuff	7	5.7	8.2	7.28	2	36.2	17.0	63	1,130	553	1	181	60.1	-955	54	-473

NP = Neutralization Potential  
 NNP = Net Neutralization Potential  
 MPA = Maximum Potential Acidity

Samples originating from the ore zone and footwall contained sulphur ranging from 8.20% to 37.2% by weight. The majority of the sulphur was present as sulphide, which when present as pyrite ( $\text{FeS}_2$ ) can be acid generating (Table 7-5). Sulphide concentrations in each of the major waste rock types on the hanging wall side of the orebody were relatively low by comparison to the ore zone and footwall waste rock. Most of the hanging wall rocks exhibited a significant ability to neutralize acid, as evidenced by their positive NNP values, while the rest had limited acid consuming capacity and are considered to be potentially acid generating (Figure 7-1). Samples with high acid generation potential, particularly from the ore zone, have either relatively inactive sulphide minerals, or have sufficiently high levels of neutralizing minerals to keep the paste pH well above 5.0 (Figure 7-2).

Paste pH values were observed to be greater than 6.0 for all but the footwall with the exception of one ore and one hanging wall sample. This suggests that reactive carbonate minerals are present in the majority of the hanging wall and ore zone samples.

A close relationship exists between paste pH, neutralization potential (NP) and carbonate content (Figures 7-3 and 7-4). This relationship indicates that a significant level of carbonate is present and reactive and was manifested in an alkaline pH which ranged between 6 to 9 in all samples. Generally, the carbonate content of the rocks accounted for most of the NP (Figure 7-4).

Relationships between paste pH, net neutralization potential (NNP) and maximum potential acidity (MPA) indicated that samples with high levels of sulphur were no more reactive than those with less reported sulphide (Figures 7-1 and 7-2). This was commonly noted in the ore samples. Prior oxidation in these rocks was indicated by their low paste pH values.

No relationship was noted between ABA parameters and hole location, suggesting that acid generating behaviour is most closely related to rock type.

#### *7.1.2.1 Conclusion*

The potential for acid generation, based on these results, was in agreement with results of ABA testwork done in 1983 and 1985 by Norecol and B.C. Research.

# Kutcho Creek Project

## Acid Base Accounting (Phase I and II)

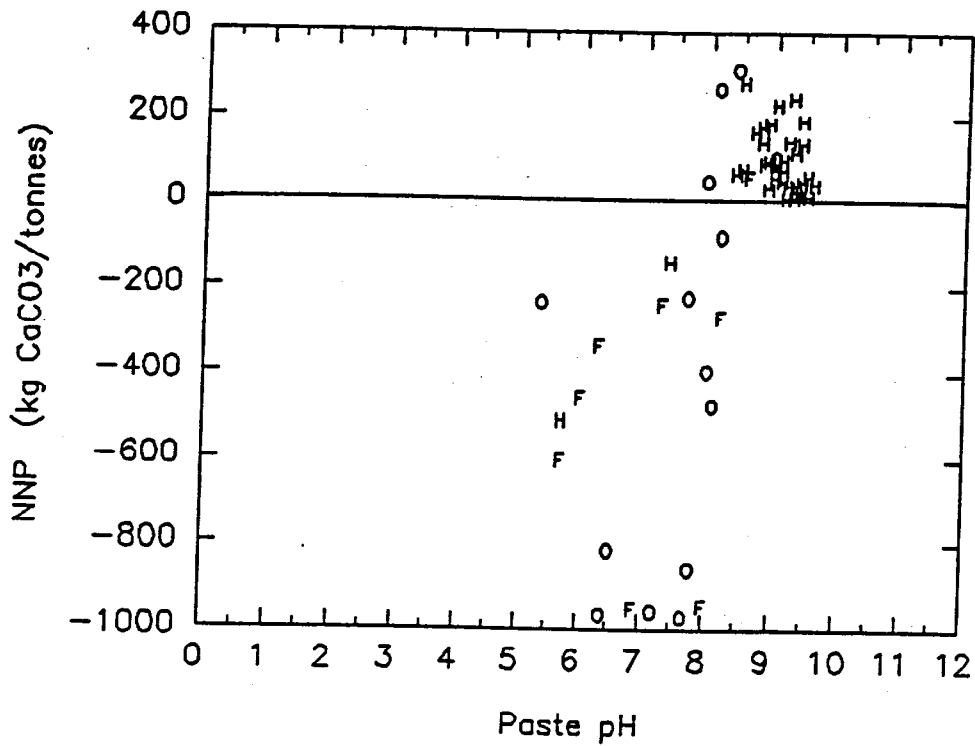


Figure 7-1: Net Neutralization Potential vs. Paste pH

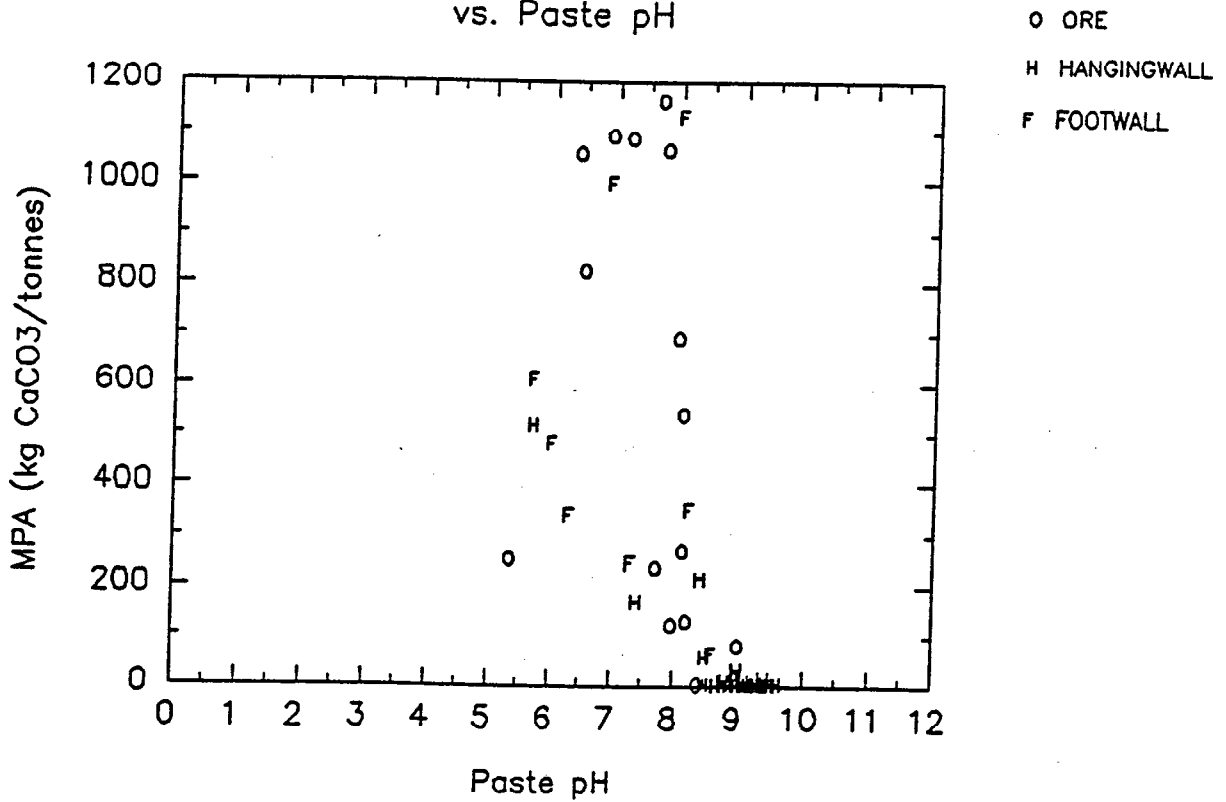


Figure 7-2: Max. Potential Acidity vs. Paste pH

# Kutcho Creek Project

## Acid Base Accounting

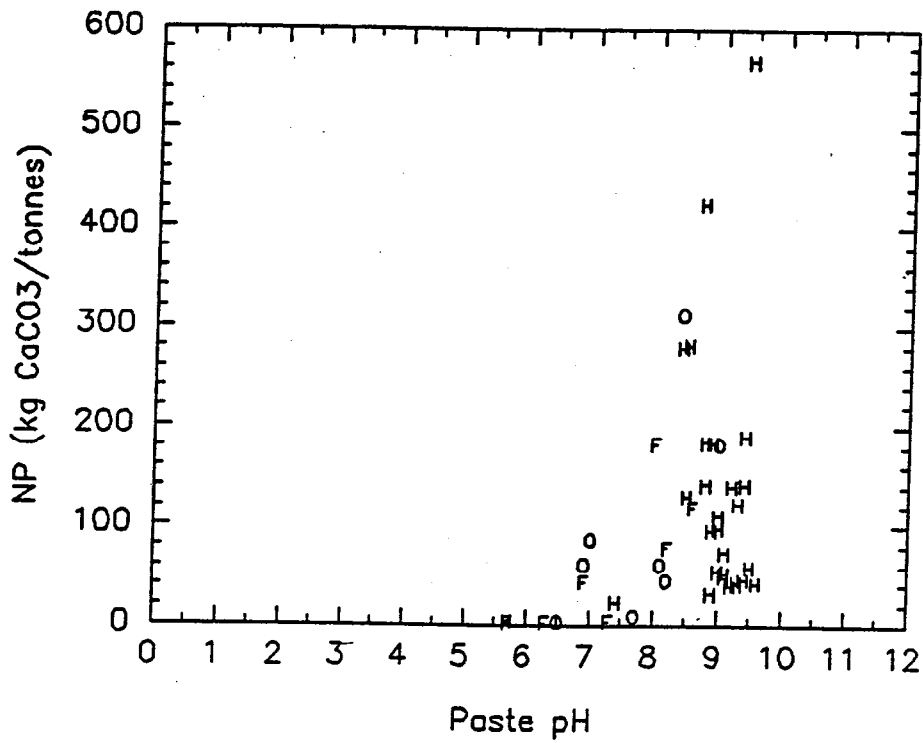
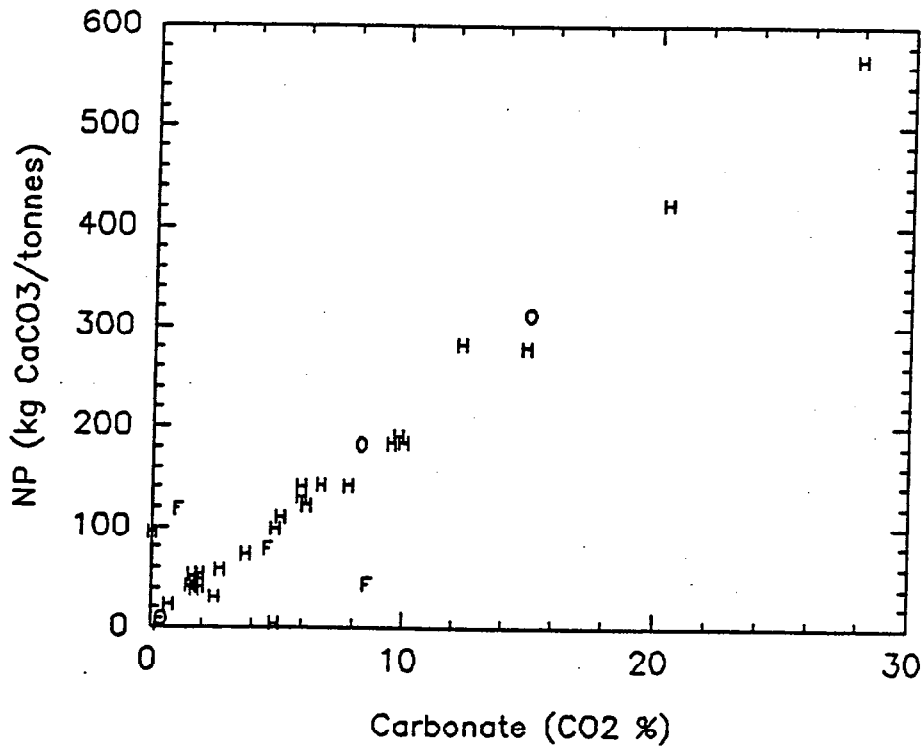


Figure 7-3: Neutralization Potential vs. Paste pH



O ORE  
H HANGINGWALL  
F FOOTWALL

Figure 7-4: Neutralization Potential vs. Carbonate

A study done by Ferguson and Morin (1990) generally concluded that, based on limited data, the mean NNP value would be accurate in predicting the potential for ARD; therefore, negative NNP values for the Kutcho footwall rock, indicate the potential to generate acid and the positive NNP values for the hanging wall rock have indicated the potential to consume acid.

Although the majority of NNP values for the hanging wall samples were positive, the range of values (-513 to 553 kg CaCO<sub>3</sub>/tonne) indicates that acid generation is probable within some zones of the hanging wall rocks.

### **7.1.3 Mineralogical Investigation**

Results from the petrographic study indicated that the rocks represented in the Sumac adit consisted of metamorphically recrystallized tuffs flanking a chert/carbonate exhalite sequence with disseminated and massive sulphides.

Pyrite contained in many of the Kutcho samples was found in a variety of forms and crystal structures. Fine-grained pyrite was found in the ore zone and adjacent rock units, particularly in the footwall siliceous tuff. Crystal straining, or anomalous anisotropy, was evident in some crystals and most pronounced in the footwall siliceous pyritic tuff.

Crystal straining is caused when pyrite undergoes physical stretching and straining. Crystals, as such, would be expected to oxidize at a greater rate than pyrite crystals which are well formed, euhedral and unstrained which are considered relatively stable and comparatively nonreactive.

A substantial carbonate context, predominantly dolomite with localized development of calcite and siderite, was found in rocks of the hanging wall and the massive sulphide ore zone.

Following is a brief summary of the mineralogical studies presented by rock type. Table 7-6 provides a summary of mineralogical composition and modal distribution.

**Table 7-6**  
**Summary of Mineralogical Investigation**

<b>Rock Type</b>	<b>Minerals (in order of decreasing abundance)</b>	<b>Carbonate Content</b>	<b>Potential of ARD</b>
<b>Hanging Wall:</b>			
Meta-gabbro (88KA1-3)	Plagioclase crystal clasts, biotite, amphibole, and epidote in a matrix of felsitic plagioclase, quartz, sericite.	2-5 % (principally calcite). One sample contained roughly 30% quartzite, of which 10% carbonate was present.	No
Felsic ash tuff (88KA4-5)	Fine-grained, siliceous and felsitic aggregates (quartz/plagioclase), sometimes with sericite, carbonates, limonite.	3-20 % (primarily calcite) 3% carbonate for sample 88KA-4, 20% for sample 88KA-5.	No
Quartz feldspar crystal tuff (88KA6-11)	Homogenous unit composed of a felsitic quartzo-feldspathic matrix with sericite, and containing coarse relict crystal clasts of plagioclase and quartz. Epidote in minor quantities.	Trace-2 % (calcite, ankerite).	No
Crystal lapilli tuff (88KA12-13)	Quartz (phenocrysts and ground mass), plagioclase (albitized), sericite (moscovite), carbonate (calcite), epidote, chlorite.	18-26 % (primarily calcite, ankerite and siderite) 18% carbonate for sample 88A-12, 26% for 88KA-13.	No
Mafic ash tuff (88KA14)	Quartz, chlorite, sericite, carbonate, pyrite, plagioclase.	7 % Carbonate as random permeations, granular pockets and porphyroblast-like clumps in the chert.	No
<b>Sulphide Ore Zone</b> (88KA-16, 18-21)	55-75% sulfides, with a gange of dolomite and quartz. Sulphides consisting of pyrite chalcopyrite, spharelite, bornite and digenite, in various proportions, plus traces of tetrahedrite and galena.	13-50 % (predominantly dolomite with minor siderite).	Yes
<b>Footwall</b> Quartz sericite lapilli tuff (88KA-15, 17, 22)	Dolomite, quartz, sericite, chlorite, chalcopyrite, pyrite, traces of spharelite, tetrahedrite and galena.	Trace of carbonates in 88KA-17 and 88KA-22. 57% dolomite in sample 88KA-15. (Dolomite not as reactive as calcite to acid test).	Yes

### *7.1.3.1 Mineralogical Descriptions*

#### *Meta-Gabbro*

These samples were composed primarily of plagioclase crystal particles, biotite, amphibole and epidote in a matrix of plagioclase. The overall character of the rock has been described as a metamorphic greenstone.

Carbonate minerals in the meta-tuff phase were present at 2-5% and were determined to be principally calcite. One sample contained approximately 30% quartzite, of which 10% carbonate was present as patches or bands of intergrowth within the quartz. These grains are anhedral in shape ranging up to 0.2 mm in size, and presumed to be either ankerite or siderite ( $\text{FeCO}_3$ ). Limonite staining of the carbonate minerals was also noted.

#### *Felsic Ash Tuff*

The fragments making up these samples included fine-grained, cherty aggregates, which grade to, or are intercalated with, felsitic minerals composed largely of plagioclase which constitute 52% of the rock; sericite is also present within the quartz-feldspar aggregates.

Up to nearly 20% of the carbonate present is fine-grained intergrowths and patchy segregations (up to 1.0 mm in size) which may occur as thin wisps intergrown with sericite. Some of the carbonate is extensively limonitized, whereas other carbonate is clear and colourless. The limonitization may have been caused by irregular weathering along joints and fractures on an iron-rich carbonate, or may simply be a distinct carbonate. Limonite may also be present as goethite. Effervescence of the carbonates which occurred on contact with dilute acid and suggests that the carbonate is calcitic; subsequent X-ray diffraction tests confirmed the presence of calcite and ankerite.

#### *Quartz Feldspar Crystal Tuff*

Probably derived from a quartz feldspar porphyry, the predominant minerals, quartz and feldspar, are crystals of 0.2-2.0 mm in size scattered through a fine-grained felsitic matrix with interstitial flecks of sericite. Plagioclase making up the groundmass, is albitized, and shows some replacement by epidote grains up to 0.5 mm diameter.

Carbonate presence is very minor (1-2%), occurring as rare, small pockets and veniform gashes. Both clear, low-relief calcite and finer, cloudy limonite-stained ankerite have been noted.

Some small euhedral grains of pyrite were also observed within a lens of mosaic quartz. The presence of rare, scattered euhedral grains of pyrite up to 1.0 mm in diameter was also noted, along with some chalcopyrite, sphalerite, bornite and galena. The sulphides did not appear to have undergone oxidation.

#### *Crystal Lapilli Tuff*

These samples appear to have been derived from the same quartz-feldspar porphyry as the crystal tuff, but have undergone more intense alteration. No plagioclase is recognizable, but some quartz phenocrysts of 1.0 to 2.0 mm are still evident. Sericite is abundant as fine flakes (0.05 mm long) which have replaced the groundmass. Pyrite was observed (1%) as clusters of well formed, individual cubes.

This rock, although similar to the felsic crystal tuff in texture and mineralogy, has a much higher carbonate content (18-26%) than the aforementioned. The carbonate occurs as irregular pockets and intergrowths of relatively coarse granular mosaic texture (grains up to 1.0 mm and larger). It is located within fine foliaceous variants and is also interstitial to the feldspar crystal clasts in the tuff. Carbonate minerals were also intimately associated as granular intergrowths with quartz. For the most part, the carbonates were clear and relatively coarsely crystalline. Their reactivity with dilute acid strongly suggests that much of the carbonate is in the form of calcite; although some carbonate with limonitic staining (presumably a ferruginous carbonate, such as ankerite or siderite) also reacted with acid. The X-ray diffraction spectrum shows a major peak close to the position for calcite and a minor peak for dolomite.

#### *Mafic Ash Tuff*

This rock exhibits the same general characteristics as the previous tuffs, including sericitic and fine felsitic/quartzitic minerals and recrystallized granular aggregates. This sample contains less recognizable feldspar and more abundant exhalative intercalation along with what has been tentatively identified as chlorite.

Carbonate is present as porphyroblast-like grains and granular pockets and is moderately abundant (7%). Disseminated sulphides are also a significant component



(5%) and occur in all the mineralogical lithotypes. Primarily, these constitute pyrite as individual grains ranging in size from a few microns to 0.5 mm. Traces of chalcopyrite and sphalerite are also present, although generally independent of the pyrite.

*Dolomite Breccia (within ore zone)*

Petrographic examination indicates that carbonate is the major constituent (57%). The carbonate, however, was found to be relatively non-reactive with dilute acid and was confirmed through X-ray diffraction to be dolomite which occurs as anhedral mosaic aggregates from 0.05-0.5 mm in size.

Disseminated sulphides, such as pyrite and chalcopyrite are abundant and range up to 2.0 mm in size. The chalcopyrite is also present as coarser segregations, often with subhedral grains of pyrite included, although pyrite is present as individual grain clusters. The complete freshness of the sulphides amongst the carbonate and carbonate/quartz aggregates have no features which would explain any unusual susceptibility to oxidation; however, anomalous anisotropy was noted, indicating that this pyrite could be more reactive due to the straining of the crystal structure.

*Massive Sulphides*

The ore zone is composed predominantly of sulphides for which pyrite is the dominant mineral. The grains are 0.02-0.5 mm in size, polygonal in shape and are aggregated as compact mosaics. Some anisotropy in pyrite crystals was reported. Chalcopyrite and sphalerite tend to form an interstitial network phase within the pyrite aggregate, suggesting that they are recrystallized components. Some samples also included bornite, digenite, galena and chalcocite.

The principal gangue mineral is interstitial carbonate (13-29%), which occurs as granular aggregates of grain size 0.05-0.3 mm. Carbonate minerals are of two types: clear low-relief calcite and cloudy, high relief dolomite or ankerite. X-ray diffraction has identified the carbonate to be a mixture of calcite and dolomite present as monomineralic fragments, suggesting a well-segregated mode of occurrence in the rock. Interstitial quartz and sericite also make up the groundmass.

### *Quartz Sericite Lapilli Tuff*

This sample was reported as a yellowish coloured intensely quartz-sericite-carbonate altered rock with complete destruction of any of its former igneous texture. Occasional quartz phenocrysts are still recognizable but show strong alteration at their margins to coronas of sericite and recrystallized quartz which has undergone straining.

Rock fragments were composed of microgranular aggregates of quartz grains ranging in size from 0.03-0.15 mm, with well-oriented, interstitial flakes of sericite up to 0.1 mm long. The sericite forms the groundmass and has a definite preferred orientation, defining a foliation. The aggregate is probably a recrystallized chert, as evidenced by portions of shaley intercalations in weakly schistose siliceous aggregate.

Sulphides are almost entirely pyritic, occurring as sporadic clusters and strings of partially coalescent subhedral to euhedral individuals, 0.01-0.5 mm in size. These are scattered liberally throughout the altered rock, together with small quantities of chalcopyrite and sphalerite. Much of the pyrite is present as liberated, angular, monomineralic fragments which may have fragmented from thin compact pods and lenses. Generally, the pyrite is fresh, homogeneous and is often locked within a tight siliceous host without any apparent indication of unusual susceptibility to oxidation. However, anomalous anisotropism (crystal distortion) was observed in the pyrite through reflected-light examinations of polished sections.

#### *7.1.3.2 Summary of Mineralogical Investigation*

The footwall and hanging wall samples generally include a variety of rock types of felsic volcanic affinities; these include ash tuffs, crystal tuffs and lapilli tuffs. These are in turn overlain by a mafic volcanic or meta-grabbro.

Mineralogy is dominated by quartz and feldspar. The principle accessory minerals include sericite, carbonates and pyrite.

The presence of sericite and carbonate minerals suggest the parent rock, presumably a variation of a quartz-feldspar porphyry, has metamorphically undergone a pervasive alteration and recrystallization.

The mineral which has a direct effect on acid generation capacity is carbonate. Carbonate minerals (principally calcite) showed a significant presence in most samples ranging from 2-57% of the sample.

All of the samples contained sulphides. The sulphides consisted mainly of pyrite with minor occurrences of chalcopyrite, sphalerite, bornite and galena.

Pyrite was found in a variety of crystalline forms which appear to have varying degrees of reactivity. Some pyrite was observed as well-formed, or euhedral, crystals which are relatively stable and non-reactive. However, the presence of subhedral and anhedral pyrite was also noted; pyrite in these forms has a higher reactivity, and would be expected to weather faster than euhedral pyrite. Anomalous anisotrophism, or crystal distortions caused because the pyrite has undergone physical stretching and straining, was observed in the footwall rock. The pyrite in this rock is expected to be more reactive because the crystal bonds between the exposed atoms on the surface of the pyrite are likely significantly weaker than those within well-formed isotropic pyrite.

There was little or no evidence of oxidation in any of the samples which were examined.

#### *7.1.4 Laboratory Humidity Cells (Non-Blended)*

Laboratory humidity cell testwork was performed for Phase I and II of the research program. Phase I humidity cell testwork involved separate examination of all of the rock types found in the adit. Phase II testwork dealt with blends of acid-consuming and acid generating waste rock to simulate the three large-scale (20 tonne) pads. Results of Phase I humidity cell testwork (non-blended) are presented below. Results of Phase II laboratory humidity cell testwork (blended) are detailed later in Section 7.2.1.

Twenty-two samples representing the major rock types intersected in the Sumac adit were examined in the Phase I humidity cell tests. Results for leachate quality during humidity cell testing are presented in Appendix B.

For the purpose of predicting acidic drainage, the parameters of most interest in humidity cell tests are pH and sulphate. Weekly pH values give insight to the state of competition between acid generating and acid neutralizing reactions in the sample. If the pH has become strongly acidic, the rate of the acid generating reaction has overwhelmed any neutralization potential, and will continue to do so until the acid generating material has been completely oxidized or until an acid control technique has

been implemented. If the pH is near neutral, the acid consuming reactions are dominant and will continue to maintain the pH until all reactive carbonate minerals are exhausted. At this point, the pH will begin to decrease if the rate of acid generation has not declined.

#### *7.1.4.1 pH*

The pH value of leachate from samples taken from the hanging wall zone ranged between 6.99 to 8.89 during the 20-week test cycle (Figure 7-5). Leachates for samples from the footwall showed acid generation demonstrated by lower than neutral pH with ranges in pH value from 2.94 to 7.67. The initial rinse at week one produced pH values as low as 2.94 due to the release of previously stored acid products. Following this rinse the pH values became more regular at around 4.5. The consumption of aluminum hydroxide based minerals probably accounts for the partially neutralized pH between 4 and 5; if so, the pH should drop below 4 if the humidity cell test had been extended beyond 20 cycles, until the time when the aluminum hydroxide minerals were completely consumed.

The pH of samples from the ore zone were observed to vary between 5.27 and 7.76 throughout humidity cell tests. The ore zone, based on ABA testwork, shows appreciable sulphide content which would be expected to generate acid. However the near neutral pH values indicate that carbonate minerals were available and reactive, and were neutralizing acids produced through oxidation. Calcite, dolomite and ankerite were identified in the petrographic studies as being the principle carbonate minerals capable of acid neutralization (Section 7.1.3).

The most significant difference in acid generation that was observed between the footwall and hanging wall rocks is that the pH values for the footwall rocks were much lower and showed a decreasing trend towards the end of the sample period.

#### *7.1.4.2 Sulphate*

Sulphate is an oxidation product of acid generation. As such, it reflects the weekly rate of acid generation in the humidity cells provided that sulphate is the only form of sulphur in the leachate, that all accumulated sulphate can be rinsed from the sample, and that the concentration of sulphate in the leachate is not limited by gypsum precipitation. Consequently, sulphate is generally a better initial indicator of acid

## Non-Blended Laboratory Humidity Cells

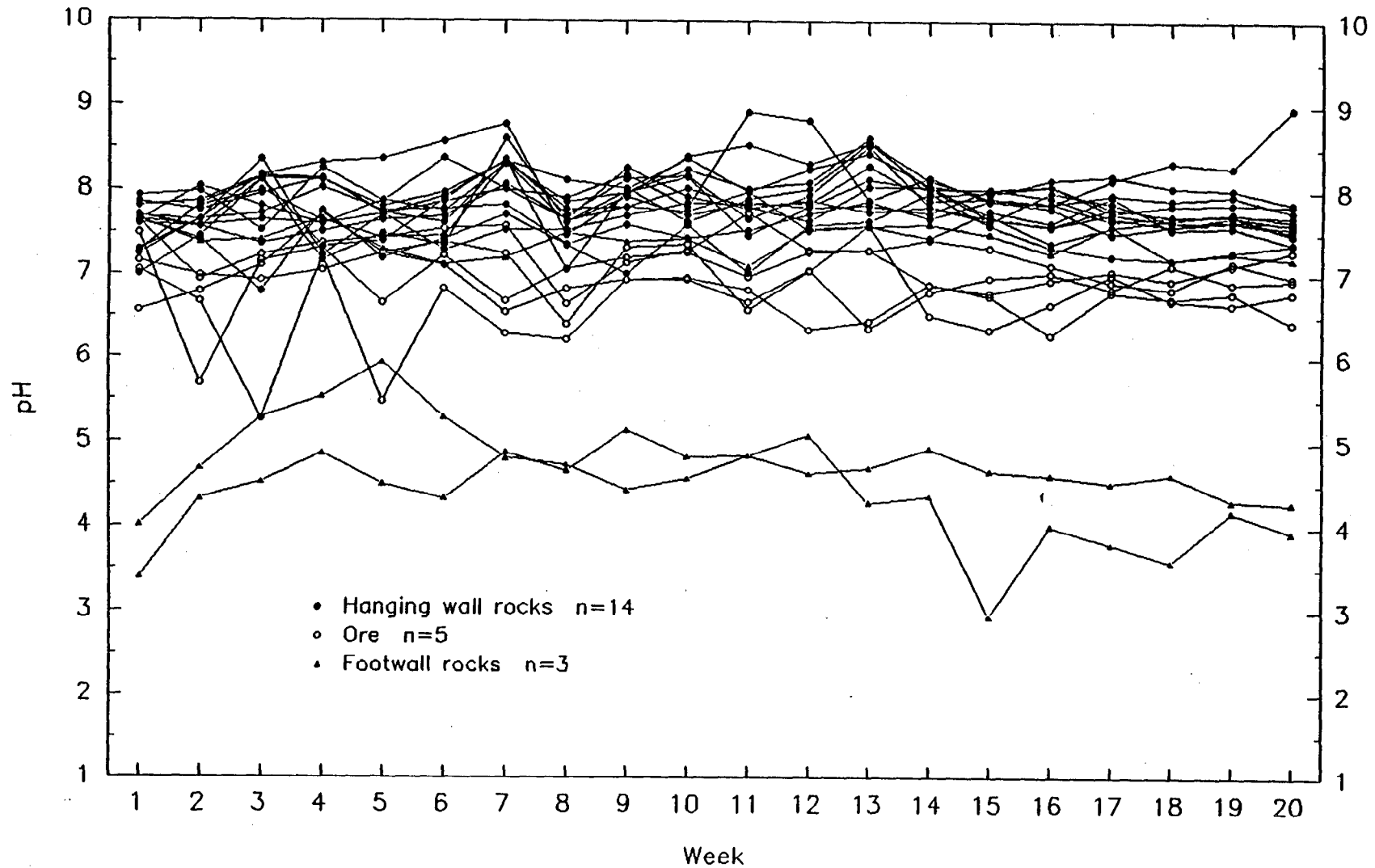


Figure 7-5: Weekly cycles of pH for Phase I Humidity Cell Tests

production than general parameters such as pH or metal release. Sulphate production from the hanging wall rock samples were generally low through the 20-cycle tests with an average production of 0.63 mg SO<sub>4</sub>/100 g of rock (Table 7-7). Sulphate production from the footwall rocks averaged 20.0 mg SO<sub>4</sub>/100 g over the 20 week cycle. However, the hanging wall rocks released a greater percentage of the total sulphate potential than the footwall and ore samples. This suggests the sulphides present were readily available and were exposed when the rock samples were crushed for the humidity cell testwork.

For the footwall and ore zone samples, previously accumulated sulphate was released during the initial rinse (Figure 7-6 and 7-7). The hanging wall rocks showed little sulphate release indicating minimal previous acid generation. One footwall sample showed a significant acceleration in acid generation, peaking at 35 mg SO<sub>4</sub>/100 g in weeks 6 through to 15, followed by a decline in acid generation to 18 mg SO<sub>4</sub>/100 g. This trend may be attributed to the gradual removal of the more reactive, fine grained sulphide minerals through oxidation, leaving the less reactive sulphides which would result in a lower acid generation rate.

Small variations in sulphate release between samples of the same rock type may be due to the particle size distributions of the samples following crushing. Samples with a higher proportion of fine material have a larger surface area, and thus have higher quantities of freshly exposed sulphides. Oxidation of these sulphides could proceed at a faster rate and cause the appearance of higher acid generation potential. Results can be normalized with respect to surface area by expressing sulphate release relative to surface area. Accordingly, estimates of surface areas have been computed, and are presented in Table 7-7 along with normalized values for the sulphate releases which were measured.

The results indicate that surface area did not have a large effect on the overall rate of oxidation over the 20 week test period (Figure 7-8). The trends of sulphate release are similar to Figure 7-6.

