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BUREAU OF MINES OPEN FILE REPORT / 1992

THE NATURAL ATTENUATION CAPACITY OF SANTA CRUZ AREA ROCKS TO PARTITION MOBILE SOLUTES FROM IN SITU LEACHATE

by Dianne C. Marozas, Steven E. Paulson, and Timothy J. Callahan

*** PREFACE

The U.S. Bureau of Mines, under a cooperative agreement with the Santa Cruz Joint Venture, owned by Santa Cruz, ASARCO Inc. and Freeport Copper Company, has started to investigate the feasibility of in situ mining a deep copper oxide deposit near Casa Grande, Arizona. Because this investigation involves a federal agency, all requirements of the National Environmental Policy Act (NEPA) must be observed. To meet these requirements, the Bureau intends to prepare an environmental assessment (EA) for this project to evaluate the significance of anticipated environmental impacts which may result. The EA provides in brief sufficient evidence and analysis for determining whether to prepare an environmental impact statement (EIS) or a finding of no significant impact (FONSI). An EIS is prepared if the action is determined to have a significant effect on the human environment. A FONSI is written if it is determined that no significant effect on the human environment will result from the proposed action. Under a FONSI, the proposed action is exempt from requirements to prepare an EIS. Preliminary investigations, discussion between Bureau and industry researchers, and comments and concerns expressed at a public meeting held in Casa Grande, Arizona in July 1990 revealed several specific issues of potential environmental concern. Those issues are: air quality; sulfuric acid handling and use; groundwater and hydrologic modeling; surface subsidence; attenuation; and recycle of fluids. Each of these issues will be addressed in a separate Bureau of Mines Open File Report (OFR) to be used as background documents in support of the EA. In addition, several other points of interest will be addressed in

other background documents, including: the overall process description; geology and hydrology; mineralogy and petrology; rock quality and structure; and geophysics. This report summarizes the results of the investigation into the natural attenuation capacity of rock from the Santa Cruz site. This material will then be incorporated by reference in the draft Environmental Assessment.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

g	gram
gpl	grams per liter
mL	milliliter
mL/min	milliliter per minute
pct	percent
ppm	parts per million

OPEN FILE REPORT

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by Dianne C. Marozas[1], Steven E. Paulson[2], and Timothy J. Callahan[3]

***ABSTRACT

The U.S. Department of Interior, Bureau of Mines (Bureau) is conducting research on the capacity of natural fluid/rock interactions to attenuate major and trace elements at the Santa Cruz In Situ Copper Mining project site. Results of the attenuation capacity tests show that the pH of mature leach solution will be changed, by reaction with rocks from the test site. As the acidity of the leach solution changes and as other chemical reactions take place, the concentration of all chemical constituents with the exception of sodium, calcium, and chloride, are reduced. Results have been partially quantified by the calculation of attenuation coefficients from the experimental test data. Calculations indicate that natural fluid/rock interactions have a significant capacity to partition solutes from the fluid to the solid phase, thereby inhibiting their subsurface migration. The combined natural attenuation capacity of rock and groundwater in the Santa Cruz study area to neutralize leachate and immobilize metals provides a feasible and reliable strategy in a post-mining closure plan, and a

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safeguard against migration of acidic leach fluids and regulated chemical constituents substantial distances from the in situ mining zone.

***INTRODUCTION

The U.S. Bureau of Mines and the Santa Cruz Joint Venture (SCJV), (Santa Cruz ASARCO Inc. and Freeport Copper Company), have initiated the Santa Cruz In Situ Copper Mining Research Project to evaluate the technical, economic, and environmental feasibility of in situ mining of copper oxide minerals. The research project is being conducted at the Santa Cruz deposit which is located about seven miles west of the city of Casa Grande, Arizona and about one and three fourths miles north of Arizona State Highway 84. The Santa Cruz deposit has not been previously mined. The surface and sub-surface owner of the property is the Santa Cruz Joint Venture. The land is retired or fallowed agricultural land last cropped in the late 1970's. The project is located in section 17, Township 6 South, Range 5 East. Location of the research project test site is shown in Figure 1.

The research project is separated into several interrelated tasks: site characterization to determine whether the geology and hydrology of the site are amenable to in situ mining; assessing the environmental compatibility of the project; construction and operation of a surface solvent extraction-electrowinning facility; and operation of the in situ mining test.

The in situ mining process to be tested at the Santa Cruz site consists of injection of dilute sulfuric acid solution into a granitic bedrock complex containing soluble copper oxide minerals through wells

constructed to protect the regional aquifer. Acid concentration of the injection fluid will be from 10 to 50 gpl (1 to 5 pct by weight). The dilute acid solution, injected through a well into an otherwise undisturbed copper mineralized zone, migrates into and through the natural fractures and pores which contain the mineralization and selectively dissolves the copper minerals, with relatively little interaction with the gangue mineralization. The copper-bearing solution then flows toward a pattern of recovery wells which surround the injection well where it is pumped from the test zone to the land surface. Copper will be recovered from the solution by solvent extraction-electrowinning, resulting in the production of copper cathode sheets. After the copper is stripped from the solution, a small quantity of acid is added to the solution to correct for any acid naturally used or consumed by the rock. Then the solution is pumped to the injection well and the process continues.

Before injection of the dilute acid solution, extensive testing was conducted to evaluate hydrogeologic conditions using wells constructed at the test site. Groundwater monitor wells were constructed to monitor test activities. Pumping tests, injection tests using local groundwater, and saline solution tracer tests in the leaching zone were conducted, and the hydrogeological condition was analyzed before testing with the dilute acid solution.

The test program conducted prior to injection of dilute acid solution was authorized under a Temporary Groundwater Quality Protection Permit and a Temporary Aquifer Protection Permit issued by the Arizona Department of Environmental Quality (ADEQ). Test wells were drilled

with authorization from the Arizona Department of Water Resources. In addition to being used to support the EA, test results will be incorporated into the Application for Aquifer Protection Permit and submitted to the Arizona Department of Environmental Quality (ADEQ). This Aquifer Protection Permit must be obtained from ADEQ before the in situ leach test with dilute acid solution can be conducted. In addition, the U.S. Environmental Protection Agency, under authority of the Federal Underground Injection Control Program, may require all injection wells to meet Class V well requirements, the primary restriction being no contaminant injected into an underground source of drinking water may cause a violation of any primary drinking water regulation under 40 CFR Part 142 or otherwise adversely affect the health of persons.

This report summarizes results from a laboratory investigation of the natural attenuation capacity of rocks from the Santa Cruz site. The investigation was designed to determine the capacity of Santa Cruz area rocks to partition mobile solutes from in situ leachate. This material is incorporated by reference in the draft Environmental Assessment.

***BACKGROUND

Geologic systems respond to outside chemical and physical perturbations in such a way as to minimize or negate the effect of the perturbation. If the perturbation is minimized it is said to be attenuated. The degree to which a particular rock system can naturally attenuate a perturbation is defined here as its natural attenuation capacity. Attenuation is driven by the fact that natural geologic environments are dynamic systems in which chemical and physical

processes continuously react to achieve a state of equilibrium between groundwater and host rock. For example, Freeze and Cherry report that pH values of groundwater from undisturbed crystalline rock environments, like the Santa Cruz site, will naturally range from 5.5 - 7.9 (*1*). If acidic solutions are injected into such a system as part of the in situ mining process, natural acid consuming hydrolysis reactions will commence in order to return groundwater in the system to its natural, near neutral pH value. Acid neutralization and solute removal are just two of many ways that a geologic system can reestablish equilibrium after a perturbation. Identification of the role of these reactions at the Santa Cruz site was the focus of an experimental study. Results of this study are presented in this paper.

As part of a mine site closure plan, natural attenuation would be desirable because neutralization and solute removal takes place underground, within the in situ mine zone's solid matrix. Natural attenuation could be an acceptable means of post mining cleanup at the Santa Cruz site, because the ore zone is hydrologically isolated from local producing aquifers. In this case, in situ restoration has several important advantages over processes that require removal of fluids from the leached ore zone: 1) objectionable materials are deposited deep below the surface, remote from an environmentally-sensitive biosphere at the surface, 2) the need to utilize limited surface waste disposal sites is eliminated, and 3) cost and energy requirements are substantially reduced due to operation of the wellfield for a shorter period of time.

Previous research has shown that naturally occurring chemical and geochemical mechanisms can retard the movement of contaminants and

degrade such compounds into less hazardous reaction products at a variety of surface tailings impoundments (*2,3,4*). Laboratory and field evidence to evaluate the effectiveness of this approach at the Santa Cruz site was needed. Therefore, an experimental testing program was developed to quantify the extent that natural physiochemical reactions, such as oxidation/reduction, acid/base neutralization, ion exchange, precipitation, and adsorption can be relied upon to achieve acceptable water quality standards at the Santa Cruz facility.

SCOPE OF REPORT

This report presents results from a series of experiments designed to quantify the changes that natural reactions will cause in the composition of mining leachate with time. Several different rock types in the Santa Cruz area were tested and the effect of rock type on attenuation was evaluated. Calculated experimental attenuation coefficients are presented as a method of quantifying attenuation capacity. Geochemical reactions that can cause subsurface attenuation of various leachate constituents are also discussed.

***ATTENUATION TESTING PROGRAM

The attenuation capacity of rock samples can be measured, quantified, and predicted by simple laboratory procedures. Natural attenuation was simulated in the laboratory by reacting leachate of a defined chemistry with a specific type and volume of rock. The resulting changes in fluid composition were carefully measured and documented.

The techniques used to measure the natural attenuation of Santa Cruz area rocks included both batch and column experimental designs. The

results suggest that geochemical reactions can transform in situ leachate from an acidic metal bearing solution to a near-neutral solution more like naturally occurring groundwater in the area.

EXPERIMENTAL PROCEDURES

Experiments to evaluate the attenuation capacity of Santa Cruz area rocks were carried out in three stages. In the first stage, single-step batch leach tests were conducted on several typical Santa Cruz area rock types. The purpose of the tests was to determine how much time was required to achieve equilibrium and how fluid:rock ratio would affect the experimental results. In each of these tests, a low pH fluid with a composition approximating that of the anticipated mature leachate was mixed with a rock sample to a specific fluid-to-rock mass ratio in 750-mL or 250-mL high density, polyethylene bottles. The fluid and rock were kept well mixed on a wrist-action shaker table for a period of 35 to 45 days. Fluid samples were taken periodically and pH was measured daily to characterize concentration changes occurring in the solution. All experiments were run at ambient laboratory temperature which was maintained at 25°C plus or minus 2°C.

Results of the single step batch tests established several important parameters for additional testing. The fact that increased reactivity was directly related to fluid:rock ratio led to the development of the second stage of testing, with the purpose of increasing the amount of rock that each volume of fluid would contact. In these tests, every 10 to 14 days the fluid was separated from the solid by centrifugation and filtration. The fluid portion was then transferred to a reaction vessel containing fresh unreacted, dry rock. Because of sampling and wetting

of the rock sample the amount of fluid decreased with each test cycle, so the amount of rock added was adjusted to keep the fluid:rock ratio constant. Elapsed time for each test varied from one to three months, with each test lasting at least three cycles. Because the effluent of one cycle was used as the starting fluid for the next cycle, these tests allowed a simulation of continuous migration of leachate through fresh rock (Figure 2). Methods for sequential batch tests such as those used in this study are described by Houle and Long (*5*).

In the third stage of testing, a series of column experiments was conducted to measure attenuation under flow conditions and to assess how the chemical composition of a fluid packet changes as it moves away from the source and contacts increasingly larger volumes of rock. Mineralized rock samples from the upper and lower copper oxide units and one unmineralized sample of the leached capping of bedrock complex were tested in the columns. Samples of drill cuttings from these zones were agglomerated and then loosely packed in a plexiglass column. Fluid was added to the top of the column, allowed to percolate downward through the unsaturated column, and collected at the base. Samples of effluent were taken for chemical analyses and measured for pH. The effluent was then recirculated through the column until the pH stabilized. At this time fresh rock was agglomerated and packed as before, and the experiment was continued.

LEACHATE FLUID CHEMISTRY

An acidic leach solution with a composition similar to that generated in the Bureau's whole core recycle leaching experiments was prepared in the laboratory for use as a starting fluid in the

experiments. The purpose was to match the expected composition of mature in situ leachate as closely as possible in order to simulate its reactivity. Major element composition of the fluid was estimated based upon the chemical analyses of fluid collected from core leaching studies (*6*). Major elements, refer to the common ions calcium, sodium, potassium, chloride, sulfur, iron, silicon, aluminum, and copper. The starting pH of fluids used in the tests ranged from 1.0 to 3.4. The composition of the starting fluid used in each test is shown in Section A of Tables 2-9. Although the starting fluids were stored in sealed containers, the fluid itself would "age" and the composition would change with time. Because similar aging reactions would be expected in the field, the aging process was also documented and the results are included in Tables 2-9.

