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Testing of Alternative Abrasives for Water-Jet Cutting at C Tank Farm

EJ Krogstad

August 2013

Pacific Northwest NATIONAL LABORATORY

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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Legacy waste from defense-related activities at the Hanford Site has predominantly been stored in underground tanks, some of which have leaked; others may be at risk to do so. The U.S. Department of Energy's goal is to empty the tanks and transform their contents into more stable waste forms. To do so requires breaking up, and creating a slurry from, solid wastes in the bottoms of the tanks. A technology developed for this purpose is the Mobile Arm Retrieval System. This system is being used at some of the older single shell tanks at C tank farm. As originally planned, access ports for the Mobile Arm Retrieval System were to be cut using a high- pressure water-jet cutter. However, water alone was found to be insufficient to allow effective cutting of the steel-reinforced tank lids, especially when cutting the steel reinforcing bar ("rebar"). The abrasive added in cutting the hole in Tank C-107 was garnet, a complex natural aluminosilicate. The hardness of garnet (Mohs hardness ranging from H 6.5 to 7.5) exceeds that of solids currently in the tanks, and was regarded to be a threat to Hanford Waste Treatment and Immobilization Plant systems. Olivine, an iron-magnesium silicate that is nearly as hard as garnet (H 6.5 to 7), has been proposed as an alternative to garnet.

Pacific Northwest National Laboratory proposed to test pyrite (FeS_2), whose hardness is slightly less (H 6 to 6.5) for 1) cutting effectiveness, and 2) propensity to dissolve (or disintegrate by chemical reaction) in chemical conditions similar to those of tank waste solutions. Cutting experiments were conducted using an air abrader system and a National Institute of Standards and Technology Standard Reference Material (SRM 1767 Low Alloy Steel), which was used as a surrogate for rebar. The cutting efficacy of pyrite was compared with that of garnet and olivine in identical size fractions. Garnet was found to be most effective in removing steel from the target; olivine and pyrite were less effective, but about equal to each other.

The reactivity of pyrite, compared to olivine and garnet, was studied in high-pH, simulated tank waste solutions in a series of bench-top experiments. Variations in temperature, degree of agitation, grain size, exposure to air, and presence of nitrate and nitrite were also studied. Olivine and garnet showed no sign of dissolution or other reaction. Pyrite was shown to react with the fluids in even its coarsest variation (150−1000 μm). Projected times to total dissolution for most experiments range from months to ca. 12 years, and the strongest control on reaction rate is the grain size.

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1.0 Introduction

Legacy waste from defense-related activities at the Hanford Site has predominantly been stored in underground tanks. Some of these tanks have leaked liquid and, in principle, all of them could eventually be at risk of doing so. Leakage can allow dangerous contaminants to seep into the ground, which could lead to groundwater contamination that might eventually discharge into the Columbia River. The U.S. Department of Energy's goal is to empty the tanks and transform their contents into more stable (glassified) waste forms.

Stabilization of the tank wastes will be done by vitrifying the solid wastes at the Waste Treatment Plant (WTP). To accomplish this, the solid wastes in the bottom of the tanks must first be broken up with a liquid to form a slurry to enable its transport to the WTP. A technology developed for this purpose is the Mobile Arm Retrieval System (MARS), which is being used at some of the older single-shell tanks at the C tank farm.

As initially planned, access ports for the MARS at C tank farm were to be cut using a high-pressure water-jet cutter. However, water alone proved to be insufficient to allow effective cutting of the steel-reinforced concrete tank lid, especially when cutting the steel reinforcing bar ("rebar"). The rebar is expected to be similar in composition to American Society for Testing and Materials (ASTM) 607/A615 steel, which represents common reinforcing steel compositions. The abrasive added to the water jet for cutting the hole in Tank C-107 was garnet, a complex natural aluminosilicate. The hardness of garnet (Mohs hardness ranging from H 6.5 to 7.5; Klein and Hurlbut 1985) exceeds that of solids currently in the tanks, and was considered a threat to WTP systems. Olivine, an iron-magnesium silicate that is nearly as hard as garnet (H 6.5 to 7; Klein and Hurlbut 1985), has been proposed as an alternative abrasive.

Pacific Northwest National Laboratory (PNNL) proposed to test pyrite (FeS_2), whose hardness is slightly less (H 6 to 6.5; Klein and Hurlbut 1985) for its cutting effectiveness, and propensity to dissolve (or disintegrate by chemical reaction) in chemical conditions similar to those of tank waste solutions. This report describes the two experiments conducted to determine the cutting effectiveness of pyrite relative to the other abrasives and dissolution of pyrite relative to the other abrasives. Experimental methods, materials, results, and associated interpretations are presented in the ensuing sections; Appendix A contains related data tables.

2.0 Methods and Materials

Experiments were developed at PNNL to test two parameters: 1) whether pyrite would be able to cut the reinforcement bars in the tank lids, and 2) whether the pyrite would dissolve in the tank waste. The first test was accomplished using a miniaturized air abrader and the three candidate abrasives. The second series of tests used leaching or reaction experiments with the three abrasives and simulated tank fluids.

2.1 Abrasion Experiments

A commercial air abrader (Figure 1) was purchased from Integral Systems, Inc. (X-blast Triple Tank) and modified for this experiment. The unit uses compressed nitrogen at 100 psi to drive abrasive through narrow nozzles at a target. Although the gas propellant pressures used (ca. 100 psi) were much lower than the water pressures used in actual water-jet cutting (ca. 50,000 psi), it was hypothesized that results from comparisons of air abrasion using the three candidate abrasives would provide indications of 1) the ability of pyrite to cut steel, and 2) an approximate relative cutting ability of the three abrasives. Compressed nitrogen was used instead of normal air to obviate the spark and explosion hazard that might have accompanied pyrite-steel impacts. Use of pyrite as an abrasive in water streams would not constitute a spark or explosion threat.

A disk (Figure 2) of National Institute of Standards and Technology (NIST) SRM 767 (Low Alloy Steel) was obtained for use as a cutting target. It was chosen because of its compositional similarity to steel meeting the standards of American Society for Testing and Materials (ASTM) 607/A615 steel, which represents common reinforcing steel compositions.

The abrader was reconfigured to use a single grain size range (106–125 μm), with the used abrasive collected on a filter by a vacuum line. The abrasion nozzle was oriented at a set angle (ca. 30°) to the upper surface of the steel disk. Abrasion was conducted for a set period of time, typically 1 to 3 minutes, producing a pit in the disk (Figure 2). The weight of the disk was compared to its pre-abrasion weight to determine the weight of the steel removed. The mass of abrasive used in the experiment was determined by the difference in the weight of material in the abrasive reservoir before and after the abrasion.

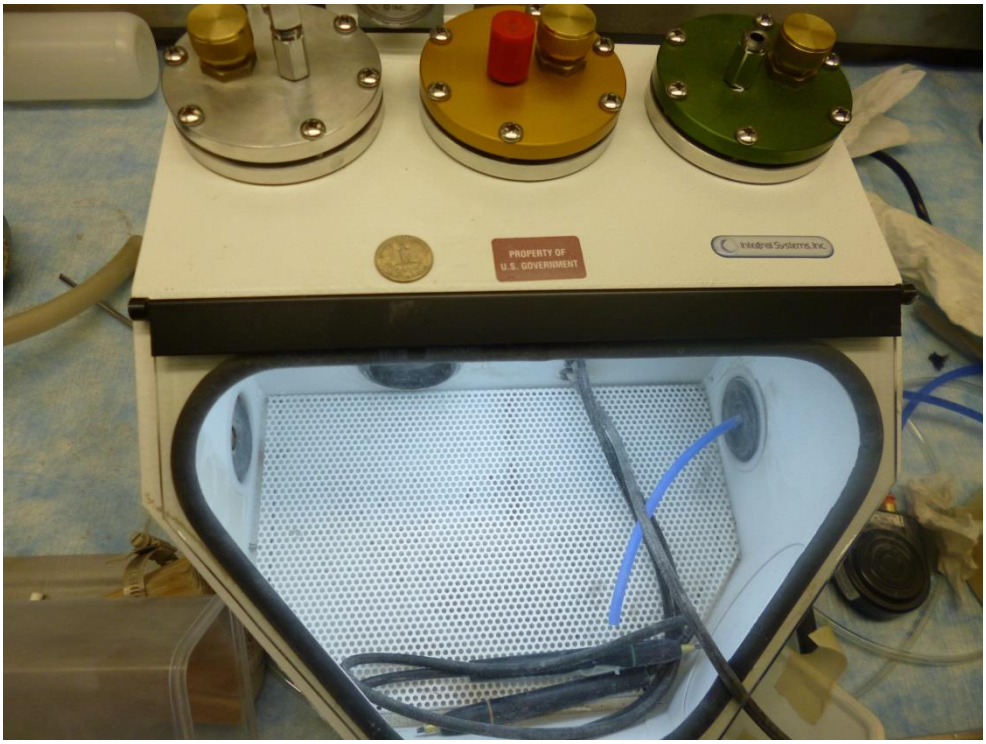

Figure 1. Miniaturized air abrader (Integral Systems Triple Blast) used in abrasion experiments. A U.S. quarter dollar coin atop the abrader provides scale.

