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The Reaction of Topopah Spring Tuff with J-13 Water at 150°C—Samples from Drill Cores USW G-1, USW GU-3, USW G-4, and UE-25h#1

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The Reaction of Topopah Spring Tuff with J-13 Water at 150°C—Samples from Drill Cores USW G-1, USW GU-3, USW G-4, and UE-25h#1

Abstract

Samples of Topopah Spring tuff selected from vertical drill holes USW G-1, GU-3, and G-4, and from the horizontal air-drilled hole at Fran Ridge were reacted with J-13 water at 150°C. The primary purpose of these experiments was to compare the resulting solution chemistries to estimate the degree of homogeneity that might be expected in thermally affected ground water in a potential nuclear waste repository at Yucca Mountain. The second purpose was to relate data obtained from welded devitrified Topopah Spring tuff collected from the potential repository depth to that previously obtained using outcrop samples.

The results show very similar aqueous phase chemistries for all samples after reaction for times up to 70 days. The largest difference in final solution concentrations was for silica in one of the samples from Fran Ridge. All vertical drill core samples gave results for silica that were in agreement to within ± 6 ppm and indicated solubility controlled by cristobalite.

The results for reaction at 150°C are in agreement with those obtained in previous experiments using surface outcrop samples from Fran Ridge. The major difference between the drill core results and the outcrop samples is found in the data for room-temperature rinse solutions. The outcrop samples show relatively large amounts of soluble salts that can be easily removed at room temperature. The data for room-temperature rinsing of drill core samples show no significant quantities of readily soluble salts. This result is particularly significant for the samples from the air-drilled hole at Fran Ridge, since drilling fluid that might have removed soluble salts was not used in the portion of the hole from which the samples were obtained. This result strongly suggests that the presence of soluble salts is a surface evaporation phenomenon, and that such materials are unlikely to be present at the depth of the repository.

Introduction

The Nevada Nuclear Waste Storage Investigations Project (NNWSI) is studying a site at Yucca Mountain, Nevada, to assess its suitability for use as a high level nuclear waste repository. As part of the NNWSI Project, Lawrence Livermore National Laboratory (LLNL) is responsible for the design of waste packages and the testing of waste package components to determine the expected performance of the waste packages under repository disposal conditions.

The reference repository horizon for NNWSI is a welded, devitrified portion of the Topopah Spring Member of the Paintbrush Tuff. The rock is predominantly a fine-grained intergrowth of quartz, alkali feldspar, and cristobalite, with a small proportion of minor or trace phases and phenocrysts (Bish et al., 1981; Vaniman et al., 1984). The phenocryst minerals are plagioclase, alkali feldspar, and iron-titanium oxides, with rare quartz and biotite (Bish et al., 1981). At Yucca Mountain, this portion of the tuff is in the unsaturated zone; the water table lies hundreds of feet below the potential repository horizon (U.S. Department of Energy, 1984).

The performance of waste packages must be understood and predicted for times of 10,000 years or more. Successful prediction of performance for these long times requires a thorough understanding of the physical and chemical conditions to which the packages will be subjected. Corrosion of the metal containment barrier and the rate of release of radionuclides from the waste form will depend strongly on the chemistry of fluids that contact the waste packages. Radioactive decay in the waste produces heat, which increases the temperature of the rock surrounding the waste packages. The heated rock will react with any water that infiltrates the repository region, and may cause changes in the water chemistry.

The expected conditions in the unsaturated zone will limit the temperature at which liquid water can contact waste packages. For the expected case with no substantial impediment to water drainage through pores and fractures in the rock, the boiling point of unconfined water will be approximately 95°C. Water contained in pores in

the rock is subject to capillary forces and may reach somewhat higher temperatures. Experiments have been conducted using samples of Topopah Spring tuff collected from an outcrop at Fran Ridge and portions of drill core from USW G-1. These samples were reacted with J-13 well water at 90 and 150°C. Results from drill core samples were consistent with those obtained from outcrop samples, provided that the soluble salts associated with the outcrop material were removed before reaction. Details of these experiments are presented in Knauss et al. (1985) and Oversby (1984a).

Chemical and mineralogical variability in the Topopah Spring tuff could lead to differences in the chemistry of water reacted with the tuff at elevated temperatures. To assess the potential for such variations, samples of tuff were selected from three of the vertical drill holes that surround the repository exploration block and from the air-drilled horizontal hole at Fran Ridge. The latter hole is on the opposite side of Fran Ridge to the outcrop from which previous samples had been collected. The locations of the drill holes, outcrop, and J-13 well are shown in Fig. 1. Several samples were selected from each drill hole to provide an estimate of vertical as well as horizontal variation. Each sample was tested for the presence of readily soluble salts by rinsing at room temperature with J-13 water. Samples were then reacted with J-13 water at 150°C.

The elevation at J-13 is lower than at Yucca Mountain, and the Topopah Spring tuff (Tpt) lies below the water table. The Tpt is the major producing horizon for J-13; thus, the water chemistry is probably close to the prevailing chemistry in the Tpt at Yucca Mountain, where the unit is in the unsaturated zone. Water samples have not yet been obtained from the unsaturated Tpt, but collection of such samples is planned as part of the exploratory shaft testing program. Until water samples are available from the unsaturated repository horizon, the water from well J-13 has been adopted as a reference water chemistry for NNWSI experimental work.

Figure 1. Map showing the location of Yucca Mountain, Fran Ridge, and well J-13. The outcrop locality for rock samples used in this work is marked Tpt-FR; Tcfb-TS is the outcrop locality for Bullfrog tuff samples. Other localities marked are drill holes.