Iron is a significant component in all of the starting fluids which have a pH of less than 3. Both ferrous and ferric forms of iron can be leached by acidic in situ fluids. Ferric iron can be leached from gangue minerals such as goethite and ferrous iron can be leached from gangue minerals such as biotite. Therefore, the oxidation state of iron in the leachate could vary. Although reducing conditions are likely to dominate at the Santa Cruz test site at depths a few hundred feet below top of bedrock complex, once solution is brought to the surface facility oxygen could cause a shift in iron's oxidation state to ferric iron. Stability of this very important metal is strongly dependent on oxidation state. Therefore, starting solutions in the attenuation experiments were made with both ferrous and ferric iron as the initial form of iron to evaluate the effects of iron oxidation state on the

attenuation process. No attempts were made to keep ferrous iron from naturally oxidizing in the laboratory.

Chemical analyses of fluids collected from core leaching tests indicate that only minor mobilization of trace metals is expected during in situ leaching at the Santa Cruz site (*6*). However in order to document how natural attenuation might affect trace metals at Santa Cruz, the starting fluids used in the second (i.e. sequential batch tests) and third (i.e. column tests) stage of experiments were spiked with metals from the EPA's primary and secondary drinking water quality lists. The metals used were arsenic, barium, cadmium, chromium, lead, mercury, selenium, silver, lithium, nickel, zinc, manganese, cobalt, and molybdenum. Insoluble barium and silver sulfates precipitated upon addition of these elements to the leachant and thus, were not included in further tests. Concentrations of trace metals in the starting fluid are shown in Section IIA of Tables 3-9. Inner transition metals (atomic number greater than 57) were not added to the starting solution but were measured in reacted samples to determine the behavior of these elements during fluid/rock interactions.

In order to determine what effect highly concentrated components in the starting fluid such as aluminum, iron, and copper had on acid neutralization, batch tests were conducted that used "cation free" dilute sulfuric acid as the starting leachate. The starting fluids in these tests were not deliberately spiked with trace metals. Data from these tests are reported in Table 8.

Major elements were analyzed at the Bureau of Mines Twin Cities Research Center by several methods such as atomic adsorption

spectrometry, including hydride generation and graphite furnace techniques, inductively coupled plasma spectrometry, and ion chromatography. Trace elements, uranium, and thorium were measured at an outside laboratory by inductively coupled plasma-mass spectrometry (ICP-MS). Analysis techniques followed standard EPA analytical methods. Blank and replicate samples were used to establish quality assurance and quality control checks.

ROCK TYPES

Rock types typically found in and near the Santa Cruz deposit were sampled from drill core and drill cutting collections. Rock types used in the tests were: granite (unmineralized), porphyry, diabase, fault gouge, conglomerate, deep basin fill, the upper copper oxide (chrysocolla) unit, the lower copper oxide (atacamite) unit, and leached capping of bedrock complex. Rocks from the lower and upper copper oxide units were used because of their proximity to the in situ leach zone. Granite and porphyry were both chosen because of their volumetric significance at the Santa Cruz site. The granite used in these tests did not contain significant copper mineralization and therefore would be representative of rock found outside of the ore zone. Fault gouge, leached capping, basin fill, and the overlying conglomerate unit were tested to evaluate rocks above the mineralized zone. Drill hole number, depth, and major mineralogy of all the samples used is shown in Table 1. The location of the drill holes used in this study with respect to the mine test site is shown in Figure 3.

For the batch tests, samples of granite, porphyry, and diabase core were crushed to less than 1/4 inch particle size. A jaw crusher was

used for initial crushing. Samples of fault gouge, basin fill and conglomerate were poorly consolidated when received and were disaggregated by hand.

For the column tests, samples of the upper copper oxide unit, the lower copper oxide unit, and the leached capping of bedrock complex were taken from drill cuttings. Drill cuttings were washed using distilled, deionized water and dried before being placed in the test columns in order to remove any residual drilling mud. It should be noted that this washing procedure may have removed at least a portion of the native clay minerals along with residual drilling muds.

The mineralogy of the rock samples was determined by X-ray diffraction and binocular microscopic analyses. A general identification of sample mineralogy is presented in Table 1. More detailed information on Santa Cruz mineralogy and whole rock geochemistry is presented in Brink (*7*).

***RESULTS - SINGLE STEP BATCH TESTS

Single step batch tests were run on granite, clay-rich granite, porphyry, and diabase. The starting solution composition and the final solution composition are displayed in Table 2. Fluid:rock ratio was varied from 10 to 1. Fluid:rock ratios given throughout this report are weight of fluid to weight of rock ratios. For these single step batch tests the starting fluid was not spiked with trace metals.

ACID ATTENUATION

Neutralization of leachate is indicated by a rise in pH. In all of the single step batch tests, pH increased. Although the change in pH units appears small (Table 2), in terms of hydrogen ion concentration in

solution natural attenuation reactions consumed from 23 to 99.6 percent of the available hydrogen ion. The extent of neutralization reactions is strongly dependent on rock type and on fluid:rock ratio. The rock reactivity sequence indicated by relative order of neutralization capacity in the single step batch tests is: diabase > porphyry > granite. Fluid:rock ratio is an even more significant factor than rock type. In the tests using diabase, a change in fluid:rock ratio from 10 to 1 decreased hydrogen ion concentration by nearly two orders of magnitude.

In all of the single step batch tests reported in Table 2, 90 to 100 percent of the overall pH change observed in each test occurred within the first day of reaction. The tests were continued for 30 to 40 days but additional changes in pH were not significant.

MAJOR ELEMENT BEHAVIOR

In all of the single step batch tests, changes in fluid chemistry diminished with time and a steady state was reached within three to seven days from the start of the experiments. In the tests where pH did not exceed 3, major elements were generally not attenuated. In fact most major element concentrations in solution increased as a result of acid leaching (Table 2). In experiments using rock samples which contained soluble copper oxide mineralization (i.e. the porphyry and diabase), copper concentration was observed to increase, indicating that copper minerals will dissolve under the conditions of the experiments. Increases in potassium, calcium, magnesium, and sodium concentrations in solution, along with pH increases, suggest that some of the neutralization capacity in the rocks tested can be attributed to cation exchange reactions.

Aluminum and iron concentrations generally increased in all of the tests with high fluid:rock ratios. However, in the 3:1 (fluid:rock ratio) diabase test, when pH increased to 3.01, iron was removed from solution. When pH increased to 3.54 in the 1:1 (fluid:rock ratio) diabase test, both iron and aluminum were removed from the starting fluid. At these pH levels, precipitation of aluminum and iron minerals can occur and these elements are removed from the leachate. Precipitation of sulfate minerals also affected solution composition as shown by changes in sulfate concentration.

***RESULTS - SEQUENTIAL BATCH TESTS

Six series of sequential batch tests were conducted. Within each series the same starting fluid and fluid:rock ratio was used for testing several different rock types. The following chart is a summary of the variables used for each series and shows the table number where the results are listed.

TABLE NUMBER	IRON OXIDATION	pH Start	FLUID :ROCK	ROCK TYPE
3	Ferrous	2.0	3	Conglomerate Porphyry Granite Basin Fill Fault Gouge
4	Ferrous	2.1	1	Conglomerate Fault Gouge
5	Ferrous	2.4	1	Granite Fault Gouge
6	Ferric	1.6	1	Granite Fault Gouge
7	No Iron	3.4	1	Granite Fault Gouge
8	No Cation Dilute Acid	2.1	1	Granite Upper Copper Oxide Lower Copper Oxide Leached Bedrock

In each table, the starting fluid chemistry is listed in Sections IA and IIA. Reaction time given in sections IA and IIA of the tables is the total time starting solution was stored in a sealed container until it was sampled. Reaction time given in section IB and IIB of the tables is the amount of time that the fluid and rock were allowed to interact during a cycle. The "no-iron" test (Table 7) is a continuation of tests 5 and 6, after iron had been removed at a pH of 3.4. The fluid

composition resulting from tests 5 and 6 was chemically duplicated and a series of sequential batch tests was run (Table 7) for four additional cycles. The final series of tests (Table 8) were run with "cation-free" dilute sulfuric acid as the starting fluid.

ACID ATTENUATION

Results from the sequential batch tests show that the acid in leachate fluids can be neutralized by reactions with rocks from the Santa Cruz site. The degree of acid neutralization is affected by rock type. Conglomerate samples which contained calcite and copper oxide zone samples which contained acid soluble copper mineralization were able to neutralize the most acid.

Acid neutralization was found to be strongly affected by the presence of multi-valenced cations such as iron, aluminum, or copper. High concentrations of multi-valenced cations in solution become an additional source of acid upon precipitation. This is caused by the fact that the precipitation of metals is an acid producing reaction if the metal is precipitated as an oxide or oxyhydroxide, as shown in equation 1.

$$M^{x+} + xH_2O = M(OH)_x + xH^+ \qquad (1)$$

where: M^{x+} is any hydrolyzable metal cation

This observation was verified in the test that used "cation free" dilute acid as the starting fluid. For example, results from tests run on granite with pure acid (Table 8) and with cation loaded leachate (Tables 3-7) shows that pH is significantly affected by the presence of multi-

valent cations. When dilute acid was used as the starting fluid, near neutral pH was reached in tests using one equivalent mass of rock, whereas when cation loaded leachate was used the final pH did not exceed 3.5 even after seven equivalent rock masses were contacted.

MAJOR ELEMENT BEHAVIOR

Major element chemistry was strongly affected by the pH changes in solution that result from fluid-rock interactions. Figure 4 is a plot of the average percentage of copper, aluminum, and iron remaining in solution as a function of pH or increasing reaction progress for the sequential batch tests. Figure 4 shows that more than 90 percent of the iron was attenuated after a pH of 3.2 was reached, more than 90 percent of the aluminum was attenuated after a pH of 4.4 was reached, and more than 90 percent of the copper was attenuated after a pH of 5.0 was reached. The Tables 2 - 8 also show that in many of the tests calcium, sodium, potassium, and magnesium concentrations generally increased as pH increased. The rise in concentration of alkali and alkali-earth cations accompanied by the loss in hydrogen ion concentration suggests that ion exchange reactions could be an important method of acid attenuation at the Santa Cruz site. Sulfate concentration decreased as pH increased indicating that the precipitation of sulfate minerals is an important method of solute attenuation. Overall, the results suggest that both neutralization and attenuation reactions were controlled and balanced by competition between acid consuming and acid producing reactions.

Aging was found to account for some of the changes observed in fluid chemistry with time. In the ferrous iron stock solution (Table 5), iron

slowly decreased with time and the solution became more acidic. This was caused by the slow oxidation of ferrous iron to ferric iron in the stock solution container and the subsequent precipitation of ferric iron minerals which releases acid (equation 2) due to hydrolysis.

$$Fe^{2+} + .25O_2 + 2.5H_2O = Fe(OH)_3 + 2H^+ \quad (2)$$

When iron was initially present as ferric iron no significant changes in major element concentration were observed with time.

TRACE METAL BEHAVIOR

Testing showed that trace metals were attenuated as the result of fluid/rock interactions. As pH increased trace metals were sequentially removed from solution to the solid phase. Figure 5 is a plot of the average percentage of cadmium, mercury, and chromium remaining in solution as a function of pH or increasing reaction progress for the sequential batch tests. Figure 5 shows that more than 90 percent of the chromium was attenuated after a pH of 3.8 was reached, more than 90 percent of the mercury was attenuated after a pH of 4.4 was reached, and more than 90 percent of the cadmium was attenuated after the pH exceeded 5.0.

The attenuation behavior of cobalt, nickel, and zinc was very similar to cadmium (Figure 5) in terms of the percentage lost from solution as a function of pH. Lithium like mercury (figure 5) was attenuated at higher pH values with about 80 percent of its starting concentration being partitioned to the solid phase. Manganese concentration increased in some of the tests, probably from the

dissolution of manganese oxide gangue minerals. Test results show that arsenic, selenium, lead, and molybdenum were all attenuated by more than 90 percent after one cycle. Arsenic and selenium concentrations decreased below 1 ppm after contact with the rock material even at the lowest pH levels. These elements could be controlled by removal onto hydrous oxide adsorption sites on the solid material (*8*). Lead and molybdenum concentrations were affected by aging in the stock solution. For example, lead and molybdenum were not stable in the stock solutions over long periods of time as indicated in Table 3. Lead concentrations changed from 14.00 to .01 ppm in 180 days while molybdenum concentrations decreased by more than 90 percent.