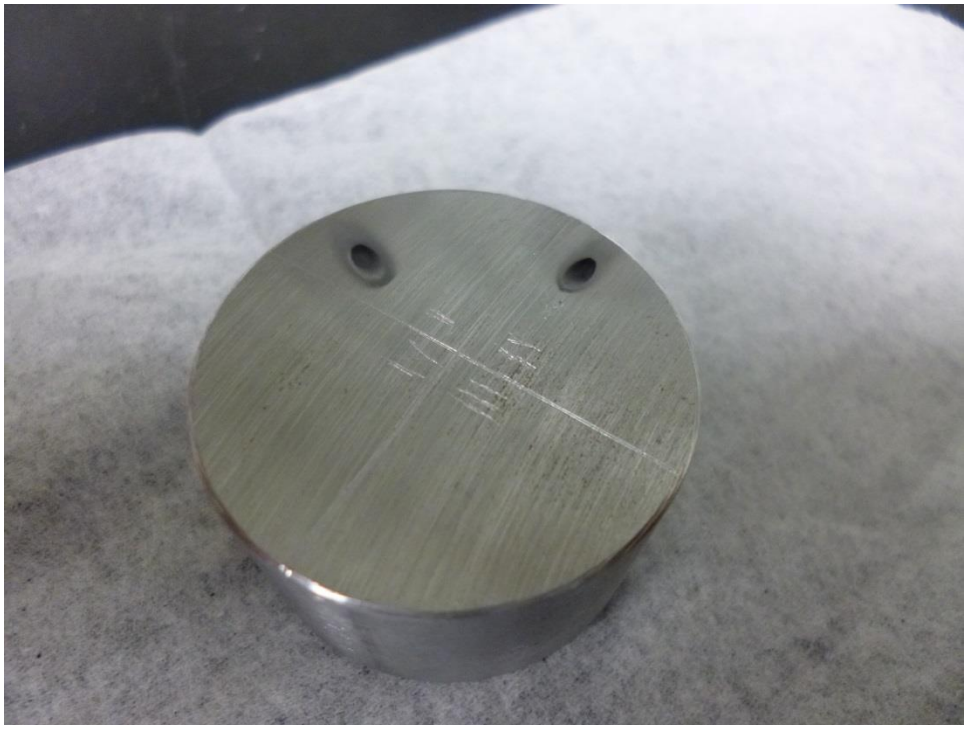

Figure 2. Sample disk of NIST 1767 (Low Alloy Steel) used as a cutting target. The top surface has been scribed into quadrants. Quadrant I (back) was abraded with garnet and 37.2 mg were removed. Quadrant II (back right) was abraded with olivine and 29.1 mg were removed. The disk is 34 mm in diameter and 19 mm thick.

2.2 Reaction Experiments

Grain sizes for the three abrasives were chosen to represent 1) "out of the bag" size like that to be used in water-jet cutting (150–1000 μm), and 2) a finer grain size (<53 μm) to increase surface/volume effects. One-kilogram samples of garnet, olivine, and pyrite were obtained from Ward's Natural Science, Rochester, New York. The grain sizes were reduced by jaw crusher and disk mill (BICO, Burbank, California). Further grain size reduction (crushing in ring mill) was conducted, followed by sieving using ASTM traceable sieves to sieve sizes <53 μm, 53–150 μm (with a subset of 106–125 μm), 150–1000 μm, and >1000 μm. Fractions of two sizes ranges, 53 μm and 150–1000 μm, were selected for leaching experiments. The choice of two fractions with such different grain sizes was initially made to enhance differences in leaching or reaction rates that might be a function of grain size.

Two solutions were prepared for the leach tests. One was made to 1 M NaOH by dissolving reagent-grade sodium hydroxide in high-purity (Milli-Q) water. This leaching solution is hereinafter referred to as Solution A. The second solution was made by dissolving reagent grade sodium hydroxide, sodium nitrate, sodium nitrite, sodium aluminate, sodium carbonate, and ferric chloride in Milli-Q purified water (Table 1). This solution is hereinafter referred to as Solution B.

Table 1. Leaching solutions, concentrations in mol/L.

	Solution A	Solution B
Component	Molarity	Molarity
NaOH	1.0	1.5
$NaNO_3$		4
$NaNO_2$		0.4
$NaAlO_2$		0.5
Na_2CO_3		0.05
$FeCl_3$		0.001

Weighed amounts of each of the three abrasives in each size range were then placed in polypropylene bottles and one of two simulated tank solutions was added. Sampling of the solution in each bottle for dissolution products (i.e., constituent elements) of the abrasives over a period of several weeks was used as the method of determining reaction progress. This approach is based upon the assumption that these dissolution products will, once formed in solution, remain in solution and not re-precipitate. An example of this approach is to assume that sulfur as sulfate (SO_4^{2-}) will be more likely to remain in solution from the decomposition of pyrite, but that ferrous iron will likely convert to ferric iron and re-precipitate as ferric oxides or hydroxides. Therefore, the dissolved sulfur was thought to be a better indicator of reaction progress in the dissolution of pyrite than iron. For the dissolution of garnet and olivine, silica and magnesium might be better indicators than, for example, iron or aluminum because of the relative insolubility of the latter two elements.

2.3 Separate Leaching Experiments

Experiments involving the leaching of garnet were given the prefix G, experiments involving the leaching of olivine were given the prefix of O, and experiments involving the leaching of pyrite were given the prefix of P. One set of experiments was started in late July and August 2012. Another set was started on August 31, 2012, and run in parallel (Table A.1). In tables of leaching data, concentrations of leach products are tabulated versus days of reaction times so that results may be compared.

2.3.1 Low-Density Polyethylene Bottles

Standard screw-top 125-mL low-density polyethylene bottles were used for the first series of experiments, and similar 60-mL bottles were used for the second series. To these were added a weighed amount of abrasive mineral, nominally 500 mg, but 100 mg in P1. A leach solution of 50 mL was also added.

2.3.2 Shaker Table

A subset of the bottles was placed on a mechanical shaker table (Figure 3) to keep the solids and the reaction solutions well mixed. The bottles were kept capped at all times (except during sampling procedures) for safety reasons. The experiments were conducted on a laboratory bench top, at 19°C.

Figure 3. Example of the leaching experiments. The bottles including both Solution A and Solution B sit atop a reciprocal shaker at room temperature (19°C). Each bottle contains 50 mL of leach solution, from with 0.5 mL was sampled intermittently for analysis.

2.3.3 Experiments in an Oven – The Effect of Temperature

A laboratory oven set at 40°C was used to constrain the effect of temperature on reaction rates. This temperature was chosen because it was considered to be more pertinent to the actual temperature in some tanks than the laboratory temperature of 19°C at which other experiments were run. The bottles in the oven were kept capped at all times (except during sampling procedures) for safety reasons and to control the evaporation of the solutions.

2.3.4 Experiments in a Fume Hood – The Effect of Exposure to Air

A subset of the experiments was placed in a fume hood with appropriate secondary containment. These bottles were kept uncapped at all times. The experiments were conducted at ambient laboratory temperatures, which averaged 19°C. Persistent evaporation required that volumes of the leaching solution be brought up to 50 mL at a rate of two to three times per week. This required large volumes of deionized water to be added to the bottles. Because the dissolved species are not considered volatile, this effect probably only resulted in temporary increases in solute concentrations. The exceptions to this were the experiments run in Solution B, in which a heavy crust formed on the bottom of the bottles.