Experimental Procedure

Rock Sample Selection and Preparation

Samples were selected from drill cores USW G-1, GU-3, and G-4 at depths representative of the reference repository horizon. Material from the horizontal drill hole at Fran Ridge was obtained from Gary Dixon, USGS. Approximately one-third to one-half of the original sample was broken off of each piece of core for use in these experiments. The remainder of the sample was archived for use in future work.

Each core sample was initially crushed using a small ceramic jaw crusher and then further processed through a small ceramic plate grinder. Crushing was continued until all material passed a 100 mesh screen (opening size 150 μm). Crushed samples were placed in a polyethylene container and homogenized using a SpexMill shaker for 5 min. The sample was then split using a micro-splitter, and the splits were homogenized using the shaker. All crushing equipment was cleaned between each sample crushing.

Rock-Water Reaction

The water used in these experiments was obtained from well J-13 at the Nevada Test Site (shown in Fig. 1). Water sampling and storage procedures are described in Oversby (1984a). All experiments were conducted in Teflon capsules encased in metal containers. Standard Parr Acid Digestion Bombs (model number 4745) were used. The bombs were cleaned at 150°C before use by the procedure given in Oversby (1984a).

The first series of experiments used all 14 rock samples and was conducted using a procedure modified from the standard rock-water interaction procedure described by Oversby (1984a). The purpose of the modification was to investigate the sequential effects of the reaction of the same rock sample with fresh ground water. The experiments used 0.8 g of rock powder and 12 ml of J-13 water for each reaction step. The rock sample was weighed into a Teflon capsule and then the water was added by weight. The capsule was sealed and the unit was shaken by hand for 2 min. The rock powder was then allowed to settle and the rinsing solution was removed by decanting, leaving the rock powder in the Teflon cup. Solutions were filtered through #40 filter paper and then through 0.1- μm filters. The filtered solutions

were split into three portions: (1) for anion analysis, stored in a plastic tube; (2) for alkalinity, stored in glass; and (3) for cation analysis, acidified with 2 drops of 50% HNO_3 per 6 ml of solution and stored in plastic tubes. This procedure is described in more detail in Oversby (1984a) as the room-temperature pretreatment step. For the results of the first experiment series these samples are called Day 0.

Following completion of the room-temperature rinse, fresh J-13 water was added to the capsules and the sealed capsules were placed upright on the floor of an oven set at 150°C. The samples remained in the oven for 24 hours, were removed and allowed to cool until they could be opened, and the liquid was decanted as described above. Solutions were filtered and split for analyses as above. These samples are referred to as Day 1 in the results tabulation.

Fresh J-13 water was added to the samples and the closed capsules were placed in the oven on a roller assembly. This device provides a slow rolling motion of the vessels and prevents the rock powder from sticking to the bottom of the capsule. Samples were left in the roller oven for two or three days. At the end of the specified period, the bomb assemblies were placed upright on the floor of the oven for two hours to allow the solids to settle to the bottom of the capsule and facilitate removal of the liquid. Decanting and sampling were done as described above; in addition, the pH of the anion split was measured. These samples are labeled Day 3 or Day 4 in the results tabulation. The day designation is measured from the start of the experiment, so Day 3 samples represent 2 days of reaction of the fresh J-13 with the rock. Up to this point the procedure was identical to the standard reaction procedure with the pretreatment steps described by Oversby (1984a).

The variation in the standard procedure used in these experiments was to add fresh J-13 water to the rock after its initial 2- or 3-day reaction period and then to repeat the reaction step. Samples treated for 2 days in the first reaction step were then treated for 3 additional days. This produced samples labeled in the results as Day 6. Sampling procedures were identical to those used for the first reaction step. Samples initially treated for 3 days did not undergo an additional short reaction interval. Following sampling at Day 4 or Day 6, fresh J-13 water was added to the rock and

the samples were returned to the oven, where they remained until 70 days after the start of the experiment, at which time final samples were taken. Rock powders were then recovered and stored as described by Oversby (1984a).

The first experiment series was run from April through July 1983, and solution analyses were completed in September 1983. Based on the results of the first experiments, a second series of experiments using three of the rock samples was planned. The second series followed the standard experimental procedure with the optional pretreatment step being used for each sample. In addition, one of the samples was tested without applying the pretreatment step. The sample weight used was 0.8 g, and reaction times at 150°C were 12, 20, 36, and 48 days. Weight loss of the capsule, which corresponds to loss of fluid by evaporation, was monitored for each test. The maximum weight loss was 5 to 6% for the longest tests. The pH measurements were made before filtration of the samples to avoid equilibration of the solution with atmospheric CO₂. These experiments were run from February through April 1984. Analyses were performed on solutions from March through June 1984.

Cation analyses were performed using an automated inductively coupled plasma (ICP) spectrometer system. Details of the system are given by Peck et al. (1979). The system uses a polychromator operated in the fixed-channel mode, giving simultaneous analysis for 28 elements. The system is calibrated with standard solutions, and the operator employs a "check standard" that is run as a regular sample during each series of analyses. During the course of these experiments some difficulties were encountered with results for boron. The difficulty was identified through the use of control blank samples of J-13 water that are regularly submitted along with the hydrothermal test solutions. The control blanks are given identification numbers that make them appear to the ICP operator to be part of the hydrothermal test set.

Table 1 gives a summary of results on J-13 control blank samples. Analyses for which there are no boron data represent the problem period.