INNER TRANSITION METAL BEHAVIOR

Because neither uranium or thorium were added to the starting fluids, measurable concentrations of these elements in solution were derived from the solid material. Uranium is mobilized upon acid reaction with minerals in granite. In the tests where granite was the starting material, the concentration of uranium and thorium increased from 0 to about 6 ppm. In tests where the pH increased to values of greater than 4.5, the uranium that was initially mobilized was attenuated to concentrations less than .01 ppm.

***RESULTS - COLUMN TESTS

Three column experiments were conducted on drill cuttings from boreholes at the Santa Cruz test site. Samples from the upper copper oxide unit, the lower copper oxide unit, and the leached capping of bedrock complex were used in the tests.

The composition of the starting fluid was based on the average fluid composition in the sequential batch tests after the pH had reached 3.4. Because many of the metals including iron, arsenic, lead, selenium, and molybdenum, had been attenuated to low concentrations at this pH in the sequential batch tests, these elements were added only in trace amounts to the starting fluid.

One thousand grams of rock were mixed with the starting leach fluid to agglomerate the solids, which were then loosely packed in a plexiglass column (12" long, 1.5" inner diameter). Fluid was dripped from the top of the column at a rate of .18 mL/min, allowed to percolate through the unsaturated rock sample, and collected at the base. Samples of effluent were taken for chemical analysis and measured for pH. The effluent was then recirculated through the column until the pH stabilized. At this time 1000 grams of fresh rock was agglomerated, packed in the column, and the experiment was restarted. Each addition of 1,000 grams of fresh rock to the column constitutes a "pass" in Table 9. The recycling continued until the amount of effluent that reported to the collection tank was too small to continue. Each test consisted of 4 passes. Each test started with 600 grams of fluid and used 4000 grams of rock. Fluid:rock ratios for the final pass in each of the tests were about 0.05. Results of the column tests are shown in Table 9.

ACID ATTENUATION

Results show that during the column tests an increase in pH values occurs in all rock types tested and that the extent of neutralization reactions is dependent on rock type. The rock reactivity sequence indicated by the column tests in order of neutralization capacity is

upper copper oxide unit > lower copper oxide unit > leached capping of bedrock complex. Both copper oxide units contain copper mineralization which can rapidly dissolve to release copper and consume acid. In addition to dissolution of acid soluble minerals, the low overall fluid:rock ratios achieved in the column tests allowed for significant increases in the overall impact of ion-exchange reactions which consume hydrogen ions in exchange for alkali and alkali-earth cations.

MAJOR ELEMENT BEHAVIOR

At the pH values reached in the column experiments on samples from the upper and lower copper oxide units, aluminum concentration was significantly attenuated from 2400 ppm to about 5 ppm by a pH of about 4.6. Ninety percent of the starting copper concentration was attenuated by a pH of 4.6 and a copper concentration of only 4 ppm remained in solution at a pH of 7.8. Sulfate concentrations decreased by nearly 30 percent when the pH increased to > 4.5, indicating that the precipitation of sulfate minerals was an important method of solute attenuation.

Results, given in Table 9, of column tests using samples from all three rock units show that sodium and calcium concentrations generally increased as pH increased. The increase in concentration of these cations accompanied by the decrease in hydrogen ion concentration suggests that ion exchange reactions were significant within each of these rock zones. In the absence of any readily acid soluble minerals in the leached capping of bedrock unit, ion exchange may be the only mechanism available for rapid acid consumption and consequently metal attenuation. Overall, the results suggest that the major metal

components of in situ leachate namely iron, aluminum, and copper will be attenuated by natural fluid:rock interactions occurring within the rock zones surrounding the Santa Cruz test site.

TRACE METAL BEHAVIOR

Results from the column tests indicate that trace metal concentration in the fluid phase is strongly dependent on pH. All of the trace metals in the starting solution were significantly attenuated by the time the pH reached 7.8. Zinc and manganese were initially leached from each of the rock types tested, but 95 percent of the starting concentration as well as the added value of both elements was partitioned to the solid by the time the pH reached 7.8. Cobalt, nickel, chromium, cadmium, selenium, and mercury were attenuated to <0.6 ppm by a pH of 7.8. Lead and molybdenum were attenuated to less than detectable values after the second pass in all tests. Arsenic which was not added to the starting solution because it was strongly attenuated in the batch tests, increased slightly in some of the passes but never exceeded .09 ppm in solution. Lithium was moderately attenuated and showed similar decreases in concentration with every pass regardless of pH or rock type.

INNER TRANSITION METALS BEHAVIOR

Uranium was mobilized upon acid reaction with minerals in each of the rock types tested. In the upper copper oxide unit, the concentration of uranium increased from background to about 9 ppm after pass 2 (Table 9). As the pH increased to > 4.7 in pass 3 and 4 the uranium that was initially mobilized, was attenuated to less than .2ppm by a pH of 7.8. Uranium was also significantly attenuated in the pH

range from 3.89 to 4.57 during the lower copper oxide unit column test (Table 9).

Thorium was detected in the first pass fluids collected from each of the three column tests. However, thorium was attenuated to less than detectable concentrations in all of the subsequent passes through the rock material.

ATTENUATION CAPACITY OF THE SANTA CRUZ AREA

Quantitative descriptions of the effects of natural attenuation on contaminant migration can be made by calculation of attenuation coefficients (Kd). Attenuation coefficients as used in this report (*9*) are defined here as:

$$Kd = \frac{\text{mass of solute partitioned to the solid per unit mass of solid}}{\text{concentration of solute in solution}} \quad (3)$$

A positive attenuation coefficient value indicates that the solute component is removed from the fluid phase. The magnitude of the attenuation coefficient value is indicative of the mobility of the solute during fluid flow through the solid. An attenuation coefficient of zero indicates that the solute is not affected by fluid/rock interaction. A negative attenuation coefficient value indicates that the component is mobilized from the solid phase into solution.

Attenuation coefficients were calculated from the experimental data presented in Tables 3-7 and 9 by using the following equation:

$$Kd = (Cf - Ce)/Ce * V/M \quad (4)$$

where for each individual element:

Cf - concentration in the starting "STOCK" solution (ppm)

Ce - concentration in solution at the end of a cycle or pass (ppm)

V - volume of the starting solution in the first cycle of the sequential batch tests (mL), or
- volume of solution at the start of the column tests (mLs)

M - total mass of rock contacted during the batch or column tests (grams).

For concentrations reported as less than i.e. "<" values in Tables 3-9 the detection limit was used for the concentration value in the calculation. This method of calculation results in a minimum attenuation coefficient for those constituents attenuated to below detection limit during the tests. Calculated attenuation coefficients are tabulated for the sequential batch tests in Table 10 and for the column tests in Table 11. Table 10 shows the maximum and minimum attenuation coefficient value (Kd) for each batch test that fit the rock type and pH range criteria indicated in the table. The number of tests that fit each criteria are shown in the first row of the table. Table 11 shows the calculated elemental attenuation coefficients for all of the column test "passes" ranked according to the final pH value for each pass.

Calculated attenuation coefficient (Kd) values, given in Table 10, from the sequential batch tests are positive for all solutes except magnesium, sodium, calcium, chloride, uranium, and thorium. Calculated attenuation coefficient (Kd) values, given in Table 11, from the column tests are positive for all solutes except sodium, calcium, arsenic,

chloride, molybdenum, uranium, and thorium. Negative values for magnesium, sodium, and calcium are expected because these elements generally increase in solution as a result of ion exchange and/or dissolution reactions.

Attenuation coefficient (Kd) values for arsenic were very high in the sequential batch tests, indicating complete or nearly complete partitioning to the solid phase for the conditions of these tests. Attenuation coefficient values for arsenic in the column tests were negative or near zero because the starting fluid was prepared to simulate a leachate at a pH of about 3.4 and did not contain any arsenic. In addition, contact between the fluid and the rock mobilized low concentrations in some of the column test passes.

Attenuation coefficient (Kd) values for molybdenum were very high in the sequential batch tests, indicating complete or nearly complete partitioning to the solid phase for the conditions of these tests. Attenuation coefficient values for molybdenum for the column tests are reported as zero for passes 2 - 4 in all of the rock types tested. This is because the starting solution was prepared to simulate a leachate at a pH of about 3.4 and contained 0.01 ppm molybdenum and the concentration in passes 2 through 4 was less than the detection limit. Therefore, the Kd could not be accurately determined but would be very close to zero.

Chloride values are reported as zero because all changes in concentration for chloride were within the limits of error for analytical determination of chloride. Chloride is typically a

nonreactive constituent in fluid/rock systems and therefore the assignment of a Kd of zero is reasonable.

The calculated attenuation coefficients for both uranium and thorium are negative for both the sequential batch tests and the column tests. This is in part because neither element was added to the starting fluids and at low pH both were mobilized from the rock material into the fluid. Although uranium showed an increase in solution at low pH values, this increase was followed by a decrease as the pH increased above 4.5. An attenuation coefficient can be calculated based on a solution with uranium at its peak concentration value of 8.80 ppm at a pH of about 3.8 to a solution with a concentration of pH 4.5. If this calculation is made using data given in Table 9 for the upper copper oxide unit column test, the attenuation coefficient is 1.29. Runnels et al. (*10*) report a similar uranium concentration reductions at pH values in this range. Runnels' report indicates that uranium solubility in liquid wastes from uranium mining can be controlled by precipitation of uranium minerals such as carnotite ($K(UO_2)_2(VO_4)_2 \cdot H_2O$) and by adsorption onto ferric oxyhydroxides in the pH region from about 5 to 7.5.

In both the sequential batch tests and the column tests, thorium concentration in solution increased during low pH conditions, and after additional cycles or passes, thorium concentrations decreased at higher pH values. For example, after the first pass of the column tests for both the upper and lower copper oxide units, thorium concentration had increased from <0.004 ppm to 0.06 ppm (Table 9). In both test the thorium concentration was reduced to below the detection limit of 0.029

ppm in the second pass. A minimum attenuation coefficient calculated from this data is 0.52.

During initial preparation of simulated mature leach solution to be used as starting solution for the single step batch tests, barium and silver precipitated as sulfates immediately upon addition of these constituents to the solution. Because these constituents were not stable in the solution, they were not included in starting solution for the sequential batch tests and the column tests. Exclusion of silver and barium from the tests has precluded calculating an attenuation coefficient for these constituents, but their behavior in the mature leach solution indicates that they would be immobile in situ, during the planned copper mining test.

***CONCLUSIONS

The results of the experiments demonstrate that in situ natural attenuation could be used as a reliable and feasible strategy in a post-mining closure plan and as a safeguard against the migration of leach fluids from the mining zone. The capacity of rocks within the Santa Cruz area to behave as chemically-active barriers capable of modifying in situ leachate has been measured. Some of the stratigraphic horizons that act as physical barriers to acid migration away from the Santa Cruz mine site also behave as geochemical barriers. The conglomerate layer, the upper copper oxide unit, the lower copper oxide unit, and the deep basin fill layers were shown to be the most reactive rock types in the area. All of these rock formations lie between the active in situ leaching zone and the near-surface aquifer. Tests showed that in situ leachate was neutralized to a pH near 7 during reaction with these rock

types. The results of these tests suggest that fluids containing acidic leachate would be neutralized well before entering the alluvial aquifer.

Acid attenuation capacity necessary to account for neutralization may be closely linked to H^+ exchange. The importance of this reaction depends on the capability of H^+ to compete with other cations for occupancy on the exchange sites. The "relative replacing power" of cations, including H^+, is determined by the mineralogy of the material, the exchange capacity, and the nature of the ions. Hydrogen has been shown to compete favorably with Na^+, and in some cases, with the other major cations. Results of the geochemical tests show that increasing pH is directly related to the attenuation of many metal components in the fluid. Studies report that regardless of the methods by which solutions are neutralized, concentrations of most elements are virtually identical at a specific pH value. Field and laboratory observations support the conclusion that pH is the dominant factor controlling the chemical quality of water in solution. It is expected that dilution of leachate with native groundwater at a near neutral pH would initiate pH dependent precipitation reactions that would bring about the same kinds of pH dependent attenuation results observed in the laboratory tests.