Based on the study by Ferguson and Morin (1991) the pH and sulphate results show the hanging wall rocks belong to the typical Type Ib-Alkaline category and the footwall rocks may be classified as Type II-Acid. Type Ib behaviour, which is the most common, typically produces a neutral pH with sulphate production high in the beginning and decreasing towards the end (convex curve). An explanation for the decreasing sulphate is as follows; the initial rinse of the cycle releases previously accumulated sulphate

**Table 7-7**  
**Average Weekly Sulphate Production**  
**Rates for Non-Blended Laboratory Humidity Cells**

Sample	Surface Area (m <sup>2</sup> /kg)	Sulphate Production			Mean sulphate Concentration (mg/L)	Sulphate per m <sup>2</sup> (mg/m <sup>2</sup> )
		Weekly Average (mg/100gm)	Total (mg/kg)	% of Total <sup>a</sup>		
<b>Hanging Wall:</b>						
<b>Meta-gabbro</b>						
88KA-1	9.3	0.5	93	7.4	10	0.50
88KA-2	7.0	0.4	78	8.1	8	0.56
88KA-3	7.3	0.4	89	12.5	4	0.61
<b>Felsic ash tuff</b>						
88KA-4	6.2	0.6	119	1.7	11	0.95
88KA-5	5.6	0.2	38	-	2	0.34
<b>Quartz feldspar crystal tuff</b>						
88KA-6	5.5	1.0	190	5.7	15	1.72
88KA-7	6.1	0.2	36	2.4	2	0.29
88KA-8	4.6	0.2	44	6.4	2	0.47
88KA-9	4.6	0.1	24	2.9	1	0.26
88KA-10	4.0	0.4	84	-	4	1.04
88KA-11	4.1	1.2	246	3.0	17	3.03
<b>Crystal lapilli tuff</b>						
88KA-12	6.3	0.3	50	13.9	2	0.40
88KA-13	5.5	0.3	65	0.5	2	0.59
<b>Chert, mafic ash tuff</b>						
88KA-14	7.0	3.0	601	0.5	35	4.29
<b>Sulphide ore zone:</b>						
88KA-16	7.7	8.1	1626	0.1	120	10.5
88KA-18	8.4	6.5	1307	0.1	110	7.78
88KA-19	10.2	10.4	2076	0.3	170	10.2
88KA-20	10.6	14.3	2866	0.3	200	13.5
88KA-21	10.6	16.8	3356	0.3	250	15.8
<b>Footwall:</b>						
<b>Quartz sericite lapilli tuff</b>						
88KA-15	10.2	7.5	1496	0.6	100	7.36
88KA-17	5.6	20.5	4107	1.7	230	36.8
88KA-22	5.5	32.0	6404	1.4	500	58.3

**a: Amount of sulphate produced as % of total theoretical sulphate if all sulphur converts to sulphate.**

## Non-Blended Laboratory Humidity Cells

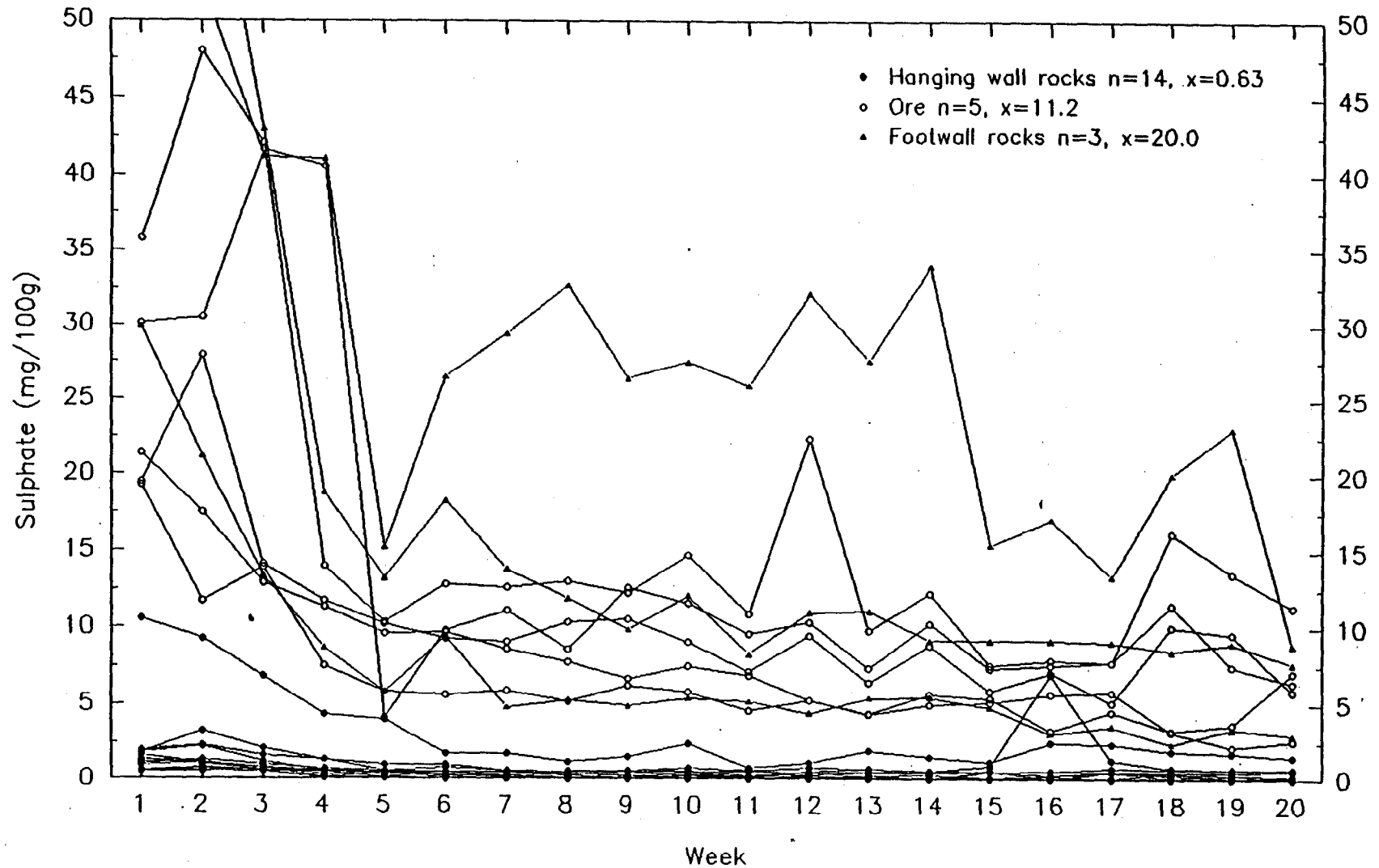
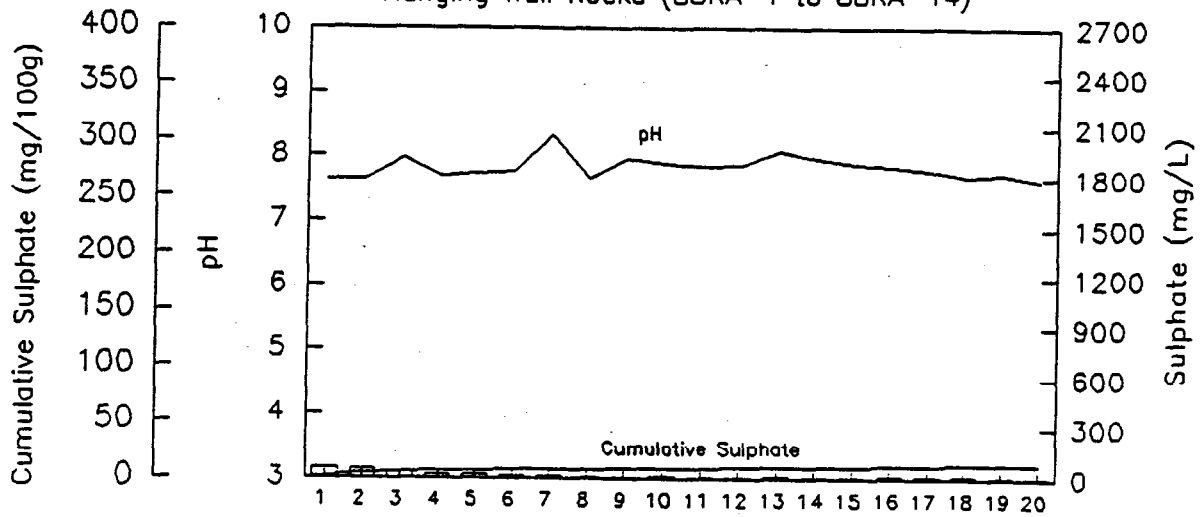


Figure 7-6: Weekly Cycles of Sulphate from Phase I Humidity Cell Tests

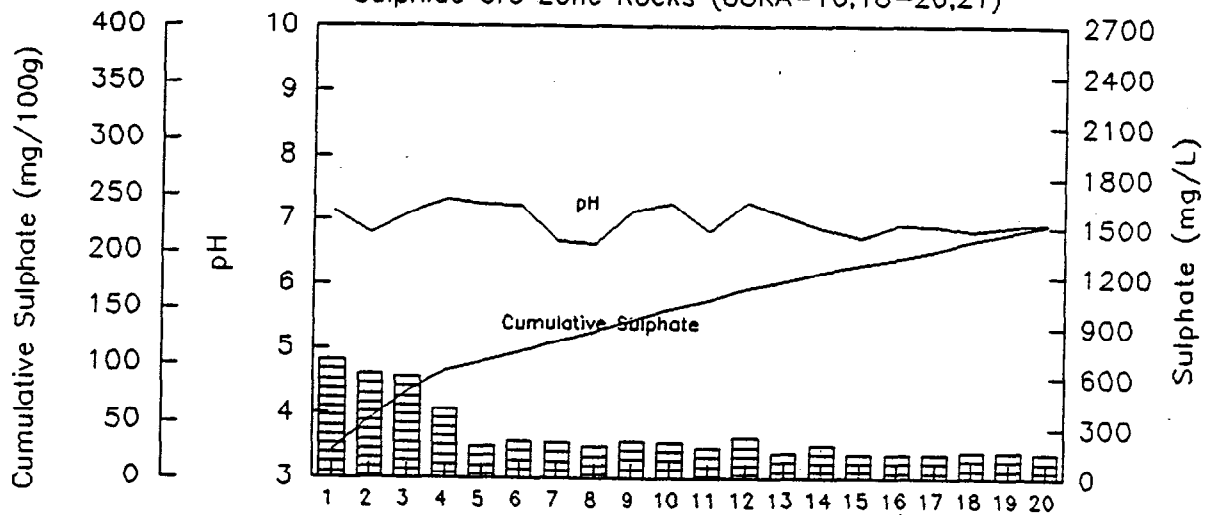


### Non-Blended Laboratory Humidity Cells

Hanging Wall Rocks (88KA-1 to 88KA-14)



Sulphide Ore Zone Rocks (88KA-16,18-20,21)



Footwall Rocks (88KA-15,17,22)

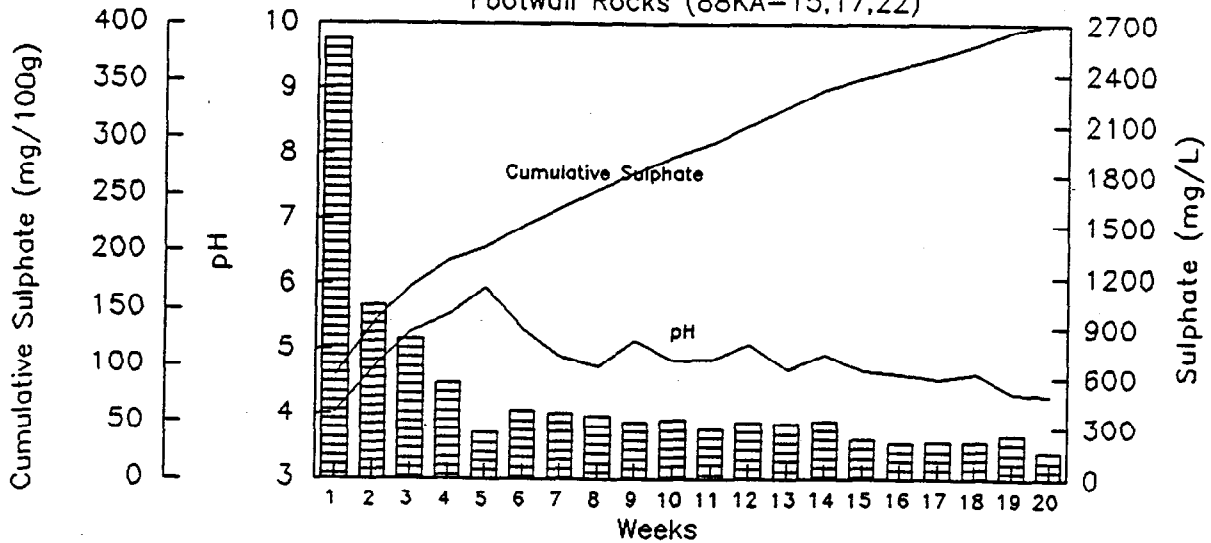


Figure 7-7 Weekly Cycles of Cumulative Sulphate, Sulphate and pH.



## Non-Blended Laboratory Humidity Cells

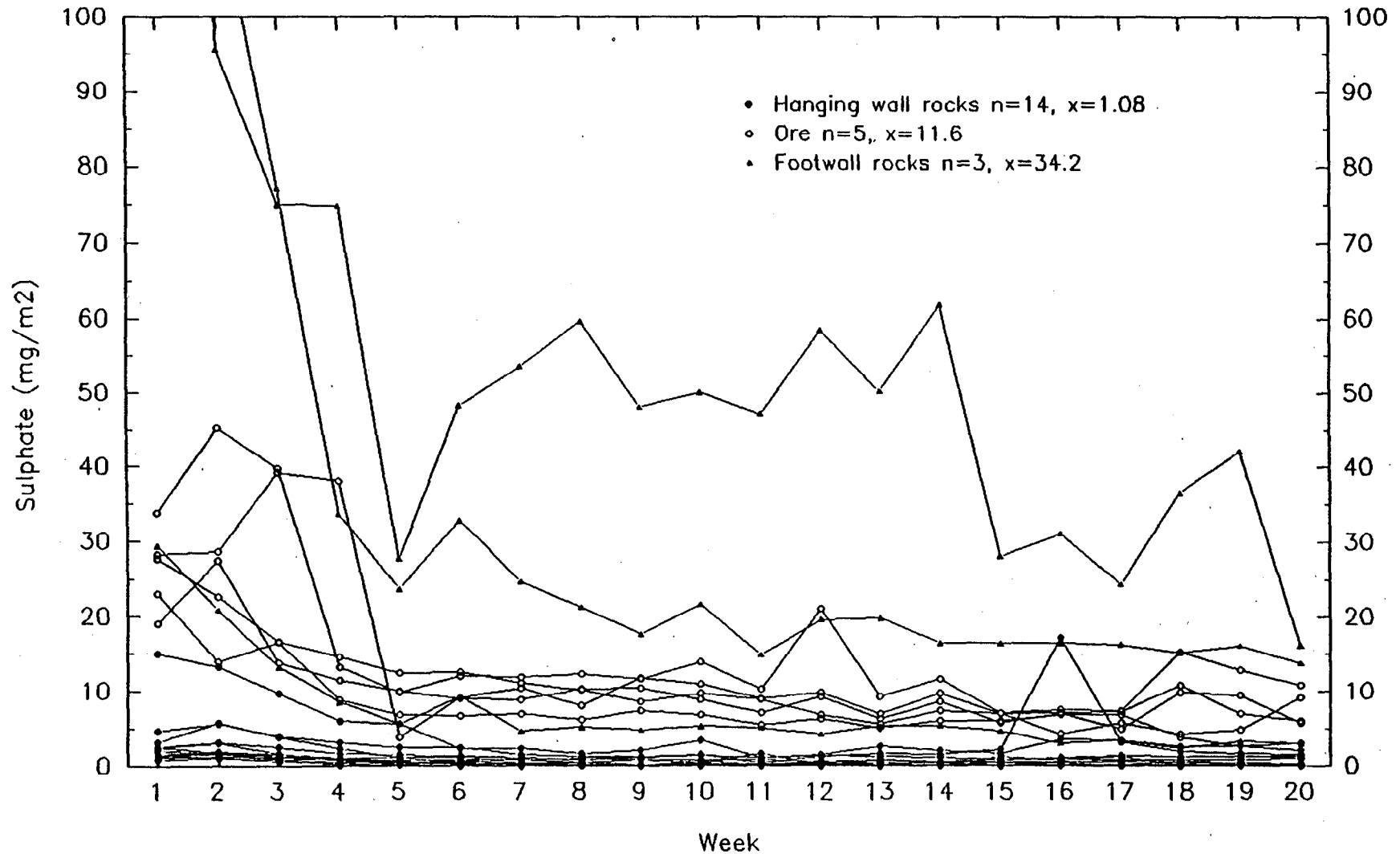


Figure 7-8: Weekly Cycles of Sulphate Normalized to Surface Area for the Phase I Humidity Cell Tests

products; as the oxidation proceeds, a weathering rind may develop and/or coatings of secondary minerals may form on sulphide surfaces which will decrease available reactive surfaces. The rate of sulphate production, as previously discussed, would involve the variations in reaction rates with sulphide morphologies and crystal sizes. As detailed by Ferguson and Morin, the relative reactivity of sulphide minerals can be examined by comparing sulphate production rates. Based on the available database, three categories have been assigned: high, medium and low. Phase I studies agree with the results from Ferguson and Morin in that the samples with a very high percentage of sulphide exhibit low reactivity (Figure 7-9). This is because not all the sulphur is available for reaction, either because the crystals are large, or all contain massive sulphides versus disseminated.

#### *7.1.4.3 Metals*

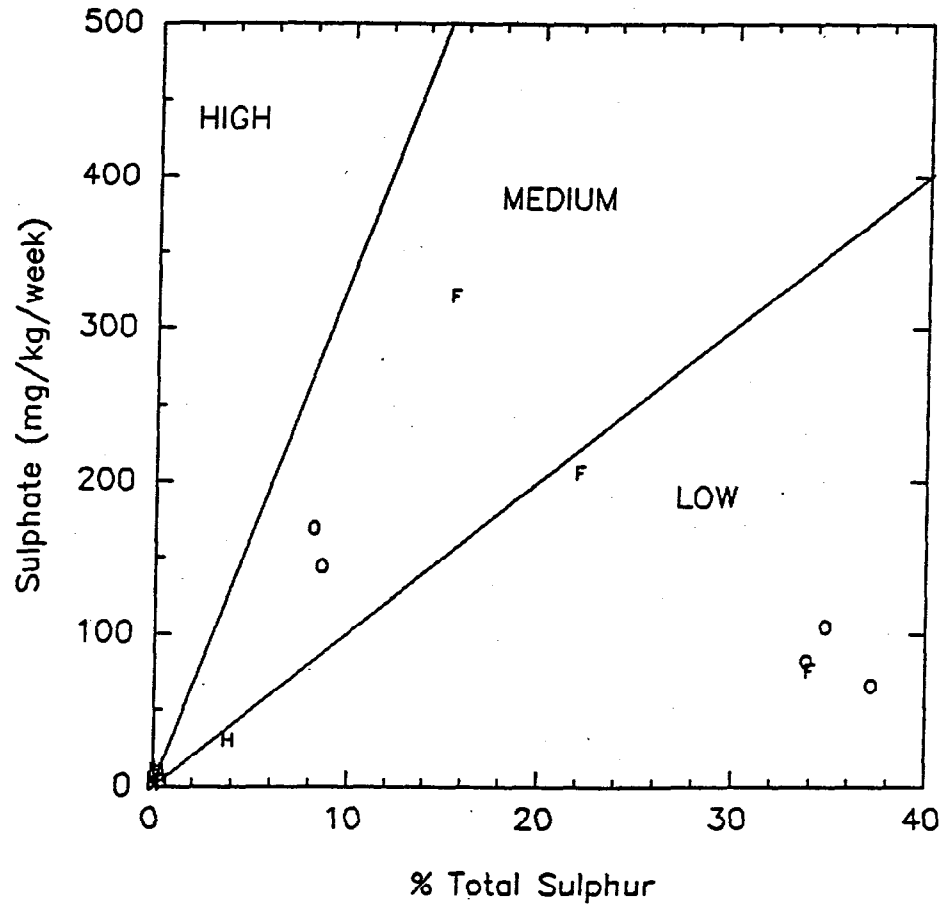
Metal concentrations in leachates from rock samples undergoing humidity cell testing typically vary as much as an order of magnitude between weekly cycles. Without extensive examinations of crystal structures and intensive quality-assurance procedures, the reasons for such variations cannot be ascertained. In any case, metal leaching is often most appropriately interpreted by examining the total metal releases over the 20 cycle tests and in observing general trends, rather than by interpreting week-to-week variations. Table 7-8 summarizes metals released from the laboratory humidity cells during each week for the 20 weeks of testwork. Figure 7-10 graphically shows the trends in metals releases.

Background concentrations of metals in rinse water used can confound the interpretation of metals in humidity cell leachates, particularly when these metals are present in very low concentrations. Although deionized distilled water is recommended for rinsing, contamination caused by impurities in tap water can be substantial, even if tap water has been distilled. Laboratory data indicate that rinse water was occasionally contaminated during humidity cell testing of Kutcho Creek samples.

#### *Aluminum*

Aluminum release in humidity cell testing is known to be pH controlled. Aluminum is released if leachable aluminum is made available during grinding of the sample or by

# Kutchko Creek Waste Rock



- H Hanging wall
- o Ore
- F Footwall

Figure 7-9: Sulphate vs Total Sulphur

**Table 7-8**  
**Non-Blended Laboratory Humidity Cells**  
**Average Total Metals Released (mg/L)**

Week of Cycle	Rock Type		
	Hanging Wall	Ore Zone	Footwall
1	0.17	23.8	636
2	0.19	5.91	52.3
3	0.10	5.76	30.0
4	0.08	5.00	15.1
5	0.07	3.84	6.59
6	0.23	3.89	9.87
7	0.12	2.79	12.1
8	0.08	3.55	9.44
9	0.06	3.06	10.7
10	0.06	3.02	8.12
11	0.10	4.04	8.45
12	0.07	3.54	5.31
13	0.10	3.14	6.60
14	0.09	5.58	4.99
15	0.13	5.04	6.83
16	0.29	3.20	7.02
17	0.10	2.40	8.93
18	0.11	3.87	28.5
19	0.12	5.55	16.8
20	0.06	3.97	7.08

**Note:** Hanging wall rocks includes samples 88KA-1 to 88KA-14.  
Sulphide ore zone includes samples 88KA-16, -18, -19 to -21.  
Footwall rocks includes samples 88KA-15, -17 and -22.

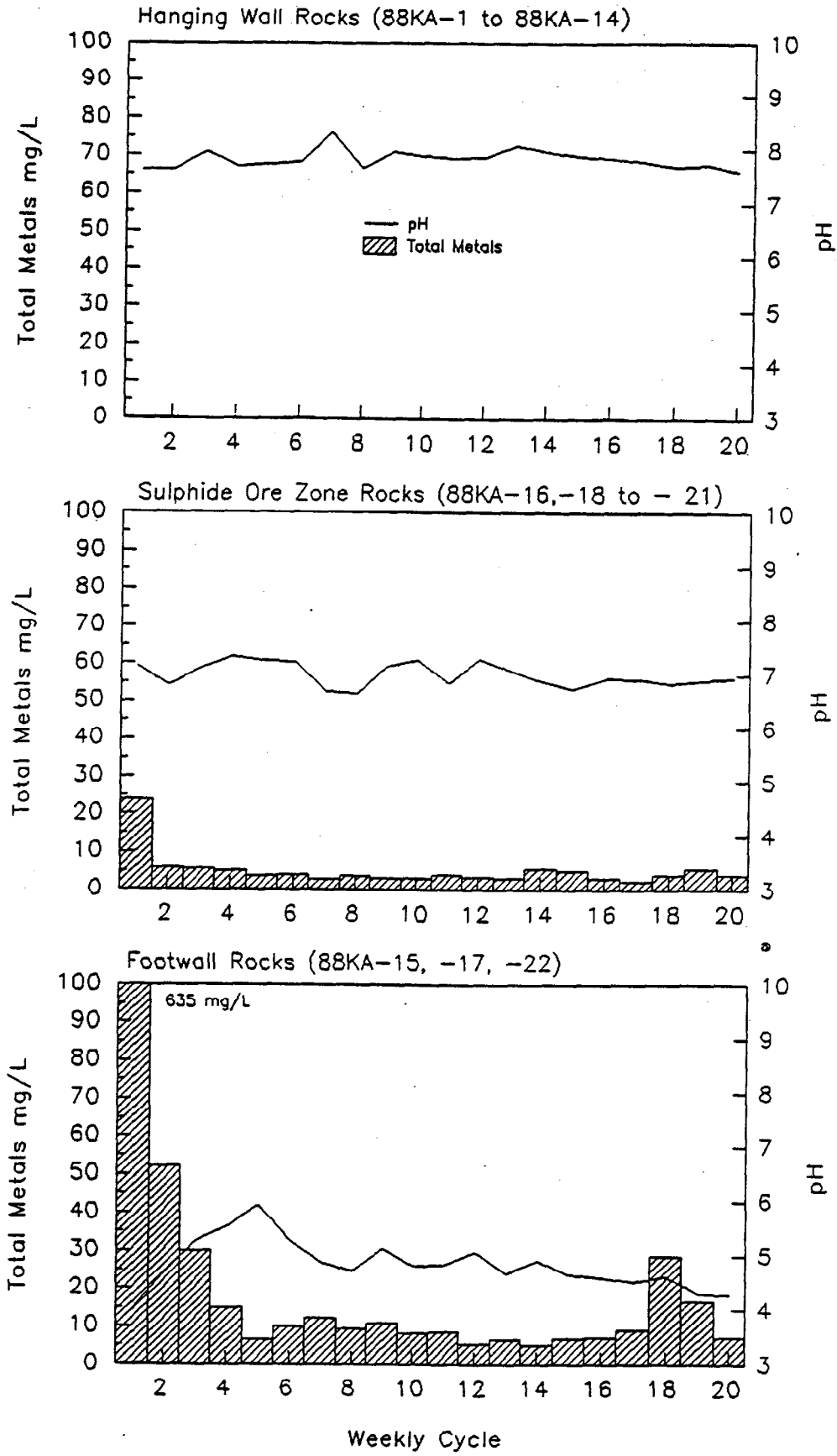


Figure 7-10: Weekly Cycles of Average Total Metals and Average pH for Non-Blended Laboratory Humidity Cells



prior weathering. In general, rinse water from hanging wall samples contained between 30 and 90  $\mu\text{g/L}$  aluminum per cycle. Rocks from the ore zone released virtually no aluminum, and laboratory analyses were always near the detection limit of 5.0  $\mu\text{g/L}$ .

The release of aluminum by the footwall waste rock sample was evidence that aluminum release is strongly pH dependent. The initial rinse, containing 8,320  $\mu\text{g/L}$  of aluminum at relatively low pH, was followed by 11 cycles in which the release was less than 30  $\mu\text{g/L}$  at higher pH. When the pH was observed to eventually fall below 4.0-3.5, weathering in the rock was accelerated, and aluminum levels in rinse water rose considerably to a high of 2,830  $\mu\text{g/L}$  on week 18.

In addition to pH, aqueous complexes can affect metal concentrations in the rinse water. The formation of aluminum-sulphate complexes from the sample could have contributed to higher aluminum levels in rinse water; however, sulphate concentrations in rinse water have not increased with aluminum, suggesting that this enhancement of aluminum leaching was not significant.

### *Arsenic*

Rinse water from hanging wall rock samples contained between 0.5 and 3.5  $\mu\text{g/L}$  arsenic per cycle. For the most part, there were no identifiable trends in arsenic release during the 20 cycle tests; data were variable up to an order of magnitude.

Rocks from the footwall and from the ore zone released relatively low quantities of arsenic, ranging between 0.1 and 0.3  $\mu\text{g/L}$ , on average. However, substantial quantities of arsenic were released when the pH dropped below its plateau of 4-5.

### *Cadmium*

Although several samples demonstrated a small initial washout, cadmium concentrations in all of the hanging wall samples were below the detection limit of 0.2  $\mu\text{g/L}$ . Ore and footwall waste have a much higher cadmium washout. The washout does not appear to have been caused by oxidation of sulphide minerals containing cadmium, since there is no comparable sulphate release which could be correlated to the observed cadmium levels. The highest cadmium concentrations observed were in an ore sample, which averaged 90  $\mu\text{g/L}$ .

### *Copper*

Copper concentrations in cell rinse waters exhibited large variations in many of the humidity cell tests. Many large peaks generally obscure results and render mean values almost meaningless.

Of the meta-gabbro samples, mean copper releases are in the order of 0.4-4.0  $\mu\text{g/L}$ , when peak values are omitted. Similarly, the remaining hanging wall samples average 1.0-15.0  $\mu\text{g/L}$  copper in rinse water. All but four of the hanging wall samples exhibited their highest concentration of copper on cycle six. The peak concentrations ranged from 14-380  $\mu\text{g/L}$ , suggesting that an analytical error or cross-sample contamination in the laboratory is more likely accountable than contamination in rinse water.

Copper concentrations in rinse water from samples of ore was highly variable, ranging from 70-300  $\mu\text{g/L}$ , excluding peak concentrations. The highest peaks observed were 2,450  $\mu\text{g/L}$  and 2,780  $\mu\text{g/L}$ , although the latter can be attributed to washout in cycle 1.

Footwall rocks leached significant levels of copper during the initial washout of the samples and throughout the duration of the test. Washout values corresponded to 208 and 345  $\mu\text{g/L}$  due to prior oxidation and acid generation. Rinse waters from the footwall rocks remained highly variable and demonstrated some obvious correlation with pH. When the measured pH was above 6.0 the copper concentration was at its minimum (670  $\mu\text{g/L}$ ), however, when the pH dropped below 4.0 during cycle 15 copper levels rose steadily until cycle 18 when they reached 37,500  $\mu\text{g/L}$ .

### *Iron*

Iron in solution is usually a product of iron-sulphide oxidation. However, iron responds readily to complex solid-liquid and aqueous reactions such as oxidation-reduction, hydrolysis and precipitation-dissolution. The solubility of iron minerals is primarily dependent on pH and redox potential. Consequently, low iron concentration in rinse water from a waste rock sample cannot be taken as evidence that the sample has a low acid generation potential.

Very few of the hanging wall rock samples released measurable concentrations of iron into the rinse water solutions. Meta-gabbro rocks produced quantities in the range of 15 to 126  $\mu\text{g/L}$ , but these releases began after cycle 10, for the most part. Footwall rocks, however, demonstrated high levels of first-flush iron which was liberated during prior



oxidation. Acidic cycle 1 rinse waters contained up to 319 mg/L of iron. Following a pH drop to 3.0 in cycle 15 the footwall again produced high levels of iron (up to 17.2 mg/L), reflecting a strong dependence on pH, as discussed.

### *Lead*

Virtually none of the hanging wall waste rock samples produced rinse waters containing detectable quantities of lead. Samples from the ore zone have released varying quantities of lead up to 220 mg/L, which would probably correlate with their galena content.

Rinse waters from the footwall samples generally had higher lead concentrations during the final 10 weeks of the humidity cell tests averaging 4.5 and 10  $\mu\text{g/L}$ . The reason that lead releases were increasing throughout the duration of the tests is likely related to the gradual pH decline over time, leading to accelerated weathering.

### *Manganese*

Minerals containing manganese include oxides, hydroxides and carbonates and sulphides. Consequently, the liberation of manganese from rocks undergoing weathering can occur from many different minerals. The oxidation of sulphide minerals containing manganese, such as hauerite ( $\text{MnS}_2$ , which is isostructural with pyrite), could be deduced if rinse waters contained both manganese and sulphate. However, acid generation in the sample could also cause dissolution of neutralizing carbonate minerals bearing manganese, such as rhodochrosite ( $\text{MnCO}_3$ ). In any case, correlations of manganese with sulphate and pH are common.

Generally, there is some correlation between sulphates and manganese in rinse waters from the hanging wall samples. Sulphate washout from prior oxidation was evident in the majority of these rocks during the initial 2-3 weeks, and is typically accompanied by elevated manganese concentrations in the range of 17-340  $\mu\text{g/L}$ . Following washout however, manganese levels normally decline to average concentrations in the range of 3-22  $\mu\text{g/L}$ .

Rinse water from samples taken from the ore zone and footwall display a similar pattern of elevated manganese levels in the initial washout, followed by lower, stable manganese concentrations in subsequent weeks. For ore zone samples, initial washout values were in the neighborhood of 3,000-4,600  $\mu\text{g/L}$ , and these were followed by more stable

weekly manganese liberations of 400-2,000  $\mu\text{g/L}$ . Washout levels from the footwall material were considerably higher at 37-44 mg/L due to prior oxidation.

### *Mercury*

Mercury, commonly associated with pyrite, marcasite, stibnite and sulphides of copper, was liberated from the hanging wall rocks. None of these samples exhibited a first flush of mercury. In fact, the first instance of mercury above the detection level occurred in cycle six. For the most part, mercury levels measured after week 6 ranged between 0.05-0.30  $\mu\text{g/L}$ .

Generally, mercury concentrations in rinse waters from ore zone and footwall samples were highly variable between cycles. Peak values were between 0.3 and 0.45  $\mu\text{g/L}$ , except for one occurrence of mercury at a concentration of 2.2  $\mu\text{g/L}$ , which was observed on week 3 from an ore sample. Weekly background concentrations of mercury in rock of the ore zone and footwall more commonly averaged between 0.01 and 0.08  $\mu\text{g/L}$ .

### *Zinc*

The principal zinc-bearing mineral in the Kutcho deposit is sphalerite ( $\text{ZnS}$ ), and it is predominantly associated with the pyrite in the ore zone. Rinse waters of hanging wall samples rarely contained detectable concentrations of zinc, although some washout of zinc in cycles one and two was evident. Zinc levels in leachates from ore and footwall samples are higher and range between 100 and 7100  $\mu\text{g/L}$  on average, excluding major peaks. For the most part, the highest zinc concentrations observed in rinse water occurred in the first rinse at cycle one. Analyses of initial rinse waters from ore samples gave results of 4.5-49.4 mg/L, and for footwall waste rock this figure is increased to 125 mg/L and 502 mg/L. Clearly, this is evidence of prior oxidation.

#### *7.1.4.4 Conclusions*

The rate of acid generation and sulphate production in humidity cell tests has demonstrated that the rate of acid production is not a function of net neutralization potential (NNP). Samples with the most negative NNP (ranging from -238 to -969 t  $\text{CaCO}_3$  eq/1000 t), from the massive sulphide ore zone, were found to be lower acid-producers than was the footwall material. Footwall rock, for example, had

intermediately negative NNP values of -238 and -462 t CaCO<sub>3</sub> eq/1000 t, and yet, were much higher acid producers in humidity cell tests. This result is not surprising, but serves to illustrate that actual acid production is likely dependent on the mineralogy and crystallinity of the pyrite contained in a rock sample, and on the surface area available for oxidation.

Neutralization potential in the footwall rock appears to be largely unreactive. Total neutralization potential for the footwall rocks were in the range of 15-20 t CaCO<sub>3</sub> eq/1000 t. Petrographic analyses performed on the footwall rocks have identified dolomite and ankerite as the most abundant carbonate minerals. Dolomite (calcium-magnesium carbonate) has been recognized as having very slow reaction kinetics when exposed to acid. Similarly, ankerite, an iron-calcium carbonate with limited neutralization potential within the 5-6 pH range, is not highly reactive. Neither of these minerals reacted with dilute hydrochloric acid during the petrographic studies, either before or after humidity cell testing. These results are confirmed by paste pH results from footwall rocks, which indicated that prior acid generation in the sample had not been neutralized. It is likely that a proportion of the neutralization potential in each of the rock types is similarly unreactive. However, paste pH's were sufficiently high in the hanging wall rocks to suggest that the neutralizing minerals in these rocks units are reactive.

Many of the rock samples exhibited a washout of sulphate and metals during the first few cycles of the humidity cell tests. This is due to oxidation and acid generation of the samples which may have occurred before the channel samples were cut from the walls of the adit. Additionally, there is the possibility that the pyrite had been slowly generating acid *in-situ* prior to any physical disturbance caused by mining/exploration activities.

The rates of sulphate production and metal release do not appear to be largely influenced by the sizes of the particles making up the samples. Normally, a waste rock containing reactive sulphides oxidizes more rapidly if the sample is crushed into fine particles because of the large surface area which is available for oxidation. One possible explanation for small surface area effects could be a reduction in air circulation within the humidity cell which may result from a particularly fine-grained sample. Air may short-circuit through the sample material, taking the path of least frictional resistance. It is plausible that this could result in slower oxidation of the sulphides despite a samples' high surface area. However, a more plausible explanation concerns the crystallinity of pyrite.

Pyrite was found in a variety of crystalline forms which appear to have varying degrees of reactivity. Large grained crystals and massive intergrown crystals exhibited low reactivity because much of the particle is unavailable for oxidation.

Fine-grained pyrite (raspberry-like aggregates of tiny spherical particles of pyrite) was not observed in petrographic studies, but the sulphate releases observed in some humidity cell tests may suggest the presence of framboidal pyrite, which is known to oxidize rapidly in kinetic testing.

Similar to sulphate production, metal leaching was found not to be highly dependent on a sample's available surface area. A chemical equilibrium between the solids and the water retained on the surface of the particles appears to control the metal leaching, creating an aqueous concentration which is independent of surface area and time. Time-dependent kinetic reactions are likely only operative until equilibrium is attained.

## **7.2 Examination of Blending**

Two varieties of humidity cell tests were performed using blends of acid generating and acid consuming waste rock to determine if blending would be a suitable AMD mitigation option. Humidity cell tests were performed: 1) in the laboratory using one kilogram of blended waste rock for each humidity cell, and 2) at the Kutcho site using 20 tonnes of blended waste rock for each plot. Results of the blended humidity cell tests are now presented, beginning with the laboratory testwork.

### **7.2.1 Laboratory Blended Humidity Cells**

Laboratory humidity cell testwork was carried out to complement the large, field scale testwork. Blending ratios were identical to those used in the field. The test methodology was identical to that discussed previously.

To assess how well the blending of waste rocks controlled acid drainage the leachate water quality was monitored each week for the 20 week duration of the humidity cell tests. The parameters of concern for the leachate water quality monitoring were pH, sulphate and total metals. A brief description of the trends in leachate water quality is now presented.

### 7.2.1.1 pH

During the 20 week test the leachate pH from all the blended samples remained slightly higher than neutral and fluctuated, at most, one pH unit (Figure 7-11). This was an indication that acid production was offset by neutralizing minerals in the samples. By comparison, pH of the unblended footwall sample showed a continuous decrease in pH as the neutralizing minerals were consumed (Figure 7-7).

### 7.2.1.2 Sulphate

As mentioned previously, sulphate is an oxidation product of acid generation and, therefore, reflects the weekly rate of acid generation in the humidity cell.

Large quantities of sulphate from all cells were released during the first few cycles of humidity cell tests (Figures 7-12 and 7-13). In the preproduction blend and five year blend (covered) the overall acid generation rates, as indicated by sulphate production, showed a gradual decline to 2.5 mg/100 g SO<sub>4</sub> after week 13. The five year blend (uncovered) released sulphate showing minimal acid generation in weeks 7 and 8; that was followed by an acceleration of acid generation peaking at 8.5 mg/100 g SO<sub>4</sub> in weeks 9 through 15, then down to a gradual decline to less than 4.5 mg/100 g SO<sub>4</sub> by week 20. By week 20, all blends were showing a slight increase in sulphate production. The summary of sulphate production rates for all blends is given in Table 7-9.

Results of these tests show the category of acid generation to be a Type Ib (Ferguson and Morin 1991), in which any generated acid is being successfully neutralized and the oxidation rate is gradually decreasing.

By comparison, the average rate of sulphate production or acid generation from the unblended footwall sample was 35 mg/100 g SO<sub>4</sub> for the 20 cycle test which is a factor of 5 higher than the worst-case blended sample (Table 7-9).

The average sulphate release of each blend was normalized with respect to surface area. Particle size distribution analysis was performed on each rock type during Phase I and was calculated as a weighted proportion for each blend. Surface areas were computed and are presented in Table 7-9.

The results show that surface area did not have an appreciable effect on acid generation for the blended humidity cells (Figure 7-14).

## Blended Laboratory Humidity Cells

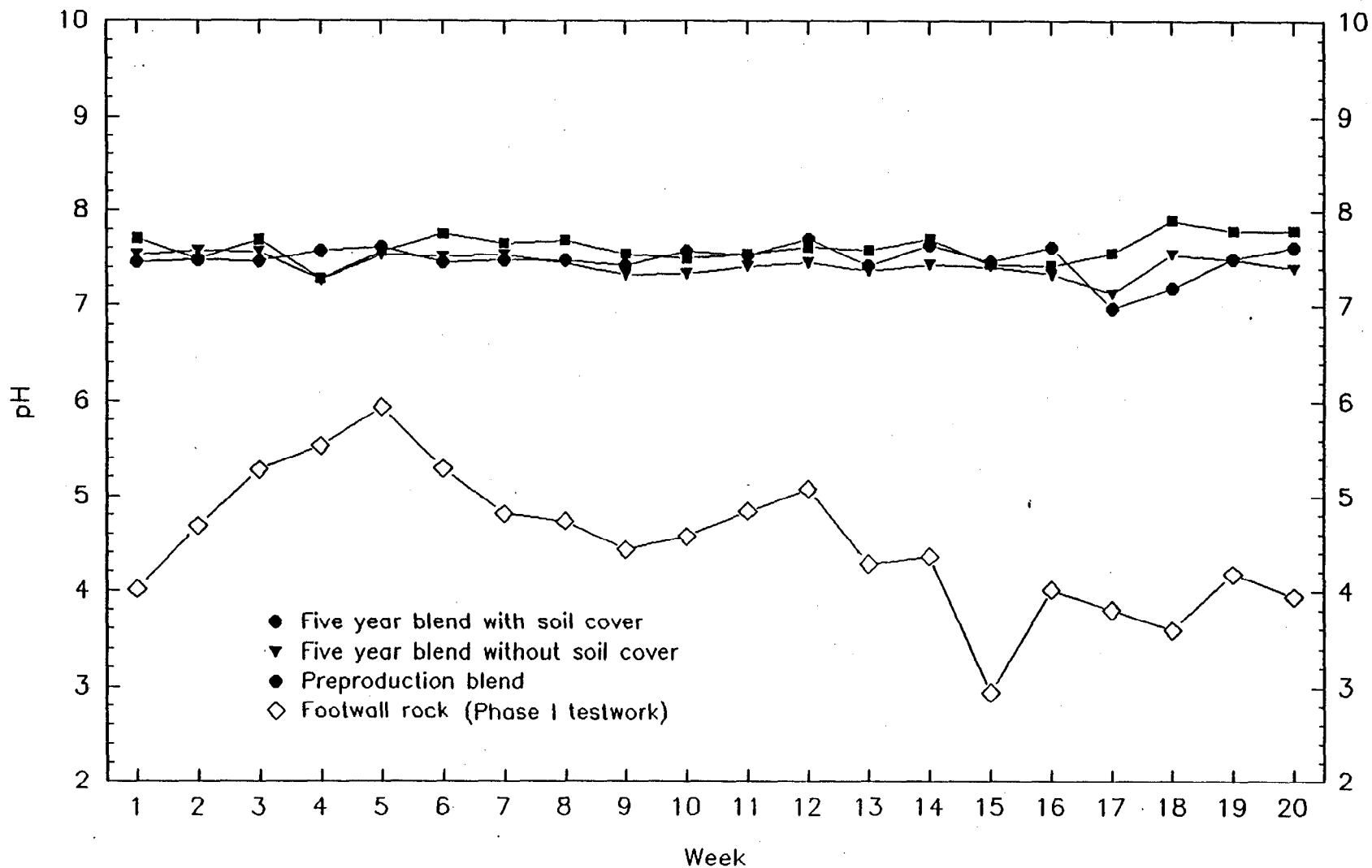


Figure 7-11: Weekly Cycles of pH for Phase II Humidity Cell Tests

**Table 7-9**  
**Average Weekly Sulphate Production Rates**  
**for Blended Laboratory Humidity Cells**

Humidity Cell	Blend Ratio Acid Generating: Acid Consuming	Sulphate Production		% of Total Sulphate <sup>b</sup>	Surface Area <sup>c</sup> (m <sup>2</sup> /kg)	Average Sulphate Production (mg SO <sub>4</sub> /m <sup>2</sup> )
		Weekly Average <sup>a</sup> (mg/100 g)	Total (mg/kg)			
Preproduction Blend	1:1.1	3.65	730.1	0.13	5.95	6.76
Five Year Blend	2:1	6.47	1,294.8	0.12	5.73	12.2
Five Year Blend with Soil Cover	2:1	5.54	1,048.5	0.1	5.73	9.89
Footwall* (Sample 22)	Determined by ABA to be Acid Generating	32.0 <sup>a</sup>	6,404	0.17	-	-

- a) From Phase I humidity cell testwork Appendix D.
- b) Amount of sulphate produced as % of total theoretical sulphide if all sulphide converts to sulphate.
- c) Calculated as weighted averages from Phase I particle size analysis.