The boron content for these samples was reported as below detection limits. The problem was subsequently identified as having been caused by incorrect data storage and reduction in the computer control system. This resulted in reporting results for boron that were systematically low by about 0.1 ppm. Since this is approximately the boron concentration in J-13 water, the results for boron were reported near or below the detection limit (i.e., close to zero). The boron problem was corrected in May 1984. Table 1 gives the standard deviation of the population for the control blank analyses. The precision of an individual analysis should be similar to that of the control blanks since the compositions of the reacted solutions are quite similar to the starting J-13 composition.

Anion analyses were performed using a Dionex Model 2110i Ion Chromatograph with a "fast run" AS4 separator column and an anion fiber suppressor. Detection limits are 0.1 ppm for chloride and fluoride, and 0.2 ppm for nitrate and sulfate. Alkalinity measurements were made using a Technicon Autoanalyzer, an automated version of the standard alkalinity titration. This measures the sum of the OH⁻, HCO₃⁻, CO₃²⁻, and any titratable anions, such as H₃SiO₄⁻, in solution. For samples with pH in excess of 8.0 with significant amounts of silica in solution, the latter species can make a substantial contribution to alkalinity.

Data for control blank samples of J-13 for anion and alkalinity measurements are given in Table 1, parts b and c. Data for anion analyses on 8/30/83 are systematically low and have been excluded from the averages in the row labeled "Reaverage." Analyses for nitrate were erratic during the period from 3/30/84 through 5/10/84. The problem was traced to a batch of plastic tubes that had been cleaned in nitric acid and were not rinsed sufficiently to remove all traces of the acid. Nitrate concentrations for the period before the discovery of the test tube rinsing problem may be high by random amounts, and should be disregarded. This involves all samples from the second experiment series. For properly rinsed test tubes, the precision of nitrate analyses should be comparable to that of sulfate analyses.

Table 1a. Data for cation concentrations in J-13 control blanks, mg/l.

Date	Al	B	Fe	Si	Ca	K	Mg	Na	Li
7/19/83	0.009	0.121	0.009	27.0	11.9	5.46	1.88	43.4	
8/04/83	0.003		0.002	26.2	13.5	5.19	2.07	44.9	
9/13/83	0.001	0.120	0.002	27.0	12.8	4.54	1.91	43.3	
10/24/83	0.013	0.125	0.008	26.9	13.3	4.89	1.93	43.6	
12/06/83	0.012		0.004	27.5	12.5	5.09		45.5	
12/16/83	0.012			27.5	12.5	5.09		45.5	
Av2/15/84	0.040		0.015	26.2	12.2	4.73	1.90	41.2	
3/07/84	0.009		0.004	27.8	10.5	5.67	1.86	43.3	
Av3/07/84	0.011		0.004	27.0	13.0	5.51	1.92	43.4	
4/09/84	0.015			28.1	14.8	5.00	1.96	50.2	0.051
Av6/13/84	<0.002	0.138	0.005	27.3	12.8	5.10	1.92	44.7	0.042
6/19/84	<0.002	0.137		26.6	12.9	4.81	1.84	46.9	0.043
6/20/84	0.028	0.146	0.017	27.5	12.8	5.57	1.98	45.2	0.043
Av6/22/84	0.019	0.137	0.015	26.6	12.6	4.92	1.91	44.5	0.042
Average	0.014	0.132	0.008	27.1	12.7	5.11	1.92	44.7	0.0441
Std dev	0.011	0.009	0.005	0.54	0.89	0.32	0.06	2.0	0.0032

Table 1b. Anion concentrations in J-13 control blanks, mg/l.

Date	F	Cl	NO ₃	SO ₄
8/30/83	1.8	5.3	6.4	13.4
9/30/83	2.3	6.8	9.3	19.8
Av3/14/84	2.3	6.6	9.0	18.1
Av3/26/84	2.4	7.1	9.2	18.5
3/30/84	2.3	6.8	18.0	19.0
4/02/84	2.4	7.0	9.1	19.0
4/03/84	1.3	7.4	13.1	18.6
5/04/84	2.3	6.9	7.0	18.4
5/04/84	2.3	6.9	6.4	18.5
5/10/84	2.2	6.9	5.4	18.4
Average	2.2	6.8	9.3	18.2
Std dev	0.33	0.53	3.57	1.65
Reaverage	2.2	6.9	9.6	18.7
New std dev	0.32	0.21	3.63	0.47

Table 1c. Alkalinity by Technicon Autoanalyzer, J-13 control blanks.

Date	meq/l	HCO ₃ (ppm)
7/27/83	2.29	140
8/05/83	2.13	130
5/02/83	2.16	132
1/11/84	2.46	150
3/13/84	2.10	128
Average	2.23	136
Std dev	0.13	8.1

Results and Discussion

The rock samples used in these experiments were selected to be representative of the mineralogy of the repository horizon. Samples were taken from drill core USW GU-3 at depths of 1057.5, 1072.5, 1096.0, and 1120.7 ft, which covers the central portion of the potential repository horizon. Vaniman et al. (1984) have described the mineralogy and petrology of samples taken from this drill core. For this horizon, the Topopah Spring Member consists of approximately 20% quartz, 10% cristobalite, and 70% alkali feldspar. Trace phases are biotite (~1% at 1130 ft), smectite clay (<1%), and manganese-rich phases that generally occur as fracture coatings. Calcite and fluorite also occur as rare authigenic minerals; a sample taken from a fracture at a depth of 1027 ft contains about 40% each of calcite and fluorite (Vaniman et al., 1984). The groundmass texture is generally either cryptocrystalline or spherulitic at this depth in the Topopah Spring tuff.