Uranium mobilized by acid leaching from granite, was shown to decrease in concentration as pH increased. These experiments showed that uranium concentration is sensitive to changes in the pH of the fluid phase. Previous experimental work supports these observations. Much technical work has been completed on the migration behavior of uranium by researchers working on developing procedures to restore mine sites involved in the production of uranium (*11,12*). Runnels et. al. (*10*)

experimentally determined the partition coefficients of major and trace metals in uranium tailings fluids at Canon City, Colorado. Runnels et al. also found that uranium migration was highly sensitive to changes in the pH of the migrating fluid, with higher mobility in acidic fluids. They found evidence that precipitation of carnotite exerted a control on the solubility of uranium, and presented an Eh-pH diagram, which shows the conditions under which uranium is most mobile. Other researchers have also investigated the uptake of radiotracers by natural sediments (*4,13,14,15*). Although system conditions investigated by these reports differs from those expected at the Santa Cruz site these studies confirm earlier observations that uranium that might be mobilized will attenuate when the pH rises to a sufficient level.

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TABLE 1 - Santa Cruz Area rock types used in the attenuation experiments

LABEL	Rock Type	Hole #	Footage	Mineralogy
BASIN FILL	Deep Basin Fill	HC1	560-600	quartz, albite, K-feldspar, mica
CONGLOMERATE	Conglomerate	SC22	605-625	quartz, albite, calcite, muscovite K-feldspar
FAULT GOUGE	Fault Gouge	C1	931-933	quartz, albite, K-feldspar, clay, goethite
CLAY-RICH GRANITE	Clay-rich Granite	SC19	1361-1370	quartz, K-feldspar, clay-altered plagioclase, sericite
GRANITE	Unmineralized Granite	SC19	1257-1361	quartz, K-feldspar, muscovite, kaolinite
PORPHYRY	Porphyry	SC46	1510-1545	quartz, K-feldspar, clay-altered plagioclase, kaolinite, biotite
DIABASE	Diabase	SC19 A	1449-1450	biotite, chrysocolla, plagioclase
LEACHED BEDROCK	Leached Bedrock	C1	1048-1053	quartz, K-feldspar, sericite, clay, goethite
UPPER COPPER	Upper Copper Oxide Unit	T2	1250-1330	quartz, K-feldspar, sericite, goethite, chrysocolla
LOWER COPPER	Lower Copper Oxide Unit	T2	1670-1750	quartz, K-feldspar, sericite, atacamite, goethite

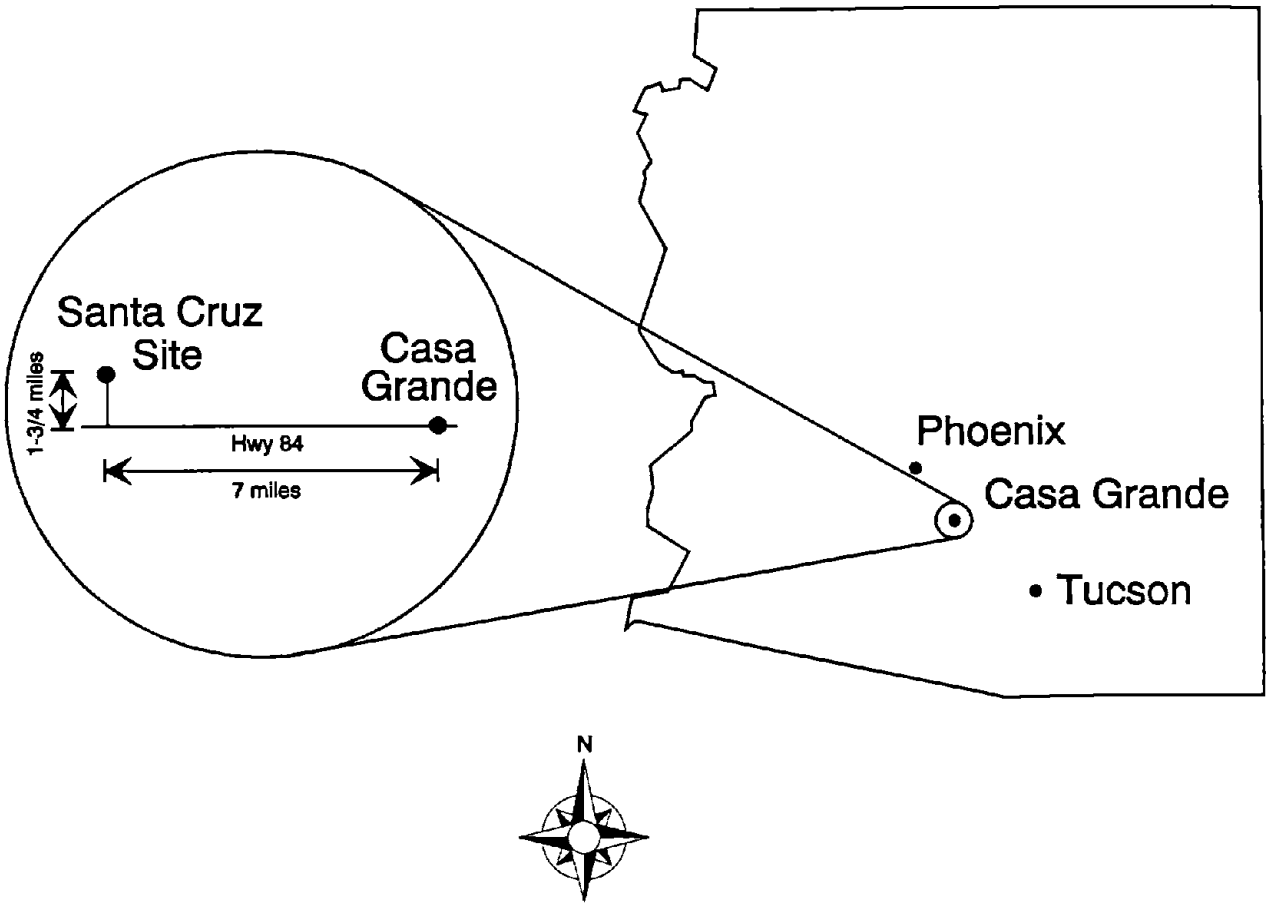
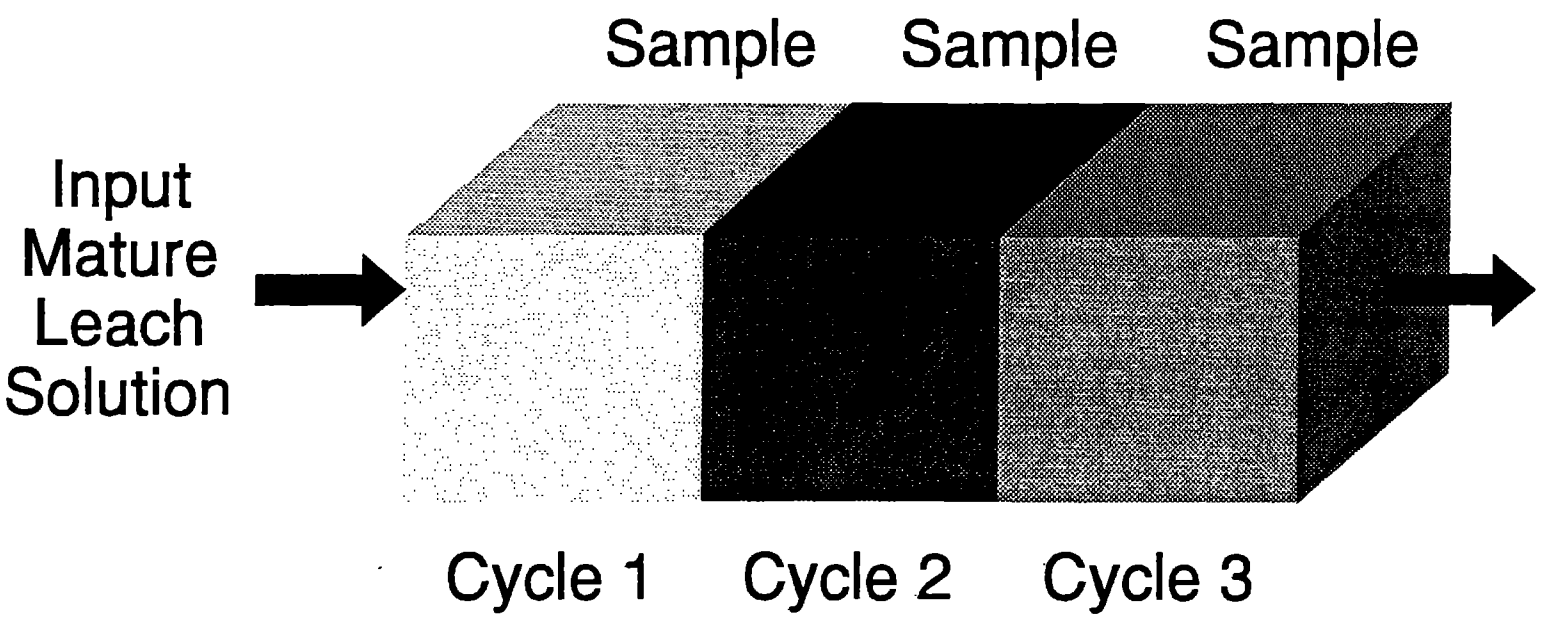


FIGURE 1. - Location map of the Santa Cruz in situ copper mining research project test site.

SCHEMATIC DIAGRAM OF CYCLIC BATCH TESTS



Analysis of Chemical Evolution During Flow

Figure 2 - Schematic diagram of sequential batch testing.

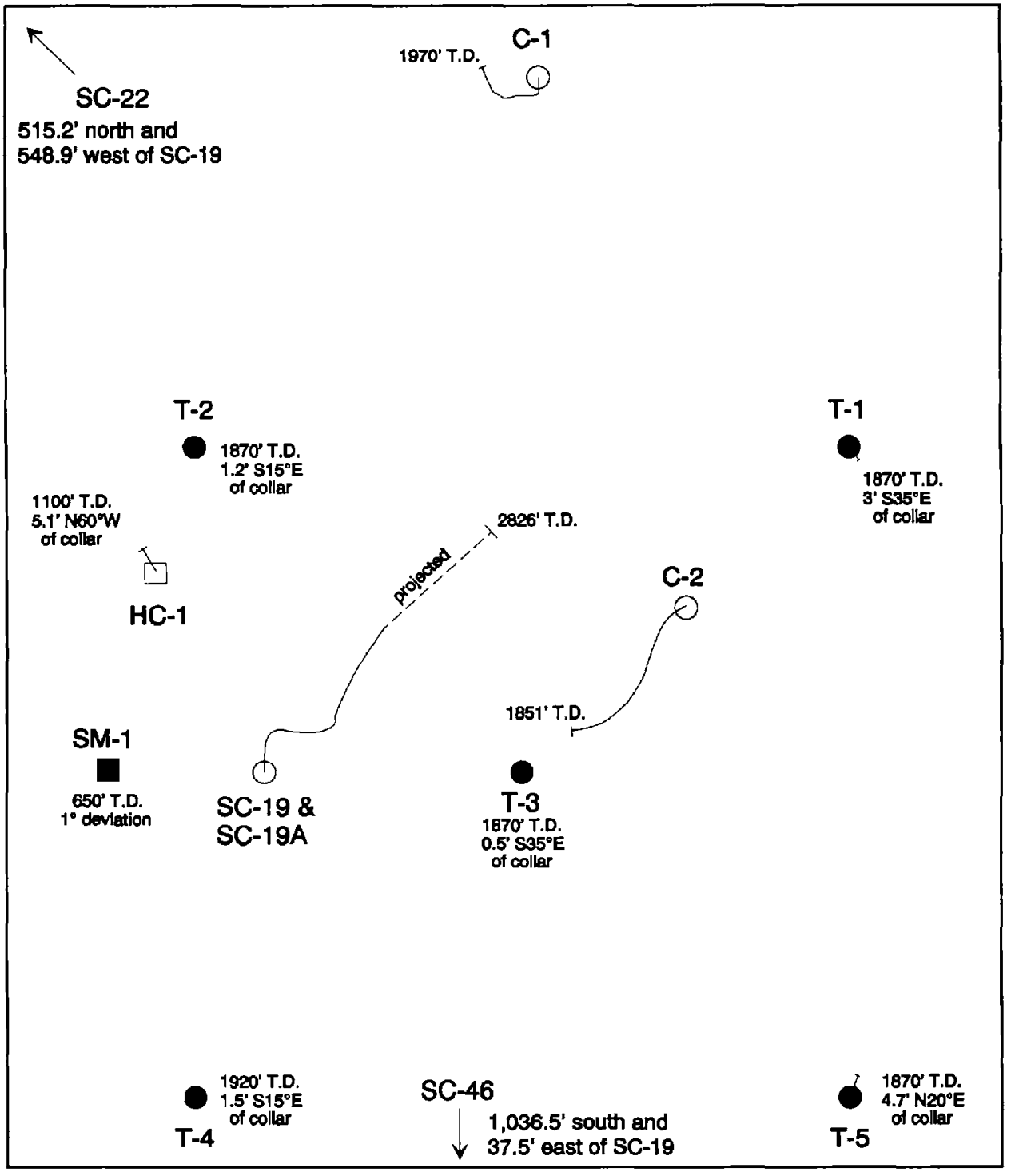


Figure 3 - Location map of drill holes and deviations around the Santa Cruz Test Site (Holes T1, T2, T3, T4, and T5)