2.4 Chemical Analyses of Reaction Products in Solution

Analysis of reaction products was conducted by sampling of 0.5 mL from each bottle at somewhat irregular intervals. The sample aliquots were diluted 100:1 in 2% nitric acid and submitted for analysis by inductively coupled optical emission spectrometer. These analyses were made using the Environmental Sciences Laboratory (ESL, Geosciences Group, Energy and Environment Division) standard quality assurance-quality control methods. The data were input into ESL's Laboratory Information Management System, and reviewed by an independent Geosciences Group scientist for conformity with ESL standards.

3.0 Results

The results derived from the abrasion and reaction experiments are described in the following sections.

3.1 Abrasion (Cutting) Experiments

The relative abrasivity of the three compared abrasives using the miniature air abrader was determined on NIST 1767, Low-Alloy Steel, because it was thought to best mimic the characteristics of the material used for rebar in the steel-reinforced concrete in the lids of the tanks (Table 2; Figure 4). Garnet proved to be the best abrader, removing the most steel for the amount of abrasive used. Olivine was less efficient, requiring about 1.4 times the amount of abrasive to remove the same amount of steel. Pyrite abrasion tests yielded variable results, from highly efficient to about as efficient as olivine. The sum of the pyrite abrasion tests provided an abrasion efficacy that was approximately equal to that of the olivine test.

Table 2. Results of abrasion tests.

	Mass Abrasive Used	Steel Target Removed	Steel Removed/Abrasive Used	Abrasive Used/Steel Removed
Units	g	g	g/g	g/g
Garnet	22.14	0.0372	0.00168	595
Olivine	24.10	0.0291	0.00121	826
Pyrite 1	3.05	0.0068	0.0063	159
Pyrite 2	11.66	0.0124	0.00106	943
Pyrite 3	8.39	0.0095	0.00113	885
Total pyrite tests	**22.08**	**0.0287**	**0.00130**	**769**

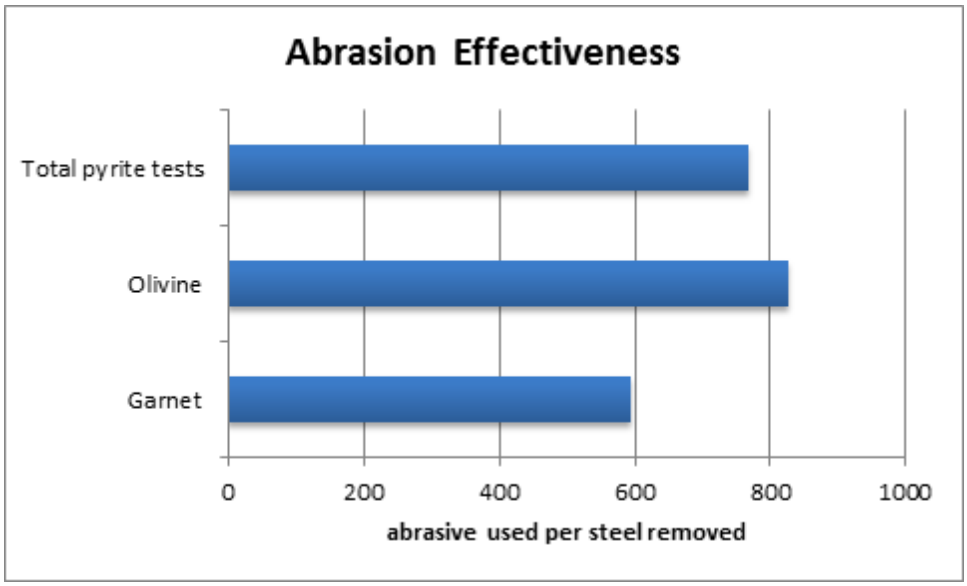

Figure 4. Relative abrasion effectiveness of the three abrasives on a weight basis. Note that garnet is the most effective abrasive, and that olivine is somewhat less effective at removing steel. The total steel removed by pyrite divided into the amount of pyrite used in the three tests is comparable to that for olivine and pyrite.

It should be noted that the results of this air abrasion test merely demonstrate that pyrite, like the other two abrasives, is capable of cutting the target steel disk. It should not be concluded from these results that quantitative estimates could be made of the amount of any particular abrasive that would need to be added to a high-pressure water-jet cutting apparatus to cut a particular amount of steel-reinforced concrete.

3.2 Reaction Experiments

The results of the reaction experiments are presented below first for garnet and olivine, then pyrite, followed by projections of reaction completion times.

3.2.1 Garnet and Olivine Leaching Experiments

There was no obvious reaction in the garnet and olivine leaching experiments (Figure 5 through Figure 10), except for the minor Fe-oxide coatings in Figure 10. Furthermore, two each of the direct measurements of the mass loss from four of the garnet and olivine leaching experiments, (Table 3 − O101, O109, G101, and G109) showed very little loss of mass. This mass loss could be due to loss of more soluble impurities in the minerals and not the olivine and garnet themselves. This is consistent with the elemental concentration data from the leaching experiment analyses that show little evidence for dissolution products appearing in solution (Table A.2). In fact, dissolution products Mg, Al, Fe, and Si, decrease with time, except for the experiments using Solution B, in which Al and Fe were introduced as a part of the leaching solution. Therefore, there is no evidence that reactions progressed during the experimental time period. These leaching experiments are not discussed further in this report.

Figure 5. Garnet, coarse fraction (150–1000 µm) before leaching. Sizes shown are not intended to be representative. This view shows conchoidally fractured garnet with flaky, dark biotite (mica) impurities.

Figure 6. Garnet, coarse fraction (150–1000 µm) after leaching in Solution A (Experiment G101). Sizes shown are not intended to be representative. This sample had an apparent loss over 109 days of 1.0% of its mass (Table 3), which may have been due to loss during recovery and filtering, or dissolution of mineral impurities.

Figure 7. Garnet, coarse fraction (150–1000 µm) after leaching in Solution B (Experiment G109). Sizes shown are not intended to be representative. This sample had an apparent loss over 109 days of 2.5% of its mass (Table 3), which may have been due to loss during recovery and filtering, or dissolution of mineral impurities.

Figure 8. Olivine, coarse fraction (150–1000 µm) before leaching. Sizes shown are not intended to be representative.

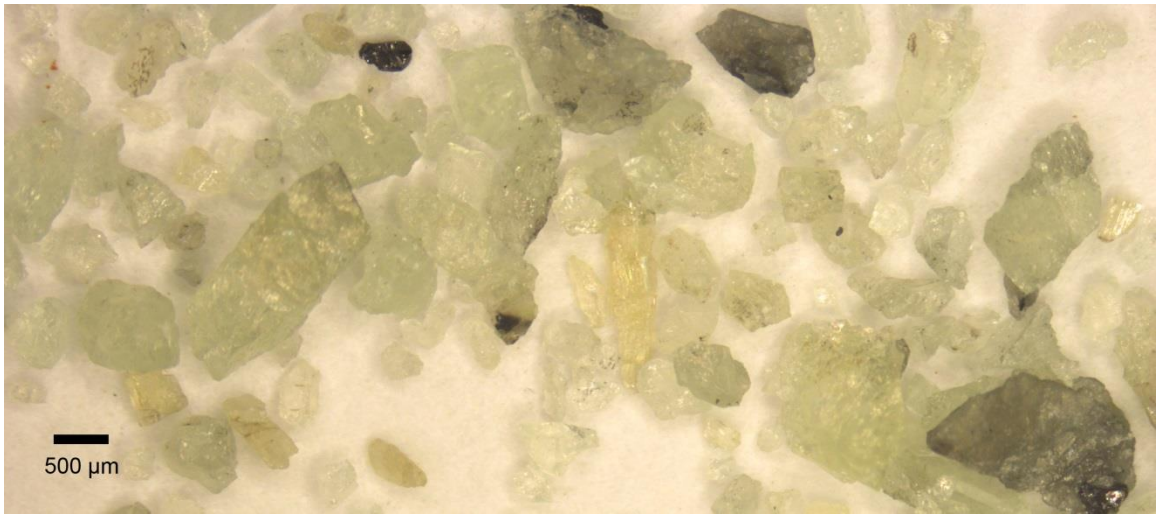

Figure 9. Olivine, coarse fraction (150–1000 µm) after leaching in Solution A (Experiment O101). Sizes shown are not intended to be representative. This sample had an apparent loss over 109 days of 2.6% of its mass (Table 3), which may have been due to loss during recovery and filtering, or dissolution of mineral impurities.