Samples were selected from drill hole USW G-1 at depths of 1068.7, 1123.6, 1159.0, and 1246.9 ft. The mineralogy and petrology of this drill core has been described by Bish et al. (1981). They examined thin sections from 1191-, 1240-, and 1286-ft depths and give x-ray diffraction data for these and five other depths ranging from 1063 to 1274 ft. The average proportion of major minerals is 15% quartz, 40% cristobalite, 40% alkali feldspar, and 5% montmorillonite clay. The thin sections showed the rock to be densely welded, with primary devitrification followed by vapor phase alteration during cooling of the rock, and later diagenetic recrystallization. The 1286-ft sample, which is within a meter of the virophyre, had veins filled with clinoptilolite, and the rock within a millimeter of the vein was altered to clinoptilolite and clay. The texture showed primary spherulites of cristobalite and alkali feldspar transgressing all vitric boundaries. The sample from 1240 ft, near the bottom of the potential repository horizon, was similar to the 1286-ft sample, but the vein filling material was quartz rather than clinoptilolite. The 1191-ft sample was also similar, but had veins that showed some leaching and had no filling material. All three samples had iron-titanium oxides with slight oxidation (ilmenite-magnetite). The 1240-ft sample contained a trace amount of altered pyroxene. Clinoptilolite was noted to be limited to minor occurrences of fracture filling or lining cavities in the region of the core above 1280-ft depth (Bish et al., 1981).

Warren et al. (1984) provide a description of the minor and trace phases in the USW G-1 drill core. They give the abundance of such phases in the thin sections from 1191 and 1240 ft based on point counting of 500 points. The 1191-ft sample contains 1.2% lithic fragments, 1.8% felsic fragments (of which 91% are plagioclase), and the following accessory phases given in ppm by volume: allanite, 280; apatite, 8; zircon, 21; iron-titanium oxides, 590; and biotite, 290. The 1240-ft section contained 3.2% lithic fragments, 2.6% felsic fragments (82% plagioclase), and trace phases in ppm by volume of apatite, 8; zircon, 17; iron-titanium oxides, 460; and biotite, 280.

Samples from USW G-4, the principal borehole for the Exploratory Shaft, were taken at depths of 1181.9, 1210.3, and 1230.8 ft. The preliminary lithologic log for this drill hole describes samples from 1127.9 and 1293.0 ft. Both samples are described in the core log as densely welded, devitrified ash flow tuffs containing about 1% phenocrysts. The 1127.9-ft sample contains an average of 13% lithophysae; the other sample contains no lithophysae. The log notes that small amounts of lithophysal cavities (less than 2%) were found between 1180 and 1190 ft.

The samples from the horizontal hole at Fran Ridge (UE-25H#1) were taken from the air-drilled section. The distances refer to distance from the exterior surface of the rock into the ridge. Samples were taken at 78.2, 125.8, and 176.5 ft into the hole. There is no detailed description of this material. Knauss (1984) discussed the relationship of the Fran Ridge outcrop to the drilling pad for the horizontal drill core. He concluded that they are in approximately the same portion of the Topopah Spring stratigraphic section, and that they are in a welded, devitrified interval of the tuff that lies above the potential repository horizon.

Anion data for the room-temperature rinse solutions and the sequential reaction stages at 150°C are given in Tables 2 through 5. The data marked as suspected to be low were from analyses run on 8/30/83 in a set for which the control blank sample gave low values. Comparison of the data in Tables 2 through 5 with the average value measured for J-13 water in Table 1 shows that there is no detectable increase in the anion content of the water due to reaction with the rock. Nor is there any increase in anion content of the water during the room-temperature rinsing stage. The outcrop samples from Fran Ridge would give

Table 2. Fluoride concentration, mg/l.^a

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	2.1	2.7	2.1		2.3	3.0
GU-3 1072.5	2.1	3.5	2.8		3.1	3.7
GU-3 1096.0	2.5	2.3	2.2		2.5	3.5
GU-3 1120.7	2.1	2.6	2.2		2.1	2.5
G-4 1181.9	2.1	2.2	5.3		2.3	3
G-4 1210.3	2.1	2.3		5.2		3
G-4 1230.8	2.1	2.3	4.5		2.4	3
G-1 1068.7	2.1	2.2		4.8		2
G-1 1123.6	2.0	2.2		3.1		2
G-1 1159.0	2.0	2.0		5.9		2
G-1 1246.9	2.3	2.3		4.2		3
UE-25h#1 78.2	2.4	2.3	3.9		2.6	3
UE-25h#1 125.8	2.4	2.3	4.1		2.2	2
UE-25h#1 176.5	2.2	2.2	4.1		2.4	2

^a Data given to one significant figure are suspected to be low by 0.5 ppm.

Table 3. Chloride concentration, mg/l.^a

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	7.1	6.6	6.3		6.8	9.0
GU-3 1072.5	6.7	6.2	6.8		6.6	7.0
GU-3 1096.0	6.6	6.3	6.7		6.6	7.9
GU-3 1120.7	6.7	6.5	7.0		6.7	8.2
G-4 1181.9	7.0	6.4	7.0		6.5	6
G-4 1210.3	6.5	6.7		7.4		7
G-4 1230.8	6.8	6.7	6.7		6.4	8
G-1 1068.7	6.7	6.7		7.0		6
G-1 1123.6	6.6	6.7		7.0		7
G-1 1159.0	8.3	6.8		7.4		6
G-1 1246.9	6.8	6.7		7.0		7
UE-25h#1 78.2	7.7	6.7	7.2		6.4	7
UE-25h#1 125.8	7.5	6.4	6.7		6.7	6
UE-25h#1 176.5	7.6	6.4	6.8		6.7	6

^a Data given to one significant figure are suspected to be low by 1.5 ppm.