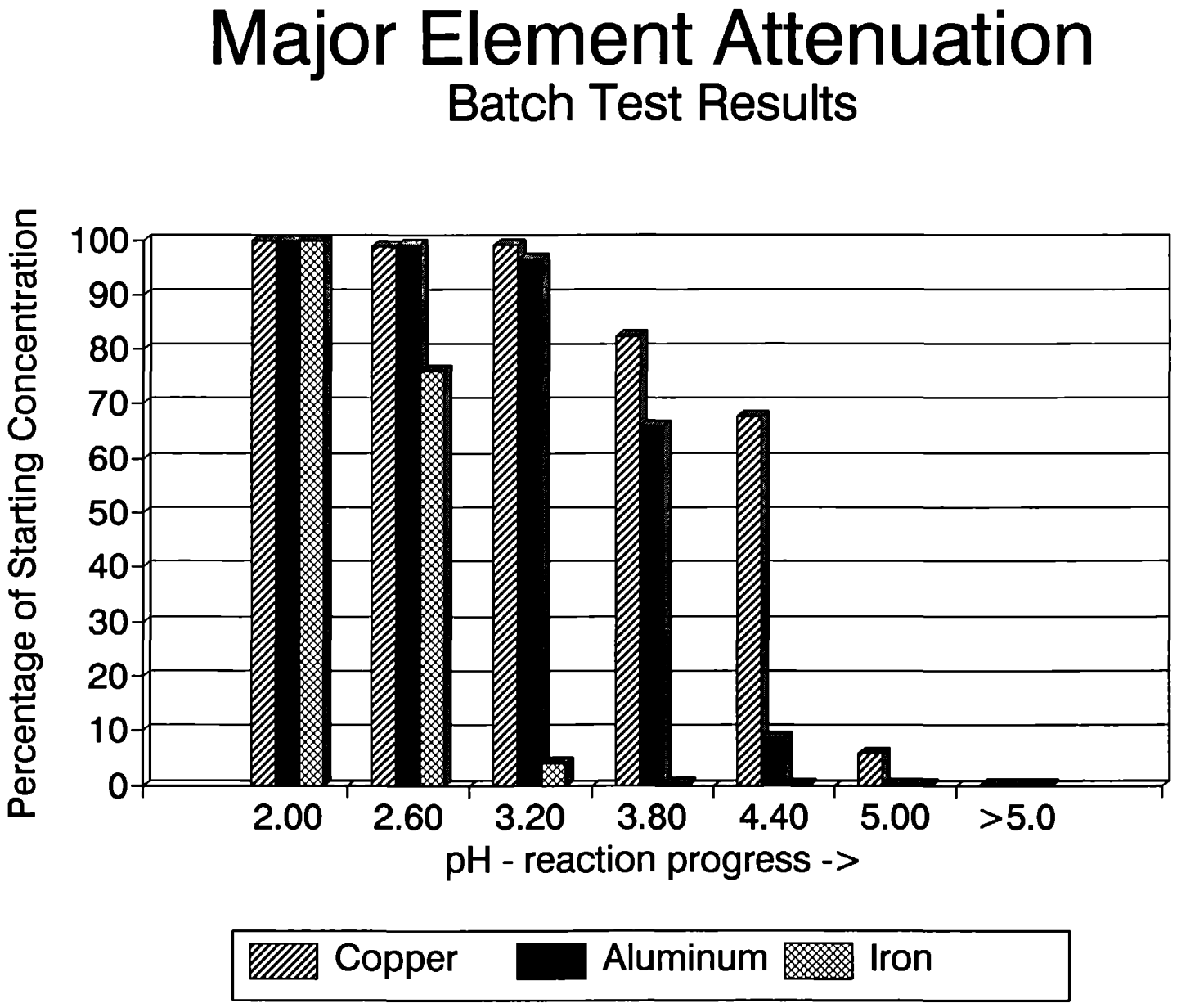


Figure 4 - Depiction of the average attenuation of Major elements (in percent of starting composition) in the sequential batch tests. pH and reaction progress increase from left to right on the x-axis. The starting fluid (100 percent) represents concentrations at pH = 2.

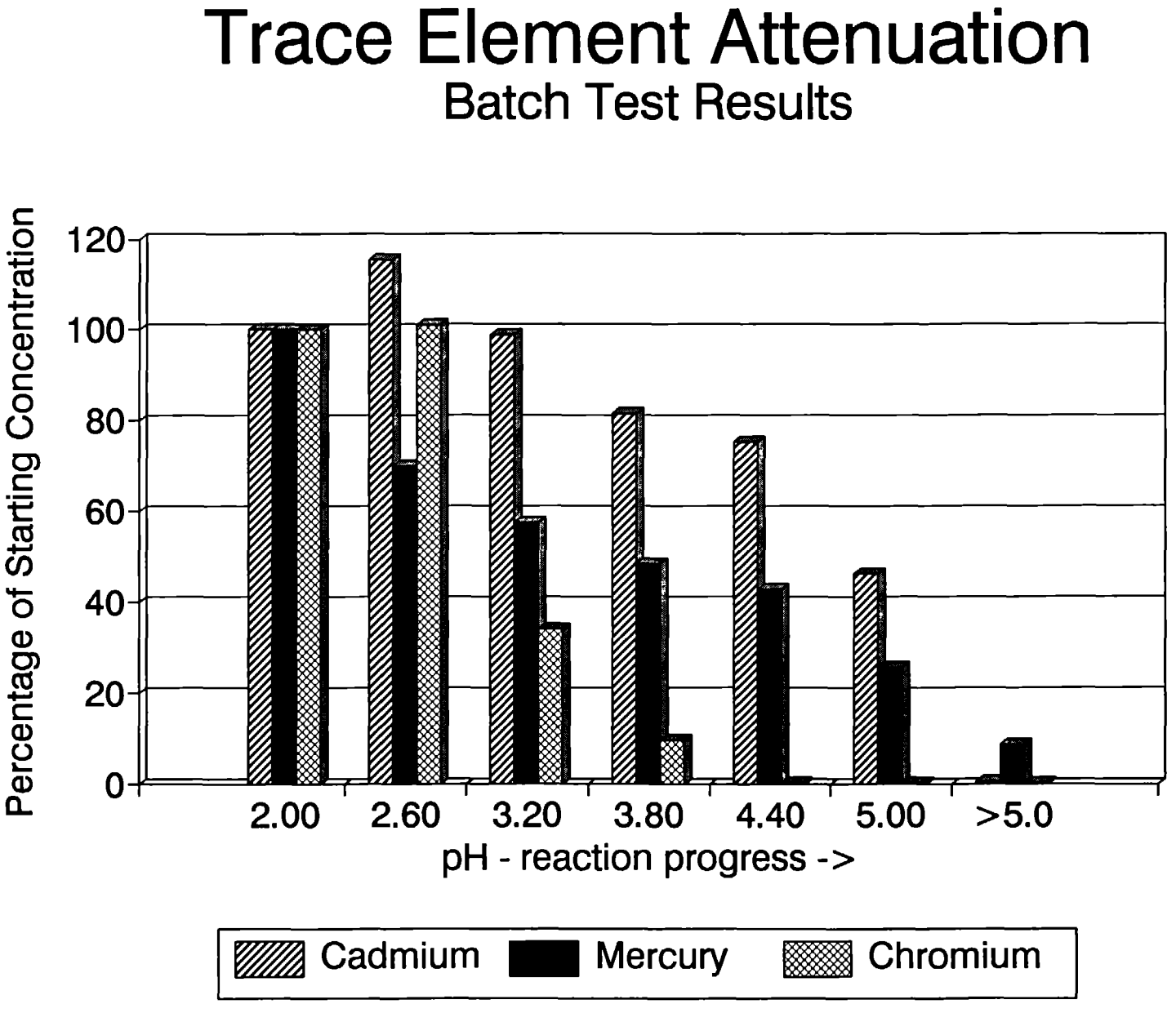


Figure 5 - Depiction of the average attenuation of select trace elements (in percent of starting composition) in the sequential batch tests. pH and reaction progress increase from left to right on the x-axis. The starting fluid (100 percent) represents concentrations at pH = 2.

TABLE 1 - Santa Cruz Area rock types used in the attenuation experiments

LABEL	Rock Type	Hole #	Footage	Mineralogy
BASIN FILL	Deep Basin Fill	HC1	560-600	quartz, albite, K-feldspar, mica
CONGLOMERATE	Conglomerate	SC22	605-625	quartz, albite, calcite, muscovite K-feldspar
FAULT GOUGE	Fault Gouge	C1	931-933	quartz, albite, K-feldspar, clay, goethite
CLAY-RICH GRANITE	Clay-rich Granite	SC19	1361-1370	quartz, K-feldspar, clay-altered plagioclase, sericite
GRANITE	Unmineralized Granite	SC19	1257-1361	quartz, K-feldspar, muscovite, kaolinite
PORPHYRY	Porphyry	SC46	1510-1545	quartz, K-feldspar, clay-altered plagioclase, kaolinite, biotite
DIABASE	Diabase	SC19A	1449-1450	biotite, chrysocolla, plagioclase
LEACHED BEDROCK	Leached Bedrock	C1	1048-1053	quartz, K-feldspar, sericite, clay, goethite
UPPER COPPER	Upper Copper Oxide Unit	T2	1250-1330	quartz, K-feldspar, sericite, goethite, chrysocolla
LOWER COPPER	Lower Copper Oxide Unit	T2	1670-1750	quartz, K-feldspar, sericite, atacamite, goethite

TABLE 2 Single Step Batch Attenuation Test Results - (concentrations are in ppm)

	pH	Fluid:Rock	Si	Al	Fe	Cu	Mg	Ca	Na	K	Cl	SO4
STARTING FLUID	1.03		5.4	275.9	148.5	2249.3	169.8	84.9	40.3	159.2	332.8	14030.9
GRANITE	1.14	10	135.5	345.7	98.1	1961.0	135.5	93.4	60.7	191.6	308.2	13447.2
	1.24	5	107.5	471.9	227.0	2085.0	143.4	113.5	59.7	250.9	277.7	12150.6
CLAY-RICH	1.16	10	92.9	320.9	92.9	1841.0	126.7	80.2	30.0	177.3	271.3	12409.8
GRANITE	1.24	5	124.1	410.5	424.8	2038.0	133.6	100.2	47.7	238.7	245.2	10963.0
PORPHYRY	1.43	10	261.7	842.7	532.2	2661.0	354.8	266.1	97.6	403.6	285.0	11970.0
	1.64	5	236.8	819.5	455.3	2049.0	364.2	364.2	100.2	318.7	261.9	11799.8
	1.95	3	209.3	872.1	348.8	1919.0	308.1	523.3	157.0	261.6	280.8	11795.3
DIABASE	1.89	10	228.1	777.6	466.6	5288.0	414.7	725.8	150.3	362.9	282.4	12143.6
	3.07	3	104.3	321.2	36.3	3670.0	241.9	458.8	262.8	221.1	266.7	8786.1
	3.54	1	78.2	93.8	9.8	2267.0	179.8	430.0	387.0	191.5	254.8	5096.6

TABLE 3 SEQUENTIAL BATCH TEST RESULTS - FLUID ROCK = 3, FERROUS IRON, (concentrations are in ppm)