Figure 10. Olivine, coarse fraction (150–1000 µm) after leaching in Solution B (Experiment O109). Note that the Fe-oxide coating on grains is likely due to precipitation of the Fe from the leaching solution. Sizes shown are not intended to be representative. This sample had an apparent loss over 109 days of 1.2% of its mass (Table 3), which may have been due to loss during recovery and filtering, or dissolution of mineral impurities.

Table 3. Mass loss of garnet (G-) and olivine (O-) during selected leaching experiments (weights in grams).

	Initial Weight	Final Weight	Difference	% Loss	Days
O101	0.5015	0.4886	0.0129	2.57	109
O109	0.4960	0.4902	0.0058	1.19	109
G101	0.4967	0.4920	0.0047	0.95	109
G109	0.5040	0.4915	0.0125	2.48	109

3.2.2 Pyrite Leaching Experiments

In contrast to the appearance and leachate chemical analysis data for garnet and olivine (above), reactions of pyrite with the leaching solutions were obvious in both photographic data (Figure 11 through Figure 13) and chemical leaching data. The pyrite before leaching was bright; it had a metallic luster and gold color. After leaching, the formation of crusts of Fe-oxides and/or hydroxide (the solid reaction products were not analyzed) can be seen to have formed over all surfaces.

Leaching data for pyrites showed that sulfur concentrations increased for most experiments over time (e.g., Figure 14). Because complete dissolution of pyrite would have occurred once the concentration of sulfur in solution reached an average of about 53,500 ppb in solutions diluted 100x from the sampled solution (10,700 for P1, which had 100 mg of pyrite, rather than 500 mg), in all the following diagrams reaction progress can be seen in relation to the concentration. Only one experiment shown, P5 in Figure 14, approaches the concentration indicative of complete dissolution. Data for the leaching reactions are given in Table A.2, and prominent results are shown in the figures that follow.

Figure 11. Pyrite, coarse fraction (150–1000 µm) before leaching. Sizes shown are not intended to be representative.

Figure 12. Pyrite, coarse fraction (150–1000 µm) after leaching in Solution A (Experiment P101). Sizes shown are not intended to be representative. In this experiment, approximately 17% of the pyrite dissolved in 137 days, as indicated by the sulfur in solution (Table A.2).

Figure 13. Pyrite, coarse fraction (150–1000 µm) after leaching in Solution B (Experiment P109). Sizes shown are not intended to be representative. In this experiment, approximately 3.1% of the pyrite dissolved in 137 days, as indicated by the sulfur in solution (Table A.2).

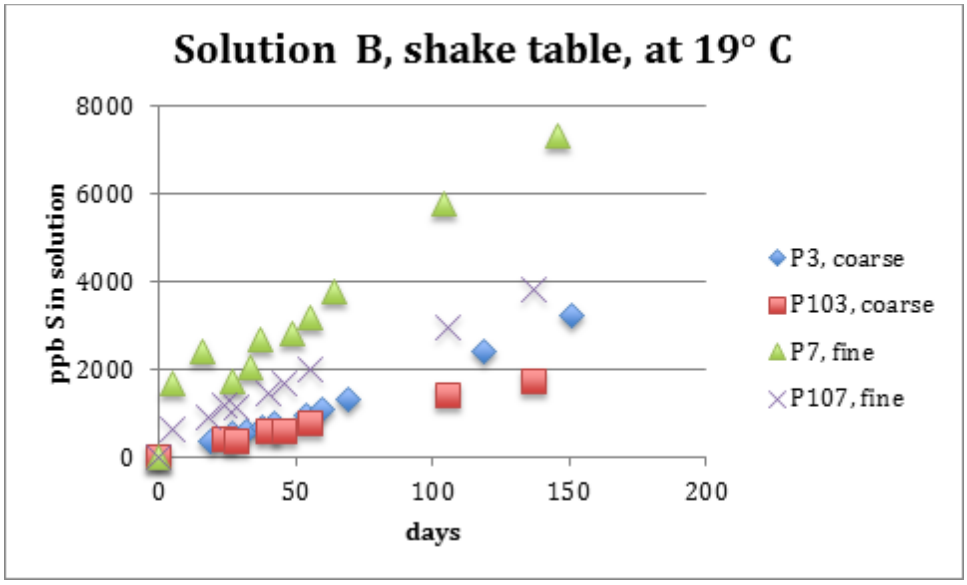

Figure 14. The effects of grain size in Solution B. Experiments P3 and P103 both reacted more quickly than did their coarse-grain equivalents P7 and P107.

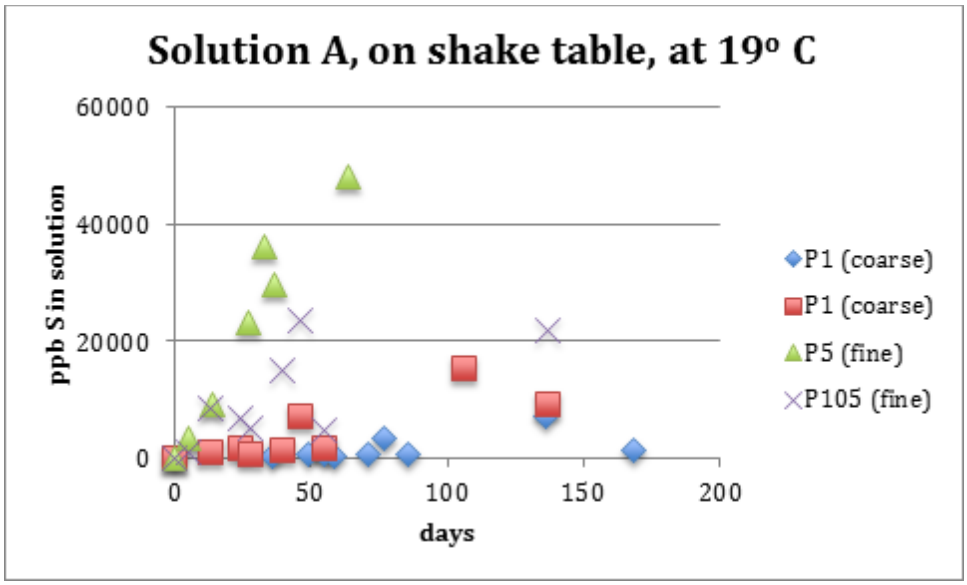

Figure 15. The effects of grain size in Solution A are shown here. The two fine-grained samples reacted much more quickly, with P5 reaching apparent complete dissolution at 64 days. Note also that they reached higher degrees of dissolution (S concentration) than did their equivalents in Solution B in Figure 14.

3.2.2.1 Solution Composition When Open to Air

Reactions among the Solution A experiments progressed faster and the detection of reaction products occurred before those of Solution B. In fact experiments P4, P104, P8, and P108, which were open to air at 19°C in Solution B, made minimal progress, probably because of the precipitation of salts on the pyrite. This precipitation may have completely armored the pyrite and thus precluded further oxidation of the iron and sulfur. Sulfur was not detected in the solutions.

3.2.2.2 Effect of Temperature

Reactions run at 40°C did not differ greatly from those run at 19°C (Figure 16). In these experiments, the solutions were all Solution B. It might be surmised that the presence of components in Solution B negatively affected the alteration of the pyrite, such that the elevated temperature did not result in more rapid reaction progress.

3.2.2.3 Effect of Grain Size

The variable with the greatest effect on reaction rate was grain size; the fine-grained pyrite reacted much faster than the coarse-grained pyrite. Reactions among the fine-grained (< 53 μm) samples occurred before and ran faster than those of the coarse fraction (150–1000 μm), as seen in Figure 14, Figure 15, and Figure 17. In some fine-grained samples (e.g., Figure 16) reaction completion within a few weeks was indicated by the sulfur concentration of the leach solution.