Table 4. Nitrate concentration, mg/l.^a

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	6.2	6.2	7.0		7.0	8.9
GU-3 1072.5	6.3	6.1	7.5		7.5	8.4
GU-3 1096.0	6.1	6.3	7.5		7.5	16.0
GU-3 1120.7	6.1	6.1	7.0		7.2	8.9
G-4 1181.9	7.0	7.5	7.5		7.5	7
G-4 1210.3	7.0	7.7		7.8		7
G-4 1230.8	7.2	7.8	7.7		7.5	8
G-1 1068.7	7.7	7.7		7.8		7
G-1 1123.6	7.5	7.7		7.2		7
G-1 1159.0	7.2			7.5		7
G-1 1246.9	7.3	7.7		7.2		8
UE-25h#1 78.2	7.5	7.5	7.9		7.2	7
UE-25h#1 125.8	7.2	7.2	7.8		7.5	7
UE-25h#1 176.5	7.2	7.7	7.8		7.5	7

^a Data given to one significant figure are suspected to be low by 1.5 ppm.

Table 5. Sulfate concentration, mg/l.^a

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	17.5	17.2	16.0		16.4	20.9
GU-3 1072.5	16.4	16.4	15.8		16.5	17.3
GU-3 1096.0	17.7	16.5	16.2		16.0	19.7
GU-3 1120.7	16.5	16.5	17.2		17.2	18.0
G-4 1181.9	17.0	17.2	17.6		16.4	14
G-4 1210.3	16.2	17.7		17.7		16
G-4 1230.8	17.3	17.6	17.3		16.5	19
G-1 1068.7	16.9	17.0		17.2		14
G-1 1123.6	16.6	17.3		17.3		14
G-1 1159.0	16.2	16.2		17.0		14
G-1 1246.9	16.5	17.2		17.0		17
UE-25h#1 78.2	19.0	17.4	18.0		16.9	15
UE-25h#1 125.8	17.6	17.4	17.6		16.9	15
UE-25h#1 176.5	17.0	17.3	18.2		17.0	14

^a Data given to one significant figure are suspected to be low by 5 ppm.

nitrate and sulfate concentrations of approximately 70 ppm during the room-temperature rinse (Oversby, 1984b). The UE-25h#1 samples, obtained from the other side of Fran Ridge but a minimum of 78 ft from the rock surface, are free of readily soluble anion material. This strongly suggests that the presence of readily soluble salts is due to evaporation processes associated with near-surface rock samples, and that this type of material should not occur at the repository depth.

Data for pH of the solutions following reaction and for alkalinity are given in Tables 6 and 7. Carbon dioxide appears to migrate into or through the Teflon capsules with time (Oversby, 1984b). A large portion of the increase in pH and decrease in alkalinity after 70 days of reaction is probably due to the loss of carbon dioxide to the capsules. The alkalinity for 70-day samples will contain some contribution from H_3SiO_4^- because of the relatively high pH.

Aluminum concentrations are given in Table 8, boron in Table 9, iron in Table 10, and manganese in Table 11. For the room-temperature rinse solutions, several samples show rather high aluminum (G-4 1210 and 1230, and G-1 1159). Those samples also show high iron and manganese, suggesting that the origin of this material is associated with the manganese-rich phases discussed above. Boron for these samples is normal. The three samples from UE-25h#1 show moderate aluminum in the rinse solutions, but iron and manganese comparable to the high-Al G-1 and G-4 samples. These samples also show high boron, the origin of which is not known.

Aluminum concentrations in the Day 1 reacted samples are from 1 to 3 ppm, and between 0.3 and 2 ppm for 2 days of reaction (Day 3 samples). This is consistent with results from the Fran Ridge outcrop samples, which showed an early peak in aluminum followed by a slow decrease with time (Oversby, 1984a). Aluminum for the 3-day reaction interval (Day 6 samples) is somewhat higher than expected for the GU-3 samples and correlates with high iron and manganese. For other 3-day reaction time samples (Day 4 or 6) aluminum, iron, and manganese are at expected levels. Aluminum and iron concentration values after 70 days of total reaction time (reaction interval of 64 or 66 days) are consistent with those found for 31- and 48-day reaction times from outcrop samples (Oversby, 1984a). Boron results are low throughout for the vertical drill core samples and slightly above the J-13 level for the horizontal hole at Fran Ridge.

Silicon data are found in Table 12. Rinse samples show a lower concentration than in J-13, indicating some precipitation of silicon. Silicon in solution increases with reaction time for all samples except the GU-3 1072 Day 70 sample, the Day 1 vs Day 3 samples for GU-3 1096 and UE-25h#1 78, and the Day 3 vs Day 6 sample for UE-25h#1 78. The low silicon in the Day 70 sample for GU-3 1072 ft appears to be an analytical error. Data for 48 days of reaction for this sample show normal silicon (see below). The concentrations of boron, calcium, and sodium for the Day 70 sample are also low, suggesting that the sample analysis is in error, perhaps due to aspiration of air along with the liquid. Final silicon concentrations for all three of the samples discussed above are low; for this reason a second series of experiments using these three samples was conducted. Results are discussed below.