I. MAJOR ELEMENT CHEMISTRY

	DESCRIPTION		REACTION TIME (days)	FINAL pH	Si	Mg	Ca	Al	Fe	K	Na	Ca	Cl	SO4
A.	STARTING	STOCK	0	2.00	25	1900	4800	2800	6400	1900		740		
	FLUID	STOCK	180	2.10	25	1211	4340	2927	3531	2120	544	717	7232	28930
B.	CONGLOMERATE	CYCLE 1	7	2.72	79	1015	3552	2283	715	1116		766		
		CYCLE 2	22	3.20	56	1320	4800	2360	36	1080		960		
		CYCLE 3	10	3.73	35	1252	3942	1229	6	1554		835		
		CYCLE 4	10	3.80	16	1117	2915	274	0	1625		670		
		CYCLE 5	17	4.64	28	1510	256	4	0	1209	1043	829	4511	3917
	PORPHYRY	CYCLE 1	7	2.17	65	1463	5593	3786	3227	2452		860		
		CYCLE 2	22	2.20	46	1113	3846	2632	860	1316		779		
		CYCLE 3	10	3.09	48	1453	4539	3329	91	1059		878		
		CYCLE 4	10	3.30	47	1313	4690	3283	49	1595		915		
		CYCLE 5	17	3.29	26	1660	4144	2271	15	998	945	615	6344	17043
	GRANITE	CYCLE 1	7	2.14	40	1124	3780	2758	2656	1941		828		
		CYCLE 2	22	2.16	50	1530	5176	3825	1305	2138		1103		
		CYCLE 3	10	2.96	50	1133	4427	2986	75	1544		731		
		CYCLE 4	10	3.22	49	1237	4124	3299	24	1705		907		
		CYCLE 5	17	3.20	31	1834	4778	3077	13	1293	645	633	7046	22017
	BASIN	CYCLE 1	7	2.37	34	1131	3392	2570	1645	1439		771		
	FILL	CYCLE 2	22	2.93	50	1416	4081	3121	60	1700		1152		
		CYCLE 3	10	3.40	32	1231	3385	2051	6	954		821		
		CYCLE 4	10	3.49	45	1856	4780	2699	4	1659		928		
		CYCLE 5	17	3.52	23	2056	1449	1449	3	1047	1079	667	6692	14195
	FAULT	CYCLE 1	7	2.14	40	1131	3803	2570	3084	1850		843		
	GOUGE	CYCLE 2	22	2.34	75	1358	4527	3773	1019	2264		793		
		CYCLE 3	10	3.01	34	1118	3862	2846	36	1931		691		
		CYCLE 4	10	3.33	54	1179	3684	3193	12	2407		884		
		CYCLE 5	17	3.27	32	1825	3079	3101	6	1914	687	623	6868	22103

II. TRACE ELEMENT CHEMISTRY

	DESCRIPTION		REACTION TIME (days)	FINAL pH	Zn	Co	Ni	Se	Cr	As	Cd	Hg	Li	Mn	Pb	Mo	U	Th
A.	STARTING	STOCK	0	2.00	19.00	23.00	33.00	20.00	17.00	18	23.00	13.00	17.00	20.00	14.00	22.00	0.01	0.00
	FLUID	STOCK	180	2.00	28.26	30.28	30.28	5.35	29.27	15.14	28.26	7.27	35.33	30.28	0.01	1.51	0.01	0.03
B.	CONGLOMERATE	CYCLE 1	7	2.72	26.89	29.43	28.41	0.53	13.21	0.38	28.41	8.93	29.94	70.02	0.01	0.11	0.11	0.16
		CYCLE 2	22	3.20	30.00	32.80	32.40	0.40	3.40	0.00	30.00	10.00	32.40	148.00	0.02	0.01	0.24	0.14
		CYCLE 3	10	3.73	27.83	30.15	30.15	0.49	0.72	0.04	27.83	8.58	21.10	173.93	0.02	0.01	0.35	0.14
		CYCLE 4	10	3.80	21.32	22.34	20.31	0.25	0.06	0.00	21.32	6.40	10.15	142.16	0.05	0.00	0.30	0.03
		CYCLE 5	17	4.64	13.10	14.11	13.10	0.14	0.01	0.02	13.10	3.83	4.94	131.00	0.01	0.00	0.01	0.00
	PORPHYRY	CYCLE 1	7	2.17	30.12	33.99	32.27	0.42	30.55	0.43	30.12	9.90	33.13	47.33	0.02	0.29	0.39	0.07
		CYCLE 2	22	2.20	41.50	30.37	28.34	0.37	24.29	0.01	29.35	8.40	30.37	53.65	0.01	0.01	1.42	0.11
		CYCLE 3	10	3.09	45.39	33.29	33.29	0.39	17.85	0.00	30.26	8.78	36.31	72.63	0.02	0.06	2.27	0.07
		CYCLE 4	10	3.30	46.90	32.83	30.49	0.28	12.90	0.00	30.49	7.97	35.18	82.08	0.02	0.03	2.81	0.04
		CYCLE 5	17	3.29	34.30	23.20	20.17	0.36	4.44	0.01	21.18	5.14	20.17	60.52	0.02	0.02	2.52	0.02
	GRANITE	CYCLE 1	7	2.14	30.65	32.69	32.69	0.40	30.14	0.30	31.16	9.76	34.74	37.29	0.02	0.08	1.48	0.93
		CYCLE 2	22	2.16	38.25	42.76	42.76	0.38	33.75	0.01	38.25	11.48	47.26	49.51	0.02	0.02	3.38	2.16
		CYCLE 3	10	2.96	28.83	29.86	28.83	0.32	15.44	0.00	26.77	7.41	30.89	38.10	0.01	0.02	3.81	1.24
		CYCLE 4	10	3.22	32.99	32.99	32.99	0.30	12.65	0.00	30.24	8.25	35.74	43.99	0.01	0.00	5.22	0.58
		CYCLE 5	17	3.20	32.35	30.33	30.33	0.26	5.26	0.02	29.32	7.08	30.33	43.47	0.05	0.00	6.47	0.34
	BASIN	CYCLE 1	7	2.37	28.78	30.84	29.81	0.25	23.64	0.08	27.75	8.94	31.87	88.40	0.00	0.01	0.12	0.28
	FILL	CYCLE 2	22	2.93	40.81	43.21	43.21	0.50	12.00	0.00	36.01	12.00	50.41	196.84	0.01	0.00	0.34	0.21
		CYCLE 3	10	3.40	34.88	32.82	31.80	0.21	4.10	0.00	29.75	9.54	31.80	184.63	0.00	0.00	0.40	0.13
		CYCLE 4	10	3.49	33.74	33.74	33.74	0.31	2.78	0.00	28.11	9.56	30.93	269.90	0.12	0.01	0.48	0.21
		CYCLE 5	17	3.52	30.29	27.26	26.25	0.35	0.86	0.03	24.23	7.47	19.19	232.25	0.01	0.00	0.54	0.14
	FAULT	CYCLE 1	7	2.14	32.89	33.92	32.89	0.71	31.87	0.84	33.92	11.31	38.03	37.01	0.04	0.20	0.25	0.30
	GOUGE	CYCLE 2	22	2.34	37.73	41.50	41.50	0.18	32.82	0.00	37.73	13.58	49.04	45.27	0.03	1.62	0.60	0.38
		CYCLE 3	10	3.01	26.43	27.44	26.43	0.35	14.23	0.01	26.43	7.32	31.51	33.54	0.00	0.01	0.68	0.16
		CYCLE 4	10	3.33	31.93	34.39	34.39	0.66	14.06	0.07	31.93	8.60	31.93	41.76	0.01	0.01	0.93	0.12
		CYCLE 5	17	3.27	29.23	28.22	28.22	0.44	7.76	0.00	27.22	7.16	21.17	38.30	0.01	0.00	1.01	0.11

TABLE 4 - SEQUENTIAL BATCH TEST RESULTS - FLUID:ROCK = 1, FERROUS IRON, (concentrations are in ppm)

I. MAJOR ELEMENT CHEMISTRY

	DESCRIPTION		REACTION TIME (days)	FINAL pH	Si	Mg	Cu	Al	Fe	K	Na	Ca	Cl	SO4
A.	STARTING FLUID	STOCK	0	2.10	25	1211	4340	2927	3331	2120	544	717	7232	28930
B.	CONGLOMERATE	CYCLE	21	3.40	55	1624	4455	1682	96	1595		1078		
		CYCLE	16	4.73	19	1972	415	4	5	2075		1141		
		CYCLE	27	7.30	9	1213	2	0	4	1314	1278	1112	6409	3204
	FAULT	CYCLE	21	2.94	161	1405	4546	3719	248	2273		992		
	GOUGE	CYCLE	16	3.17	53	1379	4113	3339	17	2661		895		
		CYCLE	27	3.36	76	1619	3322	2001	22	2124	696	544	4834	12889

II. TRACE ELEMENT CHEMISTRY

	DESCRIPTION		REACTION TIME (days)	FINAL pH	Zn	Co	Ni	Se	Cr	As	Cd	Hg	Li	Mn	Pb	Mo	U	Th
A.	STARTING FLUID	STOCK	0	2.10	28.26	30.28	30.28	5.35	29.27	15.14	28.26	7.27	35.33	30.28	0.01	1.51	0.01	0.03
B.	CONGLOMERATE	CYCLE	21	3.40	34.49	35.93	40.24	0.97	4.89	0.22	31.62	10.35	38.81	202.65	0.02	0.49	0.34	0.07
		CYCLE	16	4.73	19.72	22.83	20.75	0.29	0.01	0.00	20.75	6.12	11.41	20.75	0.01	0.01	0.01	0.08
		CYCLE	27	7.30	0.08	0.07	0.11	0.39	0.02	0.00	0.14	1.31	7.08	0.11	0.00	0.01	0.02	0.00
	FAULT	CYCLE	21	2.94	37.19	39.26	37.19	1.20	16.74	0.00	35.13	11.16	43.39	43.39	0.01	0.20	0.74	0.27
	GOUGE	CYCLE	16	3.17	33.87	33.87	33.87	0.97	6.77	0.07	29.03	9.92	31.45	43.55	0.01	1.62	1.28	0.16
		CYCLE	27	3.36	23.36	21.33	20.32	0.56	0.89	0.07	20.32	5.59	7.62	32.50	0.01	0.01	1.22	0.07

TABLE 5 - SEQUENTIAL BATCH TEST RESULTS - FLUID:ROCK = 1, FERROUS IRON (concentrations are in ppm)

I. MAJOR ELEMENT CHEMISTRY

	DESCRIPTION		REACTION TIME (days)	FINAL pH	Si	Mg	Cu	Al	Fe	K	Na	Ca	Cl	SO4
A.	STARTING	STOCK	0	2.36	27	1868	4621	3103	2694	1388	560	628	7381	28974
	FLUID	STOCK	33	2.26	27	1857	4430	3167	2459	1484	563	600	7049	28530
		STOCK	40	2.21	39	1718	4323	3214	2411	1510	549	582	7049	28195
		STOCK	48	2.17	42	2188	4448	3371	2635	1525	538	636	7292	28758
		STOCK	63	2.10	42	1993	4519	3176	2448	1188	566	648	7074	28297
B.	GRANITE	CYCLE	33	3.11	105	1888	4464	3012	10	1576	616	614	7015	23125
		CYCLE	7	3.40	155	1677	4017	2650	11	1700	685	600	6825	21451
		CYCLE	8	3.37	116	1514	4243	2481	4	2049	722	527	6815	19398
		CYCLE	15	3.32	112	1826	3821	1396	4	2304	848	683	6490	15271
	FAULT	CYCLE	33	3.15	103	1727	3858	2784	1	1765	722	616	7135	23267
	GOUGE	CYCLE	7	3.43	157	1800	3769	2837	2	1884	730	614	6900	21563
		CYCLE	8	3.40	135	1953	3736	2630	0	2172	789	611	6570	19432
		CYCLE	15	3.34	104	1923	3179	1889	4	2402	917	683	6628	17619