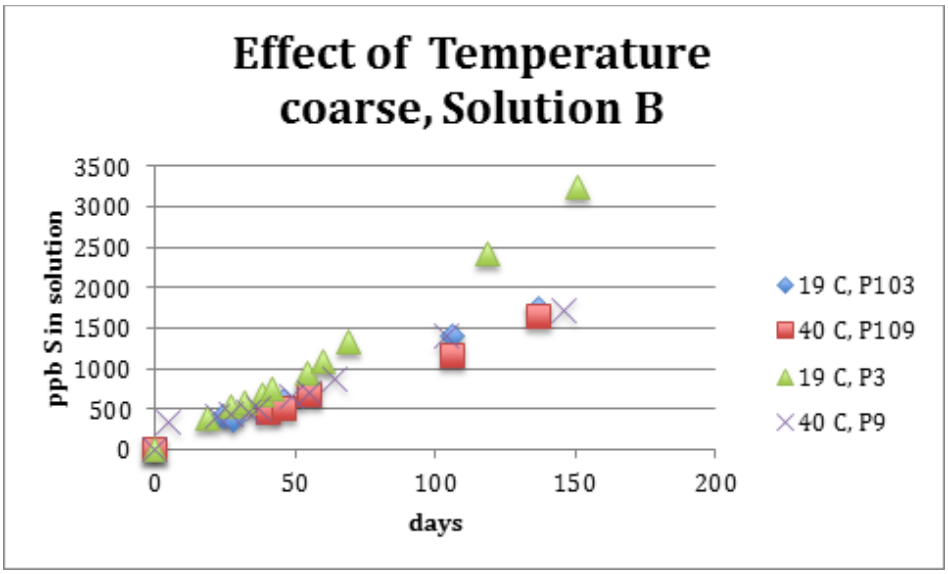

Figure 16. The effects of temperature in Solution B. Experiments P3/P103 at 19°C ran at the same rate or faster than those at 40°C (P9/P109). This may be an effect of the shaker table increasing reaction rates.

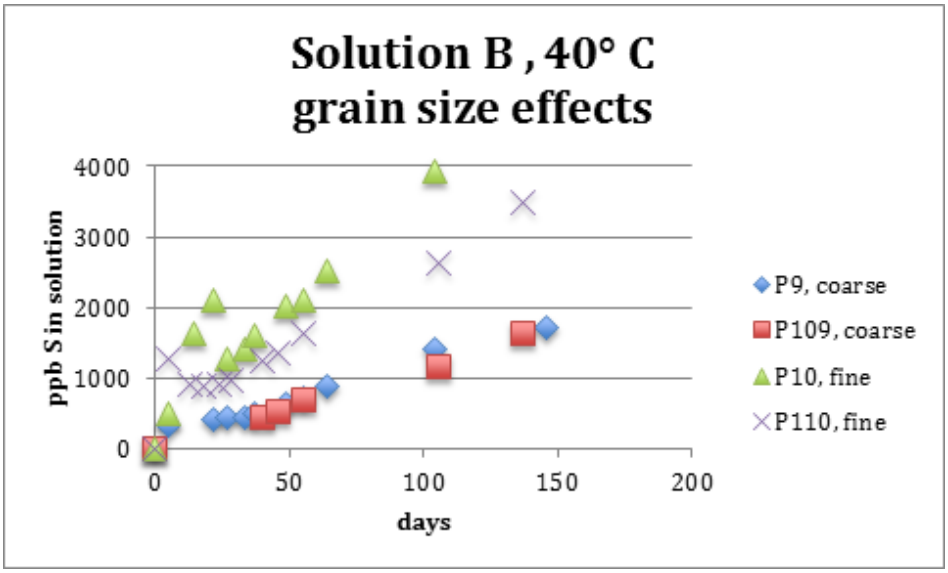

Figure 17. At 40°C, as at 19°C (see Figure 15), the grain size has a large effect on reaction rate; the fine-grained (P10/P110) experiments reacted more quickly than the coarse-grained experiments.

3.2.3 Projection to Reaction Completion Times

All experiments except P1 were run with 500 mg of pyrite in 50 mL of reaction solution. P1 was run with 100 mg pyrite in 50 mL of Solution A. The reactions would have been judged to have run to completion when 100% of the pyrite was dissolved. This would have occurred when the sulfur concentration in solution reached about 54,000 ppb in the 100x dilutions (5.4 mg/mL in the leach solutions). These reaction times were extrapolated with a linear trend-line from the reaction progress in

the various experiments (Figure 18 through Figure 20). The reaction times (time to intersection with the concentration indicating complete dissolution) ranged from months to years, except for experiments P4, P8, P104, and P108, in which precipitation of salts seems to have interfered with reaction progress.

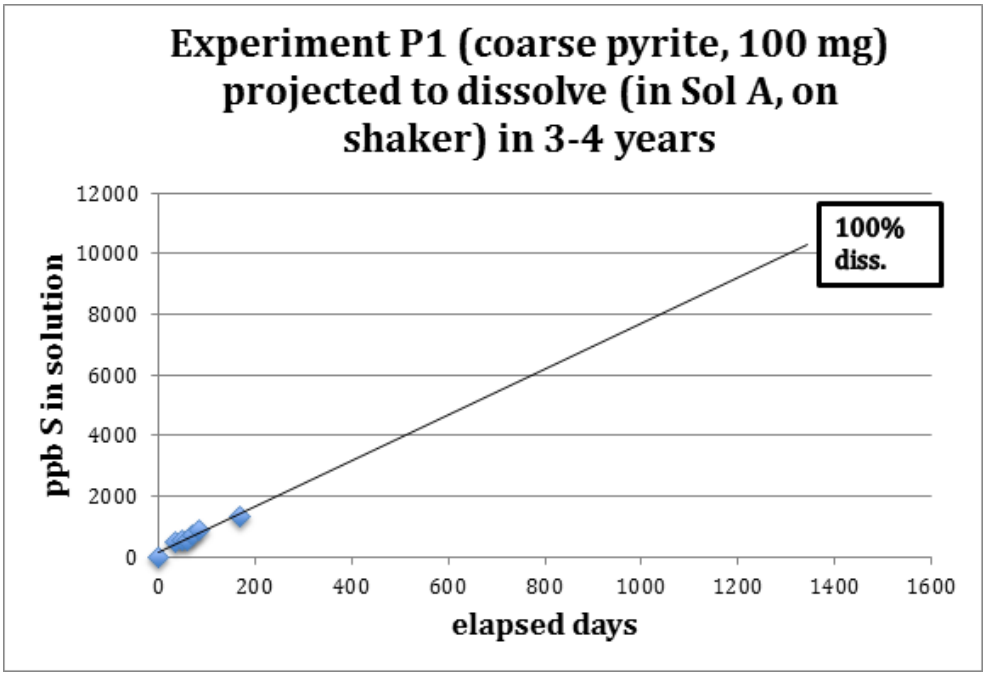

Figure 18. In this experiment, 100 mg of pyrite would be expected to completely dissolve in about 3 to 4 years, when the solution concentration would reach about 11,000 ppb.

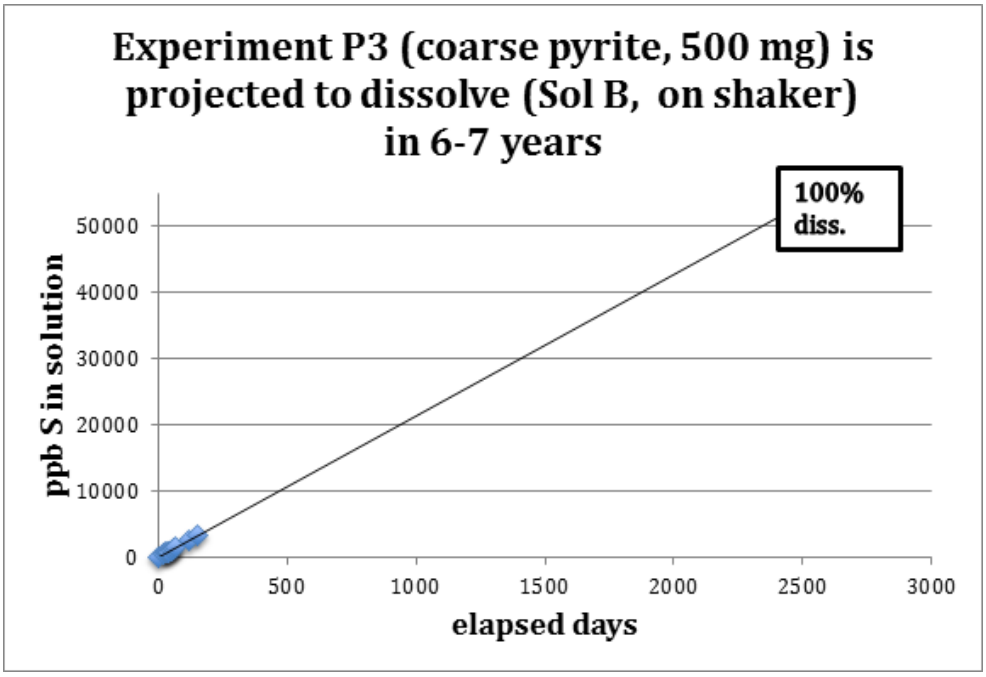

Figure 19. Coarse pyrite reaction in Solution B at 19°C was slower than in Solution A at 19°C on the shaker table (Figure 18). In this experiment, the 500 mg of pyrite are projected to have taken 6 to 7 years to dissolve.