### Blended Laboratory Humidity Cells

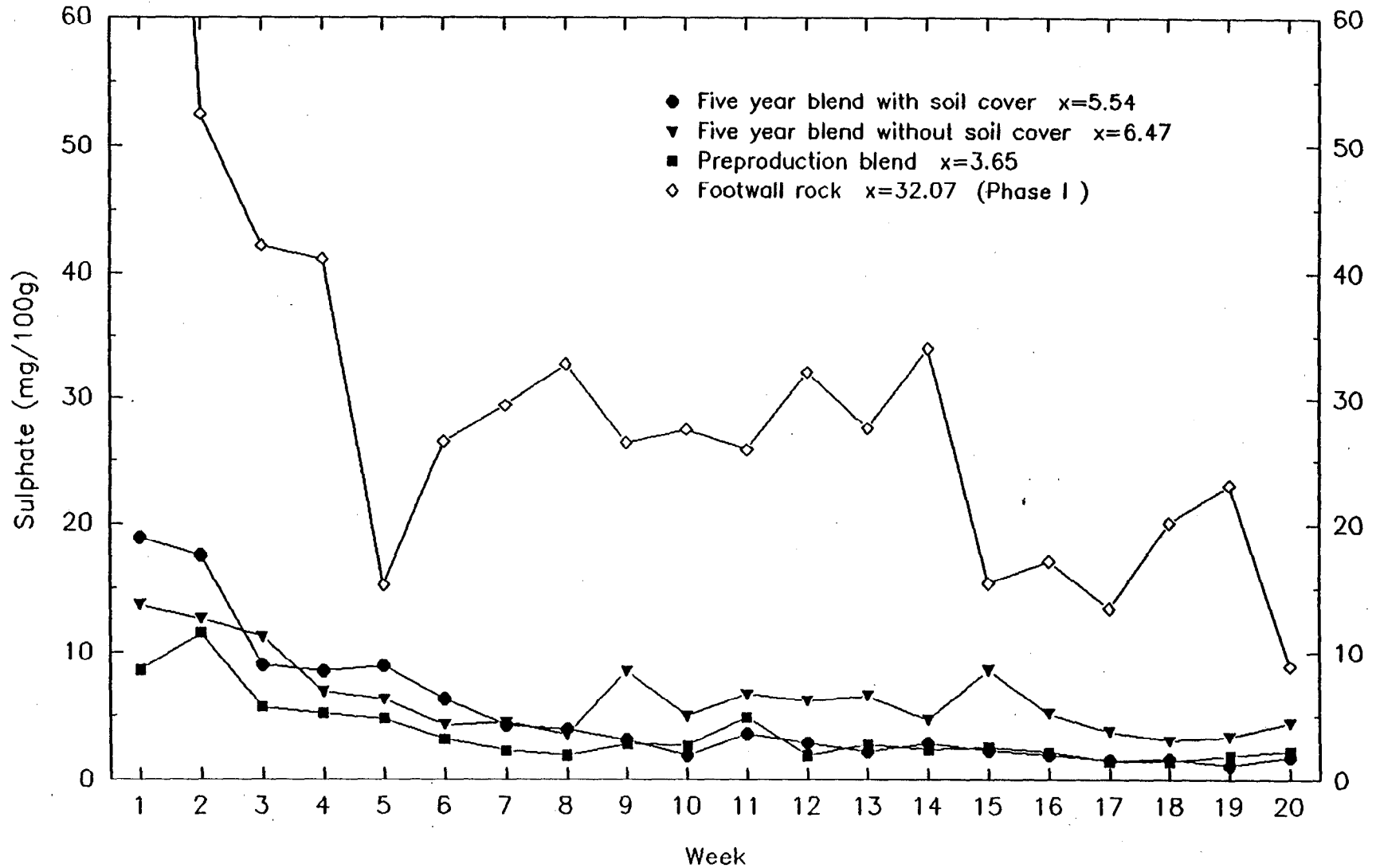


Figure 7-12: Weekly Cycles of Sulphate for Phase II Humidity Cell Tests





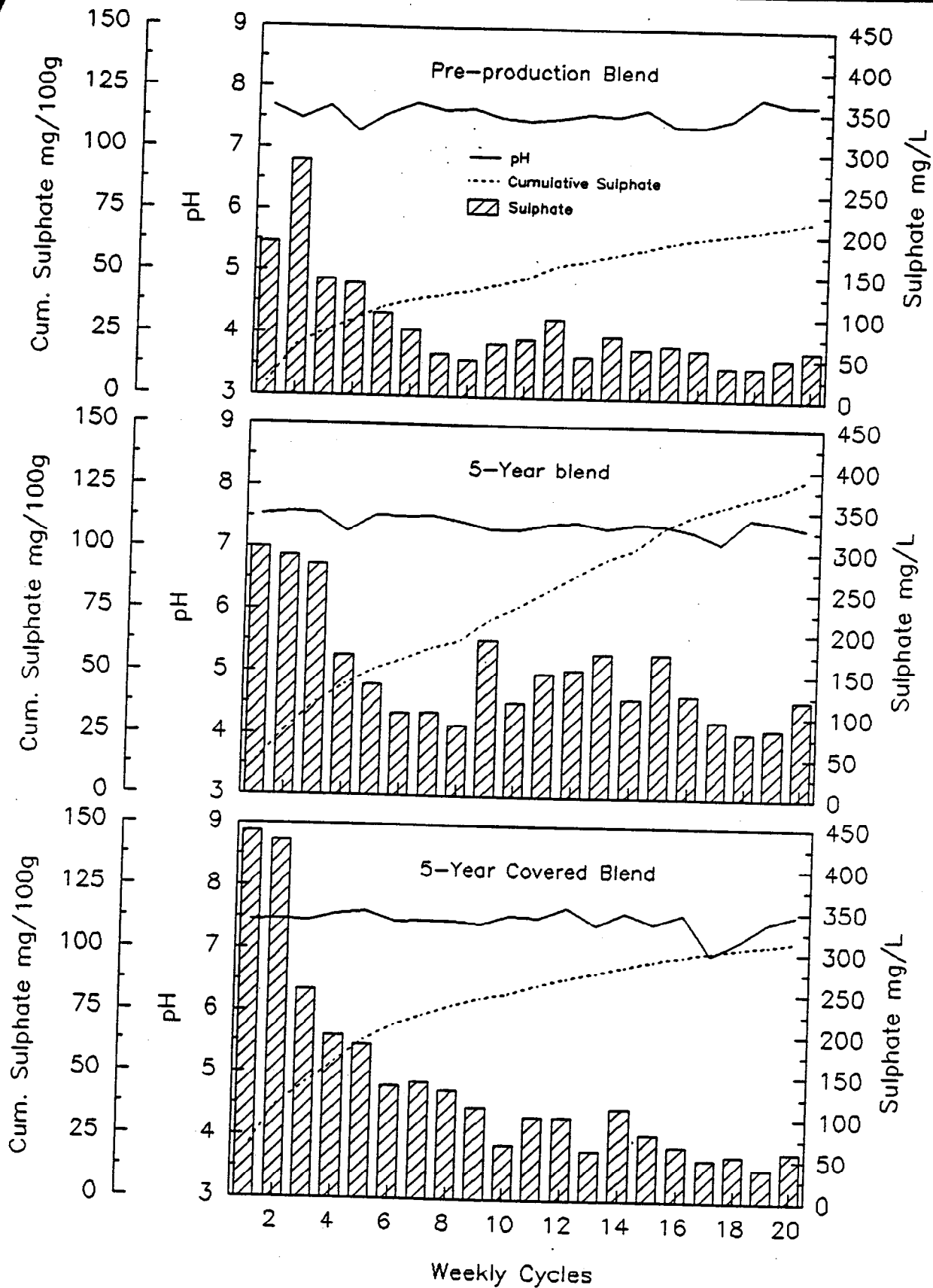


Figure 7-13 Weekly Cycles of Cumulative Sulphate, Sulphate and pH for Blended Laboratory Humidity Cells



## Blended Laboratory Humidity Cells

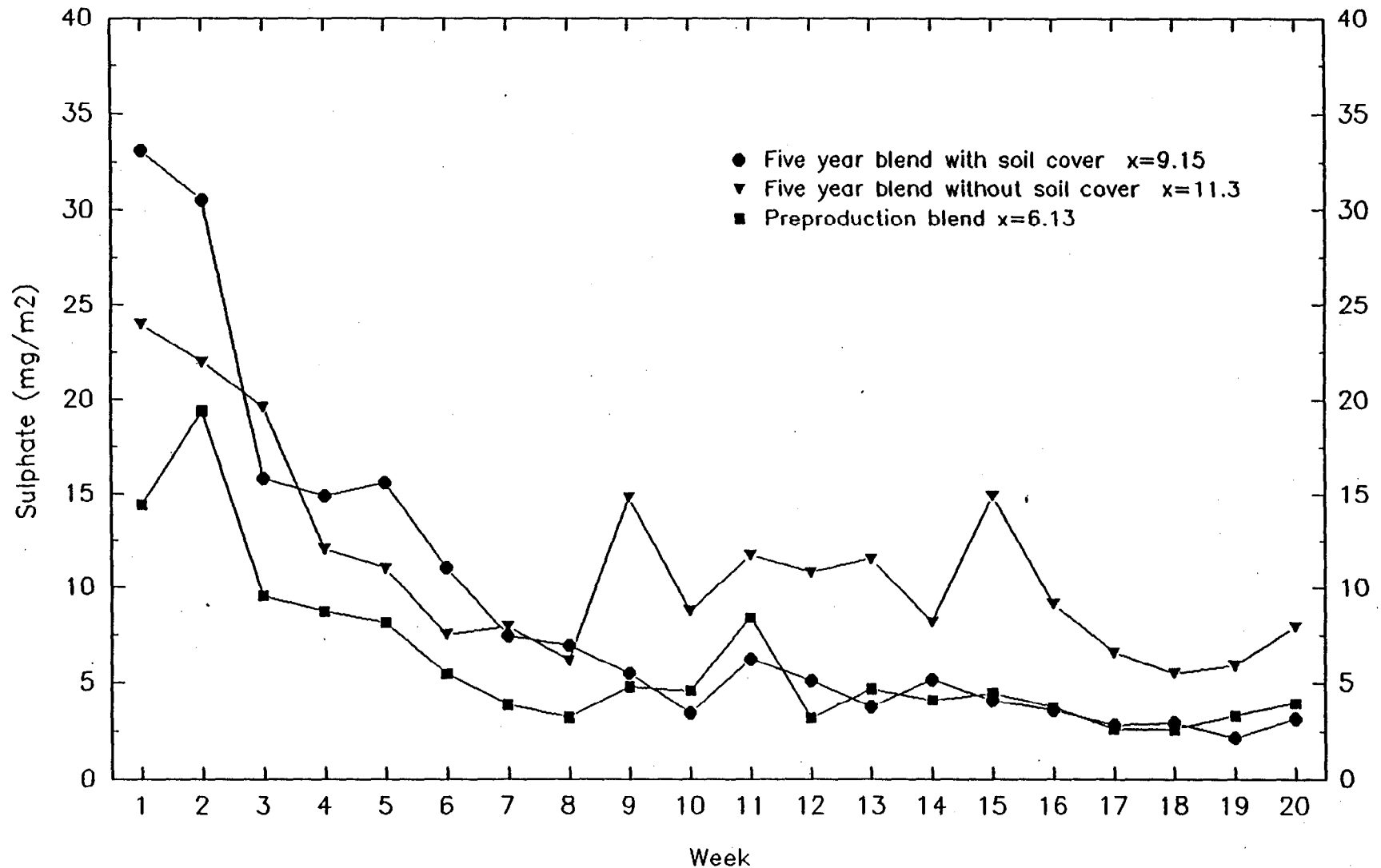


Figure 7-14: Weekly Cycles of Sulphate Normalized to Surface Area  
for Phase II Humidity Cell Tests

### *7.2.1.3 Metals*

Metal release is most appropriately interpreted by examining the total metal release over the 20 cycle test period rather than interpreting week to week individual metal variations. Figure 7-15 graphically shows total metal release from each blend over the 20 cycle test. Figure 7-16 provides a comparison to the footwall total metal release. Weekly metal concentrations are provided in Appendix B.

Much like sulphate, the total metal release shows a relatively slow and decreasing rate with only a few minor fluctuations on a week to week basis. When compared with Phase I results, the blended waste rocks of Phase II showed minimal metal release. A large variation in iron release during cycle 17 and 18 in both the five year covered and the footwall is probably due to the slight decrease in pH.

### *7.2.1.4 Conclusions*

Humidity cell experiments were completed to determine the rates of acid generation from blended waste rock. Two blends were tested: the preproduction blend at an acid generating to acid consuming ratio of 1:1.1 and a five year blend with a ratio of 2:1. Two five year blends were designed: one with a soil cap and the other without. Since the humidity cell procedure involves submersing the entire sample with wash water, the effects of a soil cap under laboratory conditions were not evident.

All blends showed a typical Type Ib - alkaline trend in which the pH remains alkaline and the acid generation, as shown by sulphate production, gradually decreased.

The average rate of acid generation for the five year blend was 6.0 mg/100 g SO<sub>4</sub> which was 1.5 times greater than the preproduction blend at 3.6 mg/100 g SO<sub>4</sub>, but 80% less than the unblended footwall rock.

Acid generation rates based on surface area indicate that the five year blend had an approximate rate 1.5 times higher than the preproduction blend. The higher rate may be attributed to a higher content of reactive sulphide in the five year blends.

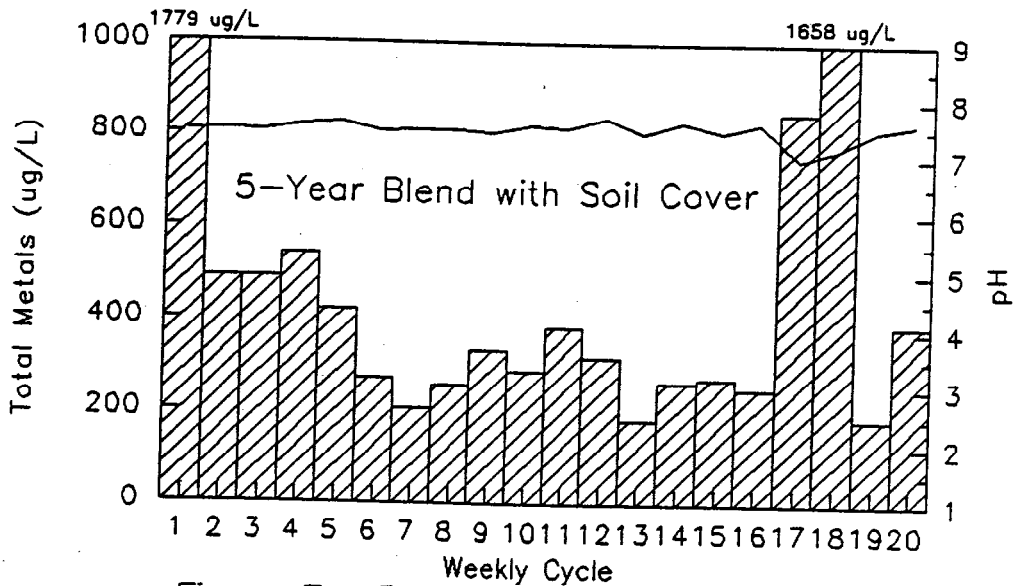
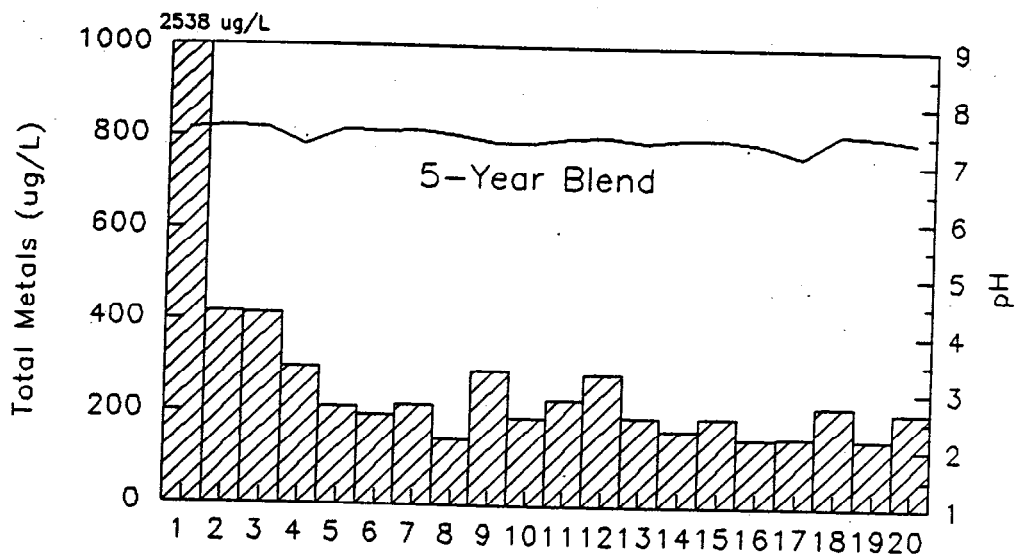
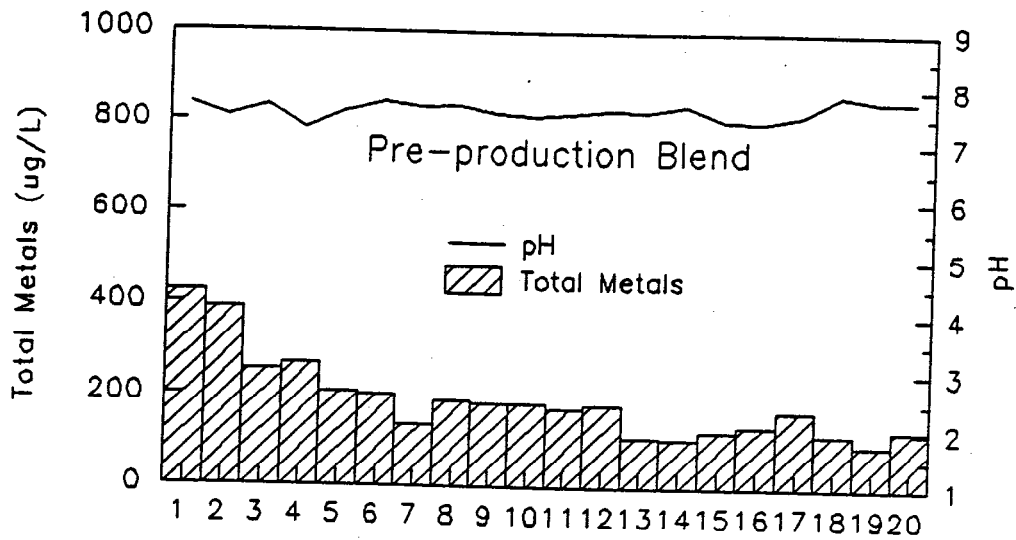


Figure 7-15: Weekly Cycles of Total Metals and pH for Blended Laboratory Humidity Cells



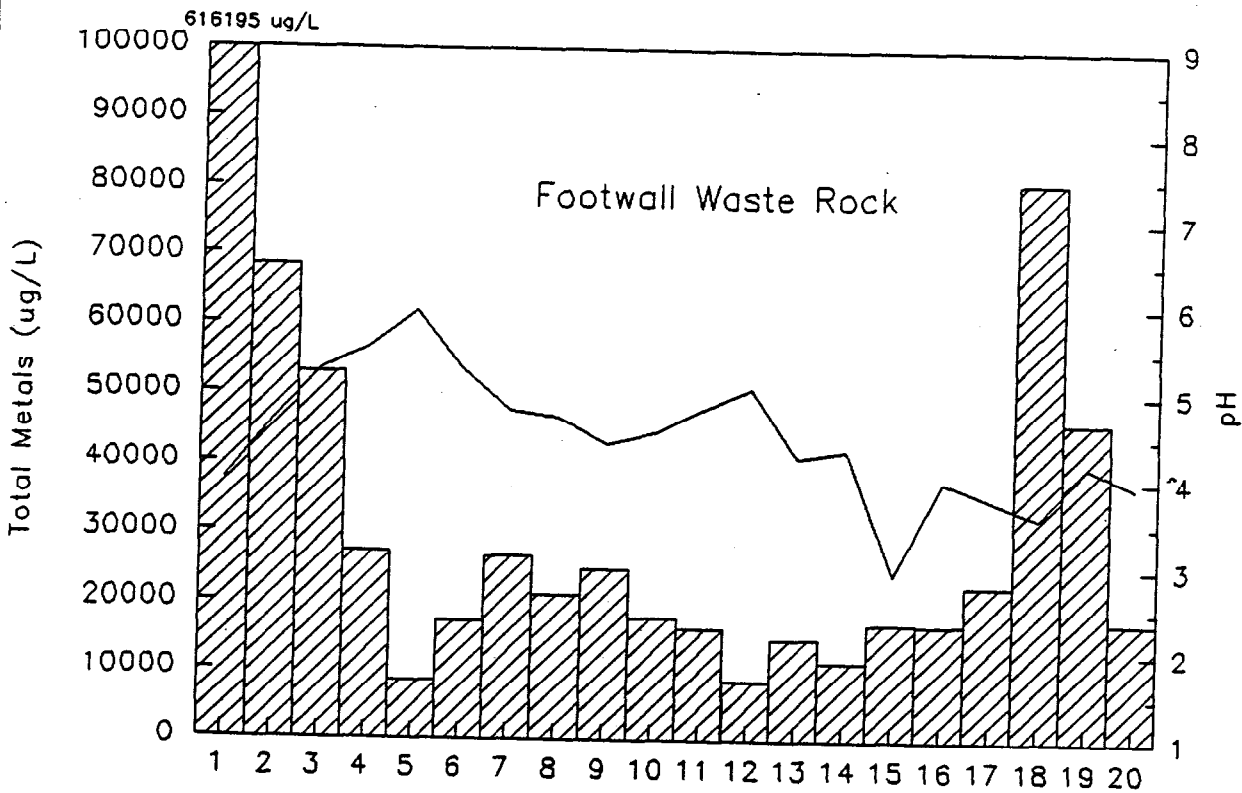
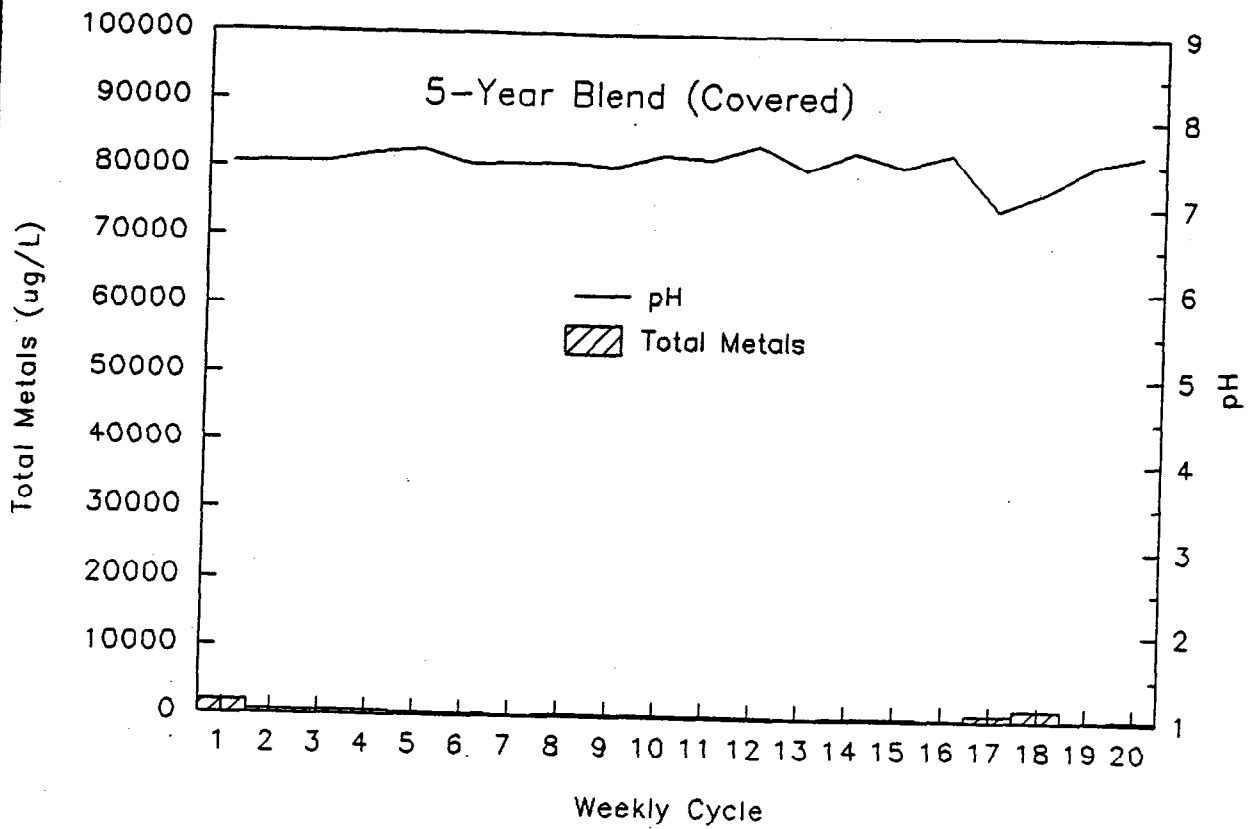


Figure 7-16: Weekly Cycles of Total Metals and pH for Laboratory Humidity Cells  
5-Year Blend (Covered) vs. Footwall Waste Rock



## **7.2.2 Field Scale Humidity Cells**

Large scale waste pads were constructed at the Kutcho project site to determine acid generation rates from various waste rock blends under actual site conditions.

Three field test pads were constructed September 1, 1989 using approximately 20 tonnes of waste rock each, blended with acid generating and acid consuming materials at blended ratios of 1:1.1 and 2:1 for the preproduction and five year blends, respectively. Two five year blends were constructed with one pad capped with till.

During Phase III of the acid generation research program, the three pads were monitored for pH, water quality, internal temperature and oxygen. Despite the fact that water quality monitoring could only be carried out for the summer months with average temperatures above freezing, some preliminary observations can be made.

### **7.2.2.1 Pad Drainage**

Results from the field test pads are influenced by the rate of flushing from precipitation events. Precipitation records for the period of research are limited so total infiltration was calculated by taking the monthly average total precipitation as presented in the Stage II EIS Report (Table 7-10).

Total infiltration from pad start up, September 1989 through to October 1991 (715 days) was 9,960 L for each pad. Thus, on average, each kg of waste rock was washed by 0.5 L of water. The accumulated flush rate of 0.5 L/kg of rock was equivalent to an average daily flush of 0.0007 L/day/kg. This value is roughly a factor of 100 less than the flushing rate used in the laboratory humidity cell tests. Consequently, by comparison with the laboratory experiments, the pads represent a less dynamic, slower flushing test, but one that better represents the natural environment.

The chemistry of the rainwater infiltrating into the pads was examined and, due to its quality, would not significantly affect the chemistry of the test pads (Table 7-11).

**Table 7-10**  
**Monthly Field Test Pad Drainage Volumes**

Month/Year	Net <sup>a</sup> Precipitation (mm)	Drainage Volume (L) (10.8m <sup>2</sup> Pad Area)
Oct./89	65.0	699
Nov./89	33.2	357
Dec./89	29.3	315
Jan./90	47.5	511
Feb./90	29.5	317
Mar./90	14.0	151
Apr./90	12.5	134
May /90	23.5	253
Jun./90	22.4	241
Jul./90	82.4	887
Aug./90	49 <sup>b</sup>	527
Sep./90	47 <sup>b</sup>	506
Oct./90	65.0	699
Nov./90	33.2	357
Dec./90	29.3	315
Jan./91	47.5	511
Feb./91	29.5	317
Mar./91	14.0	151
Apr./91	12.5	134
May /91	23.5	253
Jun./91	22.4	241
Jul./91	82.4	887
Aug./91	52.5	565
Sep./91	58.5	629
<b>Total</b>		<b>9,957</b>

a) Average precipitation data calculated for Kutcho Creek airstrip using climatological data from:

- i) Environment Canada Atmospheric Environment Service (AES) 1984-86,
- ii) Reported in the Environment Assessment Stage II Report (Norecol, 1986) for 1979-85, and
- iii) Data collected by Rescan, Aug. - Sept. in 1990.

**Table 7-11**  
**Results of Chemical Analysis Conducted**  
**on Rainwater Falling on Field Pads**

Parameter	Sep.08/90
<b>Physical Tests</b>	
Total Dissolved Solids	260
pH	6.52
<b>Dissolved Anions</b>	
Acidity	<1.0
Alkalinity	77.6
Chloride	9.5
Sulphate	43.8
<b>Nutrients</b>	
Ammonia Nitrogen	0.010
<b>Dissolved Metals</b>	
Aluminum	0.016
Antimony	<0.0001
Arsenic	0.0003
Barium	<0.010
Cadmium	0.0006
Calcium	25.4
Chromium	<0.001
Cobalt	<0.001
Copper	0.011
Iron	0.055
Lead	0.001
Magnesium	14.3
Manganese	0.023
Mercury	<0.00005
Molybdenum	0.003
Nickel	0.001
Potassium	10.7
Selenium	<0.0005
Silver	<0.0001
Sodium	1.52
Vanadium	<0.005
Zinc	0.050

< = less than

Results are expressed in milligrams per litre except for pH.



## *pH*

Values for pH have been obtained through both laboratory analysis and field monitoring by a continuous recorder. Where discrepancies exist between the field and laboratory pH, the field pH value is used because laboratory pH often reflects disturbances during shipping and storage.

The pH values which were recorded every seven minutes over the sample period between July 22 to October 12, 1990 and July 31 to August 18, 1991 have been averaged daily and are shown on Figure 7-17. The pH record for 1991 is limited because of a malfunction with the recording datalogger.

For the 1990 sample interval, each pad generally displayed similar pH behavior for the first 32 days with the pH remaining near or above neutral. After 32 days the pH of the five year (covered) pad showed a dramatic decrease to 5.5; and then recovered over a week to a pH of 7.0. After 40 days, a significant flush event occurred at which time the pH of all pads dropped to pH levels near 4.0. After this event, each pad drainage slowly recovered to near neutral pH levels again, 82 days into the sampling interval.

The pH trend shows a correlation with precipitation events which suggests that the pH may be dependent on flushing rates. During the second year of observation (1991) the pH trends started to stabilize. The preproduction and five year (uncovered) pad maintained a neutral pH, whereas the five year (covered) pad showed a dramatic decrease in pH values to as low as 3.5, toward the end of the sampling period (Figure 7-17). This suggests that the till cover affected the quality of drainage by limiting the volume of leachate, thereby increasing the concentration of acidic products flushed, or alternatively by reducing the contact of potentially neutralizing material with acid products. Measurements of leachate volumes show that the output from the covered pad is 2% of the total input compared to 11% for the uncovered pads (Table 7-12). In the absence of more supporting data, further comment on this interesting observation is unwarranted.

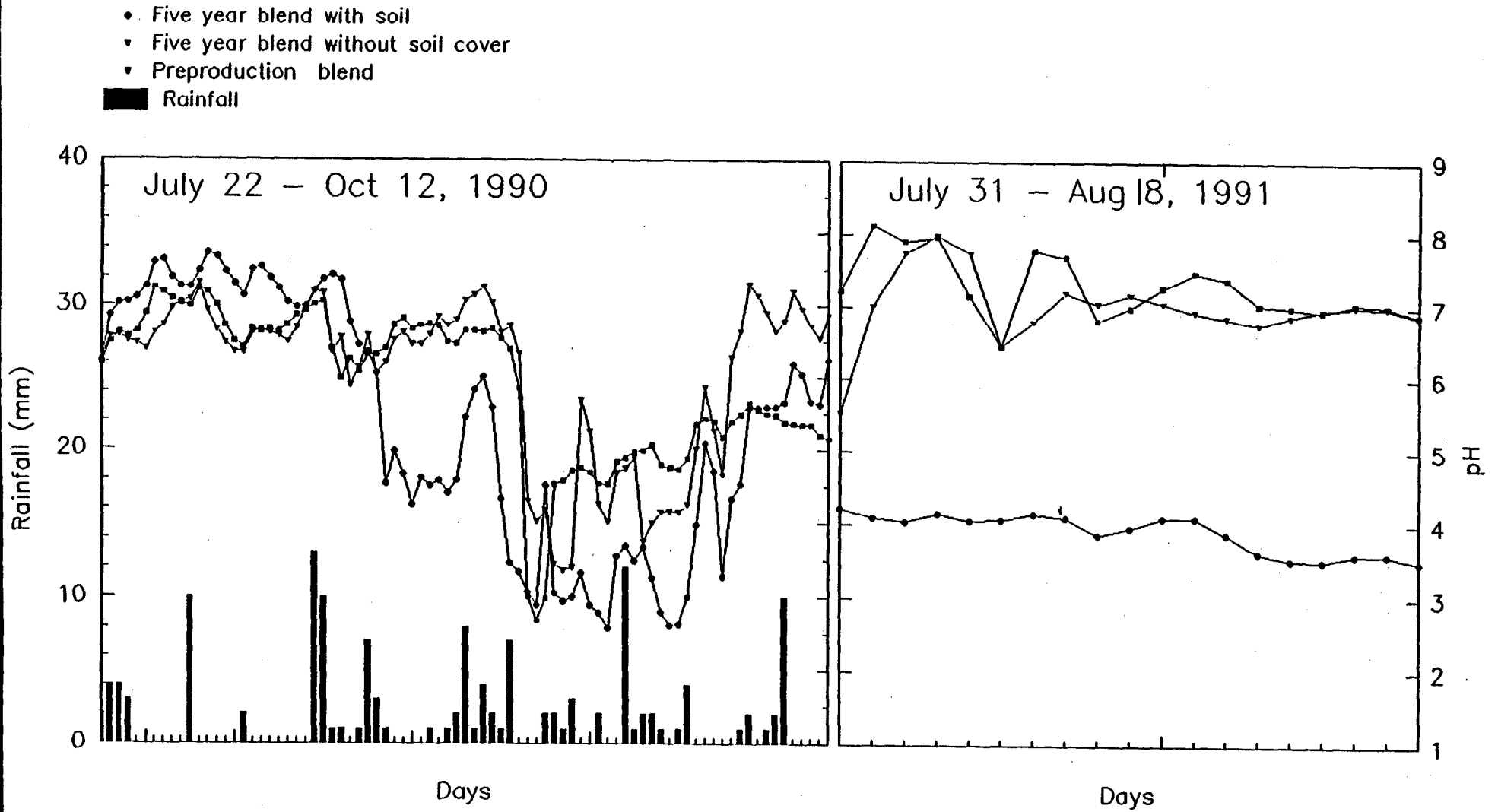


Figure 7-17: Daily pH of Field Blended Waste Rock Pads



**Table 7-12**  
**Leachate Volume from Field Waste Pads**

Pad	(Input <sup>a</sup> )	Output	
	(L)	Measured Volume (L)	% of Input
Preproduction	380	45	11
Five Year	380	45	11
Five Year (covered)	380	7	2

<sup>a</sup>: Recorded over a 21-day period (Aug.18-Sept.6, 1990)

### *Sulphate*

Sulphate concentrations for field test plots are expected to be influenced by seasonal precipitation. Acid generation products will accumulate during dry periods, winter freeze or light rains, only to be flushed with the first heavy rain or snow melt. Thus, acid drainage is proportional to water flow and the quantity of accumulated acid products remaining to be flushed.

Lab analyses for sulphate were done only on seven occasions and, at best, represent a "fixed frequency" type of sample. Data of this type are only suited for one type of analysis: trend monitoring over long periods of time (Robertson 1990).

Peak sulphate concentrations (8,470  $\mu\text{g/L}$  in preproduction, 6,030 to 8,980  $\mu\text{g/L}$  in the five year blend, Table 5-14) appear to coincide with low pH values. Since sulphate concentrations are influenced by water volume, which in this study is influenced by seasonal variation, peak concentrations coincide with flushing events (Figure 7-18).