Data for calcium are given in Table 13. All rinse solutions except the G-1 1246-ft sample have lower concentrations of calcium than J-13 water, indicating some precipitation of calcium. Concentrations of calcium after 1 day of reaction time are consistently lower than those after 2 (Day 3) or 3 (Day 4 or 6) days of reaction. This suggests that calcium initially precipitated and then partially redissolved. Final calcium concentrations are similar to those found using outcrop samples (Oversby, 1984a). Magnesium concentrations (Table 14) are somewhat lower than J-13 values in the room temperature rinse solutions, and are very low in all samples reacted at 150°C, as was found in previous work with outcrop samples.

Potassium concentrations (Table 15) in the room temperature rinse solutions and in the first of the 150°C reacted samples are higher than in J-13 water. Sodium concentrations (Table 16) for these samples are similar to J-13, with the suggestion of somewhat higher values in the Day 1 samples. The highest values are found for the Fran Ridge samples, which showed somewhat high boron concentrations. The results suggest that the phase responsible for the boron and potassium in solution might be trace amounts of alkali borate salts. Potassium decreases below J-13 concentrations with time, while sodium stays at essentially the same level. Potassium results for outcrop samples were somewhat higher than J-13 concentration for all reaction times, with the average value being about 9 ppm for times between 2 and 48 days (Oversby, 1984a).

Based on results from the first series of experiments, three samples were selected for further

Table 6. Final pH.

Sample No.	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	7.87		7.88	9.18
GU-3 1072.5	7.54		7.53	8.74
GU-3 1096.0	7.62		7.39	8.94
GU-3 1120.7	7.66		7.59	8.89
G-4 1181.9	7.48		7.42	8.77
G-4 1210.3		7.37		8.60
G-4 1230.8	7.28		7.60	8.96
G-1 1068.7		7.57		8.74
G-1 1123.6		7.54		8.70
G-1 1159.0		7.62		8.76
G-1 1246.9		7.59		8.76
UE-25h#1 78.2	7.69		7.75	9.23
UE-25h#1 125.8	7.75		7.61	9.13
UE-25h#1 176.5	7.70		7.93	9.06

Table 7. Alkalinity, meq/l.

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	1.95	1.88	1.66		1.88	1.53
GU-3 1072.5	1.83	1.85	1.65		2.05	1.32
GU-3 1096.0	1.90	1.86	1.86		1.65	1.39
GU-3 1120.7	1.79	1.74	1.74		2.10	1.34
G-4 1181.9	1.83	1.90	1.76		1.60	1.54
G-4 1210.3	1.95	1.98		1.73		1.60
G-4 1230.8	1.77	1.97	1.68		1.38	1.42
G-1 1068.7	1.93	1.77		1.60		1.52
G-1 1123.6	1.90	1.51		2.73		1.54
G-1 1159.0	1.91	1.66		1.46		1.53
G-1 1246.9	2.04	1.85		1.97		2.14
UE-25h#1 78.2	1.80	2.11	2.33		1.71	1.67
UE-25h#1 125.8	2.03	2.04	1.86		1.70	1.88
UE-25h#1 176.5	1.89	2.10	1.79		1.67	1.55

Table 8. Aluminum concentration, mg/l.

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	0.09	2.27	1.44		3.40	0.31
GU-3 1072.5	0.09	2.04	1.20		4.97	0.32
GU-3 1096.0	0.10	1.64	0.97		3.42	0.96
GU-3 1120.7	0.07	2.08	1.27		1.86	0.34
G-4 1181.9	0.08	1.99	0.45		0.73	0.99
G-4 1210.3	0.84	1.82		0.84		0.46
G-4 1230.8	1.08	1.73	0.33		0.47	0.88
G-1 1068.7	0.03	1.58		0.45		0.96
G-1 1123.6	0.04	0.88		1.29		0.77
G-1 1159.0	1.90	1.05		0.37		0.77
G-1 1246.9	0.12	0.72		0.71		0.70
UE-25h#1 78.2	0.14	3.23	2.68		2.24	1.47
UE-25h#1 125.8	0.21	2.68	1.17		1.61	1.25
UE-25h#1 176.5	0.18	2.82	1.59		2.17	0.45

Table 9. Boron concentration, mg/l.

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	0.105	0.119	0.102		0.108	0.129
GU-3 1072.5	0.106	0.120	0.111		0.114	0.074
GU-3 1096.0	0.104	0.111	0.107		0.106	0.114
GU-3 1120.7	0.102	0.128	0.113		0.111	0.119
G-4 1181.9	0.102	0.126	0.113		0.105	0.145
G-4 1210.3	0.096	0.122		0.116		0.133
G-4 1230.8	0.099	0.129	0.108		0.106	0.151
G-1 1068.7	0.099	0.130		0.115		0.149
G-1 1123.6	0.099	0.131		0.114		0.141
G-1 1159.0	0.098	0.134		0.116		0.144
G-1 1246.9	0.096	0.121		0.107		0.133
UE-25h#1 78.2	0.132	0.157	0.138		0.116	0.218
UE-25h#1 125.8	0.241	0.148	0.124		0.119	0.203
UE-25h#1 176.5	0.115	0.129	0.115		0.108	0.153

Table 10. Iron concentration, mg/l.