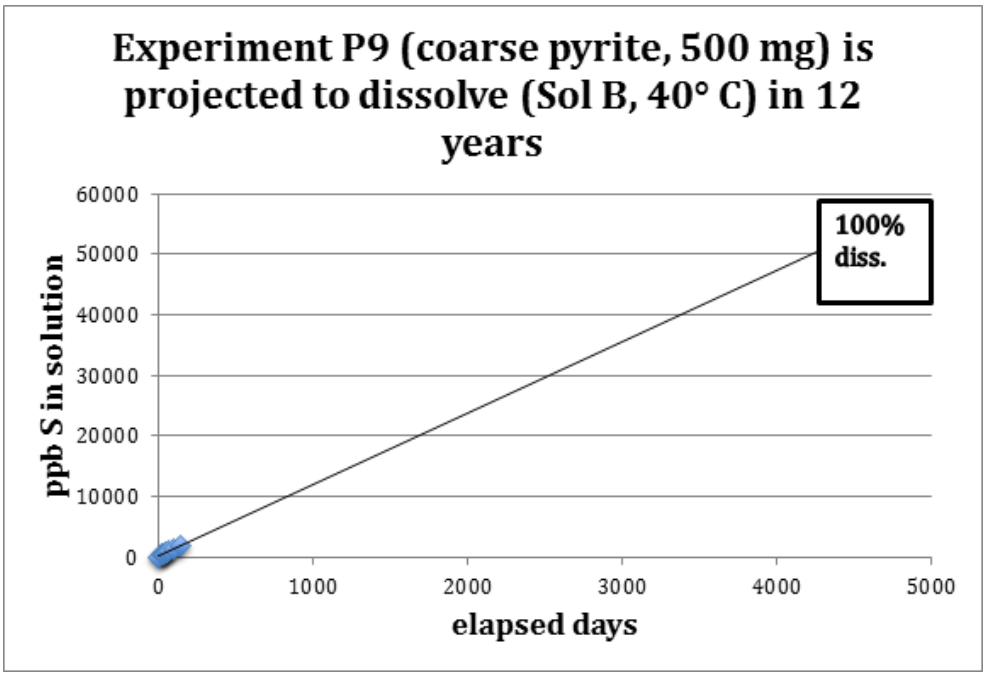

Figure 20. In this experiment, carried out in Solution B, dissolution of the pyrite is indicated to be slower than reactions in Solution A. The 500 mg of pyrite are projected to have taken 12 years to dissolve.

4.0 Interpretation of Results

Except for experiments P4, P8, P104, and P108, experiments in Solution B left open to air (and which hence precipitated thick crusts, probably Na salts) over the pyrite, all pyrite leaching experiments showed significant progress. This progress was indicated by the development of increased sulfur concentrations over time. The salt encrustations of these four reaction series no doubt impeded reaction progress for the two Solution B reactions (P4/P104, P8/P108) that were open to air.

For the other reaction series, the higher reaction rates seen for fine grain size are most significant. For some of the reaction series considerable scatter precludes fitting a single reaction progress line to the concentrations over time. This is probably the result of faults in the experimental design, such as a non-standardized sample collection method. If the leach solutions were highly stratified, as is likely because of their high total dissolved solids concentrations (and hence density), slight differences in the depth of pipette tip insertion into the solution would yield highly variable concentration results.

Coarser grain sizes, such as would be used in water-jet cutting, show reaction rates indicative of complete digestion within a decade. Note that the grain size of this coarse abrasive would be reduced significantly by use. Therefore, it is estimated that reaction times until complete dissolution of pyrite would be bracketed between the “coarse” and “fine” reaction times. This means that dissolution would be complete in less than a decade.

5.0 References

American Society for Testing and Materials (ASTM) Standard A615/A615M. 2003. "Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement." ASTM International, West Conshohocken, Pennsylvania, DOI: 10.1520/A0615_A0615M-12, www.astm.org.

American Society for Testing and Materials (ASTM) Standard A706/A706M. 2003. "Specification for Low-Alloy Steel Deformed and Plain Bars for Concrete Reinforcement." ASTM International, West Conshohocken, Pennsylvania, DOI: 10.1520/A0706_A0706M-09B, www.astm.org.

Klein C and CS Hurlbut. 1985. *Manual of Mineralogy*, 20th ed. John Wiley & Sons, New York.

Data Tables

Appendix

Data Tables

Table A.1. Experiment Key

Experiment	Start Date	
P1	7/31/12	150–1000 μm: NaOH + Shake Table
P2	8/1/12	150–1000 μm: NaOH + Open Air
P3	8/17/12	150–1000 μm: Nitrate/Nitrite + Shake Table
P4	8/17/12	150–1000 μm: Nitrate/Nitrite + Open Air
P5	8/22/12	<53 μm: NaOH + Shake Table
P6	8/22/12	<53 μm: NaOH + Open Air
P7	8/22/12	<53 μm: Nitrate/Nitrite + Shake Table
P8	8/22/12	<53 μm: Nitrate/Nitrite + Open Air
P9	8/22/12	150–1000 μm: Nitrate/Nitrite + 40°C
P10	8/22/12	<53 μm: Nitrate/Nitrite + 40°C
P101	8/31/12	150–1000 μm: NaOH + Shake Table
P102	8/31/12	150–1000 μm: NaOH + Open Air
P103	8/31/12	150–1000 μm: Nitrate/Nitrite + Shake Table
P104	8/31/12	150–1000 μm: Nitrate/Nitrite + Open Air
P105	8/31/12	<53 μm: NaOH + Shake Table
P106	8/31/12	<53 μm: NaOH + Open Air
P107	8/31/12	<53 μm: Nitrate/Nitrite + Shake Table
P108	8/31/12	<53 μm: Nitrate/Nitrite + Open Air
P109	8/31/12	150–1000 μm: Nitrate/Nitrite + 40°C
P110	8/31/12	<53 μm: Nitrate/Nitrite + 40°C

Table A.2. Leach solution concentrations, in ppb (ng/g). Experiment identities (e.g., P1, P2, etc. correspond to those in Table A.1. Experiments with "O" or "G" prefixes have the same starting dates, grain sizes, leaching solution compositions, and conditions as the equivalent experiments with "P" prefixes.

P1

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
14	77	20	21	ND	ND
21	79	15	17	ND	ND
27	ND	ND	ND	ND	ND
36	ND	ND	4	ND	453
44	ND	ND	ND	ND	ND
49	ND	ND	ND	ND	559
55	ND	ND	ND	ND	812
59	ND	41	4	ND	545
66	752	101	135	ND	#NA
71	ND	ND	12	ND	710
77	ND	448	12	ND	3365
86	ND	ND	12	ND	880
135					7328

P2

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
14	78	38	20	ND	566
20	76	12	16	ND	615
26	ND	ND	ND	ND	848
35	ND	11	4	ND	948
43	ND	12	ND	ND	2000
48	ND	11	26	ND	1180
54	ND	ND	ND	ND	1380
58	ND	19	ND	ND	1230
65	178	36	35	535	#NA
70	ND	57	12	ND	1460
76	ND	20	12	ND	2740
85	ND	206	14	ND	1895
134					7533

P3

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
4	112000	342	15	ND	ND
10	81600	673	ND	ND	ND
19	126000	329	ND	ND	390
27	126500	406	ND	ND	546
32	111000	178	ND	ND	587
38	122000	103	ND	ND	691
42	126500	123	ND	ND	757

49	112000	61	21	ND	#NA
54	112000	74	ND	ND	947

Table A.2. (contd)