Many of the observations made for pH can also be made for sulphate. A typical correlation with pH is shown in Figure 7-19. At an acidic pH, concentrations of sulphate are relatively high, whereas at a neutral pH sulphate concentrations are limited by gypsum solubility. Certainly for the blended laboratory cells, it can be concluded that the sulphate derived is the result of sulphide oxidation. As for the field

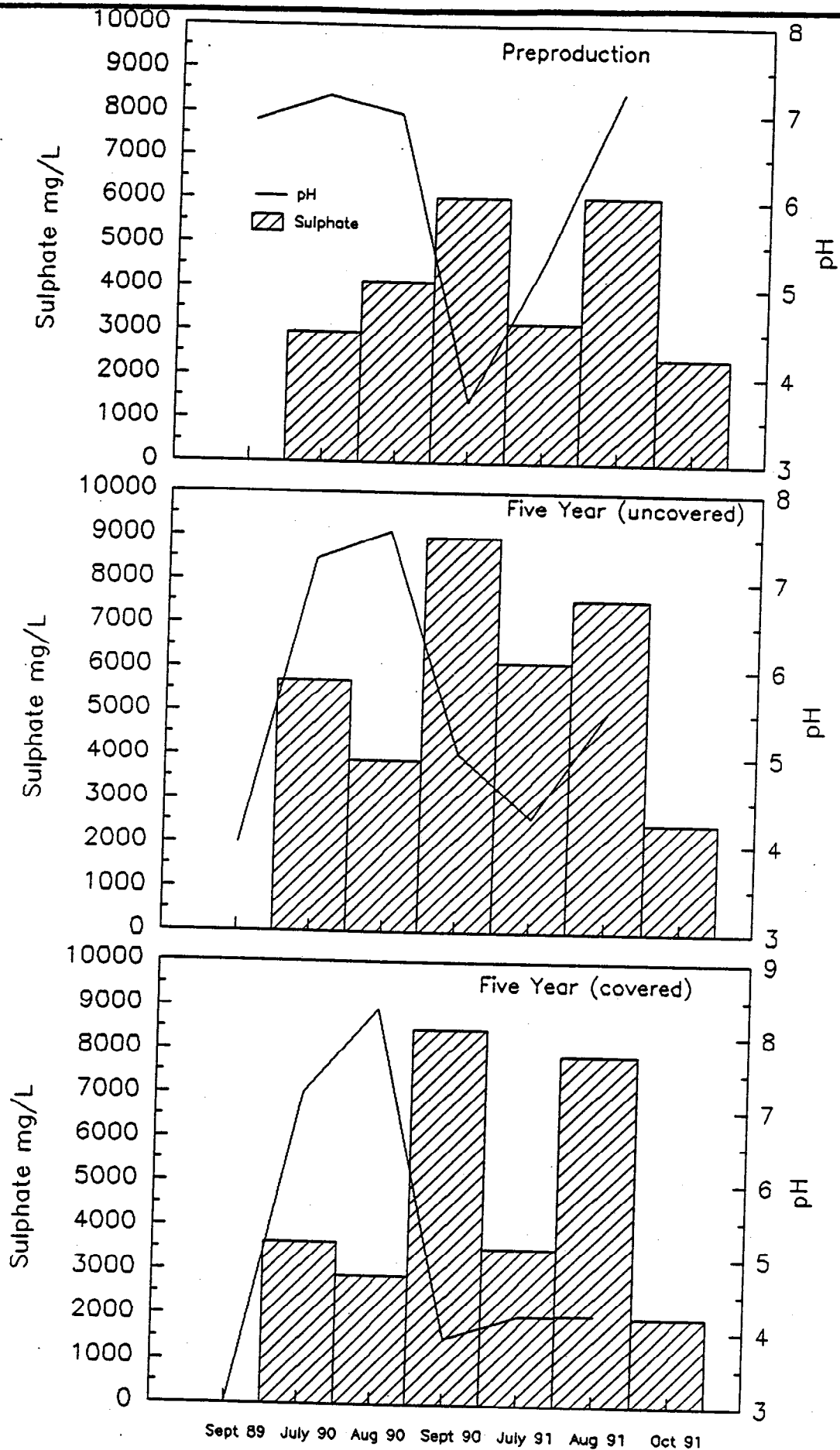


Figure 7-18: pH and Sulphate Concentrations from Blended Waste Rock Pads



# Kutcho Creek Field Scale Waste Rock Pads

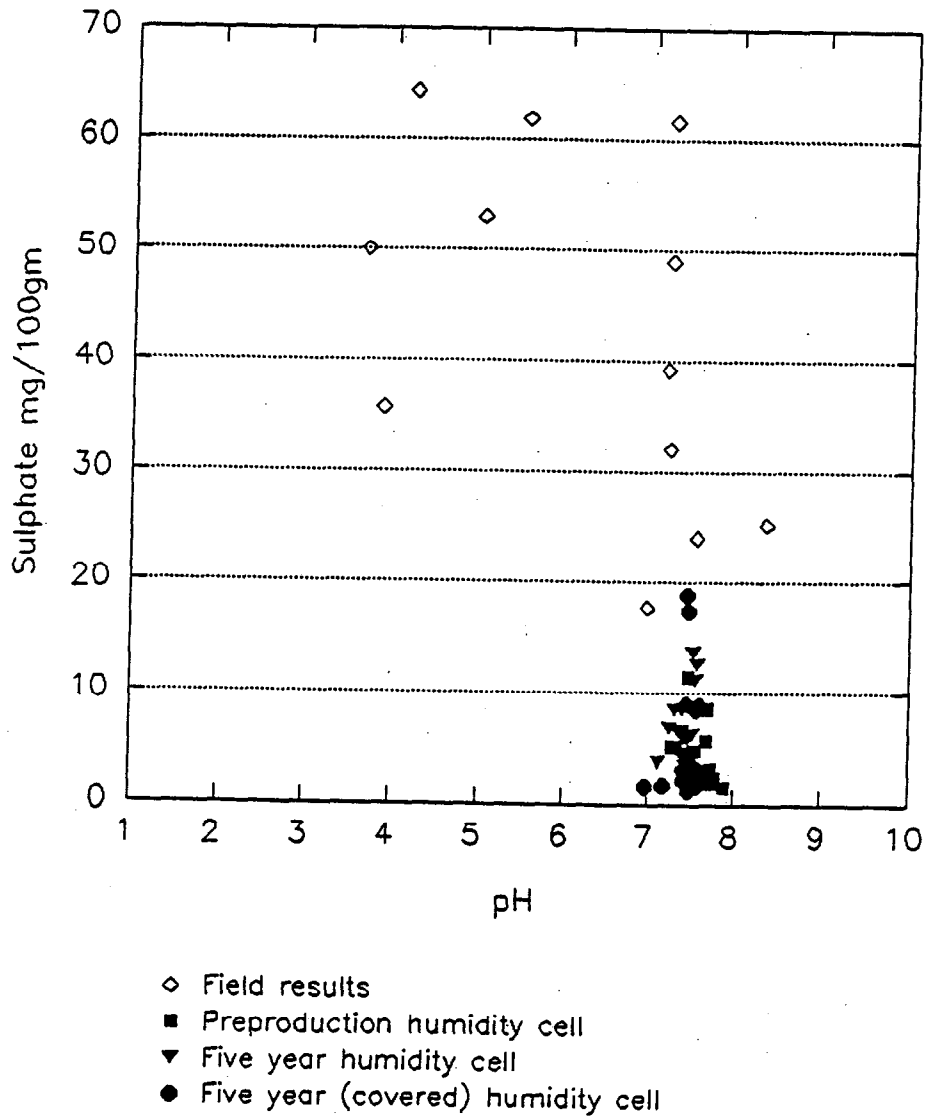


Figure 7-19: Sulphate -pH Relation for the Kutcho Creek Humidity Cell tests

blended pads, the pH-sulphate correlation is not as apparent. An obvious reason for this lack of correlation can be attributed to the sample error and the time interval between each sampling period. A white precipitate was observed in the sample buckets during several sampling campaigns which would indicate that gypsum precipitation had occurred. Sulphate peaks would have been higher in the absence of gypsum formation.

Assuming that all previously produced acid products were flushed during the spring melt, it becomes obvious from Figure 7-17 that not enough water passed through the pads during summer low rainfall periods to carry all sulphate produced by oxidation. Ignoring the small flush in week 6 from the five year (covered) blend, it was not until the 7th week in which an accumulated drainage of 839 L of rain produced the first major flush in which all acid products were released. Accumulated volumes less than 839 L would not be sufficient to completely flush a 20,000 kg waste pile. This suggests that since startup these pads underwent four complete flushes annually, with one flush shortly after spring melt, the second early to mid-June, the third early to mid-July and the fourth early to mid-September before winter freeze-up.

In 1991, the pH level showed a dramatic decrease for the five year (covered) pad. As previously discussed, this was probably as a result of the till cover which would have decreased the quantity of leachate, therefore acid products produced would be more concentrated thus producing a lower pH for the test pile with till cover.

An estimate of sulphate loadings is presented in Table 7-13. Sulphate production in all test pads appears to be similar with the five year (covered) pad producing 11.4 + kg sulphate, preproduction pad 13.0 + kg sulphate and the five year (uncovered) pad producing 13.7 + kg sulphate.

#### *Metal Concentrations*

The water analyses are summarized in Table 7-14. A fixed frequency sample, like sulphate, is only appropriate for the detection of long term trends. The results indicate that throughout the period of study, the leachates were high in dissolved solids and that the metal levels were high and variable, albeit decreasing. Peak metal concentrations correspond to peak sulphate concentrations and low pH.

**Table 7-13**  
**Sulphate Production from**  
**Field Waste Rock Pads**

	Drainage Volume (L)	Sulphate Production		
		$\mu\text{g/L}$	kg	% of Total S
<b>Preproduction</b>				
Sept./89	505	No data	-	-
Oct.-Jul.18/90	No data	3,650	-	-
Jul.18-Aug.17/90	537	2,890	1.6	0.01
Aug.17-Sept.8/90	452	8,470	3.8	0.03
Jul.3/90	No data	3,530	-	-
Jul.3-Jul.31/91	750	7,890	5.9	0.05
Jul.31-Oct.22/91	860	1,990	1.7	0.01
<b>Total</b>			<b>13.0+</b>	<b>+0.10</b>
<b>Five Year (Covered)</b>				
Sept./89	505	No data	-	-
Oct.-Jul.18/90	No data	2,960	-	-
Jul.18-Aug.17/90	537	5,100	2.2	0.01
Aug.17-Sept.8/90	452	6,030	2.7	0.01
Jul.3/90	No data	3,180	-	-
Jul.3-Jul.31/91	750	6,050	4.5	0.02
Jul.31-Oct.22/91	860	2,410	2.0	0.01
<b>Total</b>			<b>11.4+</b>	<b>+0.05</b>
<b>Five Year</b>				
Sept./89	505	No data	-	-
Oct.-Jul.18/90	No data	5,700	-	-
Jul.18-Aug.17/90	537	3,860	2.0	0.01
Aug.17-Sept.8/90	452	8,980	4.0	0.02
Jul.3/90	No data	6,140	-	-
Jul.3-Jul.31/91	750	7,570	5.6	0.03
Jul.31-Oct.22/91	860	2,480	2.1	0.01
<b>Total</b>			<b>13.7+</b>	<b>+0.07</b>

**Table 7-14a**  
**Results of Water Quality Analyses (Pre-Production)**

Parameter	Sept/89	Jul 18/90	Aug 17/90	Sep 08/90	Jul 03/91	Jul 30/91	Oct 21/91
<b>Physical Tests</b>							
Conductivity $\mu$ mhos/cm		4,940	-	-			
Total Dissolved Solids		6,700	5,300	17500	6,400	11,100	2,940
pH	6.9	3.37	6.65	3.62	3.4	6.2	4.2
<b>Dissolved Anions</b>							
Acidity		188	63.0	366	393		
Alkalinity		<1.0	29.0	3.9			
Chloride		1.1	35.8	0.7			
Sulphate		3,650	2,890	8470	3,530	7,890	1,990
<b>Nutrients</b>							
Ammonia Nitrogen		2.38	0.130	0.150			
<b>Other Tests</b>							
Total Organic Carbon		7.56					
<b>Total Metals</b>							
Arsenic	<0.0001				<0.05	<0.05	<0.05
Cadmium	0.79				0.299	0.207	0.0724
Copper	13.0				81.8	14.2	6.23
Iron	0.30				32.6	<0.005	21.4
Lead	<0.01				0.140	0.006	<0.004
Manganese	<0.005				36.8	65.8	23.8
Mercury	<0.00005				<0.0002	<0.0002	<0.0002
Silver	<0.0001				<0.001	<0.001	<0.001
Zinc	271				98.5	56.5	29.8
<b>Dissolved Metals</b>							
Aluminum		1.00	0.025	2.74		<0.005	<0.005
Antimony		<0.0001	0.0002	<0.0001		0.07	0.05
Arsenic	<0.0001	0.0003	0.0002	<0.0001		<0.05	<0.05
Barium		0.016	0.018	0.19		<0.001	<0.001
Cadmium		0.190	0.110	0.576		0.202	0.0682
Calcium	0.79	404	358	475		431	323
Chromium		<0.001	<0.001	<0.001		<0.001	<0.001
Cobalt		0.42	0.26	1.12		0.593	0.206

< = less than

Results are expressed as milligrams per litre except for pH, and Conductivity ( $\mu$ mhos/cm)



**Table 7-14a**  
**Results of Water Quality Analyses (Pre-Production)**

Parameter	Sept/89	Jul 18/90	Aug 17/90	Sep 08/90	Jul 03/91	Jul 30/91	Oct 21/91
<b>Dissolved Metals (cont'd)</b>							
Copper	13.0	8.45	3.70	61.2		14.1	5.65
Iron	0.30	3.56	<0.03	1.18		<0.005	<0.005
Lead	<0.01	0.05	<0.001	<0.001		0.006	<0.004
Magnesium		566	407	1110		1,150	359
Manganese	<0.005	34.5	17.2	94.2		65.1	23.8
Mercury	<0.00005	<0.00005	<0.00005	<0.00005		<0.0002	<0.0002
Molybdenum		0.002	0.015	0.004		<0.005	<0.005
Nickel		0.094	0.043	0.330		0.18	0.089
Potassium		9.50	52.1	17.1		14.6	3.76
Selenium		<0.0005	<0.0005	<0.0005		<0.01	<0.01
Silver	<0.0001	0.0005	0.0005	0.0002		<0.001	<0.001
Sodium		6.92	7.61	10.4		8.25	1.36
Vanadium		0.020	0.005	0.012		0.036	0.225
Zinc	271	58.2	25.0	150		56.2	25.5

< = less than

Results are expressed as milligrams per litre except for pH, and Conductivity ( $\mu$ mhos/cm)

**Table 7-14b  
Results of Water Quality Analyses (5-Year Covered)**

Parameter	Sept/89	Jul 18/90	Aug 17/90	Sep 08/90	Jul 03/91	Jul 30/91	Oct 21/91
<b>Physical Tests</b>							
Conductivity $\mu$ mhos/cm		4,280	-	-	-	-	-
Total Dissolved Solids		5,500	8,200	15,000	5,500	10,700	3,795
pH	3.0	3.45	6.62	2.97	3.4	2.7	3.0
<b>Dissolved Anions</b>							
Acidity		418	120	1,230	334		
Alkalinity		<1.0	46.5	<1.0			
Chloride		1.7	15.4	0.7			
Sulphate		2,960	4,100	6,030	3,180	6,050	2,410
<b>Nutrients</b>							
Ammonia Nitrogen		1.37	<0.005	0.150			
<b>Other Tests</b>							
Total Organic Carbon		6.16	-	-			
<b>Total Metals</b>							
Arsenic	<0.0001				<0.05	0.29	<0.05
Cadmium	1.83				0.193	0.283	0.0954
Copper	190				38.7	40.3	9.08
Iron	206				22.1	307	52.7
Lead	<0.01				<0.004	0.039	<0.004
Manganese	<0.005				43.7	79.9	47.8
Mercury	<0.00005				<0.0002	<0.0002	<0.0002
Silver	<0.0001				<0.001	<0.001	<0.001
Zinc	440				80.1	104	58.0
<b>Dissolved Metals</b>							
Aluminum		2.25	0.028	9.66		5.91	1.77
Antimony		0.0001	<0.0001	<0.0001		0.17	0.10
Arsenic		0.0003	0.0003	0.0001		<0.05	<0.05
Barium		0.018	0.021	0.017		<0.001	<0.001
Cadmium		0.420	0.140	0.847		0.229	0.0905
Calcium		357	390	502		468	384
Chromium		0.002	0.001	0.011		<0.001	<0.001
Cobalt		0.140	0.580	1.66		0.817	0.440

< = less than

Results are expressed as milligrams per litre except for pH and conductivity ( $\mu$ mhos/cm)

**Table 7-14b  
Results of Water Quality Analyses (5-Year Covered)**

<b>Parameter</b>	<b>Sept/89</b>	<b>Jul 18/90</b>	<b>Aug 17/90</b>	<b>Sep 08/90</b>	<b>Jul 03/91</b>	<b>Jul 30/91</b>	<b>Oct 21/91</b>
<b>Dissolved Metals (cont'd)</b>							
Copper		35.9	1.67	105		46.4	8.75
Iron		38.5	0.073	120		271	16.4
Lead		0.069	0.150	0.010		0.024	<0.004
Magnesium		439	717	775		839	402
Manganese		39.4	45.7	119		98.0	47.5
Mercury		<0.0005	<0.0005	<0.00005		<0.0002	<0.0002
Molybdenum		0.002	0.005	<0.001		<0.005	<0.005
Nickel		0.090	0.077	0.370		0.143	0.088
Potassium		6.87	23.8	12.2		10.0	4.36
Selenium		<0.005	<0.0005	0.0005		<0.01	<0.01
Silver		0.0003	0.0006	0.0001		<0.001	<0.001
Sodium		5.00	8.14	7.41		4.96	1.60
Vanadium		0.027	0.005	0.016		<0.005	0.223
Zinc		117	48.2	254		101	54.9

< = less than

Results are expressed as milligrams per litre except for pH and conductivity ( $\mu$ mhos/cm)

**Table 7-14c**  
**Results of Water Quality Analyses (5-Year Uncovered)**

Parameter	Sept/89	Jul 18/90	Aug 17/90	Sep 08/90	Jul 03/91	Jul 30/91	Oct 21/91
<b>Physical Tests</b>							
Conductivity $\mu$ mhos/cm		6,850	-	-	-		
Total Dissolved Solids		8,700	8,100	18,500	11,500	12,400	3,959
pH	4.0	6.48	7.23	5.84	3.3	7.1	3.5
<b>Dissolved Anions</b>							
Acidity		258	52.0	196	760		
Alkalinity		37.0	39.2	39.0			
Chloride		0.8	58.0	<0.5			
Sulphate		5,700	3,890	8,980	6,140	7,570	2,480
<b>Nutrients</b>							
Ammonia Nitrogen		0.180	0.350	0.078			
<b>Other Tests</b>							
Total Organic Carbon		6.90	-	-			
<b>Total Metals</b>							
Arsenic	<0.00001				<0.05	<0.05	<0.05
Cadmium	1.71				0.681	0.193	0.0836
Copper	68.3				89.2	4.96	5.18
Iron	46.4				35.0	1.28	310
Lead	<0.01				0.089	0.005	<0.004
Manganese	<0.005				98.0	97.0	41.3
Mercury	<0.00005				<0.0002	<0.0002	<0.0002
Silver	<0.0001				<0.001	<0.001	<0.001
Zinc	560				277	66.1	39.1
<b>Dissolved Metals</b>							
Aluminum		0.006	0.007	0.010		<0.005	<0.005
Antimony		<0.0001	<0.0001	<0.0001		<0.05	0.05
Arsenic		0.0003	0.0002	<0.0001		<0.05	<0.05
Barium		0.018	0.028	0.013		<0.001	<0.001
Cadmium		0.370	0.130	0.332		0.193	0.0754
Calcium		442	478	402		456	543
Chromium		<0.001	<0.001	<0.001		<0.001	<0.001

< = less than

Results are expressed as milligrams per litre except for pH, and Conductivity ( $\mu$ mhos/cm)

**Table 7-14c**  
**Results of Water Quality Analyses (5-Year Uncovered)**

Parameter	Sept/89	Jul 18/90	Aug 17/90	Sep 08/90	Jul 03/91	Jul 30/91	Oct 21/91
<b>Dissolved Metals (cont'd)</b>							
Cobalt		0.880	0.450	0.950		0.820	0.326
Copper		5.14	1.46	5.00		4.98	4.40
Iron		<0.030	<0.030	<0.030		1.20	0.259
Lead		0.004	<0.001	<0.001		0.005	<0.004
Magnesium		864	648	1,220		1,390	391
Manganese		82.2	40.5	125		94.0	41.2
Mercury		<0.00005	<0.00005	<0.00005		<0.0005	<0.0002
Molybdenum		0.004	0.007	0.004		<0.005	<0.005
Nickel		0.170	0.029	0.220		0.180	0.092
Potassium		7.94	77.7	9.90		7.12	1.49
Selenium		<0.0005	<0.0005	<0.0005		<0.01	<0.01
Silver		0.0004	0.0004	0.0002		<0.001	<0.001
Sodium		6.64	16.2	9.27		7.58	1.39
Vanadium		0.019	<0.005	0.011		<0.005	0.219
Zinc		147	27.3	143		65.1	33.2

< = less than

Results are expressed as milligrams per litre except for pH, and Conductivity ( $\mu$ mhos/cm)

For cadmium, copper, lead and zinc, maximum aqueous concentrations consistently exceeded the Canadian Council of Resource and Environment Ministers (CCREM 1987) guidelines for the protection of freshwater aquatic life (Figures 7-20, 7-21 and 7-22).

#### 7.2.2.2 Temperature

The temperatures within each test pile as compared to ambient over the research period of October 1989 to February 1991, are shown in Figure 7-23. Temperatures recorded were, on average, a little higher than ambient but generally followed the ambient seasonal trend. The piles tend to show a buffered lag as compared to the seasonal variation of the ambient temperature period. There is no obvious indication of heat production through acid generating reactions.

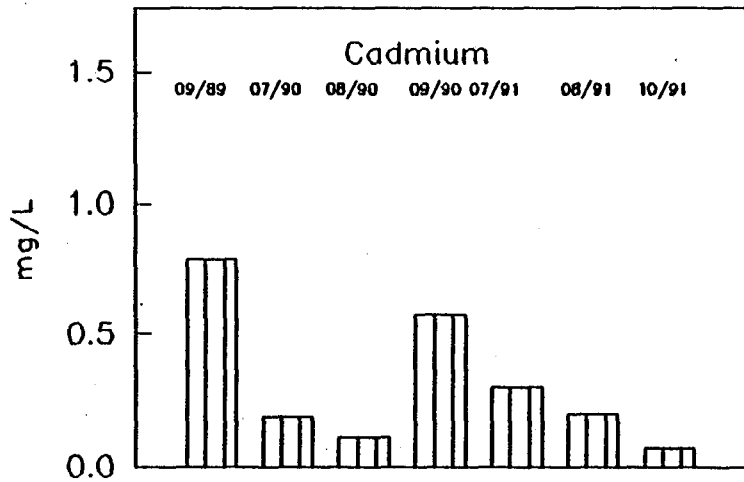
#### 7.2.2.3 Oxygen

Gaseous flux through a waste rock pile can significantly affect reaction rates of acid generation and neutralization (Morin *et al.* 1991). The oxygen content recorded from within each test pile did not differ significantly from atmospheric oxygen levels (Table 7-15). This suggests that ample oxygen was available for acid generation reactions, presumably because the rock piles were sufficiently permeable to allow air to infiltrate freely.

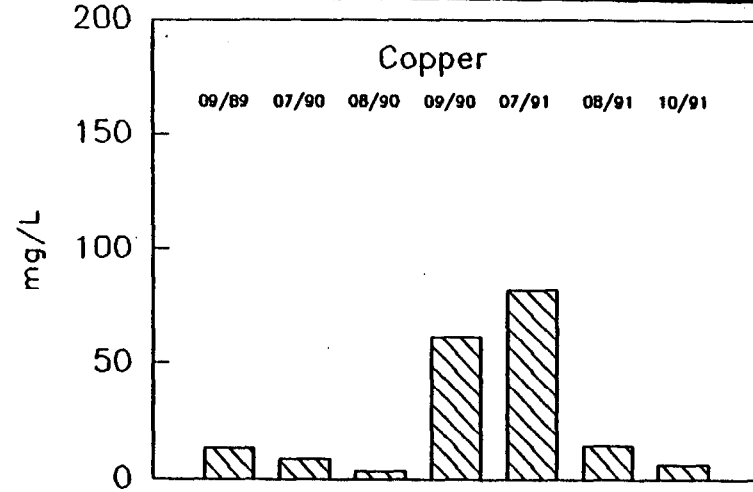
Table 7-15

#### O<sub>2</sub>% Measured in Test Piles

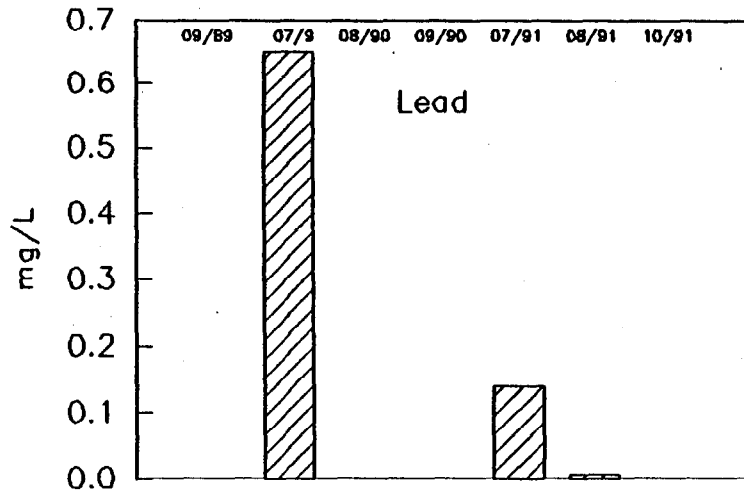
	Sept/89	Aug 18/90
Preproduction	20.8	20.1
5-Year (no soil)	20.4	19.4
5-Year (soil)	20.2	19.8



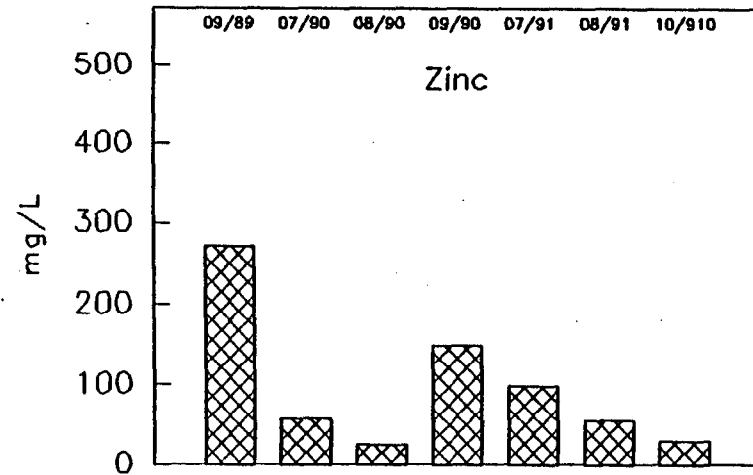
CCREM Guideline for Cd is 0.0002-0.0018 mg/L (hardness dependant).



CCREM Guideline for Cu is 0.002-0.004 mg/L (hardness dependant).



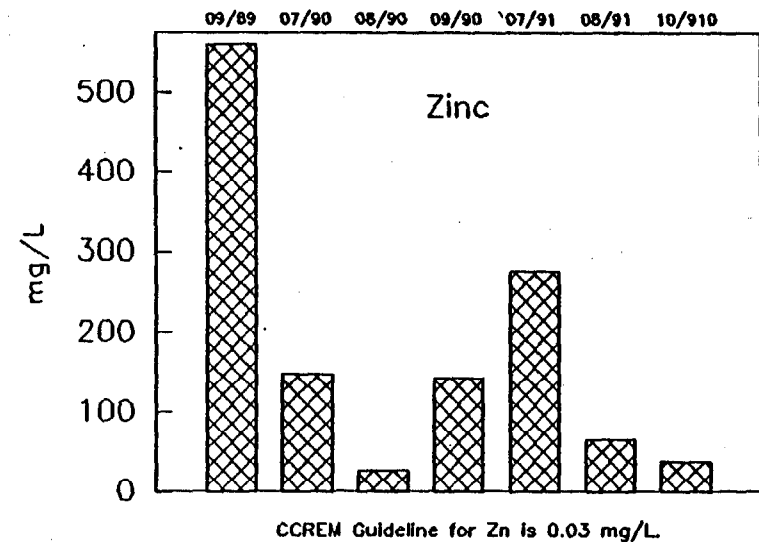
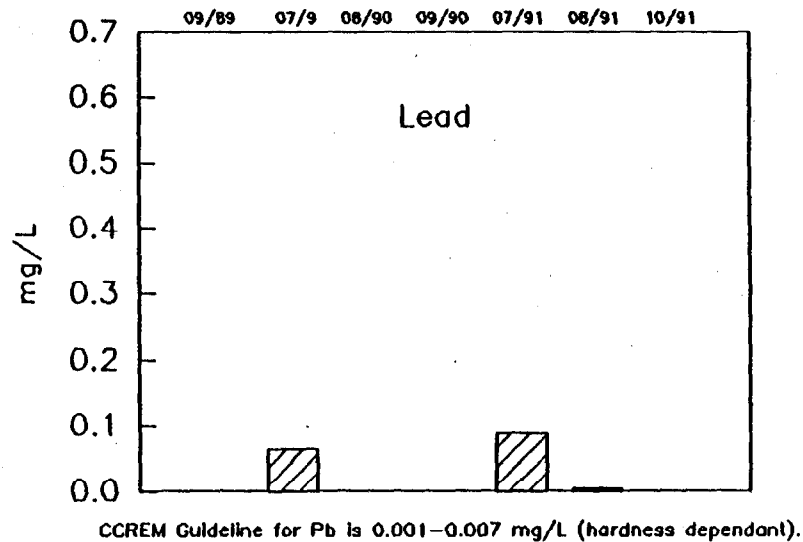
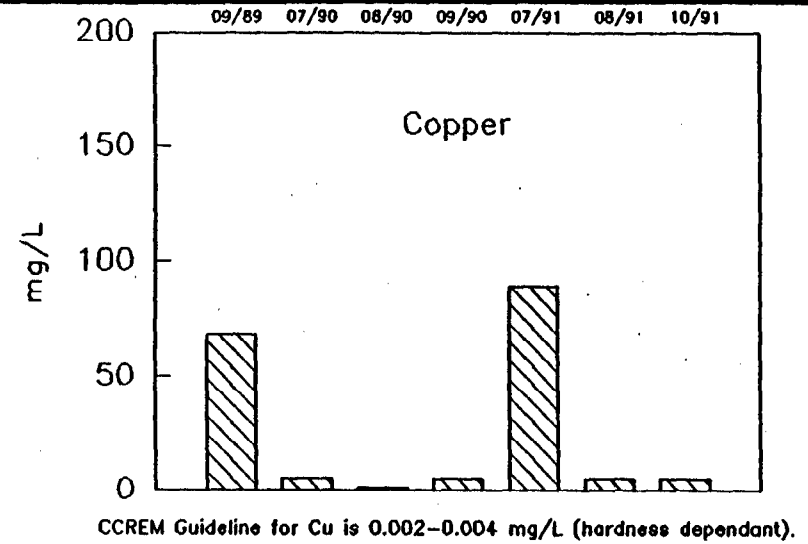
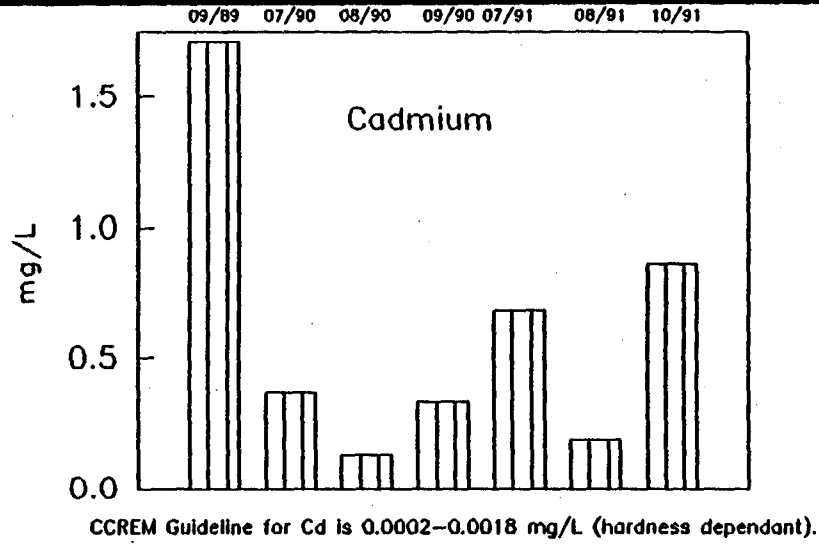
CCREM Guideline for Pb is 0.001-0.007 mg/L (hardness dependant).



CCREM Guideline for Zn is 0.03 mg/L

Note: CCREM Guidelines are maximum allowable metal concentrations for protection of freshwater aquatic life.

Figure 7-20: Concentration of Metals in Leachate from the Preproduction Waste Rock Pad

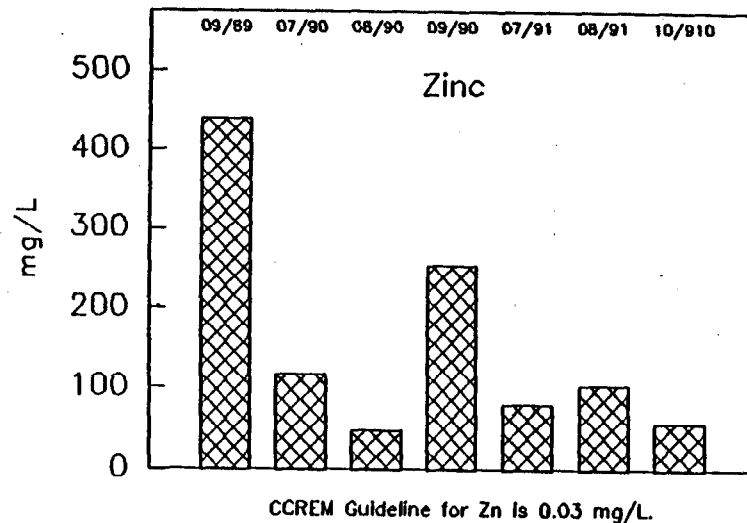
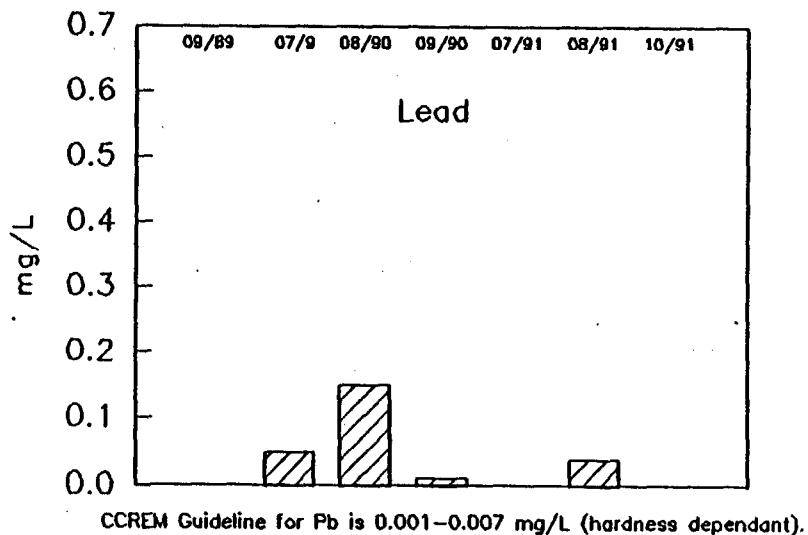
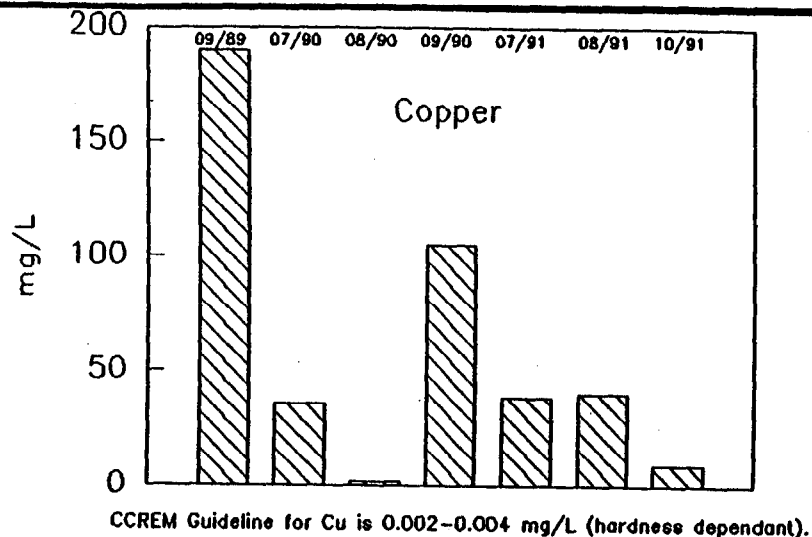
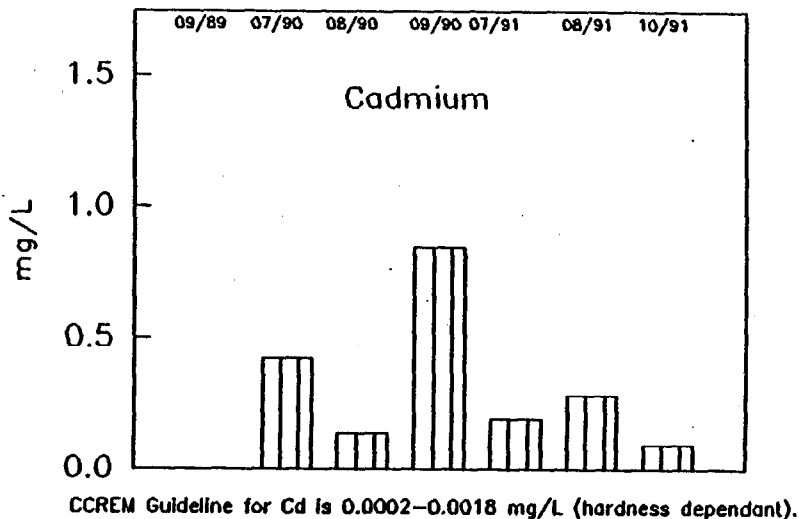


Note: CCREM Guidelines are maximum allowable metal concentrations for protection of freshwater aquatic life.

Figure 7-21: Concentration of Metals in Leachate from the Five Year Waste Rock Pad (no soil cover)







Note: CCREM Guidelines are maximum allowable metal concentrations for protection of freshwater aquatic life.