II. TRACE ELEMENT CHEMISTRY

	DESCRIPTION		REACTION TIME (days)	FINAL pH	Zn	Co	Ni	Se	Cr	As	Cd	Hg	Li	Mn	Pb	Mo	U	Th
A.	STARTING	STOCK	0	2.36	22.00	21.00	19.00	0.25	24.00	9.50	28.00	12.00	18.00	29.00	0.00	0.00	0.01	0.00
	FLUID	STOCK	33	2.26	19.00	20.00	18.00	0.13	19.00	9.70	20.00	15.00	17.00	21.00	<.010	0.02	<.005	<.029
		STOCK	40	2.21	14.00	16.00	15.00	0.65	14.00	7.90	17.00	10.00	15.00	16.00	<.007	0.06	<.002	0.02
		STOCK	48	2.17	24.00	23.00	22.00	0.54	14.00	11.00	23.00	11.00	25.00	23.00	<.006	0.05	0.00	<.005
		STOCK	63	2.10	20.00	20.00	19.00	0.56	19.00	7.20	21.00	15.00	17.00	22.00	<.010	0.02	<.005	<.029
B	GRANITE	CYCLE	33	3.11	24.00	22.00	22.00	0.60	5.30	<.002	22.00	4.20	25.00	25.00	0.01	<.006	2.20	0.16
		CYCLE	7	3.40	26.00	22.00	22.00	0.49	3.60	<.002	22.00	4.00	20.00	27.00	<.006	<.006	5.50	0.26
		CYCLE	8	3.37	24.00	19.00	19.00	0.47	1.50	<.002	19.00	3.50	12.00	25.00	0.01	<.006	7.40	0.15
		CYCLE	15	3.32	21.00	16.00	15.00	0.07	0.23	<.002	18.00	2.50	5.40	25.00	<.007	0.01	9.00	0.06
	FAULT	CYCLE	33	3.15	23.00	22.00	21.00	0.46	5.60	0.17	21.00	7.10	24.00	27.00	0.01	< 006	0.50	0.09
	GOUGE	CYCLE	7	3.43	25.00	22.00	22.00	0.54	4.10	<.002	22.00	7.20	18.00	30.00	<.006	0.01	0.75	0.13
		CYCLE	8	3.40	24.00	21.00	19.00	0.41	2.40	<.002	20.00	6.40	11.00	30.00	<.006	<.006	0.87	0.09
		CYCLE	15	3.34	18.00	16.00	15.00	0.44	0.54	0.06	17.00	5.90	3.10	28.00	<.007	0.03	1.00	0.07

TABLE 6 - SEQUENTIAL BATCH TEST RESULTS - FLUID:ROCK = 1, FERRIC IRON, (concentrations are in ppm)

I. MAJOR ELEMENT CHEMISTRY

	DESCRIPTION		REACTION TIME (days)	FINAL pH	Si	Mg	Cu	Al	Fe	K	Na	Ca	Cl	SO4
A.	STARTING	STOCK	0	1.57	67	1893	4328	3614	1287.00	1205	573	678	9454	28707
	FLUID	STOCK	24	1.55	67	1673	4636	3522	1261.00	1179	593	690	8190	25101
		STOCK	63	1.52	65	1966	4269	3496	1287.00	1136	564	672	9144	27913
		STOCK	100	1.54	68	1955	4212	3598	1257.00	1127	605	773	9030	27660
B.	GRANITE	CYCLE	24	3.08	116	1681	4738	3197	8.50	2049	706	672	9188	23435
		CYCLE	39	3.22	111	1954	4293	2573	6.30	2105	752	666	8849	18918
		CYCLE	37	3.28	98	1811	3924	1519	<.21	2647	886	776	8307	13985
	FAULT	CYCLE	24	3.06	113	1747	4288	3491	6.60	2094	772	703	9201	23527
	GOUGE	CYCLE	39	3.25	96	2089	3732	2783	6.00	2546	865	643	9011	20157
		CYCLE	37	3.29	97	1976	3121	1906	<.21	3239	993	763	8476	15858

II. TRACE ELEMENT CHEMISTRY

	DESCRIPTION		REACTION TIME (days)	FINAL pH	Zn	Co	Ni	Se	Cr	As	Cd	Hg	Li	Mn	Pb	Mo	U	Th
A.	STARTING	STOCK	0	1.57	22.00	23.00	22.00	20.00	26.00	24.00	26.00	10.00	19.00	39.00	4.70	22.00	0.005	0.023
	FLUID	STOCK	24	1.55	21.00	21.00	20.00	19.00	25.00	23.00	26.00	11.00	18.00	38.00	4.70	22.00	0.004	0.005
		STOCK	63	1.52	18.00	18.00	17.00	16.00	21.00	19.00	23.00	10.00	15.00	33.00	4.50	19.00	0.003	0.001
		STOCK	100	1.54	17.00	18.00	17.00	13.00	18.00	15.00	18.00	15.00	9.40	29.00	3.40	13.00	<.005	<.029
B.	GRANITE	CYCLE	24	3.08	21.00	20.00	18.00	0.14	5.90	0.07	25.00	8.60	15.00	34.00	0.04	0.08	3.200	0.390
		CYCLE	39	3.22	19.00	17.00	15.00	0.21	0.65	<.2	22.00	7.60	11.00	32.00	0.01	0.03	5.600	0.190
		CYCLE	37	3.28	22.00	18.00	18.00	0.48	0.29	0.01	17.00	5.30	10.00	35.00	0.02	0.02	6.500	0.061
	FAULT	CYCLE	24	3.06	21.00	19.00	18.00	0.23	7.70	0.08	24.00	9.70	16.00	36.00	0.01	0.03	0.760	0.200
	GOUGE	CYCLE	39	3.25	19.00	17.00	16.00	0.19	1.20	0.04	22.00	8.80	8.40	36.00	0.01	0.01	1.200	0.100
		CYCLE	37	3.29	20.00	18.00	17.00	0.37	0.36	<.002	17.00	6.60	4.50	40.00	<.006	<.006	0.990	0.055

TABLE 7 - SEQUENTIAL BATCH TEST RESULTS, FLUID:ROCK = 1, (concentrations are in ppm)

I. MAJOR ELEMENT CHEMISTRY

	DESCRIPTION		REACTION TIME (days)	FINAL pH	Si	Mg	Ca	Al	Fe	K	Na	Ca	Cl	SO4
A.	STARTING	STOCK	0	3.40	96	2313	3581	2291	0.26	2492	1155	610	11411	15940
	FLUID	STOCK	9	3.40	117	2459	3628	2419	7.60	2378	1189	585	8984	14374
		STOCK	22	3.37	96	2456	3517	2345	6.00	2077	1108	612	10215	16901
		STOCK	30	3.37	105	2288	3656	2181	3.00	2352	1154	684	10373	16064
		STOCK	37	3.40	110	2325	3644	2213	0.44	2437	1140	559	9508	15497
B.	GRANITE	CYCLE 1	9	3.35	111	2409	3466	1917	4.70	2777	1229	688	9679	14131
		CYCLE 2	13	3.39	95	2321	3243	1094	4.30	3187	1315	879	10478	12189
		CYCLE 3	8	3.44	110	2236	3195	759	4.40	3295	1358	799	9943	10593
		CYCLE 4	7	3.65	107	2394	3005	537	2.10	3884	1368	537	8642	9267
	FAULT	CYCLE 1	9	3.47	121	2401	3480	2401	3.60	2587	1247	744	10206	15702
	GOUGE	CYCLE 2	13	3.39	102	2400	3048	2199	1.90	3005	1304	838	10252	14166
		CYCLE 3	8	3.40	114	2269	2979	1322	2.50	3275	1342	750	10034	12924
		CYCLE 4	7	3.56	108	2300	2796	1082	3.80	4059	1421	789	8791	11317

II. TRACE ELEMENT CHEMISTRY

	DESCRIPTION		REACTION TIME (days)	FINAL pH	Zn	Co	Ni	Se	Cr	As	Cd	Hg	Li	Mn	Pb	Mo	U	Th
A.	STARTING	STOCK	0	3.40	49.00	48.00	46.00	1.10	3.90	<.002	58.00	19.00	30.00	36.00	1.20	0.02	0.01	<.005
	FLUID	STOCK	9	3.40	19.00	19.00	17.00	0.08	1.30	0.025	24.00	15.00	8.40	38.00	0.60	<.014	<.005	<.029
		STOCK	22	3.37	18.00	18.00	17.00	0.76	1.30	<.002	24.00	15.00	9.50	37.00	0.58	<.014	<.005	<.029
		STOCK	30	3.37	14.00	15.00	14.00	0.51	0.84	<.002	20.00	9.60	8.70	29.00	0.56	0.06	0.01	.004
		STOCK	37	3.40	14.00	15.00	14.00	<.014	0.87	<.002	21.00	9.90	9.30	30.00	0.52	0.01	0.02	0.01
B.	GRANITE	CYCLE 1	9	3.35	18.00	18.00	17.00	0.29	0.36	0.039	23.00	8.30	7.20	38.00	<.007	0.02	2.80	0.06
		CYCLE 2	13	3.39	17.00	16.00	15.00	0.67	<.051	0.026	20.00	7.50	3.10	36.00	< 007	0.01	4.60	0.03
		CYCLE 3	8	3.44	18.00	16.00	15.00	0.05	< 051	0.059	21.00	7.50	2.60	38.00	<.007	0.01	7.10	0.05
		CYCLE 4	7	3.65	17.00	15.00	14.00	0.05	<.051	<.002	20.00	6.60	0.97	36.00	<.007	< 005	7.50	0.02
	FAULT	CYCLE 1	9	3.47	18.00	18.00	17.00	0.05	0.72	0.089	24.00	9.70	8.20	39.00	<.007	0.01	0.24	0.04
	GOUGE	CYCLE 2	13	3.39	17.00	16.00	16.00	0.14	0.08	<.002	22.00	8.80	2.50	37.00	<.007	0.05	0.47	0.04
		CYCLE 3	8	3.40	16.00	15.00	14.00	0.23	<.051	0.002	20.00	8.30	1.60	37.00	<.007	< 005	0.59	0.04
		CYCLE 4	7	3.56	16.00	15.00	14.00	0.05	<.051	0.026	20.00	8.10	0.69	39.00	< 007	<.005	0.72	0.04

TABLE 8 - SEQUENTIAL BATCH TEST RESULTS - FLUID:ROCK = 1, DILUTE ACID (concentrations are in ppm)

I. MAJOR ELEMENT CHEMISTRY

	DESCRIPTION		REACTION TIME (days)	FINAL pH	Si	Mg	Cu	Al	Fe	K	Na	Ca	Cl	SO4
A.	STARTING FLUID	STOCK	0	2.12	<.027	<.003	0.02	<.007	0.07	8.70	<.05	0.06	0	500
B.	GRANITE	CYCLE 1	7	5.49	37.00	4.30	3.00	1.60	0.12	160.00	59.00	35.00	0	550
	LOWER COPPER	CYCLE 1	7	6.09	21.00	5.60	5.80	1.40	0.37	210.00	181.00	76.00	330	471
	UPPER COPPER	CYCLE 1	7	7.83	9.20	2.40	0.34	0.37	0.079	74.00	180.00	41.00	0	687
	LEACHED BEDROCK	CYCLE 1	7	7.07	9.00	4.50	0.03	0.41	0.073	200.00	52.00	17.00	0	488

II. TRACE ELEMENT CHEMISTRY

	DESCRIPTION		REACTION TIME (days)	FINAL pH	Zn	Co	Ni	Se	Cr	As	Cd	Hg	Li	Mn	Pb	Mo	U	Th
A.	STARTING FLUID	STOCK	0	2.12	<.049	0.002	0.036	0.007	0.018	0.017	<.0009	<.0016	0.044	<.0024	0.003	<.0009	<.0003	<.0005
B.	GRANITE	CYCLE 1	7	5.49	0.160	<.001	<.005	0.040	0.032	<.0002	0.004	<.0017	0.210	0.370	0.002	0.014	0.0038	<.0005
	LOWER COPPER	CYCLE 1	7	6.09	0.950	0.120	0.660	<.009	0.013	0.017	0.002	<.0017	0.200	0.630	0.002	0.016	0.0003	0.0009
	UPPER COPPER	CYCLE 1	7	7.83	0.006	<.001	<.005	<.009	0.009	0.017	0.004	<.0017	0.150	0.013	<.0007	2.200	0.2000	<.0005
	LEACHED BEDROCK	CYCLE 1	7	7.07	0.011	0.004	<.005	0.033	0.010	0.027	<.009	0.003	<.013	0.140	<.0007	0.710	<.0003	<.0005

TABLE 9 - COLUMN TEST RESULTS (concentrations are in ppm)

I. MAJOR ELEMENT CHEMISTRY

	DESCRIPTION		pH	Si	Mg	Cu	Al	Fe	K	Na	Ca	Cl	SO4
A.	STARTING FLUID		3.44	49	2469	3579	2439	6.80	2121	1253	614	10947	17464
B.	LEACHED BEDROCK	PASS 1	3.45	54	2447	3732	2249	7.30	2298	1310	692	10113	16356
		PASS 2	3.51	69	2393	3589	2138	12.00	2240	1451	738	9601	15635
		PASS 3	3.63	23	2262	3417	1870	20.00	1570	1639	854	11536	14228
		PASS 4	3.78	45	2341	3039	1294	43.00	1232	2033	924	11318	11247
	UPPER COPPER	PASS 1	3.61	33	2367	2595	1640	100.00	2200	1765	768	10742	14125
		PASS 2	3.79	28	2379	2941	618	36.00	2492	2379	806	9231	10297
		PASS 3	4.71	22	1897	536	11	5.50	1228	3549	1183	10901	5045
		PASS 4	7.83	9	805	4	5	5.30	578	7091	1635	12411	6001
	LOWER COPPER	PASS 1	3.65	31	2326	5475	1749	5.70	2305	1482	741	11125	15893
		PASS 2	3.75	39	2366	5808	1312	4.90	2388	1807	731	9056	14748
		PASS 3	3.89	38	3321	6334	569	6.70	1993	2965	1139	11581	11963
		PASS 4	4.57	16	2015	371	5	3.80	1061	5462	1299	12342	4807