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	<0.002	0.007	0.017		0.144	0.051
GU-3 1072.5	<0.002	0.003	0.016		0.226	0.066
GU-3 1096.0	<0.002	<0.002	0.023		0.259	0.126
GU-3 1120.7	<0.002	0.004	0.073		0.087	0.051
G-4 1181.9	0.004	0.003	0.007		0.019	0.064
G-4 1210.3	0.027	0.004		0.019		0.031
G-4 1230.8	0.065	0.008	0.006		0.006	0.053
G-1 1068.7	<0.002	0.002		0.011		0.047
G-1 1123.6	<0.002	0.015		0.053		0.053
G-1 1159.0	0.028	0.008		0.036		0.028
G-1 1246.9	0.003	0.002		0.024		0.050
UE-25h#1 78.2	0.018	0.006	0.963		0.005	0.105
UE-25h#1 125.8	0.036	0.002	0.009		0.006	0.114
UE-25h#1 176.5	0.014	0.015	0.008		0.004	0.035

**Table 11. Manganese concentration, mg/l.
J-13 Mn < 0.0006 mg/l.**

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	0.011	0.001	0.008		0.021	0.001
GU-3 1072.5	0.009	0.002	0.009		0.032	0.004
GU-3 1096.0	0.006	0.001	0.005		0.019	0.002
GU-3 1120.7	0.011	0.001	0.025		0.012	0.002
G-4 1181.9	0.012	0.006	0.002		0.009	0.012
G-4 1210.3	0.025	0.006		0.012		0.005
G-4 1230.8	0.043	0.009	0.002		0.003	0.012
G-1 1068.7	0.008	0.004		0.004		0.008
G-1 1123.6	0.008	0.005		0.031		0.007
G-1 1159.0	0.025	0.004		0.003		0.005
G-1 1246.9	0.007	0.032		0.011		0.014
UE-25h#1 78.2	0.022	0.010	0.026		0.002	0.035
UE-25h#1 125.8	0.023	0.007	0.002		0.002	0.016
UE-25h#1 176.5	0.022	0.008	0.002		0.002	0.004

Table 12. Silicon concentration, mg/l.

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	23.1	57.8	57.2		69.7	108
GU-3 1072.5	22.8	59.5	60.3		78.4	58.7
GU-3 1096.0	22.8	48.2	45.4		49.9	74.2
GU-3 1120.7	22.8	68.0	77.8		82.3	103
G-4 1181.9	23.0	65.1	70.9		76.1	99.2
G-4 1210.3	23.4	63.9		78.9		99.0
G-4 1230.8	23.7	68.8	75.7		81.3	102
G-1 1068.7	22.0	72.1		88.9		98.5
G-1 1123.6	22.6	75.4		94.9		100
G-1 1159.0	24.1	70.9		89.3		102
G-1 1246.9	22.7	67.9		88.0		107
UE-25h#1 78.2	24.7	59.2	48.5		45.3	74.4
UE-25h#1 125.8	24.5	71.6	67.3		66.4	110
UE-25h#1 176.5	24.7	61.0	55.8		55.6	109

Table 13. Calcium concentration, mg/l.

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	7.96	2.85	4.84		4.52	3.78
GU-3 1072.5	7.45	2.88	4.62		7.29	1.62
GU-3 1096.0	7.29	4.81	7.64		6.73	2.23
GU-3 1120.7	7.48	1.77	5.90		6.23	2.79
G-4 1181.9	9.65	3.55	6.24		4.88	2.83
G-4 1210.3	9.82	4.25		6.00		3.01
G-4 1230.8	9.45	4.10	6.40		4.60	3.35
G-1 1068.7	9.47	2.77		5.18		3.12
G-1 1123.6	10.5	2.54		3.72		2.14
G-1 1159.0	10.5	2.47		3.44		2.93
G-1 1246.9	14.4	7.97		6.42		3.87
UE-25h#1 78.2	8.01	3.10	5.39		4.18	2.36
UE-25h#1 125.8	7.15	2.66	4.92		5.06	3.41
UE-25h#1 176.5	8.71	3.37	5.19		4.08	3.23

Table 14. Magnesium concentration, mg/l.

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	1.51	0.057	0.081		0.151	0.099
GU-3 1072.5	1.60	0.067	0.098		0.284	0.075
GU-3 1096.0	1.35	0.059	0.067		0.195	0.238
GU-3 1120.7	1.82	0.057	0.166		0.146	0.134
G-4 1181.9	1.20	0.321	0.075		0.115	0.151
G-4 1210.3	1.69	0.255		0.124		0.072
G-4 1230.8	0.93	0.246	0.065		0.062	0.108
G-1 1068.7	1.71	0.328		0.095		0.147
G-1 1123.6	1.95	0.401		0.551		0.160
G-1 1159.0	1.86	0.338		0.085		0.106
G-1 1246.9	0.69	0.189		0.186		0.188
UE-25h#1 78.2	1.89	0.403	0.164		0.052	0.169
UE-25h#1 125.8	1.54	0.309	0.062		0.055	0.129
UE-25h#1 176.5	1.47	0.263	0.065		0.046	0.055

Table 15. Potassium concentration, mg/l.

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	7.9	7.4	4.7		4.6	1.5
GU-3 1072.5	8.1	7.1	4.5		5.7	2.2
GU-3 1096.0	7.1	7.1	4.7		5.8	1.3
GU-3 1120.7	7.1	6.5	4.2		3.4	1.3
G-4 1181.9	6.7	6.9	4.9		4.2	1.0
G-4 1210.3	7.4	8.1		5.0		1.3
G-4 1230.8	6.8	6.5	4.0		3.5	0.9
G-1 1068.7	6.8	8.4		5.1		1.2
G-1 1123.6	5.3	7.1		5.7		1.7
G-1 1159.0	6.6	7.4		5.5		1.2
G-1 1246.9	6.2	7.5		5.4		1.4
UE-25h#1 78.2	8.8	10.2	8.5		6.6	2.6
UE-25h#1 125.8	8.6	10.8	7.8		7.5	3.4
UE-25h#1 176.5	9.0	10.4	8.0		7.0	2.5

Table 16. Sodium concentration, mg/l.