Figure 7-22: Concentration of Metals in Leachate from the Five Year Covered Waste Rock Pad

## KUTCHO CREEK PROJECT

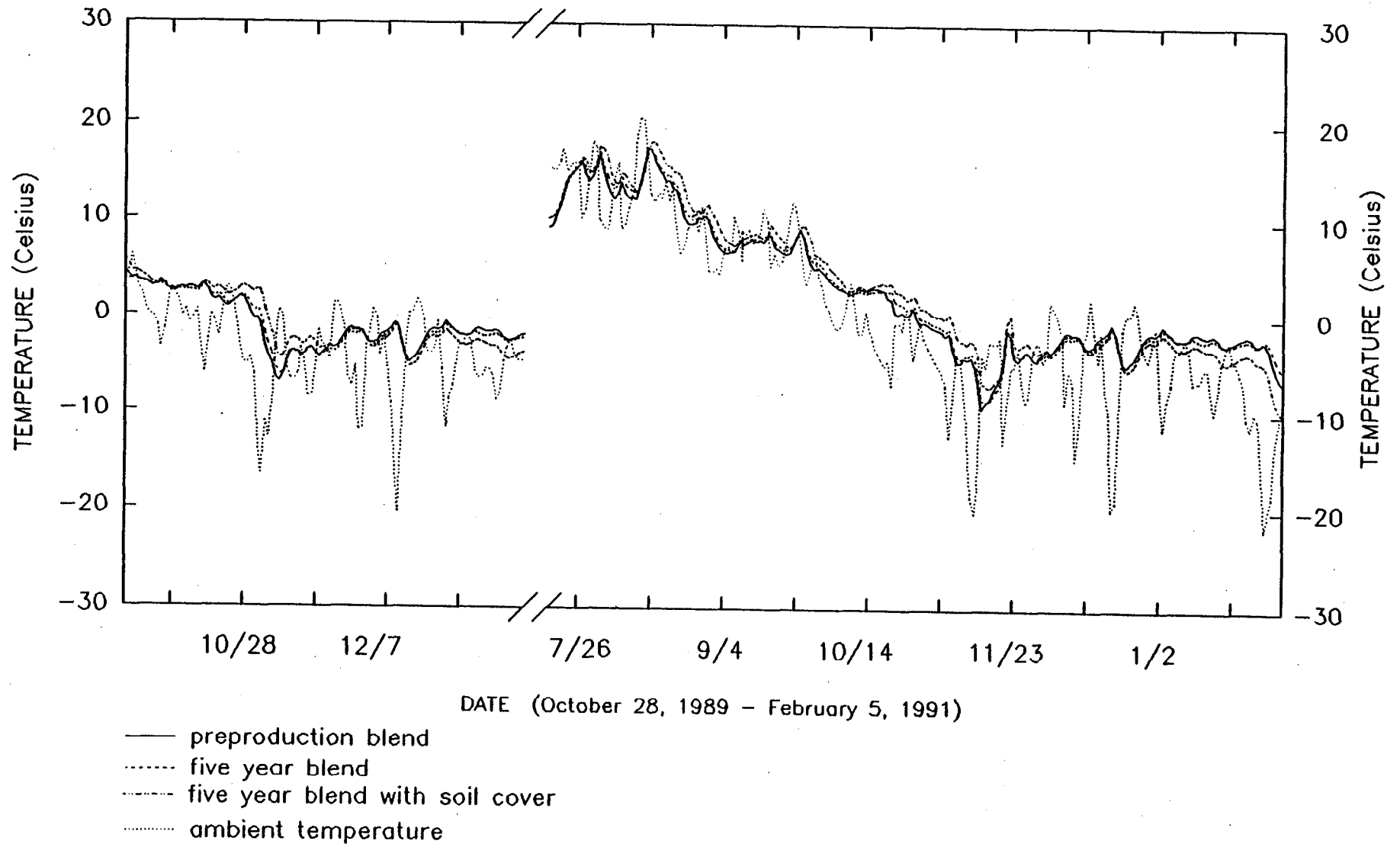


Figure 7-23: Temperatures of Waste Rock Piles

#### 7.2.2.4 *Lysimeter Test*

As discussed in Morin *et al.* (1991), the movement of water into, through and out of the waste rock pile represents a primary pathway for contaminant migration. The pattern of water movement is determined by several processes and the reader is directed to Morin *et al.* for further information.

The determination of flow through the waste pads was not fully successful. After the first spring freshet, both five year blend boxes showed signs of leakage from the base of the pads. Water did not show preferential channelling toward any portion of the piles. It should be noted that the design of the lysimeters would not have permitted the detection of flow preferentially channeling toward the centre or edge of the pad.

#### 7.2.2.5 *Conclusions*

In order to determine the acid generation characteristics and the viability of blending (acid generating waste rock with acid consuming waste rock) small-scale waste rock pads were constructed at the Kutcho site.

Essentially, two ratios of acid generating to acid consuming were designed, preproduction at 1:1.1 and two five year blends at 2:1. One five year blend was capped with till in an attempt to control acid drainage by reducing infiltration. The chemical trends in pad seepage through time were most affected by on-site precipitation. Significant levels of accumulated acidity could be released from all pads after a sufficient quantity of rainfall was allowed to percolate through the pile. By comparison, the flushing rate is roughly a factor of 100 less than the flushing rate used in the laboratory humidity cells.

As the experiment proceeded the effects of the till cap became apparent. The leachate pH produced by the five year (uncovered) and preproduction blends were near neutral. In contrast the leachate pH from the five year (covered) pad dramatically dropped to between 3 and 4. With the volume of leachate substantially reduced through inclusion of the till cover, the quantity of acid products overwhelmed any neutralization potential thus producing an acidic pH.

### **7.3 Prediction of Acid Generation Rates**

One of the objectives of the study program was to determine the effect and rates of acid generation over short and long periods. The static and kinetic investigations from Phase I, Phase II and Phase III acid generation testwork provide a basis for predicting the rate of acid generation that is likely to occur in the field.

#### **7.3.1 Short-Term Predictions of Acid Generation for Blended Waste Rock**

A general indication of acid generation is sulphate production. Acid generation for the blended humidity cell samples from the Kutcho area, as indicated by sulphate production, can be classified as a typical Type Ib; whereby the acid generation rate gradually decreases while the pH remains neutral. The waste rock pads did not display such a clear trend because of variables such as the monthly rate of rainfall and limited sulphate data. However, clearly as time progressed two of the waste rock pads showed a tendency towards a neutral pH.

Rates of acid generation calculated on a weight basis, indicate that the ratio for the blended rocks were significantly reduced by a factor of 5 as compared to the footwall sample.

Water flushing rates apparently affected the rate of acid generation on the waste rock pads because acid generation decreased as flushing decreased. However, closer examination of the data for the waste rock pads indicated that flushing only affects the apparent rate of acid generation through insufficient rinsing of acid products below a certain threshold volume of flushing water. A subsequent large flush will remove the accumulated acid products. Above the threshold flushing volume, acid generation was independent of the flushing rate.

#### **7.3.2 Long-Term Prediction of Acid Generation for Blended Waste Rock**

The best available information for predicting long term acid generation for the Kutcho project is the sulphate data from the blended samples tested in humidity cells and acid base accounting of rock lithologies. Humidity cell experiments in this study were carried out for a period of 20 weeks. Long-term acid generation rates were predicted using a relatively simple mathematical expression that describes a best-fit extrapolation of data. This procedure assumed that only half of the acid consuming components were available, and that all sulphide minerals were reactive.

The extrapolated rate is based on the sulphate production or the acid generation rate as determined in the humidity cell testwork. It is an over estimation because the rate in theory, should decrease as available sulphides are oxidized. This extrapolation is useful for estimating at what point in time will the present rate of acid generation consume the neutralization potential of the sample. Two "best-fit" curves are presented for each blend in Figures 7-24 and 7-25.

Based on Figures 7-24 and 7-25 blends of 1:1.1 and 2:1 ratios will exceed their neutralization potential at the earliest within 100 and 150 weeks, respectively.

In theory, acid generation will proceed until all available sulphide minerals in the blended sample are consumed. Extrapolation of data indicated that the earliest the sulphides will be completely consumed in is 175 weeks, as determined in the 1:1.1 preproduction blend and 400 weeks for the 2:1 five year blend. In other words, acid generation would continue for another 85 weeks without neutralization for the 1:1.1 blend and another 250 weeks for the 2:1 blend.

# KUTCHO CREEK PROJECT PRE PRODUCTION BLEND

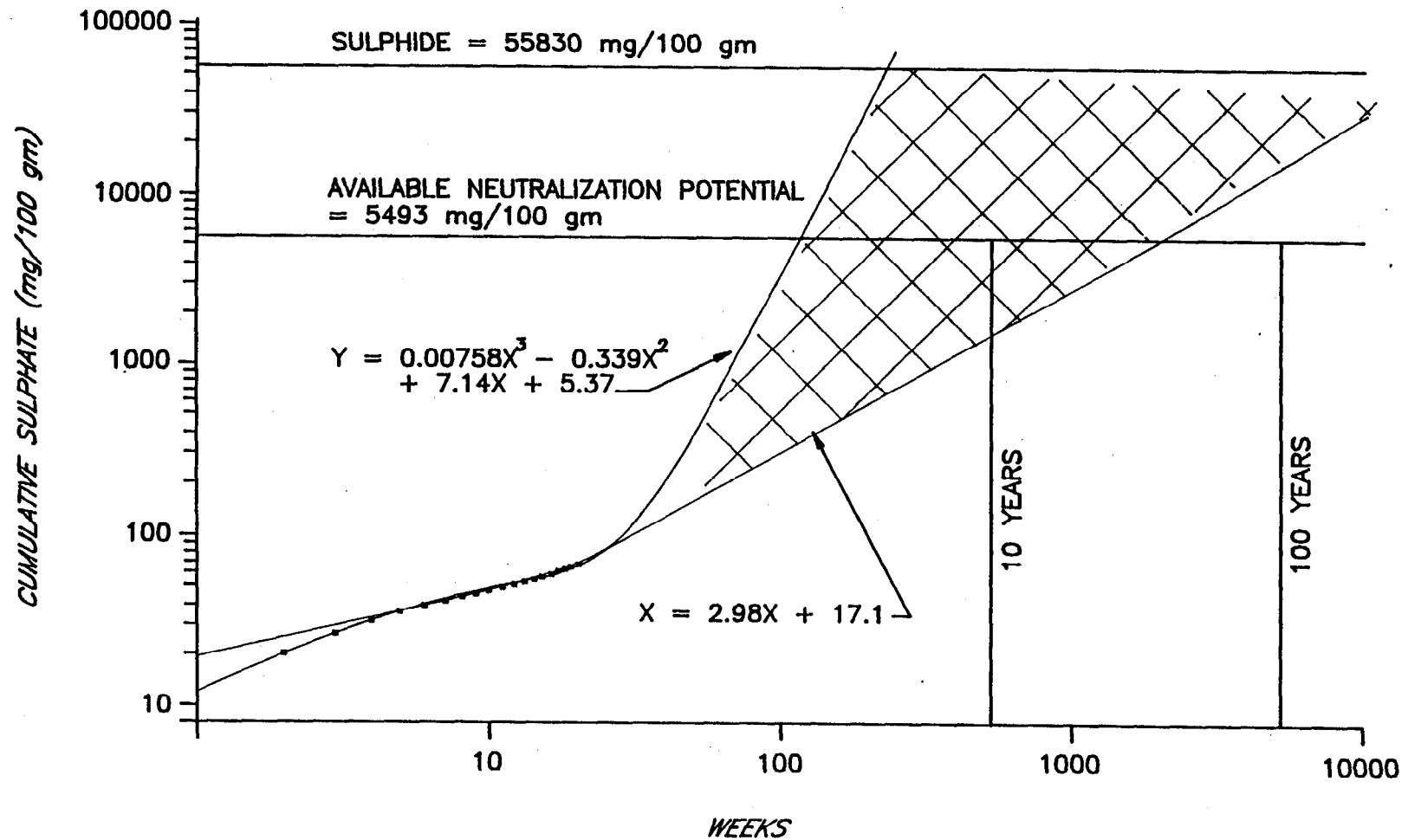


FIGURE 7-24 : LONG TERM PREDICTION FOR PRE PRODUCTION BLEND



# KUTCHO CREEK PROJECT FIVE YEAR BLEND

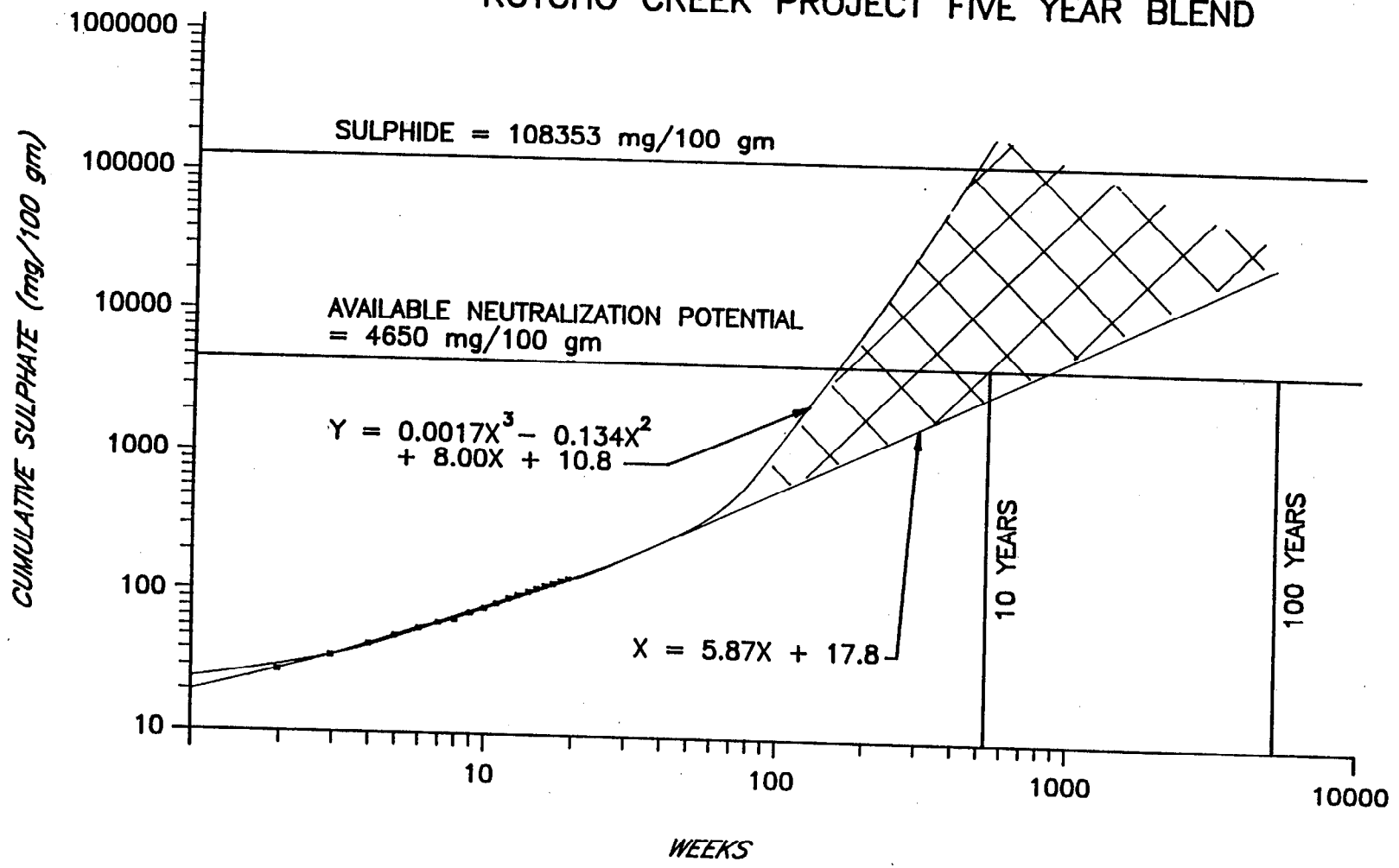


FIGURE 7-25 : LONG TERM PREDICTION FOR FIVE YEAR BLEND



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## **8 - Prevention of Acid Rock Drainage**



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## **8.0 PREVENTION OF ACID ROCK DRAINAGE**

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The purpose of this chapter is to present a brief synopsis of the several long term ARD control options that various mining projects have implemented. This concluding chapter also discusses the applicability of each ARD control strategy for waste rock disposal at Kutcho Creek.

### **8.1 Overview**

Control of ARD is predicated on preventing the conditions which lead to acid generation. Acid generation can best be prevented by excluding either oxygen or moisture from contacting the sulphide, and can be slowed down by inhibiting the activity of the bacterium *Thiobacillus ferrooxidans*. Several strategies are available to prevent ARD, including: biocidal control of bacteria, in situ neutralization, alternate dump construction, the use of surface covers and liners, and underwater disposal techniques. Alternatively, the sulphuric acid produced by the oxidation of pyrite can be neutralized through the addition of alkaline materials, or by blending acid producing and acid consuming waste rock.

### **8.2 Options for ARD Mitigation**

To evaluate whether blending will be a viable technique to prevent ARD at Kutcho, an estimate of the quantities and proportions of acid generating and acid consuming waste rock that will be liberated from development of the Kutcho Creek orebody was determined. The estimated quantities and proportions of acid generating and acid consuming waste rock were used to design field-scale blended waste rock piles. Long term predictions for sulphate production from the blended waste rock pads show that blending of Kutcho waste rock, even at 1:1, would not be a viable option for ARD mitigation. However, a number of other strategies could be considered. According to the *Critical Literature Review of Acid Drainage from Waste Rock* (Morin *et al.* 1991), five separate methodologies for ARD control have been employed in the past, with varying degrees of success.

The control of bacterial populations within the waste rock pile may decrease or prevent acid generation. The efficacy of chemical treatment to coat particle surfaces, thereby

inhibiting bacterial activity and acid production, has been studied by a number of researchers. The types of chemicals that were examined included: organics and inorganics such as food preservatives and low molecular weight organic compounds, detergents and alkaline chemicals such as lime, sodium carbonate and potassium phosphate. Researchers concluded that regardless of the type of compound used the amendments were not able to control acid generation reactions occurring inside of the waste piles. Furthermore the expense associated with reapplication of the amendments due to their solubility is considerable. Because the compounds are all soluble but could not penetrate to oxidation zones within the interior of the waste rock piles, their usefulness to control ARD is limited.

The addition of alkaline materials to control pH, and therefore acid generation, has also been examined. Some typical *in situ* neutralization strategies include: blending of acid consuming and acid generating rock, positioning of alkaline materials upgradient of acid generating rock, and placement of alkaline materials in a collection trench downstream of the acid source. The success of blending waste rock depends primarily upon the amount of water percolating through the waste rock piles, characteristics of the waste rock, and the amount of acid neutralizing material available. Use of the alkaline trench is only recommended for situations in which the hydrologic system is well understood, and is amenable to manipulation. Alkaline trenches are best suited for treatment of mildly acid generating waste rock since the quantity of neutralizing material necessary for the treatment of highly acid waste rock is usually prohibitive.

Alternative dump construction techniques, or encapsulating the acid generating waste rock within a nonreactive material, may also be implemented to mitigate ARD. Success of this strategy depends upon many factors including the types of waste rock that are available, how thoroughly the alkaline and acid generating materials are mixed, and the ability of the encapsulating material to prevent entry of oxygen and moisture. This strategy relies upon *in situ* neutralization, therefore, the difficulties associated are similar to those discussed in the previous paragraph.

Another method is the use of covers and seals which prevent oxygen and water from contacting reactive waste rock. There are numerous avenues for oxygen and water to enter a waste rock pile; therefore, to effectively seal an acid generating waste rock pile, the following requirements must be met:

## **PREVENTION OF ACID ROCK DRAINAGE**

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- top surface must be covered to prevent infiltration of rainfall and air movement;
- side slopes ought to be covered to eliminate infiltration of water, as well as diffusion or advection of air;
- top and side-covers should be stabilized to inhibit erosion; and
- the covers must be resistant to cracking, root penetration, burrowing by animals and deterioration due to weathering (freeze/thaw).

Cover materials used in the past include compacted clay, till or topsoil, peatland bog, concrete, asphalt, HDPE, and wax blends. Each cover material possesses advantages and disadvantages. Generally, topsoiling and revegetation did not significantly restrict water infiltration and, therefore, failed to provide long term control of acid generation. A layered soil cover may provide a more effective infiltration barrier. Each layer of the cover performs a specific function to restrict water and oxygen access, and to promote long term stability. Flexible synthetic membranes, or geomembranes, are effective provided they are properly installed on a well prepared foundation. However, geomembranes are susceptible to extraneous factors such as puncture during installation, photochemical degradation, and their stability is affected by differential settling of the waste rock. Geomembranes used in conjunction with composite covers are effective at limiting oxygen and water transport to acid generating waste rock. Wax blends are new products and have not received comprehensive testing to determine if they are an effective treatment to control ARD.

### **8.3 Recommendations for Waste Rock Treatment at Kutcho Creek**

The most popular strategy used to mitigate ARD is underwater disposal. Confining reactive waste rock beneath the water table prohibits oxidation of pyrite due to the low diffusivity of oxygen in water. Diffusion of oxygen is restricted under saturated conditions; nevertheless, a small amount of oxygen transfer continues to occur and could possibly impact benthic populations in natural bodies of water. Underwater disposal offers a long term solution, provided the water table does not fluctuate and the waste rock is under a sufficient depth of water, at all times. If a natural body of water is not within the general vicinity of the mine a disposal facility may have to be constructed. Design and construction of an underwater storage facility is usually quite costly.

## **PREVENTION OF ACID ROCK DRAINAGE**

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Nevertheless, disposal of reactive waste rock in a tailings impoundment may prove to be the most efficient and cost effective method of ARD mitigation at Kutcho Creek. Because the tailings slurry will be discharged at a high pH (probably >9), the supernatant will have a significant capacity to neutralize acid products which may have formed on the waste rock during the time between initial exposure to the atmosphere and ultimate disposal of the tailings impoundment. In addition, the mixture of coarse waste rock and fine tailings will be relatively impermeable, which will prevent oxygen-bearing water from circulating through the sulphide waste rock.

To minimize storage requirements and to ensure that only the acid generating waste rock is routed to the tailings impoundment, waste rock should be segregated according to its acid generating or acid consuming properties. Segregation of waste rock should commence during preproduction and continue throughout mine development. Waste rock segregation at Kutcho should be relatively easy since the contacts separating the various rock lithologies are quite distinct. Hanging wall waste rock, which is generally acid neutralizing, would be stored separate from footwall waste rock which is predominantly acid generating. Nonreactive hanging wall waste rock liberated during preproduction may be used for construction of the tailings impoundment.

Prior to completion of the tailings impoundment the reactive, acid generating footwall waste rock could be detained on an impermeable waste rock pad. The temporary waste rock pad would be sloped in order to collect any acid drainage produced from exposure of the waste rock to weathering. Acid rock drainage could then be treated via lime addition to increase its pH and decrease its concentration of metals. Once the neutralizing agent has been added to the rock pile runoff, it would be contained in a lined sludge pond. Any materials precipitating from the rock pile run off would collect at the bottom of the sludge pond. Sludge pond supernatant, providing it meets water quality guidelines, could be decanted and subsequently discharged to the receiving watercourse(s).

The sludge pond would be sized according to the surface area of the acid generating rock pile and the expected quantity of precipitation. The quantity of neutralizing agent required to effectively raise the pH of acid rock drainage may be determined through a series of bench scale tests. To enhance the chemical reaction between rock pile runoff and the neutralizing agent, the mixture is usually passed through a series of baffles contained within a launder box. This type of ARD control strategy has been successfully

integrated at another mine, located in northern British Columbia. A conceptual schematic of this treatment strategy is detailed by Figure 8-1.

One disadvantage of this strategy is that it will increase the storage volume requirements for the impoundment. This will increase the cost of the facility and may necessitate a reevaluation of the hydrology of the impoundment area, in order to ensure that there will be sufficient water available to maintain coverage of the potentially acid generating rock at all times.

Based upon the information presented here, blending of waste rock is not a viable option to control acid drainage at Kutcho Creek. Of the several alternate control strategies previously mentioned it appears that segregation of acid generating and acid consuming waste rocks and subsequent underwater disposal of the Kutcho acid generating waste rock is the most applicable strategy.

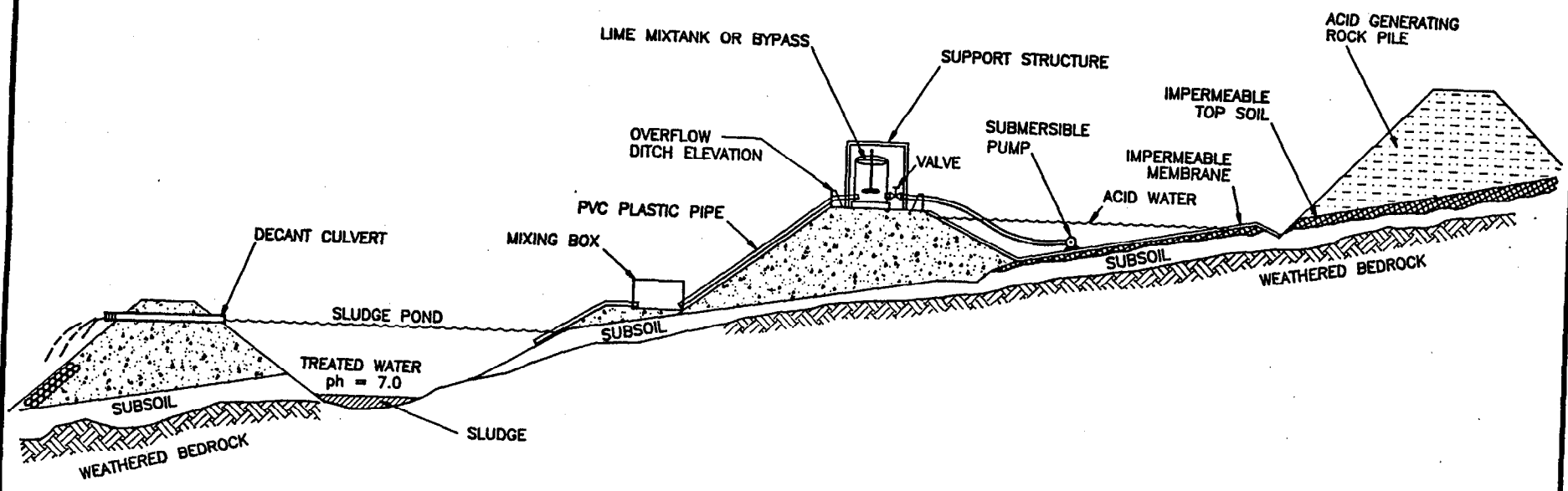


Figure 8 - 1 Conceptual Reactive Waste Rock Pad Design

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**TEST PROCEDURES**  
**Acid Base Accounting**  
**Humidity Cell Testwork**  
**B.C. Research**

**Acid Base Accounting**

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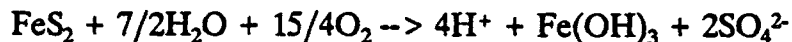
## GENERAL ACID BASE ACCOUNTING TEST PROCEDURES

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### Total Sulphur and Maximum Potential Acidity

Total sulphur is determined using a Leco sulphur analyzer. The sample is heated to approximately 1600°C with a stream of oxygen passing through the sample. Sulphur dioxide is released from the sample and collected in a solution, which is then titrated to determine the total sulphur. Total sulphur is usually reported as the percentage of sulphur relative to the entire sample (%S).

Total sulphur (as %S) is converted to maximum potential acidity in units of kilograms of CaCO<sub>3</sub> equivalent/tonnes of sample (or t of CaCO<sub>3</sub> equivalent/1000 t of sample) through multiplication by 31.25. This conversion factor is derived as follows. Firstly, it is assumed that the pyrite is completely oxidized by oxygen and water to sulphate and solid Fe (OH)<sub>3</sub>.



Then, it is assumed that hydrogen ions produced in the reaction are incompletely neutralized by CaCO<sub>3</sub> to a pH not greater than 6.



Based on this reaction pair, stoichiometrically the acidity produced by 1 mole of sulphur is neutralized by 1 mole of CaCO<sub>3</sub>. One gram of sulphur in 100 g of material (1% S) is equivalent to 0.03125 moles of sulphur which would be neutralized by 0.03125 moles of 3.125% CaCO<sub>3</sub>. This concentration is conventionally expressed as 31.25 kg CaCO<sub>3</sub>/tonne of material. Thus, the conversion factor is theoretical and is based on geochemical assumptions depending on the acid-generating conditions. Realistically, the conversion factor could be significantly greater than or less than 31.25.

**Paste pH**

Paste pH is measured by a pH/reference electrode assembly and a pH meter. The electrode assembly is placed into the paste formed by mixing water and powdered rock in a specific ratio and the pH is read from the meter.

A paste pH greater than the pH of the mixing water indicates immediate neutralization has occurred and a pH above 7 suggests either the presence of reactive calcite or the contamination by drilling fluids. A paste pH of less than 4.0 indicates that the material contains readily available acidity from prior acid generation and the material is toxic to most plants.

**Neutralization Potential**

The total amount of neutralizing minerals including carbonates and hydroxides present in the material is determined by treating a sample with a known excess of standardized hydrochloric acid. The sample and acid mixture is heated to ensure the reaction between the acid and neutralizing minerals is complete. The amount of unconsumed acid is then determined by titrating with standardized sodium hydroxide to pH 7.

Neutralization potential is calculated by converting the amount of base to a calcium carbonate ( $\text{CaCO}_3$ ) equivalent, commonly in units of kg/t of sample, t/1000 t, or % carbon dioxide ( $\text{CO}_2$ ). This expression of neutralization potential as  $\text{CaCO}_3$  is deceiving in that most natural neutralizing minerals are not capable of neutralizing pH above a value of 6. Furthermore, there is some uncertainty in the hydroxide titration in that some minerals will re-precipitate, but at varying rates, which affects the amount of hydroxide needed to reach pH 7.

**Humidity Cell Testwork**

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## HUMIDITY CELL TEST PROCEDURES

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The humidity cell apparatus used for Kutcho Creek waste rock testing was designed and assembled according to specifications provided by Rescan. These cells are substantially improved over conventional humidity cells because they allow both air and rinse water to circulate through the waste rock samples more uniformly. A conventional humidity cell typically consists of a circular plastic cell with two ports (intake and exhaust) for circulating air and water. Air is blown into the lower port located on the side wall, and exits through the top port. Because air behaves as a fluid and travels along the path of least resistance, it does not circulate evenly through the sample in a conventional cell. Rather, the air tends to short circuit by moving upwards toward the exit port. Consequently, the sample material is not uniformly subjected to the same degree of humidity cell testwork moist and dry air, and correspondingly, may not oxidize evenly. Rinsing of the sample material is also problematic in a conventional humidity cell because rinse water cannot be entirely drained from the cell due to the side wall location of the drain port. The sample is disturbed if the cell is tipped to one side in order to drain more rinse water through the side port.

The modified humidity cell prevents the obvious problems of non-uniform air circulation and incomplete draining of wash water. A one kilogram sample is placed on a fine mesh plastic screen supported by a perforated acrylic plate inside a circular plexiglass cell having an inside diameter of 100 mm. Air is directed up through the sample via an entrance port on the bottom of the cell, and exits via a port on the top. For soaking the sample, the top lid of the cell is removed and a 500 mL aliquot of water is added which completely submerges the sample. The water is subsequently drained through a port located on the bottom of the cell. The test procedure is detailed below.

Rock samples were initially jaw crushed to minus 3/8 inch and subsequently cone crushed to minus 1/4 inch until a minimum of 80% (by weight) of the sample passed through a 1/4 inch mesh. One kilogram of the crushed material was then placed in the humidity cell and the lid sealed. For the first 3 days of the 7 day cycle, moist air was blown through the sample. This was followed by 3 days of dry air being blown through

the cell. Moist air (100% humidity) is supplied by bubbling air through airstones submerged in a manifold partially filled with water which is maintained at a temperature of 30°C. Dry air at room temperature is achieved by two silica gel column desiccating filters on the air supply line.

On the 7th day of the test cycle, 0.50 L of distilled water is poured into the cell where it completely submerges and soaks the rock sample for a period of 1.0 hour. The leachate is then drained from the cell and filtered through a 0.45  $\mu\text{m}$  filter. It is subsequently analyzed for pH, acidity, alkalinity, sulphate and the following 9 metals: aluminum, arsenic, cadmium, copper, iron, lead, manganese, mercury, and zinc. Metals which are known to be present at higher concentrations are analyzed by inductively coupled argon plasma (ICAP) and direct flame atomic absorption spectroscopy (AAS). Low concentration elements are determined by graphite furnace AAS; arsenic and mercury are measured by hydride generation AAS and cold vapour AAS, respectively.

As described above, the test procedure used with the modified humidity cells differs from that used with conventional humidity cells. The modified test uses a 1.0 kg sample and flushes the sample with 500 mL of water. Conventional humidity cell testing typically uses 200 g samples and flushes the samples with 250 mL of water. Because the ratio of sample weight to volume of flush water is 2.5 times higher in the modified test, the concentration of materials leached from the samples is also significantly higher. Consequently, the absolute concentration of the parameters monitored from Phase 1 of Kutcho Creek humidity cell testwork should not be directly compared to test results where conventional humidity cell test procedures were used. The kinetics of the reactions are of major significance in the humidity cell results, and not necessarily the absolute concentration of a specific parameter.



**B.C. Research**

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## **B.C. RESEARCH TEST PROCEDURES**

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### **Initial Test (Chemical)**

#### **Sample**

The sample must be taken in such a manner that it is truly representative of the type of mineralization being examined. A composite consisting of split drill core or randomly selected grab samples should be satisfactory. The number of samples to be examined will depend on the variability of the mineralization and must be left to the discretion of the geologist. The bulk sample is crushed to a size which can be conveniently handled, (i.e. -5 cm), thoroughly mixed, and coned and quartered to obtain a representative 1 kg sample. This sample is then ballmilled to pass a 400 mesh screen, dried at 60°C, and is used for sulphur assay, the titration test and if necessary the confirmation test.

#### **Assay**

The ballmilled sample is assayed in duplicate for total sulphur in a Leco furnace. The acid production potential of the sample, expressed as kg of sulphuric acid per tonne of sample, is calculated on the basis of the total sulphur assay.

#### **Titration Test**

Duplicate 10-g portions of the ballmilled sample are suspended in 100 ml of distilled water and stirred for approximately 15 minutes. The natural pH of the sample is recorded. The sample is then titrated to pH 3.5 with 1.0 N sulphuric acid on a Radiometer automatic titrator. The test is continued until less than 0.1 ml of acid is added over a 4-h period. The total volume of acid added is recorded and converted to kg per tonne of sample. This is the acid-consuming ability of the sample, i.e.

$$\text{acid-consuming ability (kg/tonne)} = \frac{\text{ml of 1.0 N H}_2\text{SO}_4 \times 0.049 \times 1000}{\text{wt of sample in g}}$$

$$\text{or for a 10-g sample} = \text{ml of 1.0 N H}_2\text{SO}_4 \times 4.9$$

### Interpretation

If the acid consumption value (in kg of acid per tonne of sample) exceeds the acid-producing potential (kg per tonne), the sample will not be a source of acid mine drainage and no additional work is necessary. If the acid consumption is less than the acid production potential, the possibility of acid mine water production exists and the confirmation test is conducted. The sample is titrated to a pH of 3.5 and no lower because of the possibility of growth of the acid-generating bacterium *Thiobacillus ferrooxidans* at pH's below 3.5.

### Confirmation Test (Biological)

#### Shakeflask Leaching Test

Duplicate 30-g portions (or a smaller amount if the sulphide content exceeds 2%) are placed in 250 ml Erlenmeyer flasks with 70 ml of a nutrient medium containing 3 g/l  $(\text{NH}_4)_2\text{SO}_4$ ; 0.10 g/l KCl; 0.50 g/l  $\text{K}_2\text{HPO}_4$ ; 0.50 g/l  $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ ; 0.01 g/l  $\text{Ca}(\text{NO}_3)_2$ . Sufficient sulphuric acid is added (either 12 or 36 N) to bring the pH to 2.5. The flasks are shaken for approximately 4 h during which the pH should be between 2.5 and 2.8. If necessary additional acid is added until the Ph remains in that range. The flasks are inoculated with 5 ml of an active *Thiobacillus ferrooxidans* culture. The weight of the flasks and contents are recorded and the flasks are capped with a loose cotton plug and incubated at 35°C on a gyratory shaker.

Before monitoring or sampling the experiment leach flasks, distilled or deionized water is added to replace that lost by evaporation. The pH and concentration of a dissolved metal (e.g. iron, copper or zinc, if applicable) are monitored for the first three days to ensure that the pH remains below 2.8. Thereafter, the pH is recorded every second day until microbiological activity has ceased (as evidenced by a steady pH or dissolved metal concentration) or until the pH drops to 1.8.

When microbiological activity has ceased, half the weight of feed originally used is added (15 g), the flask is shaken for 24 h and the pH is recorded. If the pH is greater than 3.5, the test is terminated. If it is 3.5 or less, half the weight of feed (15 g) is again added and the flask is shaken for 24 h. If the pH is less than 3.5 or greater than 4, the test is terminated. Otherwise, the sample is shaken for an additional 48 h and the final pH is recorded.

### **Interpretation**

The object of this test is to determine if the sulphide-oxidizing bacteria can generate enough sulphuric acid from the sulphides present to satisfy the acid demand of the sample. Experience has shown that not all sulphide minerals are amenable to microbiological attack nor do they all oxidize completely, so that the acid production potential indicated by the sulphur assay may be excessive. If the bacteria generate the acid, microbiological action will continue on a self-sustaining basis once it becomes established, and acidic mine water will result. In this test, the acid demand is satisfied initially by adding sulphuric acid. This permits the bacteria to generate the maximum amount of sulphuric acid from the sample concerned. Once microbiological action has ceased, half the original sample weight is added. If there has not been sufficient acid production, the pH will approach the natural pH of the sample (i.e. above pH 3.5) and the sample is reported as not being a potential source of acid mine water. If the pH remains at 3.5 or below, the remainder of the sample is added and the sample is shaken for up to 72 h before measuring the final pH. If the pH is still in the leaching range, i.e. pH 3.5 or below, there is a strong possibility that natural leaching will occur and acid mine drainage will be produced. If the pH is above 3.5, there is no possibility of acid mine drainage occurring.

If the sample produces excess acidity, there is the possibility of metal recovery by microbiological leaching. A measure of this potential can be obtained by estimating the percentage of the contained metal which has been solubilized during the leaching test. Under such circumstances, it may be desirable to promote microbiological action as a means of recovering valuable metals from a waste material. In such a system, suitable precautions must be taken to prevent the metal and acid-rich leach waters from entering the natural drainage system of the surrounding area.

A degree of caution must be exercised in extrapolating the test results to coarser samples. Both the available surface area and the amount of exposed sulphides will be reduced leading to a reduction in both the acid consumption and the potential acid production. Experience has shown that generally relatively more gangue than sulphides is exposed at the larger particle sizes, although this may not always be the case.