II. TRACE ELEMENT CHEMISTRY

	DESCRIPTION		pH	Zn	Co	Ni	Se	Cr	As	Cd	Hg	Li	Mn	Pb	Mo	U	Th
A.	STARTING FLUID		3.44	14.00	14.00	13.00	0.70	0.90	<.002	21.00	9.50	8.60	30.00	0.59	0.01	0.01	<.004
B.	LEACHED BEDROCK	PASS 1	3.45	15.00	15.00	13.00	0.05	0.80	0.01	21.00	10.00	8.70	31.00	0.01	0.01	0.08	0.04
		PASS 2	3.51	25.00	17.00	15.00	0.59	1.00	0.06	24.00	13.00	8.20	45.00	<.01	<.014	0.24	<.029
		PASS 3	3.63	33.00	16.00	15.00	0.41	0.89	0.08	24.00	12.00	6.60	54.00	<.01	<.014	0.45	<.029
		PASS 4	3.78	50.00	15.00	13.00	0.24	0.62	0.09	23.00	11.00	4.60	60.00	<.01	<.014	0.46	<.029
	UPPER COPPER	PASS 1	3.61	51.00	15.00	13.00	0.05	0.31	<.002	23.00	6.60	9.00	37.00	0.02	0.08	6.50	0.06
		PASS 2	3.79	66.00	16.00	15.00	0.16	0.06	0.04	23.00	6.20	6.50	45.00	<.01	<.014	8.80	<.029
		PASS 3	4.71	88.00	12.00	10.00	0.34	<.056	0.01	15.00	2.60	6.00	40.00	<.01	<.014	0.92	<.029
		PASS 4	7.83	0.50	0.35	0.43	0.21	<.056	<.002	0.61	0.50	3.60	2.80	<.01	<.014	0.16	<.029
	LOWER COPPER	PASS 1	3.65	32.00	14.00	13.00	0.16	0.33	<.002	21.00	7.20	8.50	31.00	<.007	0.09	0.63	0.06
		PASS 2	3.75	66.00	17.00	15.00	0.08	0.22	0.03	24.00	8.50	6.50	40.00	<.01	<.014	0.90	<.029
		PASS 3	3.89	120.00	19.00	16.00	0.33	0.06	<.002	22.00	4.80	6.00	50.00	<.01	<.014	0.88	<.029
		PASS 4	4.57	110.00	12.00	9.60	0.21	<.056	0.01	13.00	1.20	4.10	43.00	<.01	<.014	0.01	<.029

TABLE 10 ATTENUATION COEFFICIENTS DERIVED FROM BATCH TESTS

	1.50 - 3.39										3.40 - 4.49								4.50 - 7.30	
	GRANITE		FAULT GOUGE		PORPHYRY		CONGLOMERATE		BASIN FILL		GRANITE		FAULT GOUGE		CONGLOMERATE		BASIN FILL		CONGLOMERATE	
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
# tests	13		14		5		2		2		3		5		3		3		3	
pH	2.14	3.39	2.14	3.39	2.17	3.30	2.72	3.20	2.37	2.93	3.40	3.65	3.40	3.56	3.40	3.80	3.40	3.52	4.64	7.30
Si	-1.12	0.10	-1.11	0.03	-1.84	-0.03	-2.04	-0.91	-0.83	-0.77	-0.50	0.01	-0.49	0.00	-0.54	0.64	-0.45	0.08	-0.11	0.89
Mg	-0.35	0.23	-0.30	0.21	-0.52	0.15	-0.14	0.58	-0.24	0.21	-0.01	0.13	0.03	0.07	-0.25	0.10	-0.37	-0.02	0.22	0.00
Cu	-0.27	0.44	-0.07	0.42	-0.67	0.21	-0.16	0.67	0.11	0.84	0.07	0.09	0.03	0.13	-0.03	0.55	-0.09	1.79	5.50	917.72
Al	-0.39	0.92	-0.37	0.59	-0.68	0.30	0.40	0.85	-0.10	0.42	0.13	1.35	-0.08	0.13	0.74	11.16	0.09	0.91	381.16	5498.42
Fe	-0.91	4012.87	-0.31	4001.42	0.10	233.49	10.97	151.64	3.08	90.30	0.44	150.36	-0.88	4049.43	33.59	>10K	667.15	952.45	351.07	>10K
K	-0.45	0.58	-0.46	0.44	-0.41	1.32	1.59	2.70	1.27	1.42	-0.20	-0.13	-0.25	-0.04	0.33	0.48	0.28	1.48	0.01	0.80
Na	-0.21	-0.07	-0.26	0.05	-0.45	-0.45	NM	NM	NM	NM	-0.12	-0.07	-0.15	-0.02	NM	NM	-0.44	-0.44	-0.51	-0.27
Ca	-0.58	0.15	-0.45	0.15	-0.50	0.18	-0.42	-0.19	-0.63	-0.21	-0.15	0.05	-0.25	0.04	-0.33	0.08	-0.23	0.07	-0.22	0.14
Cl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO4	0.10	0.66	0.04	0.58	0.74	0.74	NM	NM	NM	NM	0.22	0.29	0.01	0.25	NM	NM	0.93	0.93	3.77	6.75
Zn	-0.43	-0.02	-0.42	0.10	-0.53	-0.19	-0.10	0.15	-0.51	-0.05	-0.16	-0.08	-0.22	-0.01	-0.18	0.38	-0.23	-0.06	0.25	165.44
Co	-0.48	0.13	-0.45	0.20	-0.33	0.33	-0.13	0.09	-0.50	-0.05	-0.06	0.00	-0.17	0.00	-0.16	0.41	-0.10	0.10	0.19	202.70
Ni	-0.48	0.13	-0.45	0.23	-0.19	0.53	-0.11	0.20	0.50	0.05	0.09	0.00	-0.18	0.00	-0.25	0.57	-0.10	0.14	0.27	128.82
Se	0.85	92.02	-0.27	55.51	14.77	35.22	20.50	27.29	16.07	61.21	-0.08	0.10	-0.19	0.20	4.54	23.53	12.80	29.71	5.97	39.71
Cr	-0.22	41.31	-0.24	32.76	-0.13	5.96	3.65	12.61	0.71	2.38	2.90	7.81	0.21	3.78	4.99	561.61	7.45	29.60	686.90	3122.23
As	-0.95	>10K	0.00	>10K	102.64	>10K	118.13	>10K	564.81	>10K	0.47	2442.52	-0.98	2390.75	69.42	>10K	451.23	>10K	672.07	>10K
Cd	-0.43	0.08	0.50	0.18	-0.19	0.36	-0.10	-0.02	-0.36	0.06	-0.03	0.02	-0.12	0.03	-0.11	0.38	-0.06	0.15	0.21	94.34
Hg	-0.76	2.63	-1.07	1.11	-0.80	0.44	-0.56	-0.45	0.65	0.56	0.16	1.87	0.02	0.73	0.30	0.16	-0.29	-0.02	0.11	2.14
Li	0.42	1.21	0.46	2.22	-0.04	0.80	0.15	0.54	-0.50	0.33	-0.10	3.73	-0.04	1.33	-0.09	2.86	0.13	0.75	1.22	6.56
Mn	-0.64	-0.06	-0.55	-0.03	-1.08	-0.53	-1.70	1.32	1.97	1.40	0.13	0.07	0.23	-0.02	-1.09	-0.85	-1.01	-0.78	-0.82	128.82
Pb	1.50	423.69	-2.25	378.21	-1.50	0.00	-0.83	0.00	0.00	5.33	0.45	35.66	0.36	73.28	-0.92	-0.33	-0.93	3.46	0.00	1.88
Mo	-0.47	1395.95	-0.33	1447.98	12.62	248.51	38.19	248.53	450.05	2083.06	0.16	1.13	-0.33	0.91	2.08	1582.43	152.91	445.91	70.45	1463.72
U	-2.98	0.51	-2.88	-0.38	-2.92	-1.06	-2.73	-1.59	-2.75	-1.61	-0.68	-0.43	-0.91	-0.10	-1.28	-0.97	-1.18	-0.88	-0.23	0.00
Th	-3.00	-0.27	-3.00	-0.29	-3.00	1.06	-3.00	-1.66	-3.00	-1.66	-0.60	-0.34	-0.88	-0.09	-1.32	-1.00	-1.21	-0.90	-0.99	-0.42

TABLE 11 - ATTENUATION COEFFICIENTS DERIVED FROM COLUMN TESTS
(Ranked by final pH value)

TEST-PASS	LBC-1	LBC-2	UCO-1	LBC-3	LCO-1	LCO-2	LBC-4	UCO-2	LCO-3	LCO-4	UCO-3	UCO-4
pH	3.45	3.51	3.61	3.63	3.65	3.75	3.78	3.79	3.89	4.57	4.71	7.83
Si	-0.06	-0.08	0.29	0.23	0.36	0.08	0.01	0.23	0.06	0.31	0.25	0.67
Mg	0.01	0.01	0.03	0.02	0.04	0.01	0.01	0.01	-0.05	0.03	0.06	0.31
Cu	-0.02	-0.00	0.23	0.01	-0.21	-0.12	0.03	0.07	-0.09	1.30	1.14	141.14
Al	0.05	0.04	0.29	0.06	0.24	0.26	0.13	0.88	0.66	73.03	44.15	70.22
Fe	-0.04	-0.13	-0.56	-0.13	0.12	0.12	-0.13	-0.24	0.00	0.12	0.05	0.04
K	-0.05	-0.02	-0.02	0.07	-0.05	-0.03	0.11	-0.04	0.01	0.15	0.15	0.40
Na	-0.03	-0.04	-0.17	-0.05	-0.09	-0.09	-0.06	-0.14	-0.12	-0.12	-0.13	-0.12
Ca	-0.07	-0.05	-0.12	-0.06	-0.10	-0.05	-0.05	-0.07	-0.09	-0.08	-0.10	-0.09
Cl	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SO4	0.04	0.04	0.14	0.05	0.06	0.06	0.08	0.21	0.09	0.39	0.49	0.29
Zn	-0.04	-0.13	-0.44	-0.12	-0.34	-0.24	-0.11	-0.24	-0.18	-0.13	-0.17	4.05
Co	-0.04	-0.05	-0.04	-0.03	0.00	-0.05	-0.01	-0.04	-0.05	0.03	0.03	5.85
Ni	0.00	-0.04	0.00	-0.03	0.00	-0.04	0.00	-0.04	-0.04	0.05	0.06	4.38
Se	7.18	0.06	7.18	0.14	2.03	2.39	0.29	1.01	0.22	0.35	0.21	0.35
Cr	0.07	-0.03	1.14	0.00	1.04	0.93	0.07	4.13	3.01	2.26	3.01	2.26
As	-0.49	-0.29	0.00	-0.20	0.00	-0.28	-0.15	-0.28	0.00	-0.12	-0.16	0.00
Cd	0.00	-0.04	-0.05	-0.03	0.00	-0.04	-0.01	-0.03	-0.01	0.09	0.08	5.01
Hg	-0.03	-0.08	0.26	-0.04	0.19	0.04	-0.02	0.16	0.20	1.04	0.53	2.70
Li	-0.01	0.01	-0.03	0.06	0.01	0.10	0.13	0.10	0.09	0.16	0.09	0.21
Mn	-0.02	-0.10	-0.11	-0.09	-0.02	-0.08	-0.08	-0.10	-0.08	-0.05	-0.05	1.46
Pb	34.80	17.40	20.22	11.60	49.97	17.40	8.70	17.40	11.60	8.70	11.60	8.70
Mo	-0.10	0.00	-0.53	0.00	-0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00
U	-0.56	-0.29	-0.60	-0.20	-0.60	-0.30	-0.15	-0.30	-0.20	-0.07	-0.20	-0.15
Th	-0.54	-0.26	-0.56	-0.17	-0.56	-0.26	-0.13	-0.26	-0.17	-0.13	-0.17	-0.13

LBC - Leached Bedrock Complex
UCO - Upper Copper Oxide Unit
LCO - Lower Copper Oxide Unit