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
60	117500	64	ND	ND	1100
69	110000	182	ND	ND	1335
118					2426
			P4		
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
4	124000	180	16	ND	ND
10	57400	1800	4	ND	ND
19	145000	175	ND	ND	ND
27	167000	182	ND	ND	ND
32	184000	377	ND	ND	ND
38	234000	184	ND	ND	338
42	101450	118	ND	ND	ND
49	52850	66	18	ND	ND
54	42050	31	ND	ND	341
60	23800	30	ND	ND	ND
69	11750	ND	ND	ND	332
118					368
			P5		
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
5	ND	ND	13	ND	3610
14	ND	ND	4	ND	9275
22	ND	80	12	ND	#NA
27	ND	ND	23	ND	23350
33	ND	ND	ND	ND	36200
37	162	28	34	ND	29850
44	183	29	36	ND	#NA
49	ND	16	12	ND	80050
55	ND	ND	ND	ND	92550
64	ND	ND	13	ND	48150
			P6		
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
5	ND	ND	ND	ND	867
14	ND	37	5	ND	4720
22	ND	21	ND	ND	#NA
27	ND	10	ND	ND	7180
33	ND	11	ND	ND	11950

Table A.2. (contd)

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
37	ND	35	ND	ND	9785
44	182	45	37	154	#NA
49	ND	27	12	ND	27100
55	ND	29	13	ND	30800
64	ND	ND	12	ND	14700
104					95256

P7

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
5	119000	1340	ND	ND	1710
16	241000	816	ND	ND	2410
22	123000	369	ND	ND	#NA[(a)]
27	108500	302	ND	ND	1730
33	116500	267	ND	ND	2045
37	125500	528	ND	ND	2690
44	113500	317	33	ND	#NA
49	111500	160	ND	ND	2835
55	114000	298	ND	ND	3195
64	111000	300	ND	ND	3775
104					5767

P8

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
5	127000	20300	17	ND	ND
14	141500	453	ND	ND	753
22	165000	500	ND	ND	1009
27	195500	531	ND	ND	1240
33	285000	617	ND	ND	1615
37	138500	353	19	ND	950
44	95850	256	19	151	#NA
49	44250	94	5	ND	790
55	33900	73	ND	ND	1040
64	15100	23	ND	ND	1235
104					1415

P9

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
5	142000	406	17	ND	333
14	132500	224	ND	ND	ND
22	137000	474	4	ND	410
27	121500	72	ND	ND	447
33	127500	362	ND	ND	460

Table A.2. (contd)

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
37	129500	220	ND	ND	505
44	118000	151	23	ND	#NA
49	124500	41	ND	ND	651
55	126000	77	ND	ND	712
64	126500	121	ND	ND	875
104					1414

P10

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
5	113000	249	ND	ND	494
14	120500	980	ND	ND	1635
22	134000	949	ND	ND	2110
27	120500	106	ND	ND	1275
33	124500	64	ND	ND	1420
37	132500	122	ND	ND	1605
44	117000	271	24	ND	#NA
49	122000	169	ND	ND	2030
55	121000	40	ND	ND	2115
64	120000	179	ND	ND	2530
104					3925

P101

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
5	ND	14	ND	ND	ND
13	ND	15	ND	ND	1150
18	ND	18	ND	ND	#NA
24	ND	18	22	ND	1595
28	ND	37	ND	ND	873
35	161	37	32	ND	#NA
40	ND	16	10	ND	1450
46	ND	ND	ND	ND	7245
55	ND	ND	ND	ND	1910
106					15500

P102

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
5	ND	14	ND	ND	ND
13	ND	11	ND	ND	ND
18	ND	12	21	ND	ND
24	ND	ND	ND	ND	ND
28	ND	ND	ND	ND	338
35	167	30	34	ND	#NA

Table A.2. (contd)

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
40	ND	11	10	ND	548
46	ND		ND	ND	1370
55	ND		11	ND	814
106					1401

P103

Day	Aluminum Avg	Iron Avg	Magnesium %	Magnesium Avg	Silicon Avg	Sulfur Avg
0						0
5	120000	519	0	ND	ND	ND
13	148500	621	0	ND	ND	ND
18	107500	495	0	11	ND	ND
24	135500	544	0	ND	ND	419
28	121500	435	0	ND	ND	367
35	113500	247	0	29	ND	#NA
40	114000	85	0	4	ND	578
46	113000	41	0	ND	ND	618
55	113500	27	0	ND	ND	799
106						1399

P104

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg	Sulfur %
0					0	
5	118500	473	ND	ND	ND	
13	157500	580	ND	ND	ND	
18	126000	490	ND	ND	ND	
24	149500	598	10	ND	ND	
28	142500	574	ND	ND	ND	
35	138500	594	22	177	ND	
40	102500	457	ND	ND	ND	
46	113000	473	ND	ND	ND	
55	91550	373	5	ND	ND	
106						

P105

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
5	ND	12	ND	ND	1095
13	ND	21	ND	ND	8625
18	ND	20	ND	ND	#NA
24	ND	18	ND	ND	6810
28	ND	16	ND	ND	5320
35	#NA	#NA	#NA	#NA	#NA
40	ND	252	10	ND	14900

Table A.2. (contd)

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
46	ND	ND	ND	ND	23650
55	ND	ND	12	ND	4925
106					30648

P106

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
5	ND	ND	ND	ND	627
13	ND	29	ND	ND	1520
18	ND	ND	ND	ND	#NA
24	ND	ND	ND	ND	#NA
28	ND	#NA	#NA	ND	#NA
35	#NA	#NA	#NA	#NA	#NA
40	ND	ND	ND	ND	#NA
46	ND	ND	ND	ND	#NA
55	ND	ND	10	ND	#NA
106					#NA

P107

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Silicon %	Sulfur Avg
0						0
5	121000	654	ND	ND		663
13	140500	2699	ND	ND		#NA
18	103750	560	16	ND		913
24	136500	629	ND	ND		1200
28	119500	494	ND	ND		1155
35	114500	369	25	ND		#NA
40	112500	256	4	ND		1470
46	116000	285	ND	ND		1690
55	114000	204	ND	ND		1985
106						2968

P108

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
5	136000	578	ND	ND	532
13	149000	2700	ND	ND	#NA
18	120000	531	ND	ND	600
24	154000	718	ND	ND	754
28	148500	717	ND	ND	731
35	148500	758	20	ND	#NA
40	94150	478	5	ND	593

Table A.2. (contd)

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
46	116500	554	ND	ND	697
55	84950	411	ND	ND	677
106					1170

P109

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
5	121500	496	ND	ND	ND
13	144500	507	ND	ND	ND
18	117000	208	ND	ND	ND
24	135000	106	ND	ND	ND
28	125500	50	ND	ND	ND
35	114000	73	42	ND	ND
40	121000	36	ND	ND	454
46	118000	29	ND	ND	523
55	117500	327	ND	ND	683
106					1171

P110

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
0					0
5	124000	1195	ND	ND	1275
13	139500	500	ND	ND	908
18	119000	221	ND	ND	886
24	122000	73	ND	ND	908
28	126500	61	134	ND	985
35	115000	80	35	176	#NA
40	116500	46	ND	ND	1235
46	119500	33	ND	ND	1355
55	116500	24	ND	ND	1625
106					2632

Table A.2. (contd)

O1					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
14	118	345	130	ND	3500
21	82	14	28	ND	ND
27	ND	10	58	ND	ND
36	ND	37	37	ND	ND
44	ND	10	10	ND	ND
49	23	7	7	ND	ND
55	ND	47	ND	ND	ND
59	ND	15	46	ND	ND
O2					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
14	75	33	51	ND	1790
20	78	24	36	ND	ND
26	ND	ND	52	ND	ND
35	ND	ND	46	ND	ND
43	ND	14	72	ND	ND
48	ND	38	ND	ND	ND
54	ND	28	93	ND	ND
58	ND	17	50	ND	ND
O3					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
4	112000	146	21	ND	ND
10	111000	143	ND	ND	ND
19	100650	355	810	849	ND
27	130000	155	ND	ND	ND
32	122000	157	12	ND	ND
38	131500	138	ND	ND	ND
42	123000	166	10	ND	ND
O4					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
4	116000	158	13	ND	ND
10	122000	163	ND	ND	ND
19	152500	173	ND	ND	ND
27	183500	#NA	580	335	ND
32	214500	202	ND	ND	ND
38	271500	186	ND	ND	ND
42	107000	139	43	ND	ND

Table A.2. (contd)