**LABORATORY TEST RESULTS**

**Acid Base Accounting**

**Humidity Cell Testwork**

**Grain Size Analysis**

**Mineralogical Studies**

**Acid Base Accounting**





ACID BASE ACCOUNTING 1990

ROCK TYPE	AVG. DEPTH (m.)	INTERVAL (m)	TOTAL SX (Leco)	AX. POT ACID **	NEUT. POT. **	ET NEUT POT.	PASTE pH	CO2 %	SULPHATE SX	SULPHIDE SX***	SAMPLE NUMBER
META	2.7	0.6	0.229	7	300	293	8.5	12.6	0.01	0.12	43
GABBRO	17.6	0.5	0	0	206	206	9.2	9.2	0.01	0	9
	54.6	0.6	0	0	159	159	8.7	7.7	0	0	25
	20.7	0.6	0.073	2	128	126	9.5	4	0	0	13
	14	0.6	0.155	5	99	94	9.1	2.5	0.03	0.08	29
	64.9	0.6	0.06	2	201	199	8.9	8.6	0.02	0	34
	11.2	0.7	0.548	17	218	201	8.7	11.2	0.01	0.39	40
QUARTZ	58.3	0.9	0.125	4	281	277	8.5	12.3	0	0	41
FELDSPAR	60.3	0.6	0.001	0	57	57	9.5	2.7	0	0	23
CRYSTAL	143.2	0.6	0.025	0	139	139	9.2	5.9	0	0	35
TUFF	59.7	0.6	0.094	3	41	38	9.6	1.5	0	0	14
	44.5	0.6	0.036	1	30	29	8.9	2.5	0.01	0	6
	37.2	0.6	0	0	182	182	8.9	9.5	0.02	0	19
	27.4	0.7	0	0	72	72	9.1	3.7	0	0	1
	9.1	0.6	0.426	13	566	553	9.4	27.9	0.02	0.36	47
	46	0.6	0.1	3	38	35	9.2	1.7	0.01	0	49
	112.1	0.7	0.019	0	94	94	8.9	4.9	0	0	15
	58.7	0.5	16.5	516	3	-513	5.7		0.03	17.01	3
	30.1	0.5	1.81	57	129	72	8.5	5.9	0.01	1.57	44
	93.2	0.7	0.053	2	40	38	9.3	1.9	0	0.01	11
	160.6	0.6	0.813	25	97	72	9	4.9	0	0.7	36
	51.4	0.8	0	0	47	47	9.1	1.9	0	0	2
CRYSTAL	135.9	0.6	0.98	31	109	78	9	5.1	0	0.89	16
LAPILLI	136.9	0.9	6.84	214	278	64	8.4	14.9	0.01	6.94	12
TUFF	131.1	0.6	0	0	189	189	9.4	9.8	0	0	27
	132.2	0.7	0.038	1	422	421	8.7	20.4	0	0	31
	64.9	0.6	5.33	167	22	-145	7.4	0.7	0.02	5.34	21
	77.7	0.6	0.186	6	140	134	9.4	7.8	0	0.05	24
	48.2	0.6	0.289	9	183	174	8.8	10	0	0.19	20
	90.8	0.6	0.177	6	121	115	9.3	6.1	0	0	7
CHERT	100	0.6	0	0	53	53	9	1.9	0	0	26
MAFIC	82.6	0.6	0.085	3	141	138	8.8	6.7	0	0	30
ASH	47.2	0.6	0.037	1	45	44	9.4	1.7	0	0	10
TUFF	23.2	0.6	0.125	4	42	38	9.3	1.7	0	0.02	22
	13.2	0.9	0.186	6	51	45	9.1	1.6	0.01	0.04	18
ORE	169.2	0.9	7.53	235	8	-227	7.7	0.4	0.02	8.04	32
ZONE	119.2	1.2	26.3	822	2	-820	6.5		0.09	26.73	42
	28.3	1.2	17.2	538	60	-478	8.1		0.02	16.08	48
	66.1	0.6	0.069	2	311	309	8.4	15	0	0	45
	167	0.6	2.53	79	181	102	9	8.3	0.01	2.36	37
	108.5	0.6	4.08	128	44	-84	8.2	1.6	0.02	3.73	8
	32	0.6	34.9	1090	60	-1030	6.9		0.03	35.87	4
	110.1	1.5	46.9	1470	85	-1385	7		0.07	46.74	50
QUARTZ	78.1	0.9	36.2	1130	181	-949	8		0.07	37.51	46
SERICITE	46.3	0.6	2	63	117	54	8.6	1	0	1.97	5
LAPILLI	180	1.5	10.9	341	1	-340	6.3		0.03	11.51	28
TUFF	197.8	0.6	31.9	997	42	-955	6.9	8.6	0.08	33.41	39
	190.9	0.9	7.84	245	2	-243	7.3	0.3	0.02	7.97	33
	192	1.2	11.2	350	77	-273	8.2	4.6	0.03	11.74	38
	185.3	0.6	19.5	609	1	-608	5.7		0.04	20.14	17

**Humidity Cell Testwork**

HUMIDITY CELL TESTWORK PHASE I

SAMPLE KA-1										
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE	
	VOLUME	pH			pH 4.5	pH 8.3				SULPHATE
1	0.361	7.63	183	65.1	0	7.2	0.3	36	1.3	
2	0.355	8.04	380	155.4	0	1	0.3	31	2.4	
3	0.417	7.8	160	63	0	2	0.4	12	2.9	
4	0.444	7.59	102	91	0	1	0.4	13.5	3.5	
5	0.364	7.72	75	24	0	1	0.5	11	3.9	
6	0.417	7.29	90	19.8	0	3.6	0.6	12	4.4	
7	0.364	7.54	71	24	0	1.9	0.7	11	4.8	
8	0.444	7.53	65	21	0	1.1	0.7	9	5.2	
9	0.333	7.7	61	23.1	0	0.5	0.7	6	5.4	
10	0.5	7.85	76	18.9	0	3	0.9	6	5.7	
11	0.4	7.84	64	20.2	0	0.6	0.9	5	5.9	
12	0.375	7.85	75	25.4	0	0.7	0.9	8	6.2	
13	0.444	8.29	108	5.1	0	0.6	1	9	6.6	
14	0.435	7.89	77	23.3	0	1.7	1	11.5	7.1	
15	0.417	7.91	121	34.1	0	1.6	1.1	12	7.6	
16	0.429	7.87	91	27.3	0	1.6	1.2	14	8.2	
17	0.417	7.66	78	22.3	0	1.5	1.2	12	8.7	
18	0.375	7.7	78	21.9	0	1	1.3	8	9	
19	0.5	7.72	71	20.5	0	1	1.3	2	9.1	
20	0.5	7.61	81	20.8	0	1.5	1.4	4	9.3	
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC	
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	
1	79	5.9	0.3	1			93		62	
2	59	2.3					168		8	
3	35	1.9					21			
4	100	3.3		2			9			
5	79	1.5		2			5			
6	150	2.1		7			5	0.06		
7	160	4.6		9			5			
8	93	1.9		11						
9	48	3.4		4			28	0.05		
10	55	1.5		3			6			
11	110	0.8		3	33		7	0.06		
12	100	3.9		3			14	0.26		
13	57	1.2		11			38	0.15		
14	83	3.6			20		7			
15	130	3.7		4			36	0.1		
16	190	3.9		6	40		11	0.24		
17	130	4.1		5	23	1	5	0.36		
18	110	5.8		4	23		7	0.16		
19	170	2.9		8	126		12		11	
20	53	3.9		6	23		7			

Humidity Cell Testwork Phase II

SAMPLE KA-2											
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE		
	VOLUME	pH			pH 4.5	pH 8.3				SULPHATE	CUMULATIVE
1	0.355	7.63	183	65.1	0	7.2	0.3	36	1.3		
2	0.353	8.04	380	155.4	0	1	0.3	31	2.4		
3	0.462	7.8	160	63	0	2	0.4	12	2.9		
4	0.424	7.59	102	91	0	1	0.4	13.5	3.5		
5	0.4	7.72	75	24	0	1	0.5	11	3.9		
6	0.333	7.29	90	19.8	0	3.6	0.6	12	4.4		
7		7.54	71	24	0	1.9	0.7	11	4.8		
8	0.5	7.53	65	21	0	1.1	0.7	9	5.2		
9		7.7	61	23.1	0	0.5	0.7	6	5.4		
10	0.8	7.85	76	18.9	0	3	0.9	6	5.7		
11	0.3	7.84	64	20.2	0	0.6	0.9	5	5.9		
12	0.5	7.85	75	25.4	0	0.7	0.9	8	6.2		
13	0.417	8.29	108	5.1	0	0.6	1	9	6.6		
14	0.333	7.89	77	23.3	0	1.7	1	11.5	7.1		
15	0.5	7.91	121	34.1	0	1.6	1.1	12	7.6		
16	0.4	7.87	91	27.3	0	1.6	1.2	14	8.2		
17	0.435	7.66	78	22.3	0	1.5	1.2	12	8.7		
18	0.444	7.7	78	21.9	0	1	1.3	8	9		
19	0.375	7.72	71	20.5	0	1	1.3	2	9.1		
20	0.5	7.61	81	20.8	0	1.5	1.4	4	9.3		
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC		
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L		
1	110	6.9	0.2				23		8		
2	35	2.5	1.3	1			238		384		
3	58	2.9					12				
4	68	2.2		4	33		9				
5	66	3.6		3			7				
6	150	2.1		7			5	0.06			
7	160	4.6		9			5				
8	93	1.9		11							
9	48	3.4		4			28	0.05			
10	61	1.8		3			6	0.08			
11	95	1.1			20			0.16	8		
12	65	4.3		2			8	0.08			
13	88	2.5		13	18		8	0.15			
14	86	4.8			17		5				
15	130	4.5		8	18		29				
16	180	3.8		4	19			0.17			
17	88	4.3		5	15		6	0.06			
18	140	5.6		6	33	1	7	0.12			
19	99	3.5		7			5	0.06			
20	44	3.6		5	25		7				

Humidity Cell Testwork Phase II

SAMPLE	KA-3								
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			SULPHATE
	L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.277	7.29	168	46.2	0	2.4	0.1	65	1.8
2	0.423	7.64	263	72.5	0	1.5	0.1	52	4
3	0.444	8.17	188	60.9	0	1	0.2	27	5.2
4	0.462	8.32	125	109.2	0	0	0.2	13	5.8
5	0.308	8.37	108	32	0	0	0.2	13	6.2
6	0.4	8.58	93	28.8	0	0	0.2	5	6.4
7	0.4	8.78	81	34	0	0	0.2	5	6.6
8		7.47	62	25.2	0	2.8	0.3	1	6.7
9		7.94	65	27.3	0	0.5	0.3	1	6.7
10	0.417	8.41	87	27.3	0	0	0.3	12	7.2
11	0.5	8.54	67	24	0	0	0.3	2	7.3
12	0.556	8.32	90	30.4	0	0	0.3	9	7.8
13	0.333	8.56	73	19.5	0	0	0.3	3	7.9
14	0.4	8.03	74	21.2	0	0.6	0.3	2.5	8
15	0.4	8.02	86	35.4	0	1.6	0.4	2.5	8.1
16	0.5	8.06	79	29.4	0	1.6	0.5	2	8.2
17	0.333	7.76	72	26.4	0	0.9	0.5	3	8.3
18	0.4	7.84	78	30.7	0	1	0.5	10	8.7
19	0.5	7.85	67	26.4	0	1	0.6	2	8.8
20	1	7.84	69	22.9	0	1	0.6	1	8.9
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	51	2.9	0.2				35		5
2	45	2.7					64		18
3	40	1.4					29		
4	56	1.7					11		
5	54	1.1		2			6		
6	100	2		14			0.06		
7	93	2		11					
8	58	1.9		6					
9	32	1		1			8	0.05	
10	47	0.7		2			7	0.06	
11	91	0.5		2	26		6	0.25	
12	64	2.1					5	0.05	
13	66	2.1		9	23		8	0.18	
14	69	1.6					6		
15	98	2.2		3			10		
16	150	1.9		2	23		6	0.29	
17	180	2.9		3	25		5	0.21	
18	110	2.9		2	16		6	0.08	
19	120	1.7		2	17		8		
20	45	1.7		3	20		5		

Humidity Cell Testwork Phase II

SAMPLE	KA-4								
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH	mS/cm	mg/L CaCO3	pH 4.5	pH 8.3	mg/100g	mg/L	SULPHATE
	L				**mg/L	CaCO3**			mg/100g
1	0.376	7.29	168	46.2	0	2.4	0.1	42.5	1.6
2	0.4	7.8	247	86.1	0	1.8	0.2	27.5	2.7
3	0.533	7.99	163	54.6	0	2	0.3	15	3.5
4	0.387	7.63	162	140.4	0	1	0.3	15.5	4.1
5	0.417	7.43	86	26	0	1	0.3	12	4.6
6	0.357	7.46	88	27	0	1.9	0.4	14	5.1
7	0.4	8.32	78	26	0	0	0.4	12.5	5.6
8	0.4	7.67	64	25.2	0	1.1	0.5	7.5	5.9
9	0.5	7.92	64	23.1	0	0.5	0.5	10	6.4
10	0.4	7.71	81	21	0	1.6	0.6	12.5	6.9
11	0.4	7.86	76	26.9	0	1	0.6	12.5	7.4
12	0.364	7.81	74	24.2	0	0.7	0.6	11	7.8
13	0.5	7.83	69	23.4	0	1.7	0.7	10	8.3
14	0.348	7.74	73	24.2	0	1.1	0.7	11.5	8.7
15	5	8.02	89	33.3	0	2	0.8	10	9.2
16	0.462	7.92	70	23.1	0	2	0.9	13	9.8
17	0.4	7.69	63	20.3	0	0.9	1	12.5	10.3
18	0.385	7.59	63	15.3	0	1.5	1	13	10.8
19	0.455	7.71	65	18.3	0	1	1.1	11	11.3
20	0.429	7.51	67	20.8	0	1.5	1.1	14	11.9
CYCLE	ALUMINIUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	32	1.3					19		
2	30	0.8					37		8
3	32	0.6					15		
4	28	0.2							
5	59	0.3		3			5		
6	80	0.7		6				0.05	
7	96	0.8		10					
8	29	0.3		5					
9	20	0.2							
10	28	0.1		2			11	0.08	
11	48			2					
12	36	0.6							
13	48	2.7		5		2	9	0.18	
14	49	0.8							
15	42	0.8		3			10		
16	68	0.8						0.05	
17	50	0.7		1				0.1	
18	75	1.1		1			15	0.05	
19	64	0.5		1					
20	42	0.6		2					

Humidity Cell Testwork Phase I

SAMPLE	KA-5								
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			SULPHATE
	L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.218	7.27	173	63	0	9.6	0.2	27.5	0.6
2	0.424	7.83	261	103.1	0	1.5	0.3	16.5	1.3
3	0.462	8.13	170	67.2	0	1	0.3	13	1.9
4	0.4	8.11	125	62.4	0	1	0.4	12.5	2.4
5	0.2	7.8	103	14	0	0.6	0.4	5	2.5
6	0.417	7.97	267	21.6	0	0.7	0.4	12	3
7	0.25	8.35	82	32	0	0	0.4	4	3.1
8		7.06	74	16	0	4.3	0.6	0	3.1
9		8.01	70	33.6	0	0.5	0.6	1	3.2
10		8.38	88	37.8	0	0	0.6	1	3.2
11	0.5	7.99	78	34.4	0	0.6	0.6	2	3.3
12	0.4	8.26	80	27.3	0	1.1	0.7	2.5	3.4
13	0.4	8.44	82	35.1	0	0	0.7	2.5	3.5
14		8.06	86	40.3	0	0.6	0.7	1	3.5
15		7.96	85	34.1	0	1	0.7	0	3.5
16		8.13	84	33.6	0	1.6	0.8	1	3.6
17		8.19	72	32.5	0	0.6	0.8	1	3.6
18		8.05	76	32.9	0	0.5	0.9	1	3.7
19		8.02	72	32.5	0	0.8	0.9	1	3.7
20	0.333	7.87	79	35.4	0	1.5	1	3	3.8
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	31	1.6		4			16		
2	33	1.2					17		7
3	51	0.8					6		
4	19	0.4							
5	38	0.8		3			6		
6	48	1.3		16				0.06	
7	84	1.1		3				0.05	
8	33	0.8		3				0.1	
9	24	0.3							
10	27	0.2					6		
11	59	0.3			19				
12	32	0.9						0.05	
13	59	1.8		6		3	7	0.28	
14	54	0.9			17				
15	100	1		2				0.05	
16	76	0.8							
17	63	0.7		1				0.05	
18	63	1.1			16		11	0.05	
19	57	0.7		1					
20	32	0.7		3					

Humidity Cell Testwork Phase I

SAMPLE KA-6											
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE		
	VOLUME	pH			pH 4.5	pH 8.3				SULPHATE	CUMULATIVE
1	0.3	7.24	254	67.2	0	8.4	0.3	60	1.8		
2	0.427	7.64	336	87.8	0	2	0.3	75	5		
3	0.389	7.72	312	81.9	0	1	0.4	54	7.1		
4	0.5	8.02	98	58.8	0	1.2	0.4	26	8.4		
5	0.364	7.76	83	18	0	0.7	0.5	16.5	9		
6	0.421	7.78	98	16.9	0	3.1	0.6	19	9.8		
7	0.375	7.83	72	20	0	2.3	0.7	16	10.4		
8	0.417	7.36	70	10.5	0	2.2	0.8	12	10.9		
9	0.429	7.59	68	18.1	0	3.2	0.9	14	11.5		
10	0.444	7.44	98	16.8	0	2	1	18	12.3		
11	0.545	7.54	63	17.8	0	1.7	1.1	11	12.9		
12	0.444	7.73	78	17.6	0	1.1	1.1	18	13.7		
13	0.438	7.88	85	19.5	0	2.6	1.2	16	14.4		
14	0.429	7.68	79	22.5	0	1.7	1.3	14	15		
15	0.385	7.89	78	17.9	0	1.6	1.4	13	15.5		
16	0.414	7.8	78	18.9	0	3.1	1.5	14.5	16.1		
17	0.444	7.5	73	16.2	0	0.9	1.6	18	16.9		
18	0.412	7.59	85	17.5	0	1	1.6	17	17.6		
19	0.412	7.65	75	18.3	0	1	1.6	17	18.3		
20	0.438	7.57	79	18.7	0	2	1.7	16	19		
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC		
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L		
1	23		0.8	3			290		19		
2	37	1.2		1			341		12		
3	25	0.6					187				
4	46	1.3		4			56				
5	48	2.1		3			24				
6	93	2.8		380		2	26	0.06	5		
7	74	2.1		21		1	19		5		
8	49	2		18			25	0.1			
9	35	1.4		4			20	0.09			
10	46	1.3		4			31	0.08			
11	92	0.8		3			16	0.07			
12	43	2.2		2			25				
13	50	2.7		15			22	0.08			
14	69	2						0.06			
15	110	2.7		6			16	0.05			
16	130	2		2			12	0.13			
17	80	1.8		3			15	0.07			
18	83	2.5		2			15	0.18			
19	89	1.3		3			13				
20	41	1.6		3							



Humidity Cell Testwork Phase 1

SAMPLE KA-7									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH	mS/cm	mg/L CaCO3	pH 4.5	pH 8.3	mg/100g	mg/L	SULPHATE
	L				**mg/L	CaCO3**			mg/100g
1	0.385	7.68	125	41	0	1.8	0.1	13	0.5
2	0.4	7.64	76	27.3	0	2.6	0.2	15	1.1
3	0.417	8.36	67	389.9	0	0	0.2	12	1.6
4		7.23	64	19.2	0	2	0.3	1	1.7
5	0.444	7.71	70	16.8	0	2.4	0.4	9	2.1
6	0.429	7.86	142	21.6	0	2.4	0.5	7	2.4
7	0.25	8.01	63	18	0	0.6	0.5	4	2.5
8	0.5	7.65	45	14.7	0	1.7	0.6	2	2.6
9	0.5	7.8	50	21	0	0.6	0.6	2	2.7
10	0.5	7.57	57	11.3	0	2	0.7	4	2.9
11	0.4	7.99	48	8.3	0	0.6	0.7	2.5	3
12	0.4	7.53	55	18.7	0	0.7	0.7	2.5	3.1
13		7.58	51	15.6	0	1.1	0.8	0	3.1
14	0.333	7.45	50	27.6	0	1.7	0.9	3	3.2
15	0.5	7.77	52	18.7	0	1	0.9	2	3.3
16		7.63	63	21	0	4.8	1.1	0	3.3
17	0.5	7.94	62	20.3	0	0.9	1.2	2	3.4
18	0.5	7.56	56	19.7	0	2	1.3	2	3.5
19		7.58	59	16.2	0	1	1.3	1	3.6
20		7.39	79	20.8	0	1	1.4	1	3.6
CYCLE	ALUMINIUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	58	1.7					27		
2	110	3.1					29		
3	97	3.3					23		
4	39	2.6		1			17		
5	66	2.7		2			13		
6	130	3.9		22			14		
7	83	2.7		2			11		
8	71	2.2		3			8		
9	44	2.4		2			12		
10	49	0.9		2			11	0.19	
11	92	1		2			8	0.1	
12	68	2.4		3			9	0.18	
13	68	2.7		9			9	0.12	
14	73	1.8					7		
15	120	2.7		4				0.12	
16	98	1.9		1			11	0.24	
17	71	2.7		2			12	0.12	
18	72	2.8		1			11	0.05	
19	110	2.4		3			7	0.05	
20	51	1.9		2					

Humidity Cell Testwork Phase I

SAMPLE KA-8									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.375	7.69	113	33.6	0	2.4	0.1	16	0.6
2	0.381	7.56	97	23.1	0	1.5	0.1	21	1.4
3	0.429	8.12	77	25.2	0	1	0.2	14	2
4	0.345	7.33	80	17.3	0	1.6	0.2	14.5	2.5
5	0.476	7.4	64	16	0	1	0.3	10.5	3
6	0.417	7.89	82	17.3	0	1.2	0.3	12	3.5
7	0.444	8.37	58	20	0	0	0.3	4.5	3.7
8	0.5	7.7	55	18.1	0	1.7	0.4	2	3.8
9		8.14	49	16.8	0	0.6	0.4	1	3.8
10		8.17	57	20.2	0	0.6	0.5	0	3.8
11		7.67	51	22.8	0	1	0.5	0	3.8
12	0.5	7.95	53	17.6	0	0.7	0.5	4	4
13		8.53	65	18.7	0	0	0.5	1	4
14		7.82	51	19.1	0	1.1	0.6	1	4
15		7.65	55	16.6	0	0.6	0.6	1	4.1
16	0.5	7.99	53	21	0	1.6	0.7	4	4.3
17		7.87	57	18.3	0	0.9	0.7	1	4.3
18		7.64	53	28.5	0	2	0.8	0	4.3
19	0.333	7.65	50	22.3	0	1.5	0.9	3	4.4
20		7.54	48	16.6	0	1	0.9	0	4.4
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	51	2.6	0.2				21		
2	83	2.3					41		
3	70	2.6		1			26		
4	45	1.9		2			36		
5	51	1.8		2			18		
6	130	4.1		150			15		
7	83	2.5		12			12	0.06	
8	80	2.6		5			9		
9	46	2.1		2			10		
10	54	1.8		4			10	0.06	
11	100	1		3			12	0.1	
12	75	1.9		3			10	0.31	
13	67	2.4		11			11		
14	75	1.7					8		
15	110	2.5		3			7		
16	140	1.9		4			6	0.11	
17	76	3.3		2			6	0.05	
18	91	4.1		2			17		
19	140	2.8		3			6	0.05	
20	62	2		3					

Humidity Cell Testwork Phase I

SAMPLE KA-9									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.4	7.65	120	42	0	2.4	0.1	12.5	0.5
2	0.357	7.57	89	29.4	0	1.5	0.1	14	1
3	0.364	7.65	71	18.5	0	2	0.2	22	1.8
4	0.4	7.59	68	18	0	4	0.4	2.5	1.9
5	0.4	7.88	67	22	0	1.6	0.4	2.5	2
6		7.75	71	25.2	0	1.9	0.5	1	2
7		8.31	53	22	0	0	0.5	0	2
8		7.86	48	21	0	1.1	0.6	1	2
9		7.98	46	16.8	0	0.6	0.6	0	2
10		8.16	64	21	0	0.6	0.6	1	2.1
11		7.47	50	20.7	0	0.6	0.6	0	2.1
12		7.82	49	13.7	0	0.7	0.7	1	2.1
13		8.13	53	39	0	0.6	0.7	1	2.2
14		8.02	45	19.1	0	0.6	0.7	1	2.2
15		7.68	56	22.9	0	1.6	0.8	1	2.2
16	0.4	7.59	47	16.8	0	2	0.9	2.5	2.3
17		7.81	66	26.4	0	1.9	1	0	2.3
18		7.71	58	28.5	0	1	1	0	2.3
19		7.73	52	20.3	0	4.9	1.2	0	2.3
20	0.5	7.7	62	18.7	0	1	1.3	2	2.4
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	83	2.9					21		
2	100	2.1					24		
3	80	3.5					14		
4	40	2.4		1			17		
5	65	2.3		2			16		
6	140	3.4		5			23		
7	89	2.7		3			10		
8	83	1.9		3			7		
9	44	1.8		1			8		
10	58	1.2		2			7		
11	120	0.6		2			5	0.13	
12	77	0.8		2			8	0.05	
13	78	1.9		7			12	0.05	
14	77	0.5					7		
15	120	2.4		3			7		
16	120	1.5		1			6		
17	110	3		2			9		
18	110	3.3		1			7		
19	160	2.3		2			5		
20	70	2		2					

Humidity Cell Testwork Phase I

SAMPLE	KA-10								
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			SULPHATE
	L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.357	7.6	169	49.4	0	0	28	1	0.5
2	0.371	7.56	154	35.7	0	0.1	35	2.3	1
3	0.435	7.36	103	25.2	0	0.4	23	3.3	1.8
4	0.412	7.51	104	30	0	0.5	17	4	1.9
5	0.387	7.64	85	21.2	0	0.5	15.5	4.6	2
6	0.4	7.69	85	20.5	0	0.6	12.5	5.1	2
7	0.4	8.07	71	24	0	0.6	10	5.5	2
8	0.4	7.66	59	21	0	0.7	5	5.7	2
9	0.25	8.27	56	21	0	0.8	4	5.8	2
10	0.5	7.93	64	24.4	0	0.8	4	6	2.1
11	0.412	7.79	88	20.7	0	0.8	17	6.7	2.1
12	0.4	7.89	62	16.4	0	0.8	2.5	6.8	2.1
13	0.4	7.76	61	16.8	0	0.9	5	7	2.2
14		7.82	58	17.8	0	0.9	1	7	2.2
15	0.435	7.68	69	20.8	0	1	11.5	7.5	2.2
16	0.429	7.58	60	16.8	0	1.1	7	7.8	2.3
17	0.455	7.74	59	22.3	0	1.2	11	8.3	2.3
18	0.333	7.65	61	21.9	0	1.3	3	8.4	2.3
19		7.66	55	20.3	0	1.4	1	8.4	2.3
20		7.63	52	20.8	0	1.4	0	8.4	2.4
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	95	1.6					56		
2	77	1.7					78		
3	55	2.3		2			47		
4	48	1.2		2			50		
5	55	1.3		2			22		
6	140	2.9		8			26		
7	110	2.7		9			18		
8	88	2.2		4		4	9	0.06	
9	47	2.2		2			10	0.05	
10	62	0.7		3			11	0.14	
11	86	0.5		12			14	0.32	
12	73	0.6		3			11	0.15	
13	89	1.1		7			12		
14	80	1.1					9		
15	140	2.2		3			10		
16	130	1.6		3			7	0.25	
17	100	1.5		4			7	0.09	
18	92	2.6		2			8	0.05	
19	140	1.9		3			5		
20	63	1.6		4			5		

Humidity Cell Testwork Phase I

SAMPLE KA-11									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.339	7.85	257	59.9	0	0.6	0	56	1.9
2	0.418	7.67	199	35.1	0	2.5	0.1	55	4.2
3	0.41	7.95	156	18.1	0	2	0.2	39	5.8
4	0.394	8.13	171	36	0	0.6	0.2	33	7.1
5	0.357	7.72	161	24	0	0.6	0.2	28	8.1
6	0.4	7.93	144	28.8	0	0.7	0.3	25	9.1
7	0.375	8.34	100	26	0	0	0.3	16	9.7
8	0.385	7.78	81	23.1	0	0.6	0.3	13	10.2
9	0.417	7.8	78	23.1	0	0.6	0.3	12	10.7
10	0.387	8.03	95	21.8	0	0.6	0.4	15.5	11.3
11	0.444	7.8	57	21.1	0	0.6	0.4	4.5	11.5
12	0.357	7.64	84	11.7	0	1.1	0.4	14	12
13	0.412	8.05	112	31.2	0	0.6	0.4	17	12.7
14	0.429	8.05	85	42.4	0	0.6	0.5	14	13.3
15	0.409	7.72	112	18.7	0	4	0.6	22	14.2
16	0.368	7.39	484	16	0	3.7	0.8	19	21.2
17	0.481	7.58	104	18.3	0	0.9	0.8	27	22.5
18	0.364	7.67	126	54.8	0	1.5	0.9	22	23.3
19	0.412	7.76	96	28.4	0	1	0.9	17	24
20	0.4	7.66	78	18.7	0	1	1	15	24.6
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	20	0.9	0.8	1			193		10
2	40	1.4	0.3	1			92		8
3	50	1.2		3			57		
4	21	1.1		2			74		
5	32	0.5		2			29		
6	100	2		380			26		
7	90	2.4		24			17		
8	43	1.5		19			11		
9	34	1.4		19			13		
10	44	1.1		27			15	0.17	
11	12	0.7		2			9	0.07	
12	48	0.4		8			13	0.08	
13	38	1		14			40	0.08	
14	52	1.2					13		
15	92	1.7		3			14		
16	30	6.5	9.7	78	44		640	1.3	1400
17	51	1.7		5		1	17	0.2	9
18	43	1.8		5			90	0.18	25
19	71	1.3		4			12		
20	44	1.8		3			7		

Humidity Cell Testwork Phase I

SAMPLE KA-12									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	L				**mg/L	CaCO3**			
			mg/L CaCO3			mg/100g	mg/L	mg/100g	
1	0.342	7.81	174	60.5	0	1.8	0.1	38	1.3
2	0.385	7.86	129	32.6	0	1	0.1	26	2.3
3	0.4	8.16	70	16.8	0	1	0.1	20	3.1
4	0.4	8.14	79	31.2	0	0.6	0.2	7.5	3.4
5	0.4	7.73	76	18.8	0	2	0.2	12.5	3.9
6	0.4	7.62	73	23.8	0	1.9	0.3	5	4.1
7	0.4	8.35	78	28	0	0	0.3	5	4.3
8		8.12	62	27.3	0	0.6	0.4	1	4.4
9		8.03	52	24.4	0	0.6	0.4	1	4.4
10	0.333	7.63	60	28.6	0	2	0.5	3	4.5
11		7.9	60	21.9	0	0.6	0.5	0	4.5
12	0.5	8.03	60	15.6	0	0.7	0.5	2	4.6
13	0.4	8.35	91	33.2	0	0	0.5	2.5	4.7
14		8.12	84	36	0	0.6	0.6	0	4.7
15	0.4	7.91	62	24.1	0	1	0.6	2.5	4.8
16		7.85	56	23.1	0	3.1	0.7	0	4.8
17		7.96	64	28.6	0	0.6	0.7	1	4.9
18		7.9	65	24.1	0	1	0.8	1	4.9
19		7.95	104	32.5	0	1.5	0.8	0	4.9
20	0.5	7.77	52	14.6	0	0.5	0.9	2	5
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	30	2.1	0.2				57		
2	110	1.7					43		
3	110	2.2		1			11		
4	70	1.9		2			16		
5	52	0.8		2			17		
6	130	1.9		94		2	17	0.06	
7	97	1.6		9			31		
8	75	1.5		3	21		8		
9	38	1.4		1			8	0.05	
10	22	1.2		2			14		
11	72	0.8					19	0.07	
12	50	0.5		3			15		
13	97	2		16	30		22		
14	47	0.8					45		
15	140	1.5		3			9		
16	120	1.2		1			8		30
17	86	2		2	17		18		
18	66	1.8		1			11	0.05	
19	65	0.8		2			90		
20	56	0.7		3			9		

Humidity Cell Testwork Phase I

SAMPLE KA-13									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	.L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.261	7.92	208	58.8	0	1.2	0	34.5	0.9
2	0.393	7.97	131	37.8	0	1	0.1	28	2
3	0.364	7.52	119	27.3	0	2	0.1	22	2.8
4	0.462	8.26	114	66	0	0.6	0.2	13	3.4
5	0.3	7.86	91	28	0	1	0.2	10	3.7
6	0.5	8.38	90	23.4	0	0	0.2	10	4.2
7		8.01	62	24.8	0	0.6	0.2	1	4.2
8	0.545	7.91	86	35.7	0	1.1	0.3	11	4.8
9	0.455	8.19	80	34.4	0	0.6	0.3	11	5.3
10	0.8	7.81	78	31.5	0	1	0.4	2.5	5.5
11		8.93	67	33.9	0	0	0.4	0	5.5
12	0.4	8.83	79	51.5	0	0	0.4	2.5	5.6
13	0.5	7.89	76	35.1	0	0.6	0.4	4	5.8
14	0.429	8.16	84	36	0	0.6	0.4	7	6.1
15	0.4	7.88	71	41.6	0	0.6	0.4	2.5	6.2
16		7.85	73	50.4	0	0.6	0.5	2	6.2
17	0.5	8.14	75	26.4	0	0	0.5	2	6.3
18		8.34	74	28.5	0	0	0.5	1	6.4
19	0.5	8.28	132	26.4	0	0	0.5	2	6.5
20		8.98	70	22.9	0	0	0.5	1	6.5
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	120	1.4	0.3				89		
2	120	1.9		3			23		
3	70	1.3					8		
4	54	1.5		3			38		
5	60	1.8		1			13		
6	120	1.9		80			8		
7	75	1.5		3			5		
8	51	1.2		3			16		
9	60	0.9		1			11		
10	49	1		14			10	0.06	
11	93	1.7		1			7	0.07	
12	53	1.1		1			15	0.08	
13	39	1		4			9	0.05	
14	44	1.5		48			14		
15	85	1		4					
16	76	1.2		2			6		6
17	42	1.1		2			8		
18	50	1.5		1			7		
19	63	0.7		2			5		
20	47	1.1		2					

Humidity Cell Testwork Phase I

SAMPLE	KA-14								
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			SULPHATE
	L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.326	7.65	685	57.8	0	2.6	0.1	325	10.6
2	0.388	7.41	456	32.3	0	2.4	0.2	240	19.9
3	0.378	6.79	380	22.7	0	2	0.3	180	26.7
4	0.43	7.76	206	26.4	0	1	0.3	100	31
5	0.4	7.19	169	13.2	0	2	0.4	100	35
6	0.425	7.42	185	15.1	0	2.9	0.5	40	36.7
7	0.386	7.72	132	16.4	0	0.9	0.5	44	38.4
8	0.48	7.35	90	14.7	0	0.6	0.6	25	39.6
9	0.405	7.01	118	10.5	0	2.1	0.7	37	41.1
10	0.462	7.59	163	17.2	0	1.6	0.7	52	43.5
11	0.4	7.02	120	17.4	0	2.1	0.8	20	44.3
12	0.44	7.59	132	17.6	0	0.7	0.8	25	45.4
13	0.422	7.65	148	12.9	0	1.1	0.9	45	47.3
14	0.429	7.98	191	23.3	0	0.6	0.9	35	48.8
15	0.4	7.59	136	21.6	0	5	1.1	30	50
16	0.455	7.34	73	14.7	0	2.7	1.2	55	52.5
17	0.421	7.23	154	12.2	0	0.9	1.3	57	54.9
18	0.422	7.19	139	13.1	0	1.5	1.3	45	56.8
19	0.429	7.29	141	14.2	0	1.5	1.4	42	58.6
20	0.429	7.37	122	16.6	0	1	1.4	35	60.1
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	92	0.3	4.2	4			313		73
2	18	0.9	1.3				124		12
3	25	0.5	1.1				92		5
4	20	0.5	0.2	2			34		
5	12	0.3		2			30		
6	39	0.6		210			23		
7	68			10			17		
8	28	0.5		11			17		
9	19			16			18	0.05	
10	12	0.4		47			16		
11	54	1.7		21			15	0.06	
12	26	0.5		21			16	0.08	
13	29	0.5	3.8	24			16		
14	38	0.8		61			9		
15	30	0.3	0.5	14			42	0.05	16
16	33	0.8		2			16		29
17	24	0.6		3			22	0.1	6
18	19	0.8		1			21		
19	21	0.3	0.2	3			16		
20	23	0.6		2			11		



Humidity Cell Testwork Phase I

SAMPLE KA-15									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.374	7.64	1204	39.9	0	2.8	0.1	800	29.9
2	0.424	7.38	691	20	0	1.7	0.2	500	51.1
3	0.383	7.41	670	14.7	0	2	0.3	350	64.5
4	0.435	7.67	491	11.4	0	3	0.4	200	73.2
5	0.414	7.3	340	15.2	0	1.6	0.4	140	79
6	0.47	7.12	362	15.8	0	1.9	0.5	200	88.4
7	0.417	7.2	230	14	0	1.5	0.6	115	93.2
8	0.442	7.5	212	15.1	0	0.6	0.6	120	98.5
9	0.445	7.48	194	14.7	0	2.1	0.7	110	103.4
10	0.415	7.42	222	12.6	0	1.6	0.8	130	108.8
11	0.433	7.1	268	14.5	0	2.1	0.9	120	114
12	0.44	7.56	182	10.5	0	1.1	0.9	100	118.4
13	0.45	7.58	295	16.8	0	2.2	1	120	123.8
14	0.423	7.61	252	19.1	0	1.1	1.1	130	129.3
15	0.436	7.49	183	18.7	0	2.6	1.2	110	134.1
16	0.463	7.27	186	12.6	0	1.6	1.3	67	137.2
17	0.439	7.16	215	10.2	0	1.5	1.3	82	140.8
18	0.436	7.19	167	13.1	0	2	1.4	55	143.2
19	0.425	7.27	194	14.2	0	1.5	1.5	80	146.6
20	0.429	7.19	162	10.4	0	1.5	1.5	70	149.6
CYCLE	ALUMINIUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	18	0.5	24	20			753		982
2	18	0.9	1.3				124		12
3	25	0.5	1.1				92		5
4	20	0.5	0.2	2			34		
5	12	0.3		2			30		
6	39	0.6		210			23		
7	68			10			17		
8	28	0.5		11			17		
9	19			16			18	0.05	
10	12	0.4		47			16		
11	54	1.7		21			15	0.06	
12			3.2	5		2	91	0.08	64
13		3	2.8	11		1	103	0.05	46
14		0.5	5.7	120			85		58
15		0.1	7.7	36		3	126		140
16		0.7	5.2	4		2	104	0.11	118
17	6	0.4	7.7	6			117	0.09	193
18		0.6	5.4	7		3	126	0.16	266
19		0.1	11	8		1	114	0.14	118
20		0.2	4.9	6		1	87	0.42	84

Humidity Cell Testwork Phase I

SAMPLE KA-16									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	L		ms/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.389	7.48	922	30.5	0	6.6	0.3	550	21.4
2	0.417	5.69	746	8.4	0	4	0.4	420	38.9
3	0.445	7.15	558	12.6	0	2	0.5	290	51.8
4	0.452	7.32	575	13.6	0	2	0.6	250	63.1
5	0.436	6.65	530	3.2	0	2	0.7	220	72.7
6	0.451	7.23	491	12.2	0	1.9	0.8	215	82.4
7	0.43	6.68	378	8.8	0	2.4	0.9	200	91
8	0.459	7.07	352	9.7	0	1.7	1	170	98.8
9	0.419	7.2	351	8.4	0	3.7	1.1	160	105.5
10	0.455	7.26	355	10.5	0	1.6	1.2	165	113
11	0.493	6.97	264	13.7	0	2.7	1.3	140	119.9
12	0.442	7.28	255	7	0	1.1	1.4	120	125.2
13	0.44	7.29	243	3.1	0	1.7	1.4	100	129.6
14	0.438	7.42	241	12.7	0	1.1	1.5	130	135.3
15	0.432	7.33	254	20.8	0	5.2	1.7	125	140.7
16	0.44	7.12	185	8.4	0	2.7	1.7	75	144
17	0.45	6.91	260	6.1	0	1.9	1.8	100	148.5
18	0.471	6.83	194	8.8	0	3	2	70	151.8
19	0.451	7.16	201	10.2	0	2	2.3	82	155.5
20	0.444	6.97	216	6.2	0	2	2.7	160	162.6
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	57	0.2	35	170	28		3180		4440
2		0.7	11	16			1390		1076
3		0.2	10	15			882	0.07	489
4			11	330		2	857		951
5			4.1	16			591	0.07	354
6	7	0.2	4	2450			643	0.43	333
7			3.2	628			389		269
8	6		2.6	310			356		274
9			3.5	44			454	0.11	285
10			3.4	260			393	0.06	279
11	11	0.3	2.3	30			281	0.09	177
12			3	51			324		186
13		0.2	13	350			290		165
14		0.5	3.2	240			241		147
15		0.1	5.2	320			394	0.05	510
16		1.1	2.2	10			198	0.39	176
17		0.2	6.2	13	195		266	0.11	314
18		0.5	3.3	24			206	0.24	320
19			3.8	9			198	0.15	176
20		0.2	2.6	12			175	0.26	169

Humidity Cell Testwork Phase I

SAMPLE KA-17									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	L				**mg/L	CaCO3**			
			nS/cm	mg/L CaCO3			mg/100g	mg/L	mg/100g
1	0.36	3.4	3850	0	0	1617.6	58.2	3100	111.6
2	0.506	4.32	1604	0	2	125.7	64.6	1300	177.4
3	0.43	4.52	1065	1.1	0	45.5	66.6	1000	220.4
4	0.47	4.86	858	1.3	0	22	67.6	400	239.2
5	0.426	4.5	702	0	0	17.8	68.3	310	252.4
6	0.446	4.73	837	1.1	0	14.4	69	410	270.7
7	0.406	4.88	643	1.2	0	9.8	69.4	340	284.5
8	0.433	4.66	558	1.3	0	8.6	69.8	275	296.4
9	0.413	5.14	487	2.1	0	11.3	70.2	240	306.3
10	0.403	4.83	558	1.3	0	12.4	70.7	300	318.4
11	0.415	4.84	480	1.2	0	11.4	71.2	200	326.7
12	0.44	4.63	505	1.2	0	10.2	71.7	250	337.7
13	0.444	4.69	506	1.2	0	9.7	72.1	250	348.8
14	0.438	4.93	413	2.1	0	7.4	72.4	210	358
15	0.46	4.66	414	1.2	0	12	73	200	367.2
16	0.46	4.61	349	12.6	0	13.3	73.6	200	376.4
17	0.455	4.52	422	0	0	10.2	74	200	385.5
18	0.472	4.62	354	0	0	8.4	74.4	180	394
19	0.45	4.31	397	0	1.5	9.3	74.9	200	403
20	0.453	4.28	379	0	1	10	75.3	170	410.7
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	403000	16	350	208000	319000	33	36200		12500
2	770	0.7	110	19900	2130	6	18900		46400
3	230	0.3	105	8200	379	1	8340	0.06	19500
4	30		42	4360	211	1	4006		9440
5	32		27	2910	250		2450		5680
6	58	0.7	8	2610	165		2960	0.17	6190
7	36		7.6	1560	40	1	2600	0.07	5300
8	28		4.5	1490		1	1970	0.12	3805
9	31		7.7	1360	80		2004	0.05	3730
10	13	0.2	8.8	1260	61	4	1707	0.16	3430
11	34	0.4	3.6	1190	58	3000	1550	0.36	3020
12	30	0.2	16	1660	109	5	1760	0.18	3500
13	23	0.4	5.5	1440	170	5	1060	0.05	2170
14	33	0.3	5.9	1170		3	640	0.13	1364
15	37	0.2	3.7	1250	173	8	539	0.06	1170
16	58	0.1	4.5	1110	122	3	1010		1640
17	57	0.6	3.1	1700		4	746		1310
18	42	0.6	4.1	1450	164	3	559	0.14	972
19	93		2.2	1850	337	7	642	0.09	1140
20	42	0.5	3	1740	303	6	674	0.26	1055

Humidity Cell Testwork Phase I

SAMPLE KA-18									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			SULPHATE
	L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.371	7.04	957	20	0	50.4	1.9	520	19.3
2	0.418	6.76	568	9.5	0	10.9	2.3	280	31
3	0.397	5.27	655	6.3	0	12.9	2.8	350	44.9
4	0.395	7.22	406	8.8	0	10	3.2	190	52.4
5	0.414	5.48	300	3.2	0	7.9	3.6	140	58.2
6	0.431	6.82	323	9	0	9.1	4	130	63.8
7	0.421	6.28	271	4	0	7.5	4.3	140	69.7
8	0.416	6.21	231	9.2	0	17.3	5	125	74.9
9	0.443	6.94	292	5.5	0	7.2	5.3	140	81.1
10	0.464	6.96	224	5.5	0	6	5.6	125	86.9
11	0.418	6.83	185	5.4	0	9.4	6	110	91.5
12	0.461	6.74	173	5.9	0	10.9	6.5	115	96.8
13	0.43	6.43	182	5.1	0	13.4	7.1	100	101.1
14	0.417	6.88	202	10.6	0	11.7	7.6	120	106.1
15	0.464	6.74	158	6.2	0	14	8.2	110	111.2
16	0.438	6.27	166	4.2	0	9.2	8.6	130	116.9
17	0.446	6.79	188	4.1	0	6.5	8.9	130	122.7
18	0.457	6.71	152	4.4	0	9.9	9.3	70	125.9
19	0.44	6.77	196	4.1	0	10.3	9.8	50	128.1
20	0.448	6.42	203	8.3	0	15	10.5	58	130.7
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1		0.2	270	440		44	4530		28000
2		0.1	92	160		27	2160		6770
3		0.1	108	158		100	2430	0.06	7068
4	5	2.5	100	320	28	220	1670		8160
5			84	200		68	1006		5440
6			93	560		100	1200	0.09	6450
7			79	324		68	1120		6110
8			94	400		59	978	0.12	7920
9	5		90	370		68	722	0.11	5908
10			85	420		92	641	0.13	6450
11	10		92	360		140	663	0.32	8800
12	13		110	300		120	460	0.36	6800
13			92	330		100	470	0.07	7070
14		0.1	120	600		210	556		10361
15		0.2	85	370		140	336	0.13	10280
16		0.1	72	160		120	337		7000
17			62	130		82	262	0.07	4910
18		0.6	87	220		81	304	0.14	7337
19			96	180		92	313	0.14	8206
20		0.3	85	130		56	304	0.41	8350

Humidity Cell Testwork Phase I

SAMPLE KA-19									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	L		ns/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.336	7.15	1164	19.7	0	7	0.2	580	19.5
2	0.481	6.98	1208	14	0	7.9	0.6	580	47.4
3	0.392	6.92	782	13.7	0	6.7	0.9	360	61.5
4	0.39	7.04	574	8	0	1.9	1	300	73.2
5	0.425	7.25	530	16.8	0	1.1	1	240	83.4
6	0.413	7.11	460	10.5	0	1.6	1.1	225	92.7
7	0.414	6.54	456	8.4	0	1.6	1.1	220	101.8
8	0.547	6.82	395	13.7	0	2.7	1.3	190	112.2
9	0.416	6.93	524	9.8	0	2.2	1.4	255	122.8
10	0.433	6.93	458	7.8	0	2.6	1.5	210	131.9
11	0.411	6.79	469	9.3	0	5.1	1.7	175	139.1
12	0.422	7.06	486	3.3	0	3	1.8	225	148.6
13	0.427	6.35	345	8.4	0	7.3	2.1	150	155
14	0.4085	6.79	188	10.2	0	3.7	2.3	220	163.9
15	0.421	6.96	268	6.6	0	3	2.4	140	169.8
16	0.444	7.02	316	12.2	0	3.4	2.6	160	176.9
17	0.392	6.83	242	10.4	0	2	2.6	130	182
18	0.577	7.12	406	9.8	0	4	2.9	175	192.1
19	0.48	6.9	465	11.5	0	8.2	3.3	200	201.7
20	0.454	6.94	234	7.8	0	3.5	3.4	130	207.6
CYCLE	ALUMINIUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	8	0.7	26	170		2	2470	0.19	2603
2			19	83		19	2990	0.07	4260
3			23	540		4	1506	0.32	1820
4			7.6	469		5	1250	0.06	1380
5			4.5	42		2	782		802
6			7.1	39		2	652		786
7			7.6	54		2	487	0.08	744
8		0.1	10	25		5	652		1430
9			11	45		7	735	0.05	1340
10		0.1	8.4	33		3	540		860
11		0.2	12	78		5	367		1272
12			12	86		5	551		1130
13			9.1	17		5	358	0.08	1100
14			9.6	38		3	559	0.16	2210
15		0.7	17	38		3	397	0.18	1815
16	26	0.6	12	66		4	475	0.08	2000
17		0.4	11	21		4	356	0.12	1200
18		2.3	12	79		7	510		2260
19			20	120		12	740		6760
20			10	42		3	280		2420

Humidity Cell Testwork Phase I

SAMPLE KA-20									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	L				**mg/L	CaCO3**			
		mS/cm	mg/L CaCO3			mg/100g	mg/L	mg/100g	
1	0.354	7.63	1508	18	0	4	0.1	850	30.1
2	0.407	6.94	1147	12	0	4	0.3	750	60.6
3	0.417	7.23	1131	19.4	0	3.1	0.4	1000	102.3
4	0.406	7.38	674	12	0	1.9	0.5	1000	142.9
5	0.41	7.43	709	18.9	0	1.1	0.6	100	147
6	0.436	7.55	576	12.6	0	2.1	0.6	225	156.8
7	0.505	7.58	472	15.5	0	2	0.7	220	167.9
8	0.491	6.64	370	12.4	0	2.7	0.9	175	176.5
9	0.45	7.14	600	12.9	0	1.7	1	280	189.1
10	0.446	7.27	516	8.6	0	4.3	1.1	260	200.7
11	0.436	7.74	422	12.7	0	3.2	1.3	220	210.3
12	0.433	7.3	493	12.5	0	4	1.5	240	220.7
13	0.411	7.33	463	4.2	0	5.1	1.7	180	228.1
14	0.448	6.87	438	12.2	0	2.4	1.8	230	238.4
15	0.411	6.73	338	8.8	0	3	1.9	180	245.8
16	0.447	6.93	275	10.2	0	2	2	170	253.4
17	0.411	7.04	356	10.4	0	2	2.1	190	261.2
18	0.575	6.94	438	13.7	0	3	2.2	200	272.7
19	0.469	7.12	323	9.6	0	3.1	2.4	160	280.2
20	0.441	7.29	315	11.7	0	2.5	2.5	145	286.6
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	12	0.7	23	52			4380		3580
2	14	0.2	12	62		18	1930	0.06	1250
3	6	0.2	15	1050		2	2850	2.2	1570
4	6	0.7	8.6	361		2	1830	0.17	1490
5			6	46		2	1780		1350
6			6.3	47			1500	0.08	1015
7		0.1	4.7	49			791	0.19	535
8			4.9	18		3	858	0.25	845
9			4.8	45		4	930	0.12	800
10			7.7	52		2	1110		936
11		0.3	8	120		4	970		1071
12			11	530		4	1349	0.05	1270
13		0.2	7.5	43		6	952	0.18	1030
14		0.1	21	45		6	900	0.14	1180
15		0.5	17	95		3	1198	0.14	2022
16		0.5	13	60		2	738	0.07	1130
17		0.4	10	20		2	826	0.25	959
18		0.5	9.1	100		5	820	0.09	1510
19			13	75		3	690		2170
20	7		8	39		3	620		1630

Humidity Cell Testwork Phase I

SAMPLE KA-21									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.358	6.56	1956	13.2	0	71	2.5	1000	35.8
2	0.457	6.79	1481	8	0	6.5	2.8	1050	83.8
3	0.421	7.11	1124	9	0	4.8	3	1000	125.9
4	0.424	7.72	671	10	0	1.9	3.1	330	139.9
5	0.416	7.25	733	9.7	0	4.3	3.3	250	50.3
6	0.427	7.39	625	8.4	0	3.1	3.4	300	63.1
7	0.45	7.25	608	5.3	0	2.6	3.6	280	75.7
8	0.464	6.4	573	6.2	0	3.1	3.7	280	88.7
9	0.447	7.33	584	10.9	0	2.8	3.8	275	201
10	0.452	7.36	687	5.9	0	4.3	4	325	215.7
11	0.419	6.57	560	8.5	0	7.4	4.3	260	226.6
12	0.448	7.04	625	8.3	0	6.6	4.6	500	249
13	0.436	7.59	504	0.5	0	3.7	4.8	225	258.8
14	0.41	6.51	557	6.1	0	10.2	5.2	300	271.1
15	0.422	6.33	363	5.7	0	8.9	5.6	180	278.7
16	0.439	6.64	374	6.1	0	4.4	5.8	180	236.6
17	0.459	7	357	6.2	0	3	5.9	170	224.4
18	0.579	6.69	568	3.7	0	7	6.3	280	310.6
19	0.453	6.64	680	5.8	0	8.2	6.7	300	334.2
20	0.447	6.78	525	7.8	0	5	6.9	255	335.6
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	10	0.4	350	2780		3	11800	0.07	49400
2	7	0.6	49	16		2	3870	0.08	3250
3	6		43	1140			3450	0.64	3520
4			26	363			2060		3070
5			33	150		2	2200	0.09	4220
6			19	81			1260		2180
7			11	30			803	0.15	1420
8	19		17	90			1090	0.07	2270
9			17	140		2	920	0.05	2360
10			20	95			920		1880
11		0.4	32	340		2	1180		4183
12			29	190			1254		2910
13	27		19	73			812	0.13	2370
14			62	500			1460	0.22	8430
15		0.7	34	350		1	1083		5663
16	33	0.5	22	130		1	640	0.07	2590
17		0.5	16	51			493	0.2	1790
18		0.3	15	180		1	1350	0.05	3880
19			22	350		2	1620		5890
20		0.1	17	180			1080		4230

Humidity Cell Testwork Phase II

SAMPLE KA-22									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			SULPHATE
	L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.334	4.01	4550	0	10	1184	39.5	3900	130.3
2	0.404	4.68	1776	1.2	0	95	43.4	1300	138.8
3	0.358	5.28	1608	2.9	0	60	45.5	1150	224
4	0.374	5.53	1284	4	0	28.2	46.6	1100	265.1
5	0.434	5.94	764	1.3	0	13	47.2	350	280.3
6	0.457	5.29	1022	2.1	0	2.1	47.2	580	306.8
7	0.42	4.81	1151	1.3	0	38	48.8	700	336.2
8	0.467	4.73	1169	1.2	0	29.1	50.2	700	368.9
9	0.406	4.43	1156	0	0.7	29.6	51.4	650	395.3
10	0.458	4.57	1061	1.2	0	22.2	52.4	600	422.8
11	0.454	4.84	988	1.3	0	19.1	53.3	570	448.7
12	0.494	5.08	1180	1.2	0	8	53.7	650	480.8
13	0.468	4.28	1171	0	1	25.5	54.9	590	508.4
14	0.5	4.36	1081	0	0.7	1.5	55	680	542.4
15	0.405	2.94	765	0	7.9	29.1	56.1	380	557.8
16	0.462	4.01	749	0	5.9	27.9	57.4	370	574.9
17	0.372	3.8	704	0	7.5	41.5	59	360	588.3
18	0.473	3.59	891	0	18	148	66	425	608.4
19	0.481	4.18	943	0	1.5	68.3	69.3	480	631.5
20	0.405	3.94	500	0	5	30.5	70.5	220	640.4
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	8320		2060	345000	25500	10	43800		502000
2	9		260	6310	47	2	13000		48800
3	7		200	2400	16		13700	0.07	36700
4	7		95	1490	20		8380	0.2	17200
5	5		26	670			3500		4180
6	13		45	1950	34	1	6607		8708
7	23		53	6360	323	2	7790	0.11	12040
8	23	0.4	43	5150	47	8	6540	0.32	9150
9	34		39	9490	649	9	5700	0.15	8780
10	25		36	5340	267	8	5550		6580
11	30	0.2	29	4350	184	7	5900		5908
12	12		15	1490	197	5	5157	0.07	1795
13	76	0.1	20	5230	444	10	5250	0.29	3720
14	49	0.2	14	3120	478	8	5080	0.12	2750
15	150	3	24	8860	1809	19	2561		3567
16	130	1.1	28	7270	2080	12	3210	0.11	4140
17	110	11	25	12300	2817	20	2740	0.23	4605
18	2830	3	110	37500	17200	12	3170		21000
19	250	0.5	100	16200	1180	15	5480	0.07	22900
20	120		18	8080	1450	8	1630		5930



Humidity Cell Testwork Phase II

SAMPLE FIVE YEAR									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.458	7.53	721	21	0	13.9	0.6	300	13.7
2	0.435	7.57	744	16.7	0	14.6	1.3	290	26.4
3	0.401	7.56	633	18.1	0	27.7	2.4	280	37.6
4	0.405	7.26	526	13.3	0	3.3	2.5	170	44.5
5	0.467	7.53	372	20.4	0	10.8	3	135	50.8
6	0.43	7.51	266	20.4	0	3.8	3.2	100	55.1
7	0.445	7.53	332	17.2	0	3.8	3.4	102	59.6
8	0.41	7.44	271	13.7	0	6.7	3.6	86	63.1
9	0.447	7.32	410	13.2	0	2.6	3.7	190	71.6
10	0.436	7.33	345	12.5	0	4.3	3.9	115	76.6
11	0.448	7.41	377	12.7	0	3	4.1	150	83.4
12	0.4	7.45	397	21.7	0	1.3	4.1	155	89.6
13	0.377	7.36	386	10.5	0	2	4.2	175	96.2
14	0.39	7.43	274	11.5	0	1.7	4.3	120	100.8
15	0.489	7.41	416	11.3	0	1	4.3	175	109.4
16	0.419	7.33	299	13.3	0	1.5	4.4	125	114.6
17	0.398	7.13	269	12.7	0	1.7	4.4	95	118.4
18	0.392	7.54	230	12.8	0	1.1	4.5	80	121.6
19	0.398	7.48	265	12.9	0	1.9	4.6	85	124.9
20	0.379	7.39	296	13.8	0	1.6	4.6	120	129.5
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	2.5	0.2	5.5	13	85	0.5	1650	0.85	780
2	18	0.5	0.4	3	7.5	1	380	0.025	7
3	19	0.8	0.4	0.5	7.5	0.5	360	0.025	25
4	25	3.8	0.3	3	7.5	0.5	240	0.025	17
5	43	1.6	0.2	2	7.5	0.5	150	0.025	7
6	9	0.4	0.1	0.5	7.5	0.5	160	0.05	17
7	11	2	0.1	12	7.5	5	160	0.22	18
8	17	0.4	0.1	3	7.5	1	110	0.07	2.5
9	11	0.3	0.2	3	7.5	1	170	0.025	100
10	54	0.8	0.1	3	7.5	2	110	0.025	14
11	50	0.5	0.1	3	30	8	130	0.05	8
12	39	0.7	0.1	3	25	2	200	0.05	16
13	8	0.9	0.3	3	7.5	0.5	160	0.025	14
14	2.5	0.4	0.1	3	7.5	0.5	150	0.025	2.5
15	12	0.2	0.1	4	17	0.5	140	0.025	21
16	16	0.2	0.2	2	7.5	2	110	0.025	11
17	13	0.4	0.1	3	7.5	0.5	110	0.025	16
18	11	0.4	0.1	4	53	1	110	0.025	39
19	5	0.6	0.1	2	7.5	0.5	120	0.025	14
20	12	0.2	0.1	4	20	0.5	150	0.025	21

Humidity Cell Testwork Phase II

SAMPLE FIVE YEAR (COVERED)									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	L		mS/cm	mg/L CaCO <sub>3</sub>	**mg/L	CaCO <sub>3</sub> **	mg/100g	mg/L	mg/100g
1	0.431	7.7	1445	24	0	10.6	0.5	185	185
2	0.407	7.48	1103	18.1	0	10.8	0.9	285	20.1
3	0.362	7.69	628	18.6	0	20.2	1.6	140	25.8
4	0.437	7.28	368	23.5	0	5.2	1.9	135	30.5
5	0.482	7.56	355	24.5	0	6.1	2.1	100	35.5
6	0.467	7.75	375	16.3	0	2.8	2.3	80	38.6
7	0.305	7.65	338	15.7	0	23.5	3	52	40.8
8	0.307	7.68	301	16.7	0	6.2	3.2	44	42.7
9	0.285	7.54	266	23.8	0	3.5	3.3	65	45.6
10	0.299	7.49	248	20	0	3.3	3.4	70	48.3
11	0.358	7.54	324	16.4	0	3.3	3.5	95	53.3
12	0.292	7.61	284	23.3	0	2.5	3.6	50	55.2
13	0.359	7.58	174	14	0	2.6	3.7	75	57.9
14	0.267	7.7	277	19.5	0	1.7	3.7	60	60.4
15	0.29	7.43	222	19.1	0	1.2	3.7	65	63
16	0.312	7.42	192	20.7	0	1.7	3.8	60	65.2
17	0.323	7.55	157	18.1	0	2.4	3.9	40	66.7
18	0.305	7.9	160	15	0	2.9	4	40	68.3
19	0.311	7.79	156	17.5	0	1.9	4	50	70.2
20	0.3	7.79	197	20.2	0	2.2	4.1	60	72.5
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	2.5	2.6	2.3	110	79	2	1340	0.34	240
2	10	1.6	0.6	26	7.5	2	430	0.1	13
3	19	3.2	0.3	32	32	2	350	0.18	53
4	57	40	0.2	49	110	3	200	0.18	83
5	40	0.9	0.1	39	7.5	6	310	0.08	18
6	8	2	0.1	11	7.5	0.5	230	0.08	11
7	7	0.8	0.1	1	7.5	0.5	180	0.025	10
8	30	2.5	0.2	49	50	6	99	0.45	20
9	18	4	0.3	70	7.5	3	140	0.78	90
10	60	2.7	0.1	51	63	8	79	0.54	23
11	26	2.3	0.1	24	65	120	130	0.12	17
12	37	3.2	0.1	49	82	7	120	0.82	20
13	21	2.9	0.1	20	41	2	82	0.07	13
14	16	2	0.1	54	47	0.5	120	0.18	25
15	26	1.7	0.1	55	84	6	83	0.29	19
16	35	3.1	0.2	51	45	7	80	0.24	30
17	36	2.1	0.6	35	410	4	170	0.2	190
18	47	1.9	0.7	41	1090	7	170	0.28	300
19	22	3.9	0.1	45	38	0.5	74	0.13	2.5
20	100	1.8	0.2	41	120	2	92	0.11	31

Humidity Cell Testwork Phase II

SAMPLE PREPRODUCTION									
CYCLE	LEACHATE		CONDUCTIVITY	ALKALINITY	ACIDITY		CUM. ACIDITY	SULPHATE	CUMULATIVE
	VOLUME	pH			pH 4.5	pH 8.3			
	L		mS/cm	mg/L CaCO3	**mg/L	CaCO3**	mg/100g	mg/L	mg/100g
1	0.464	7.7	461	25	0	8.6	0.4	185	8.6
2	0.405	7.48	747	21.1	0	7.5	0.7	285	20.1
3	0.404	7.69	391	18.1	0	21.6	1.6	140	25.8
4	0.348	7.28	374	16.8	0	2.4	1.7	135	30.5
5	0.484	7.56	319	23	0	7.1	2	100	35.5
6	0.405	7.75	195	25	0	1.9	2.1	80	38.6
7	0.438	7.65	200	22.1	0	8.6	2.5	52	40.8
8	0.432	7.68	266	18.6	0	8.6	2.8	44	42.7
9	0.436	7.54	202	17.2	0	4	3	65	45.6
10	0.389	7.49	246	16.5	0	4	3.2	70	48.3
11	0.525	7.54	292	21.2	0	1.8	3.2	95	53.3
12	0.375	7.61	205	17.5	0	2	3.3	50	55.2
13	0.37	7.58	214	16	0	2.3	3.4	75	57.9
14	0.404	7.7	176	19.5	0	1.7	3.5	60	60.4
15	0.406	7.43	196	15.7	0	2.1	3.6	65	63
16	0.366	7.42	181	18.6	0	0.7	3.6	60	65.2
17	0.384	7.55	195	17.6	0	1.4	3.6	40	66.7
18	0.382	7.9	144	15.8	0	1.2	3.7	40	68.3
19	0.39	7.79	177	17.5	0	1.1	3.7	50	70.2
20	0.388	7.79	180	17.5	0	1.1	3.8	60	72.5
CYCLE	ALUMINUM	ARSENIC	CADMIUM	COPPER	IRON	LEAD	MANGANESE	MERCURY	ZINC
	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L	ug/L
1	31	0.4	0.3	0.5	7.5	0.5	360	0.025	27
2	23	1.3	0.1	1	7.5	0.5	350	0.025	7
3	30	0.7	0.1	2	7.5	0.5	180	0.1	34
4	54	3.3	0.1	3	7.5	2	130	0.025	67
5	100	2.8	0.1	2	7.5	0.5	92	0.025	2.5
6	22	0.6	0.1	4	7.5	0.5	150	0.025	15
7	18	1.5	0.1	2	7.5	1	100	0.12	6
8	83	0.8	0.1	3	7.5	8	78	0.025	9
9	26	0.6	0.1	0.4	7.5	0.5	85	0.08	65
10	90	0.8	0.1	4	7.5	12	63	0.11	6
11	37	0.7	0.1	3	24	4	100	0.05	2.5
12	50	0.7	0.1	2	37	5	80	2.3	2.5
13	25	0.7	0.1	3	20	1	52	0.33	8
14	10	0.6	0.1	1	7.5	0.5	86	0.025	2.5
15	19	0.5	0.1	4	21	1	61	0.025	19
16	40	0.5	0.1	3	24	2	58	0.025	8
17	37	0.5	0.1	4	31	0.5	69	0.025	27
18	30	0.6	0.1	4	17	0.5	43	0.025	24
19	20	0.6	0.1	2	7.5	0.5	58	0.025	7
20	24	0.3	0.2	3	26	0.5	63	0.025	14

**Grain Size Analysis**

RESCAN - Kutcho Creek  
 88 - 5020  
 SCREEN ANALYSIS

SAMPLE: 88KA - 1  
 GRIND: - 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	7.2	92.8
+16 mesh	1000	64.3	28.5
+28 mesh	600	3.3	25.2
+48 mesh	300	3.9	21.3
+100 mesh	150	6.7	14.6
+200 mesh	75	5.1	9.5
+325 mesh	45	4.6	4.9
- 325 mesh		4.9	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
 88 - 5020  
 SCREEN ANALYSIS

SAMPLE: 88KA - 2  
 GRIND: - 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	4.5	95.5
+16 mesh	1000	77.6	18.0
+28 mesh	600	1.4	16.6
+48 mesh	300	1.9	14.7
+100 mesh	150	4.8	9.9
+200 mesh	75	3.2	6.7
+325 mesh	45	2.6	4.1
- 325 mesh		4.1	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
 88 - 5020  
 SCREEN ANALYSIS

SAMPLE: 88KA - 3  
 GRIND: ~ 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	7.3	92.7
+16 mesh	1000	57.7	35.0
+28 mesh	600	12.9	22.1
+48 mesh	300	7.3	14.8
+100 mesh	150	4.3	10.5
+200 mesh	75	3.8	6.7
+325 mesh	45	3.0	3.7
- 325 mesh		3.7	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
 88 - 5020  
 SCREEN ANALYSIS

SAMPLE: 88KA - 4  
 GRIND: ~ 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	19.9	80.2
+16 mesh	1000	60.8	19.4
+28 mesh	600	2.2	17.2
+48 mesh	300	2.9	14.3
+100 mesh	150	6.4	7.9
+200 mesh	75	2.5	5.4
+325 mesh	45	1.7	3.7
- 325 mesh		3.7	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
88 - 5020  
SCREEN ANALYSIS

SAMPLE: 88KA - 5  
GRIND: ~ 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	16.9	83.1
+16 mesh	1000	67.0	16.1
+28 mesh	600	1.7	14.4
+48 mesh	300	2.2	12.2
+100 mesh	150	5.0	7.2
+200 mesh	75	2.3	4.9
+325 mesh	45	1.7	3.2
- 325 mesh		3.2	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
88 - 5020  
SCREEN ANALYSIS

SAMPLE: 88KA - 6  
GRIND: ~ 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	6.6	93.4
+16 mesh	1000	77.3	16.1
+28 mesh	600	2.1	14.0
+48 mesh	300	2.5	11.5
+100 mesh	150	4.7	6.9
+200 mesh	75	2.1	4.8
+325 mesh	45	1.6	3.2
- 325 mesh		3.2	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
88 - 5020  
SCREEN ANALYSIS

SAMPLE: 88KA - 7  
GRIND: ~ 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	5.7	94.3
+16 mesh	1000	61.8	32.5
+28 mesh	600	15.7	16.8
+48 mesh	300	7.1	9.7
+100 mesh	150	2.9	6.8
+200 mesh	75	1.7	5.1
+325 mesh	45	1.6	3.5
- 325 mesh		3.5	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
88 - 5020  
SCREEN ANALYSIS

SAMPLE: 88KA - 8  
GRIND: ~ 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	4.0	96.0
+16 mesh	1000	69.7	26.3
+28 mesh	600	13.7	12.7
+48 mesh	300	5.5	7.2
+100 mesh	150	2.3	5.0
+200 mesh	75	1.4	3.6
+325 mesh	45	1.2	2.4
- 325 mesh		2.4	
CALC HEAD		100.0	



RESCAN - Kutcho Creek  
 88 - 5020  
 SCREEN ANALYSIS

SAMPLE: 88KA - 9  
 GRIND: - 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	4.5	95.5
+16 mesh	1000	74.3	21.2
+28 mesh	600	12.3	8.9
+48 mesh	300	2.8	6.1
+100 mesh	150	1.2	4.9
+200 mesh	75	1.0	3.9
+325 mesh	45	1.2	2.7
- 325 mesh		2.7	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
 88 - 5020  
 SCREEN ANALYSIS

SAMPLE: 88KA - 10  
 GRIND: - 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	3.9	96.1
+16 mesh	1000	69.7	26.4
+28 mesh	600	15.3	11.1
+48 mesh	300	5.2	5.9
+100 mesh	150	1.9	4.0
+200 mesh	75	1.0	3.0
+325 mesh	45	1.1	1.9
- 325 mesh		1.9	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
88 - 5020  
SCREEN ANALYSIS

SAMPLE: 88KA - 11  
GRIND: - 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	7.3	92.7
+16 mesh	1000	66.5	26.2
+28 mesh	600	15.4	10.7
+48 mesh	300	4.4	6.3
+100 mesh	150	2.2	4.1
+200 mesh	75	1.2	2.9
+325 mesh	45	0.9	2.0
- 325 mesh		2.0	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
88 - 5020  
SCREEN ANALYSIS

SAMPLE: 88KA - 12  
GRIND: - 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	11.3	88.7
+16 mesh	1000	52.1	36.7
+28 mesh	600	17.9	18.8
+48 mesh	300	6.9	11.9
+100 mesh	150	4.3	7.6
+200 mesh	75	2.5	5.1
+325 mesh	45	1.8	3.3
- 325 mesh		3.3	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
88 - 5020  
SCREEN ANALYSIS

SAMPLE: 88KA - 13  
GRIND: - 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	19.4	80.6
+16 mesh	1000	49.2	31.5
+28 mesh	600	15.1	16.4
+48 mesh	300	6.1	10.3
+100 mesh	150	3.8	6.5
+200 mesh	75	2.1	4.4
+325 mesh	45	1.5	2.9
- 325 mesh		2.9	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
88 - 5020  
SCREEN ANALYSIS

SAMPLE: 88KA - 14  
GRIND: - 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	25.2	74.9
+16 mesh	1000	41.2	33.7
+28 mesh	600	12.5	21.2
+48 mesh	300	6.4	14.8
+100 mesh	150	5.3	9.5
+200 mesh	75	3.5	6.0
+325 mesh	45	2.2	3.8
- 325 mesh		3.8	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
 88 - 5020  
 SCREEN ANALYSIS

SAMPLE: 88KA - 15  
 GRIND: - 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	3.8	96.2
+16 mesh	1000	53.4	42.9
+28 mesh	600	16.4	26.5
+48 mesh	300	6.9	19.6
+100 mesh	150	5.6	14.0
+200 mesh	75	4.6	9.4
+325 mesh	45	3.3	6.1
- 325 mesh		6.1	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
 88 - 5020  
 SCREEN ANALYSIS

SAMPLE: 88KA - 16  
 GRIND: - 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	4.6	95.4
+16 mesh	1000	57.2	38.3
+28 mesh	600	14.9	23.4
+48 mesh	300	6.4	17.0
+100 mesh	150	5.8	11.2
+200 mesh	75	4.6	6.6
+325 mesh	45	2.7	3.9
- 325 mesh		3.9	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
 88 - 5020  
 SCREEN ANALYSIS

SAMPLE: 88KA - 17  
 GRIND: ~ 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	25.9	74.1
+16 mesh	1000	43.7	30.4
+28 mesh	600	13.2	17.2
+48 mesh	300	5.5	11.7
+100 mesh	150	4.0	7.7
+200 mesh	75	3.0	4.7
+325 mesh	45	1.9	2.8
- 325 mesh		2.7	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
 88 - 5020  
 SCREEN ANALYSIS

SAMPLE: 88KA - 18  
 GRIND: ~ 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	3.0	97.0
+16 mesh	1000	51.0	46.0
+28 mesh	600	19.4	26.6
+48 mesh	300	7.8	18.8
+100 mesh	150	6.5	12.3
+200 mesh	75	5.2	7.1
+325 mesh	45	3.0	4.1
- 325 mesh		4.1	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
88 - 5020  
SCREEN ANALYSIS

SAMPLE: 88KA - 19  
GRIND: - 80% passing

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	2.3	97.7
+16 mesh	1000	53.5	44.3
+28 mesh	600	18.3	26.0
+48 mesh	300	6.8	19.3
+100 mesh	150	5.3	14.0
+200 mesh	75	4.5	9.5
+325 mesh	45	3.4	6.1
- 325 mesh		6.1	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
88 - 5020  
SCREEN ANALYSIS

SAMPLE: 88KA - 20

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	18.7	81.3
+16 mesh	1000	34.8	46.5
+28 mesh	600	13.0	33.5
+48 mesh	300	8.1	25.4
+100 mesh	150	9.3	16.1
+200 mesh	75	6.6	9.6
+325 mesh	45	3.9	5.7
- 325 mesh		5.7	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
 88 - 5020  
 SCREEN ANALYSIS

SAMPLE: 88KA - 21

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	13.5	86.5
+16 mesh	1000	34.7	51.8
+28 mesh	600	16.2	35.5
+48 mesh	300	10.4	25.1
+100 mesh	150	10.5	14.7
+200 mesh	75	5.7	8.9
+325 mesh	45	3.2	5.8
- 325 mesh		5.8	
CALC HEAD		100.0	

RESCAN - Kutcho Creek  
 88 - 5020  
 SCREEN ANALYSIS

SAMPLE: 88KA - 22

MESH	APERTURE (um)	WT %	CUM WT% PASSING
+1/4" mesh	3350	27.8	72.2
+16 mesh	1000	39.0	33.2
+28 mesh	600	14.7	18.6
+48 mesh	300	6.0	12.5
+100 mesh	150	5.1	7.4
+200 mesh	75	3.1	4.3
+325 mesh	45	2.0	2.4
- 325 mesh		2.4	
CALC HEAD		100.0	

**Mineralogical Studies**





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Invoice 8034

March 16th, 1989

## Samples:

22 samples of rock chips (channel samples), numbered 88 KA-1 through 22, were submitted for sectioning and petrographic examination, with special reference to textural/mineralogical features relevant to potential acid generation properties.

Samples 1 - 13 were prepared as standard thin sections, and numbers 14 - 22 as polished thin sections.

The material mounted in each case consists of rock fragments ranging in size from about 5mm down to fines in the order of 0.02mm. Each slide contains many such fragments, often comprising a range of textural/mineralogical variants. The descriptions attempt to integrate and summarize the predominant features for each sample.

## Summary:

The suite consists of metamorphically recrystallized tuffs flanking a chert/carbonate exhalite sequence with disseminated to massive sulfides.

The petrographic study generally confirms the assigned rock names from previous work (pers. comm: C. Pelletier), with a few exceptions.

Based on the present study, the samples can be subdivided as follows:

**88 KA-1, 2 and 3 (in part): Mafic crystal tuff (greenstone).**  
Composed essentially of plagioclase crystal clasts, biotite, amphibole and epidote in a matrix of felsitic plagioclase.

**88 KA-3 (in part), 4 and 5: Felsic ash tuff.** Composed of fine-grained, siliceous and felsitic aggregates (quartz/plagioclase), sometimes with sericite. Sample 3 is a mixture of this and the previous rock type. Sample 5 has relatively abundant intergrown carbonate.

**88 KA-6, 7, 8, 9, 10 and 11: Felsic crystal tuff.** A homogenous unit composed of a felsitic quartzo-feldspathic matrix with sericite, and having coarse relict crystal clasts of plagioclase and quartz. Epidote is a minor accessory.

**88 KA-12 and 13: Carbonate-rich felsic crystal tuff.** These samples appear to be a variant of the previous unit, with notable proportions (18 - 26%) of accessory carbonate. The second of the two samples shows a paucity of plagioclase crystal clasts, and appears more siliceous. It is gradational to a cherty exhalite.

**88 KA-14: Chert or siliceous ash tuff with chlorite and disseminated pyrite.** Similar to Sample 4, but with intercalations(?) of compact chloritic material, and having about 5% randomly disseminated, fine-grained pyrite.

**88 KA-15 and 19: Carbonate/chert exhalite with disseminated sulfides.** Composed of granular dolomite with accessory quartz, sericite and chlorite. Disseminated to segregated sulfides include chalcopyrite, sphalerite and bornite, as well as pyrite. These samples appear to represent weakly sulfidic variants of the exhalite unit making up the massive sulfide sections.