O5					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	ND	ND	ND	ND	ND
14	ND	280	792	860	ND
22	ND	10	4	ND	ND
27	ND	ND	ND	ND	ND
33	ND	ND	25	ND	ND
37	ND	421	1128	1310	ND

O6					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	ND	736	3760	2120	ND
14	ND	487	2755	1568	ND
22	ND	107	604	342	ND
27	ND	ND	85	ND	ND
33	ND	ND	104	ND	ND
37	ND	65	348	251	ND

O7					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	113000	211	304	188	ND
14	246000	324	145	192	ND
22	131500	616	2721	1594	ND
27	116000	214	330	224	ND
33	120000	180	147	ND	ND
37	129000	236	465	279	ND

O8					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	124000	353	554	334	ND
14	151500	177	ND	ND	ND
22	188500	216	ND	ND	ND
27	219500	240	ND	ND	ND
33	272500	238	ND	167	ND
37	106500	121	151	145	ND

O9					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	115000	148	3	ND	ND
14	125000	108	ND	ND	ND
22	133000	172	315	200	ND
27	117000	85	10	ND	ND
33	121500	71	ND	ND	ND
37	126000	600	1670	1810	ND

Table A.2. (contd)

O10					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	115000	145	47	ND	ND
14	122000	257	583	380	ND
22	135000	117	15	ND	ND
27	123000	109	ND	ND	ND
33	128000	109	17	ND	ND
37	137000	156	247	240	ND

O101					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	ND	ND	17	ND	ND
13	20	ND	9	ND	ND
18	ND	14	21	ND	ND
24	ND	ND	ND	ND	ND
28	ND	ND	ND	ND	ND

O102					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	ND	ND	4	ND	ND
13	ND	ND	ND	ND	ND
18	ND	ND	ND	ND	ND
24	ND	ND	ND	ND	ND
28	ND	ND	15	ND	ND

O103					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	122000	465	17	ND	ND
13	143000	496	ND	ND	ND
18	126000	470	ND	ND	ND
24	125500	457	ND	ND	ND
28	123500	448	ND	ND	ND

O104					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	124500	469	ND	ND	ND
13	162000	547	ND	ND	ND
18	132500	491	ND	ND	ND
24	158500	559	ND	ND	ND
28	147500	563	ND	ND	ND

Table A.2. (contd)

Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
O105					
5	ND	ND	15	ND	ND
13	ND	ND	ND	ND	ND
18	20	ND	ND	ND	ND
24	ND	ND	ND	ND	ND
28	149	23	34	ND	ND
O106					
5	ND	ND	14	ND	ND
13	ND	#NA	#NA	#NA	ND
18	ND	ND	ND	ND	ND
24	ND	30	13	ND	ND
28	ND	ND	ND	ND	ND
O107					
5	120000	466	68	ND	ND
13	148500	534	47	ND	ND
18	116500	426	44	ND	ND
24	135000	474	33	ND	ND
28	121500	451	83	ND	ND
O108					
5	134000	499	6	ND	ND
13	164500	574	ND	ND	ND
18	141500	504	ND	ND	ND
24	166500	583	ND	ND	ND
28	152500	554	ND	ND	ND
O109					
5	127500	469	4	ND	ND
13	136500	453	ND	ND	ND
18	118000	400	ND	ND	ND
24	127500	388	ND	ND	ND
28	126500	404	ND	ND	ND

Table A.2. (contd)

O110					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	119500	419	5	159	ND
13	135000	434	ND	189	ND
18	109500	321	ND	171	ND
24	134000	336	ND	ND	ND
28	128000	305	ND	ND	ND

Table A.2. (contd)

G1					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
14	88	154	60	ND	ND
21	105	15	19	ND	ND
27	17	10	ND	ND	ND
36	17	13	8	ND	ND
44	ND	28	ND	ND	ND
49	ND	ND	ND	ND	ND
55	ND	ND	ND	ND	ND
59	ND	ND	ND	ND	ND
G2					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
14	108	44	23	ND	ND
20	102	15	18	ND	ND
26	18	13	14	ND	ND
35	18	10	4	ND	ND
43	40	49	18	ND	ND
48	25	20	ND	ND	ND
54	17	ND	ND	ND	ND
	17	17	ND	ND	ND
G3					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
4	113000	145	14	ND	ND
10	106000	189	ND	ND	ND
19	117500	159	ND	ND	ND
27	127000	197	ND	ND	ND
32	118500	149	ND	ND	ND
38	124500	140	11	ND	ND
42	127000	219	12	ND	ND
G4					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
4	114000	220	13	ND	ND
10	124000	199	ND	ND	ND
19	143000	162	ND	ND	ND
27	171500	265	ND	ND	ND
32	162500	164	ND	ND	ND
38	230500	163	ND	ND	ND
42	137000	124	ND	ND	ND

Table A.2. (contd)

G5					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	91	ND	ND	ND	ND
14	119	11	8	145	ND
22	308	438	156	802	ND
27	121	ND	ND	135	ND
33	128	ND	ND	140	ND
37	127	11	3	138	ND
G6					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	94	12	6	ND	ND
14	148	106	40	199	ND
22	117	178	57	225	ND
27	51	42	11	ND	ND
33	52	30	19	ND	ND
	38	23	13	164	ND
G7					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	115000	562	94	287	ND
16	239000	516	ND	327	ND
22	126000	272	ND	154	ND
27	117000	258	ND	163	ND
33	121500	208	20	164	ND
37	120000	163	ND	157	ND
G8					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	123000	572	88	273	ND
14	147500	261	ND	169	ND
22	159500	296	23	215	ND
27	202000	194	ND	261	ND
33	258500	164	ND	347	ND
37	119000	79	ND	160	ND
G9					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	112000	134	ND	ND	ND
14	117000	99	ND	ND	ND
22	133500	222	5	ND	ND
27	120500	88	ND	ND	ND
33	123000	78	ND	ND	ND
37	131000	131	ND	ND	ND

Table A.2. (contd)

G10					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	132000	419	48	258	ND
14	128500	267	28	251	ND
22	101000	78	ND	200	ND
27	108000	72	8	186	ND
33	126000	76	ND	216	ND
37	135000	158	30	246	ND
G101					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	ND	ND	ND	ND	ND
13	22	ND	ND	ND	ND
18	27	ND	ND	ND	ND
24	31	ND	ND	ND	ND
28	33	43	ND	ND	ND
G102					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	ND	ND	ND	ND	ND
13	17	14	ND	ND	ND
18	25	#NA	ND	ND	ND
24	25	ND	ND	ND	ND
28	97	25	32	ND	ND
G103					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	120000	471	ND	ND	ND
13	140500	496	ND	ND	ND
18	108500	403	ND	ND	ND
24	135500	477	ND	ND	ND
28	121500	442	ND	ND	ND
G104					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	133500	508	7	ND	ND
13	162000	549	ND	ND	ND
18	110500	409	ND	ND	ND
24	160500	616	ND	ND	ND
28	154000	581	26	ND	ND

Table A.2. (contd)

G105					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	110	10	ND	142	ND
13	128	ND	ND	145	ND
18	134	ND	23	153	ND
24	154	ND	ND	170	ND
28	140	19	ND	160	ND
G106					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	102	11	ND	133	ND
13	127	ND	ND	149	ND
18	135	ND	ND	156	ND
24	140	ND	ND	155	ND
28	137	17	ND	148	ND
G107					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	123500	542	ND	ND	ND
13	148500	631	ND	155	ND
18	119000	529	ND	ND	ND
24	140000	629	ND	149	ND
28	119000	508	ND	ND	ND
G108					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	128500	531	ND	ND	ND
13	158000	744	36	208	ND
18	130000	526	ND	ND	ND
24	159500	640	ND	167	ND
28	155000	632	ND	160	ND
G109					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	118000	438	ND	ND	ND
13	145000	497	ND	ND	ND
18	122500	424	8	ND	ND
24	126000	390	ND	ND	ND
28	123500	674	ND	ND	ND

Table A.2. (contd)

G110					
Day	Aluminum Avg	Iron Avg	Magnesium Avg	Silicon Avg	Sulfur Avg
5	121000	491	ND	159	ND
13	141500	476	ND	189	ND
18	114000	289	ND	171	ND
24	129000	130	ND	202	ND
28	126500	93	ND	187	ND

(a) Eliminated due to serial dilution failure.
ND = not detected
NA = Eliminated data (experimental error).

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