**88 KA-17 and 22: Foliated chert (or siliceous ash tuff) with disseminated pyrite.** Composed of fine-grained quartz, with sericite as interstitial oriented flakes and schistose schlieren. Fine-grained, disseminated sulfides are notably poor in accessory base metals. These are weakly sulfidic, cherty units intercalated with the massive sulfide. Sample 14 is of similar type, but has a component of felted chlorite.

**88 KA-16, 18, 20 and 21: Massive sulfides.** Composed of 55 - 75% sulfides, with a gangue of dolomite and quartz. Pyrite is the principal component, as a compact recrystallized aggregate. The valuable base metal constituents occur as a fine-grained interstitial/pockety phase to the pyrite. They consist of chalcopyrite, sphalerite, bornite and digenite, in various proportions, plus traces of tetrahedrite and galena. Of these components, chalcopyrite is dominant in #s 16 and 21, and sphalerite with bornite and digenite in #s 18 and 20.

#### Discussion:

Oxidation of the 5 -20% disseminated sulfides in unmined wall-rocks or low grade intercalations represented by Samples 14, 15, 17, 19 and 22, has the potential to generate acid. However, the substantial carbonate content should neutralize this effect in the case of #s 15 and 19.

No mineralogical or textural reason was found to suggest that any of these units should prove disproportionately acid-producing. The pyrite is not excessively fine-grained, and there is an essential lack of intergrown pyrrhotite or marcasite - the components which are generally responsible for unusual reactivity in iron sulfides.

The carbonate in these rocks (and in the massive sulfide) is predominantly dolomite, with localized development of minor calcite and siderite.

Individual petrographic descriptions are attached, together with a set of photomicrographs illustrating salient features of the various lithotypes.

J.F. Harris Ph.D.

(929-5867)

## Estimated mode

Plagioclase	44
Sericite	5
Quartz	6
Biotite	19
Chlorite	3
Amphibole	6
Epidote	14
Carbonate	3
Sphene	trace
Rutile	trace

The fragments making up this slide show a range of textural/compositional features - probably relating to small-scale, layered variations in the body of rock sampled.

Overall, it exhibits the character of a metamorphic greenstone, developed from a volcanic progenitor of intermediate composition. The abundance of biotite is typical of derivation from a tuff. 'Metagabbro' is probably a misnomer, but serves to distinguish this relatively mafic-rich unit.

The rock consists of a matrix of fine-grained felsitic plagioclase, more or less strongly sericitized. Locally this grades to clumps of coarser granular plagioclase, in the size range 0.2 - 2.0mm, which is essentially unsericitized, and clearly represents individual crystal clasts, and lenses of the same, in the original tuff.

Green biotite forms clumps and networks of fine-felted texture, ranging to aggregates of stubby subhedral flakes, up to 0.2mm in size.

Epidote forms clusters of granules and individual stumpy prismatic grains, 0.1 - 0.3mm in size.

Amphibole (blue-green actinolite) forms occasional sheafs and meshworks of slender acicular grains.

Quartz forms scattered anhedral grains and streaks of microgranular mosaic, of grain size 0.05 - 0.2mm.

The above minerals are intergrown in various proportions with the predominant plagioclase in a heterogenous, weakly foliated aggregate.

A little carbonate is present, as scattered pockets of microgranular mosaic, to 1.0mm in size.

## Estimated mode

Plagioclase	50
Sericite	5
Quartz	1
Biotite	9
Chlorite	trace
Amphibole	15
Epidote	18
Carbonate	1
Sphene	1
Rutile	trace
Apatite	trace

This sample is of similar general character to #1, and displays the same distinctive mafic mineralogy (epidote-actinolite-green biotite).

Rock fragments consisting of rather coarse aggregates of anhedral to subhedral plagioclase, of grain size 0.5 - 2.0mm or more, are relatively more common than in #1. Meshworks of acicular amphibole (blue-green actinolite) and granules and euhedra of epidote are developed porphyroblastically throughout these aggregates.

There are also some more foliaceous fragments, consisting essentially of fine felsitic plagioclase with lenses of minutely fine-grained sericite.

Quartz, carbonate and biotite are relatively less abundant than in #1.

The coarser prismatic plagioclase aggregates have the aspect of a meta-intrusive; however, the presence, also, of fine foliaceous variants - sometimes gradational from the coarse aggregates - indicates that the latter most likely represented lenses of coarser crystal clasts in a heterogenous, lensey/layered tuff sequence, now extensively recrystallized to epidote-amphibolite grade.

## SAMPLE 88 KA-3 GREENSTONE (META-TUFF) WITH QUARTZITE (META-CHERT)

This slide consists of a mixture of fragments of two distinct types. One is of a greenstone meta-tuff of similar type to Samples 1 and 2. The other is a siliceous rock (quartzite or meta-chert). Relative proportions of the two types in the slide are approximately 70:30. The channel sample apparently embraced a lithologic contact - or the siliceous phase occurs as thin intercalations in the predominant greenstone.

### Estimated modes

	Plagioclase	52
	Sericite	10
	Quartz	1
	Biotite	15
	Chlorite	1
	Amphibole	6
	Epidote	12
	Carbonate	2
	Sphene	1
	Rutile	trace
Quartzite		
	Quartz	76
	Plagioclase	2
	Biotite	10
	Carbonate	10
	Limonite	2

The greenstone member has been described under Samples 1 and 2 (q.v.). In this slide it includes a somewhat higher proportion of the foliaceous sericitized felsite sub-type. The minor carbonate occurs, in part, as veniform segregations cutting coarse plagioclase.

The siliceous lithotype consists of even-grained mosaics of anhedral quartz, sometimes in the range 0.02 - 0.05mm, and sometimes somewhat coarser (0.05 - 0.2mm). Minute flakes of green chlorite or biotite occur intergranular to the quartz, defining a very weak foliation. Coarser, brownish biotite occurs as randomly oriented porphyroblastic clusters. Some fragments have accessory carbonate, as patches or bands of network intergrowth with the quartz. This carbonate is strongly limonite-stained, and presumably of ankeritic or sideritic composition.

Thin laminae of more feldspathic composition are occasionally seen in the quartzitic fragments.

The latter probably represent a chert member, developed locally within the greenstone tuff.

## Estimated mode

Plagioclase	52
Sericite	16
Quartz	24
Chlorite	2
Carbonate	3
Limonite	3
Opaques	trace

This sample clearly represents a change in lithology. The absence of the epidote, amphibole and biotite characteristic of the greenstone unit represented by Samples 1, 2 and 3 is notable. Coarser relict crystal clasts of plagioclase are also absent.

The fragments making up this slide include fine-grained, cherty aggregates, similar to the siliceous unit in Sample 3. These grade to, or are intercalated with, felsitic variants of generally similar appearance, but probably composed largely of plagioclase. The overall proportion of cherty quartz vs fine-grained (untwinned) plagioclase in this rock - and others of similar type in the suite - is difficult to determine, and the ratio may, in fact, be somewhat more quartz-rich than indicated in the estimated mode.

Sericite is a common constituent, forming foliaceous lenses and wisps within the quartzo-feldspathic aggregates. Fragments composed almost entirely of minutely felted sericite are also seen; these presumably represent argillaceous (shaly) intercalations within an ash-tuff sequence.

Carbonate occurs as a diffusely intergrown accessory in some of the felsitic fragments, as thin segregated laminae, and as occasional porphyroblasts.

Limonite occurs as localized wisps and network-impregnations which appear to be the result of alteration of carbonate. The latter is thus indicated as of Fe-rich (ankerite or siderite) composition.

The petrography is consistent with the classification of this unit as a felsic ash-tuff.

## Estimated mode

Plagioclase	48
Sericite	1
Quartz	26
Carbonate	20
Limonite	5
Biotite	trace
Chlorite	trace
Epidote	trace

This sample appears to be made up of a mixture of lithotypes (or variants).

It is similar in general character to #4, consisting largely of fine-grained felsitic and/or cherty aggregates representing felsic tuffs.

It includes some slightly coarser variants, probably representing concentrations of crystal clasts - but differs from #4 chiefly in its notably higher content of carbonate. This occurs as fine-grained intergrowths, patchy segregations to 1.0mm or more in size (often incorporating quartz granules), and as thin wisps and partings, intimately intergrown with sericite.

In part, the carbonate is intensely limonitized and, in part, clear and colourless. This may result from the irregular effect of weathering (say along joints and fractures) on an Fe-rich carbonate, or possibly indicates the presence of two distinct types of carbonate. Some of the rock fragments show effervescence with dilute acid, suggesting that the carbonate is, in part, calcitic. X-ray diffraction confirms the presence of both calcite and ankerite.

A few fragments are composed of aggregates of subhedral/euhedral quartz, or quartz with intergrown calcite. These have the aspect of vein material or remobilized segregations.



## Estimated mode

Plagioclase	52
Quartz	34
Sericite	10
Chlorite	1
Carbonate	1
Epidote	2
Rutile	trace
Opaques	trace

This slide includes fragments of a texturally heterogenous rock type, which is recognizably different from the previous two samples in containing more or less abundant, coarse, relict phenocrysts or crystal clasts of quartz and plagioclase, and in having a little accessory epidote.

It is texturally similar to the greenstone of Samples 1, 2 and 3, but lacks the abundant mafics of that unit. It is probably of similar origin, being a partially recrystallized crystal tuff - in this case of felsic composition. The mapped lithology is confirmed by the petrography.

The blocky crystals and crystal clumps of quartz and plagioclase, 0.2 - 2.0mm in size, are scattered through an irregularly foliated matrix of fine-grained, felsitic character (locally quartz-rich, locally feldspathic) with interstitial flecks of sericite. The quartz/feldspar grains in this matrix sometimes show partial flattening or stretching.

The felsitic component is commonly more or less sericitized, and grades to wisps and streaks composed essentially of fine-felted sericite.

Epidote occurs as randomly scattered, more or less diffuse, microgranular clumps representing embryonic porphyroblasts.

Carbonate is very minor, occurring as rare, small pockets and veniform gashes.

One fragment contains a few small grains of pyrite in a lens of mosaic quartz.

SAMPLE 88 KA-7

FELSIC CRYSTAL TUFF

Estimated mode

Plagioclase	47
Sericite	10
Quartz	38
Biotite	trace
Chlorite	2
Epidote	3
Carbonate	trace
Rutile	trace
Opagues	trace

This sample is, in all essential respects, identical to the previous one (88 KA-6).

SAMPLE 88 KA-8

FELSIC CRYSTAL TUFF

Estimated mode

Plagioclase	50
Sericite	10
Quartz	35
Chlorite	2
Epidote	3
Carbonate	trace
Rutile	trace

This sample is identical, in all essential respects, to the previous two (Samples 6 and 7).

Phenocrysts (or crystal clasts of quartz and lesser plagioclase) reach 3mm or so in size, and are relatively abundant. They are set in an irregularly-foliated felsitic matrix with intergrown sericite.

SAMPLE 88 KA-9

FELSIC CRYSTAL TUFF

Estimated mode

Plagioclase	65
Sericite	5
Quartz	25
Chlorite	2
Epidote	3
Carbonate	trace
Rutile	trace

This sample is petrographically indistinguishable from the preceding examples (#s 6, 7 and 8) of the felsic crystal tuff unit.

SAMPLE 88 KA-10

FELSIC CRYSTAL TUFF

Estimated mode

Plagioclase	66
Sericite	6
Quartz	25
Chlorite	1
Epidote	1
Carbonate	1
Rutile	trace

This sample is essentially identical to others of the felsic crystal tuff unit (#s 6, 7, 8 and 9). It contains marginally more carbonate than the previous few samples, though it is still a very minor constituent.

SAMPLE 88 KA-11

FELSIC CRYSTAL TUFF

Estimated mode

Plagioclase	60
Sericite	7
Quartz	30
Chlorite	trace
Epidote	1
Carbonate	2
Rutile	trace
Opagues	trace
Limonite	trace

This sample is another example of the felsic crystal tuff. It is mineralogically and texturally indistinguishable from the previous samples of this group.

It contains traces of limonite, derived from the oxidation of minor wisps and pockets of ferruginous carbonate

**SAMPLE 88 KA-12 CARBONATE-BEARING FELSIC CRYSTAL TUFF**

Estimated mode

Plagioclase	50
Sericite	8
Quartz	24
Carbonate	18
Rutile	trace
Limonite	trace

The fragments making up this sample comprise a variety of textural types, from foliaceous felsitic/sericitic aggregates, through similar aggregates with blocky feldspar crystals (phenocrysts or crystal clasts) to granular aggregates of quartz, plagioclase and carbonate.

The overall textural/mineralogical range resembles that seen in the previous few samples (felsic crystal tuff), and the rock type represented is clearly of essentially similar type. The justification for distinguishing it as a lapilli tuff is not evident from observing the fragmented rock on the thin section scale, though it may well be apparent (in terms of the presence of recognizably coarser lithic clasts) on the hand specimen or outcrop scale.

The principal mineralogical difference between this rock and samples 6 - 11 is in its notably increased content of carbonate. This occurs as irregular pockets and intergrowths of granular mosaic texture, sometimes relatively coarse (grains up to 1.0mm or more). It is seen within the finer foliaceous variants, interstitial to feldspar crystal clasts in the coarser crystal tuff variant, and intimately associated as 3-component granular intergrowths with quartz, and plagioclase.

For the most part, the carbonate is clear and relatively coarsely crystalline. Much of it reacts with dilute acid, and is apparently calcite. Surprisingly, this is also the case with a few patches showing limonitic staining (and which one would have assumed to be a ferruginous variety like ankerite or siderite). The X-ray diffraction spectrum confirms this, in showing the principal peak close to the position of calcite, plus a minor peak for dolomite.

Less obvious differences between this rock and Samples 6 - 11 are a lower abundance of quartz phenocrysts/crystal clasts, and the absence of accessory epidote and chlorite. Petrographically it appears to represent a carbonate-bearing facies of the felsic crystal tuff unit.

SAMPLE 88 KA-13 CARBONATE RICH, CHERTY FELSIC CRYSTAL TUFF

Estimated mode.

Plagioclase	32
Sericite	6
Quartz	35
Carbonate	26
Rutile	trace
Pyrite	1
Limonite	trace

This sample is of similar type to 88 KA-12, but has a significantly higher content of carbonate. It is also noticeably more siliceous and less feldspathic.

The carbonate forms microgranular mosaic aggregates, as irregular streaky intergrowths, and as randomly distributed, coarse, porphyroblast-like, subhedral individuals or crystal groups, of grain size up to 1.0mm or more, in the felsitic tuff matrix. It also concentrates around, and forms fracture fillings within, quartz crystal clasts, and occurs as granular intergrowths with quartz.

The carbonate in this instance shows only minor reactivity with dilute acid, and is apparently some variety other than calcite. X-ray diffraction suggests the presence of dolomite and minor siderite.

This sample shows a paucity of plagioclase crystal clasts and a markedly increased abundance of quartz clasts, compared with #11. The overall matrix composition also looks more siliceous, and the rock probably includes exhalative intercalations of chert/carbonate (chemical sediment) - now recrystallized with the crystal tuff host.

Pyrite is another constituent not seen in significant amounts in the previous samples. It occurs as a cluster of well-formed, individual, cubic euhedra, 0.1 - 1.5mm in size, in one particular rock fragment (see cut-off stub). Unfortunately the appears to have been lost by plucking during the slide preparation, so its detailed association is not known.



## Estimated mode

Quartz	50
Plagioclase	4
Sericite	14
Chlorite(?)	20
Carbonate	7
Pyrite	5
Chalcopyrite	trace
Sphalerite	trace

The rock fragments making up this sample include a variety of textural/mineralogical associations - indicative of a heterogenous lithotype exhibiting rapid small-scale (bedded/lenticular?) variations.

It is of the same general aspect as the tuffs constituting the previous samples, including foliaceous sericitic and fine felsitic/quartzitic types, and mosaic-textured (recrystallized) granular aggregates. The phenocryst-like feldspar and quartz grains, interpreted as crystal clasts in the previous samples, are not seen, though porphyroblast-like grains of carbonate are not uncommon.

The rock is mineralogically distinctive in having only minor recognizable feldspar, and in containing a rather abundant component of what is tentatively identified as chlorite. This is a colourless, low-relief, low-birefringent mineral occurring as minutely fine-grained felted aggregates. Some fragments are totally composed of this material; it also occurs as gradational pockets and lenses within chert, and interstitial to granular quartz aggregates.

Quartz is abundant, in the form of very fine-grained to more coarsely granular aggregates seemingly representing variably recrystallized chert. Microlenticular intergrowths of chert in foliaceous sericite and/or chlorite are rather common.

Carbonate is a moderately abundant accessory, as random permeations, granular pockets and porphyroblast-like clumps in the chert.

The rock type appears to consist of fine, foliaceous, sericitic ash tuffs with exhalative intercalations of chert and chlorite (the latter possibly representin original Fe-Mg smectite clays).,

Disseminated sulfides are a widespread minor component, occurring in all the described textural/mineralogical lithotypes. They are principally pyrite, as individual grains rangin in size from a few microns to 0.5mm, showing partly euhedral and partly anhedral form.

Sample 88 KA-14 cont.

Traces of chalcopyrite and sphalerite are also present, generally independent of the pyrite.

**SAMPLE 88 KA-15 CARBONATE-RICH EXHALITE WITH DISSEMINATED SULFIDES**

Estimated mode

Quartz	13
Sericite	12
Chlorite	6
Biotite	trace
Dolomite	57
Pyrite	5
Chalcopyrite	6
Sphalerite	1
Bornite	trace
Galena	trace

The mineralogy of this sample is contradictory to the field identification as a siliceous tuff. In fact, the petrography suggests that it is a variant of the previous sample (88 KA-14) in which carbonate takes the place of quartz as the major constituent.

Fragments making up the slide include minor proportions of granular quartz, foliaceous sericite and chlorite (and the latter two with intergrown grains of quartz). The principal component, however, is carbonate. This is non-reactive to dilute acid, and is probably dolomite (subsequently confirmed as such by X-ray diffraction).

This occurs as anhedral mosaic aggregates, of grain size 0.05 - 0.5mm, sometimes with accessory intergrown quartz, rather well-formed muscovite flakes, or contorted foliaceous chlorite and/or sericite.

Disseminated sulfides are rather abundant, and include relatively coarse aggregates to 2mm or more in size. They consist principally of pyrite and chalcopyrite - the latter forming the majority of the coarser segregations. Pyrite also forms included subhedral grains, down to a few microns in size, within chalcopyrite, and numerous euhedral/subhedral grain clusters in which chalcopyrite is absent or forms an interstitial component, sometimes with associated sphalerite. The pyrite in the granular clumps shows perceptible birefringence.

Rare grains of bornite and galena are also seen.

The sulfides - which are totally fresh - occur intergrown with coarse carbonate or carbonate/quartz aggregates, and also in foliaceous chlorite and sericite. They show no features which would explain any unusual susceptibility to oxidation.

This rock type appears to be a carbonate-rich, low sulfide variant of the exhalite constituting the massive sulfide intervals.

## Estimated mode

Quartz	4
Plagioclase	trace
Carbonate	20
Sericite	6
Chlorite	3
Pyrite	55
Chalcopyrite	8
Sphalerite	2
Bornite	2
Tetrahedrite	trace
Galena	trace

This sample is composed predominantly of sulfides.

The principal gangue component is carbonate, as granular aggregates of grain size 0.05 - 0.3mm. XRD scans indicate this to be a mixture of calcite and dolomite. Fragments of foliaceous/felted sericite and chlorite are also rather common. Quartz is comparatively minor.

The gangue minerals occur partly in various degrees of mutual intergrowth, but are mainly as monomineralic fragments, suggesting a rather well-segregated mode of occurrence in the rock.

Likewise, the sample shows a strong tendency for segregation of the sulfides and gangue. Sulfides are occasionally seen as more or less dense disseminations in gangue but, for the most part, occur in the slide as discrete fragments, essentially free of gangue.

Pyrite is the predominant sulfide. It occurs as equant, subhedral grains, 0.02 - 0.5mm in size, typically aggregated as compact mosaics. The shape of the pyrite grains is typically polygonal, simple cubes being essentially absent. This may indicate a primary tendency for pyritohedral form, or may be the result of metamorphic recrystallization of a fine-grained primary sulfide sediment.

The accessory minerals - predominantly chalcopyrite and sphalerite - tend to form an interstitial network phase, on a scale 10 - 50 microns, within the pyrite aggregate. Chalcopyrite and bornite are also seen as relatively coarse monomineralic fragments, to 0.5mm or more, sometimes with included pyrite grains.

The textural relationship of the bornite and chalcopyrite suggests that they are contemporaneous primary (or recrystallized) components.

Traces of tetrahedrite and galena are occasionally seen as a part of the interstitial base-metal sulfide assemblage.

**SAMPLE 88 KA-17 FOLIATED CHERTY SERICITIC TUFF WITH DISSEMINATED  
PYRITE**

Estimated mode

Quartz	69
Sericite	22
Chlorite	1
Carbonate	trace
Pyrite	8
Chalcopyrite	trace
Sphalerite	trace
Tetrahedrite	trace
Galena	trace

The fragments making up this slide are rather consistent in type, and of notably simple mineralogy.

They consist of microgranular aggregates of quartz, of grain size 0.02 - 0.2mm, with varying proportion of intergrown sericite.

The sericite mainly forms abundant, more or less well-oriented flakes in interstitial mode to the quartz (as in a sericitic quartzite or quartz-sericite schist).

Occasional fragments composed almost entirely of foliaceous sericite are seen. These probably represent portions of segregated micaceous laminae or schlieren in the overall package.

Quartz sometimes forms pockety, sericite-free segregations or individual, phenocryst-like grains (crystal clasts?) within the weakly schistose sericite-quartz aggregate.

Rare streaks and pockets of foliaceous chlorite are seen intergrown with the sericite.

Carbonate is rare, being confined to occasional interstitial intergrowths in the more coarsely granular quartz.

Disseminated sulfides are almost entirely pyrite. This occurs as individual euhedral-subhedral grains, 0.01 - 0.5mm in size, and small clusters of such grains. Rare traces of sphalerite, chalcopyrite, tetrahedrite and galena are occasionally seen in interstitial or 'moulded-on' relationship to the pyrite. The pyrite often shows the relatively strong anisotropism remarked in Sample 15.

Sulfides occur as randomly scattered, equant grains in the more siliceous matrices, and as elongate strings in the more schistose host.

This rock appears to be a thinly laminated, siliceous (cherty) ash tuff, recrystallized as a sericite-quartz schist.

## Estimated mode

Quartz	22
Plagioclase	1
Carbonate	13
Sericite	7
Chlorite	1
Biotite	trace
Amphibole	trace
Epidote	trace
Pyrite	45
Sphalerite	7
Chalcopyrite	trace
Bornite	2
Digenite)	2
Chalcocite)	
Covellite	trace
Tetrahedrite	trace
Galena	trace

This sample represents massive sulfide material which shows some significant differences from the previous sample of this type (88 KA-16).

The gangue shows a considerably higher ratio of quartz to carbonate, the two components tending to occur mainly as segregated, monomineralic fragments. Interestingly, the sample includes a few fragments (presumably representing a thin intercalated zone) of granular plagioclase with biotite, amphibole and epidote: i.e. the greenstone lithotype represented by Samples 1, 2 and 3.

Sericite occurs as compact, foliaceous aggregates and, to a minor degree, intergrown with quartz and/or carbonate.

The sulfide assemblage is distinctive for the relative abundance of sphalerite, and the dominance of bornite and digenite/chalcocite over chalcopyrite.

Pyrite is the predominant sulfide. It commonly occurs as 'loose' aggregates of sub-rounded/polygonal (occasionally elongated) grains, ranging in size from 0.02 - 0.5mm, cemented interstitially by sphalerite or by bornite and chalcocite. Some coarser grains or compact monomineralic masses of pyrite, to 2.0mm in size, are also seen.

The majority of the sulfides in the sample are as essentially liberated fragments, suggesting a tendency for segregation. Fine-grained intergrowths with gangue appear to be uncommon in this ore.

Sample 88 KA-18 cont.

Bornite and digenite or chalcocite - often intimately intergrown - are the principal Cu minerals. They show simple textural relationships with the sphalerite and the minor amount of chalcopyrite which is present, and appear to be of primary (rather than secondary enrichment) origin.

The pockety/interstitial intergrowth of the Cu-Zn sulfides with the pyrite is generally on a scale of 0.02 - 0.5mm/



**SAMPLE 88 KA-19 CARBONATE-RICH CHERT WITH DISSEMINATED AND MASSIVE SULFIDES**

Estimated mode

Quartz	19
Plagioclase	1
Carbonate	50
Sericite	7
Chlorite	2
Pyrite	17
Chalcopyrite	1
Sphalerite	1
Bornite	1
Digenite	1
Covellite	trace

This rock appears to be of similar type to 88 KA-15.

The most common rock fragments are of carbonate, as equigranular aggregates of grain size 0.02 - 0.3mm. Some of these contain minor intergrown quartz (or occasionally plagioclase) or sericite or chlorite flakes. The carbonate is indicated as dolomite by XRD.

The carbonate fragments grade, by increase in quartz content, to segregations of granular quartz, of similar grain size. 3-component intergrowths of carbonate, quartz and sericite are also seen, and there are occasional fragments composed of minutely felted chlorite.

Sulfides are relatively abundant. To a minor degree, these occur as randomly disseminated grains or small grain clumps or pockets in the various forms of host rock (more particularly the quartz-rich variants). The larger part of the sulfides, however, occurs as individual fragments, up to 5mm in size, clearly representing portions of small segregated lenses of massive sulfides.

Pyrite is the predominant sulfide. It occurs as coarse masses and as compact microgranular aggregates, sometimes with included quartz grains and chlorite flakes. In some cases the pyrite occurs as clusters of grains, 0.05 - 0.5mm in size, which are interstitially cemented by sphalerite or the various Cu minerals.

Bornite is a relatively common component in this sample. It is intergrown with chalcopyrite, in a manner which suggests it is a primary constituent.

Digenite (blue chalcocite) is also a notable component, in intimate association with bornite, and often rimming that mineral.

This sample appears to represent a weakly sulfidic, carbonate-rich exhalite unit, with intercalations of massive sulfides.

## Estimated mode

Quartz	5
Carbonate	29
Sericite	1
Pyrite	60
Sphalerite	4
Chalcopyrite	trace
Bornite	1
Digenite	trace
Galena	trace
Tetrahedrite	trace

This is another variant of the massive sulfide lithotype.

The gangue is largely carbonate (dolomite by XRD), as mosaic aggregates of grain size 0.05 - 0.5mm or more. Minor quartz and traces of sericite occur as irregular intergrown pockets and streaks in the carbonate. There are also a few fragments of segregated granular quartz and foliated quartz with sericite flakes.

The sulfides are predominantly pyrite, with a noticeably lower proportion of the valuable accessory base metals than in Samples 16 and 18.

The pyrite shows a much stronger tendency for intergrowth with the carbonate in this sample, often occurring as irregular permeations, clumps and semi-coalescent disseminations in the granular carbonate, on a scale of 0.01 - 0.5mm. These sometimes contain traces of sphalerite and Cu minerals, as fine-grained intergranular networks.

Some more segregated pyrite is seen as essentially gangue-free fragments, up to 1mm or more in size. Sphalerite, bornite/digenite and, less commonly, chalcopyrite or traces of galena and tetrahedrite occur as intergranular threads, networks and pockets, 0.01 - 0.2mm in size.

As in all the samples of this suite, the grain structure in the compact pyrite aggregates is readily apparent by virtue of a perceptible bireflectance and anisotropism.

## Estimated mode

Quartz	11
Carbonate	20
Sericite	12
chlorite	2
Pyrite	48
Sphalerite	3
Chalcopyrite	4
Bornite	trace
Digenite	trace
Galena	trace
Tetrahedrite	trace

This is another variant of the massive sulfide. It somewhat resembles 88 KA-16 in containing relatively abundant chalcopyrite.

The gangue is again predominantly carbonate with accessory quartz, but includes a notable proportion of sericite - principally as compact, locally foliaceous, felted aggregates. The carbonate is non-reactive to dilute acid, and is indicated by XRD as predominantly dolomite - possibly with minor siderite. The gangue constituents tend to be rather coarsely intergrown or segregated, and the manner of their intergrowth is not readily apparent from the slide (in which most of the constituent fragments are essentially monomineralic as regards gangue).

The sulfides show a style of textural intergrowth similar to that in the other massive sulfide samples. Pyrite is the predominant constituent, occurring as compact, granular mosaic clumps. Most of it appears in the slide as segregated gangue-free fragments, but a few instances are seen where the pyrite forms more or less dense disseminations in quartz, sericite or - more rarely - carbonate.

The base metal sulfides form interstitial flecks, pockets and networks in the massive pyrite. Chalcopyrite partly occurs as intimate, minutely fine-grained network permeations in pyrite, on a scale down to a few microns. Sphalerite, by comparison, forms mainly relatively coarse pockets and patches of matrix with included pyrite grains, on a scale up to 0.5mm or more.

For the most part, the chalcopyrite and sphalerite tend to occur mutually separated, though some cases are seen where the interstitial pockets consist of chalcopyrite, sphalerite, bornite, digenite and tetrahedrite, in simple intergrowths suggesting essential contemporaneity of formation (or more probably, the effect of recrystallization of the original sulfide aggregate).

**SAMPLE 88 KA-22 FOLIATED, SERICITIC META-CHERT WITH  
DISSEMINATED PYRITE**

Estimated mode

Quartz	67
Sericite	20
Carbonate	1
Pyrite	12
Pyrrhotite	trace
Sphalerite	trace
Chalcopyrite	trace
Bornite	trace

This sample is made up of rock fragments of rather consistent type. The majority of these are microgranular mosaic aggregates of quartz, of grain size 0.03 - 0.15mm, with rather well-oriented, interstitial flakes of sericite. The proportion of sericite varies, and where more abundant, it tends to concentrate as thin, wispy schlieren.

A few fragments are composed entirely of very fine-grained, felted/foliaceous sericite; these presumably represent portions of shaly intercalations in the predominant semi-schistose siliceous aggregate (probably a recrystallized chert).

Occasional examples are seen of relatively coarser quartz aggregates with intergrown pockets of carbonate, but overall the mineralogy is notably simple.

This rock type is essentially identical to 88 KA-17.

Sulfides are almost entirely pyrite. They occur as sporadic clusters and strings of partially coalescent subhedral individuals, 0.01 - 0.5mm in size, in the quartz-sericite host. Much of the pyrite in this sample is actually present as liberated, angular, monomineralic fragments up to 2mm or more in size - presumably the product of fragmentation of segregated, thin, compact pods and lenses.

The pyrite shows the noticeable anisotropism which appears to be a distinctive characteristic of this mineral throughout the suite.

Rare accessory interstitial chalcopyrite and sphalerite are seen - the former occasionally forming intimate, micron-sized network intergrowths in massive pyrite.

Pyrrhotite is a trace accessory not noted in other samples of the suite.

The pyrite is fresh, homogenous, and often locked within a tight siliceous host. No features were seen which would suggest any unusual susceptibility to oxidation.

## PHOTOMICROGRAPHS

All photos are by cross-polarized transmitted light at a scale of 1cm = 0.17mm, except where otherwise stated.

### SAMPLE 88 KA-1

Neg. 147-10: Typical example of greenstone tuff. Heterogeneous texture of foliaceous biotite (olive green) intergrown with granular plagioclase (grey/white: e.g. bottom). Accessories are epidote (small euhedra; pink, yellow, blue) and actinolite (bluish-green prismatic grains; top). The biotite clump includes some clusters of rutile (black).

Neg. 147-11: Another variant of the greenstone tuff. Sub-oriented acicular crystals of actinolite (greenish-orange) with tiny stubby euhedra of epidote (bright colours) in a matrix of felsitic plagioclase dusted with sericite.

### SAMPLE 88 KA-3

Neg. 147-12: Shows mixed rock types characteristic of this sample. Large fragment in centre is of greenstone tuff; consisting of clumps of plagioclase crystals (grey-white, twinned) with epidote (colours) and actinolite (acicular grains) in felsitic matrix (grey speckled). Fragment at bottom right is of related type (green biotite streaks in sericitized felsite). Fragments at top right and top left are of granular quartz (meta-chert), with intergrown carbonate (pink) in the former case.

### SAMPLE 88 KA-4

Neg. 147-13: Typical example of felsic ash tuff. Consists of fine-grained, weakly foliated, recrystallized aggregate of plagioclase and quartz (greys) with tiny oriented flecks of sericite (pinkish: e.g. bottom left). Field includes a small lens of coarser (porphyroblastic?) carbonate (pastel pinks: bottom).

### SAMPLE 88 KA-5

Neg. 147-14: Typical field, showing felsic tuff matrix with diffuse clumps of coarser plagioclase (remnant clasts) and abundant intergrown flecks and schlieren of carbonate - partly with brownish ferruginous staining.

Neg. 147-15: Another variety of the carbonate-bearing tuff. Shows clump of plagioclase crystal clasts (prismatic blue-grey grains; bottom right) and patches of carbonate (pinkish) showing brown limonitic rims. Note also, limonitized carbonate (dark, with brown glints) in the felsitic matrix.

#### **SAMPLE 88 KA-8**

**Neg. 147-16:** Typical example of the felsic crystal tuff lithotype. Note abundant subhedral crystal clasts of plagioclase (grey; speckled) and quartz (shadowy brownish grey; right) in felsitic matrix. Small, dark to brownish, rounded clumps (e.g. centre top, centre) are epidote. Field includes a pocket of flaky chlorite (left centre).

#### **SAMPLE 88 KA-12**

**Neg. 147-18:** Typical field. Shows coarse augen of twinned plagioclase (crystal clasts) at bottom. Smaller rounded grey grain (centre) is quartz. Foliated matrix is felsitic plagioclase/quartz with oriented flakes and wisps of sericite. Upper part of field shows granular aggregate of carbonate (pinkish) and plagioclase (greys, sometimes twinned), with minor quartz.

#### **SAMPLE 88 KA-13**

**Neg. 147-19:** Typical field. Clump of coarser intergrown quartz (greys) and carbonate (brownish) in matrix of recrystallized chert (top right) and granular quartz/carbonate (bottom left).

#### **SAMPLE 88 KA-14**

**Neg. 147-20:** Typical field showing poly-lithic character of this sample. Field includes quartzite-like meta-cherts (left), compact foliaceous sericite (pinkish, top right) and massive felted chlorite (speckled blue-grey; bottom right). Note presence of disseminated pyrite (opaque, black) in some fragments (especially top left; this fragment also includes brownish grains of ferruginous carbonate).

**Neg. 147-21:** Reflected light. Shows mode of occurrence of disseminated pyrite in foliaceous sericite (right) and granular meta-tuff (bottom).

#### **SAMPLE 88 KA-15**

**Neg. 147-22:** Typical field. Note predominance of fragments composed mainly of granular mosaic carbonate (pinkish grey at upper right; pastel colours at centre bottom) with intergrown quartz (grey). Fragment at top left is coarse quartz in foliaceous sericite matrix. Sulfides (opaque, black) are relatively common, intergrown with the carbonate/quartz and as disaggregated grains.

**Neg. 147-23:** Reflected light. Shows typical sulfide intergrowth in granular carbonate aggregate (dark grey). Creamy white is pyrite. Yellow is chalcopyrite. Bluish grey is sphalerite. Note textural variability of the sulfide component, from well-segregated to minutely intergrown.

**SAMPLE 88 KA-16**

**Neg. 147-24:** Reflected light. Shows typical texture of massive sulfide. Mosaic of varigranular pyrite with interstitial flecks and networks of chalcopyrite (yellow) and rare sphalerite (grey). Very dark grey/black areas are intergrown carbonate/quartz gangue.

**Neg. 147-25:** Reflected light. Example of coarser granularity in massive sulfide. Large fragment consists of subhedral pyrite mantled by segregation of chalcopyrite. Small fragment at left is intergrowth of bornite (purplish) and chalcopyrite.

**SAMPLE 88 KA-17**

**Neg. 147-26:** Typical field showing consistency of rock type. Fragments are of cherty tuff, composed of microgranular quartz with interstitial sericite (pastel colours), grading to foliaceous/felted sericite (bottom left). Black disseminated grains within the fragments are pyrite.

**Neg. 147-27:** Same field as 147-26 but plane-polarized light. Shows distribution of disseminated sulfides (black) more clearly. Note minor limonitic staining (brown) in the schistose sericite.

**SAMPLE 88 KA-18**

**Neg. 147-28:** Reflected light. Example of granular pyrite cemented by bornite (purplish) with intergrown digenite (blue). Note the slightly different shades of cream colour in the pyrite (effect of weak anisotropism).

**Neg. 147-29:** Reflected light. Example of finer-grained intergrowth in massive sulfide. Creamy white is pyrite. Grey interstitial phase, grading to pockety segregations, is sphalerite.

**SAMPLE 88 KA-19**

**Neg. 147-36:** Reflected light. Scale 1cm = 85 microns. Shows textural relationship of chalcopyrite (yellow) and bornite (pinkish brown). Lattice intergrowths and simple mutual boundary textures suggest contemporaneity of deposition (or recrystallization). Light blue-grey grain at extreme left is galena - a very minor constituent of this ore.

**SAMPLE 88 KA-20**

**Neg. 147-30:** Reflected light. Example of less massive sulfides, dispersed in carbonate gangue (dark grey). Note consistent tendency for the base metal sulfides (grey sphalerite, yellow chalcopyrite, brown bornite) to form discrete pockets or an interstitial 'cementing' phase to the pyrite clusters. Fragment at right is more massive pyrite with minor interstitial sphalerite.

**SAMPLE 88 KA-20**

**Neg. 147-31:** Reflected light. Fragment of massive pyrite. Note polygonal (recrystallized) fabric, showing perceptible anisotropism. Interstitial sulfides are very minor. A few small pockets of sphalerite can be seen (dark grey; e.g. right centre; far left), just distinguishable from the carbonate matrix (very dark grey).

**SAMPLE 88 KA-21**

**Neg. 147-32:** Reflected light. Shows typical textural associations in this sample. At top and at bottom right, fragments of finely granular pyrite with minute interstitial intergrowth of chalcopyrite. At bottom left, coarsely segregated sphalerite with intergrown pyrite.

**Neg. 147-33:** Reflected light. Typical example of a granular mosaic of anisotropic pyrite with a poly-mineralic interstitial phase of base-metal sulfides. Assemblage in this case includes tetrahedrite (lighter grey than sphalerite) along with the sphalerite and chalcopyrite. Darkest grey pockets are gangue.

**SAMPLE 88 KA-22**

**Neg. 147-35:** Reflected light. Shows mode of occurrence of disseminated pyrite in cherty/sericitic host (similar to KA-17).