Sample No.	Day 0	Day 1	Day 3	Day 4	Day 6	Day 70
GU-3 1057.5	40	43	36		36	39
GU-3 1072.5	38	42	38		39	18
GU-3 1096.0	39	42	37		38	37
GU-3 1120.7	39	45	39		37	35
G-4 1181.9	42	45	43		38	36
G-4 1210.3	42	49		45		37
G-4 1230.8	41	46	42		38	38
G-1 1068.7	39	47		43		37
G-1 1123.6	39	41		43		36
G-1 1159.0	38	42		43		39
G-1 1246.9	42	48		43		40
UE-25h#1 78.2	41	45	42		38	44
UE-25h#1 125.8	42	48	42		42	44
UE-25h#1 176.5	43	45	42		40	42

work. They were the samples that showed low silicon concentrations in the Day 70 samples: GU-3, 1072.5; GU-3, 1096.0; and UE-25h#1, 78.2. These samples were run using the normal rock-water interaction procedure with the pretreatment steps of a room-temperature rinse and an overnight-cooked rinse at the designated reaction temperature. Samples of UE-25h#1 were also run without the pretreatment steps. Since the rock does not contain significant amounts of evaporite salts, this would allow us to assess the effects of the pretreatment steps on "clean" rock samples. Reaction times of 12, 20, 36, and 48 days were selected, using 0.8 g of rock powder and 12 ml of J-13 water. The reaction temperature was maintained at 150°C.

Table 17 gives data for anions in the pretreatment solutions. The nitrate analyses, made on 4/3/84, are suspect; see the experimental procedure section for details. The pH data were obtained at the time of the alkalinity determination. The samples were taken on 2/21 and 2/22/84 and analyzed on 3/13/84. It is probable that during the interval between sampling and analysis, some uptake of atmospheric carbon dioxide occurred, and that the pH was lowered from that at the time of sampling (Oversby, 1984a). There is no evidence in the room-temperature rinse solutions for any readily soluble material; however, in the cooked-rinse solutions, the GU-3 samples show rather high fluoride and chloride. The source of the fluoride may be trace authigenic fluorite, while biotite is a possible source of chloride. These phases are both found in GU-3 core samples (Vaniman et al., 1984).

Data for the rinse solution cations are given in Table 18, and for the cooked-rinse solutions in Table 19. Samples for analysis were originally delivered so that the acidified solutions intended for ICP analysis went to the IC lab and the unacidified samples intended for IC went to the ICP lab. The unacidified samples were run by ICP on 3/7/84. The sample switch was discovered, the samples were redelivered to the appropriate locations, and the ICP analyses were done on the acidified samples on 3/23/84. The acidified samples for cooked-rinse solutions were rerun on two subsequent occasions, with the final run providing data for boron. The three analyses for the cooked-rinse acidified samples are in excellent agreement, despite the storage of the solutions for three months. The unacidified samples generally show marginally higher potassium and silicon and lower calcium and magnesium than the acidified

samples. In agreement with Day 0 data from the first series of experiments, potassium is higher than in J-13 water and calcium is lower, while the rest of the concentrations are similar in the room-temperature rinse solutions and the starting J-13 water. The concentrations of most elements in the cooked rinse solutions are in agreement with the Day 1 data given in Tables 8 through 16. Notable differences are the higher silicon and somewhat higher sodium in the Table 19 data in comparison to Day 1 data for these samples.

Data for anions, alkalinity, and pH after reaction are given in Table 20. The pH was measured at the time the sample was originally taken. Fluoride is slightly higher than J-13 values in the UE-25h#1 and GU-3 1072.5 samples, and is similar to the cooked-rinse concentration for GU-3 1096.0 samples. This confirms a source of fluoride in the latter sample, probably trace fluorite. Chloride and sulfate are similar to J-13 values for all samples; nitrate is probably affected by the previously discussed analytical problem. Alkalinity and pH are consistent with previous results for the reaction times used (Oversby, 1984a).

Tables 21 through 29 contain data for cation concentrations in the solutions after 12, 20, 36, and 48 days of reaction. Several of the solutions were analyzed twice using the same solution but on different days. Agreement between the duplicate analyses is generally better than that predicted using the standard deviation of the J-13 water control blank samples (Table 1). Aluminum (Fig. 2) shows the expected decrease in concentration with increasing reaction time. The results after 48 days for GU-3 1096 and UE-25h#1 78 are about a factor of two lower than the Day 70 results (Table 8). Outcrop samples gave aluminum = 1.12 ppm after 31 days of reaction and 1.06 ppm after 48 days (Oversby, 1984a).

Boron results (Table 22) are in agreement with the data in Table 9. The samples from GU-3 give values close to J-13 water, while the Fran Ridge sample gives higher concentrations. The sample run without pretreatment gave higher boron in solution, suggesting the presence of a minor amount of soluble boron evaporite material. Minor amounts of boron are associated with the evaporite material found on outcrop samples (Oversby, 1984b).

Results for iron (Table 23) show the values expected based on the experiments using outcrop samples (Oversby, 1984a). For GU-3 1096 and UE-25h#1 78-ft samples, the results are lower

Figure 2. Aluminum concentration as a function of reaction time for Topopah Spring tuff and J-13 water at 150°C.

than the Day 70 concentrations (Table 10). The iron data, taken in conjunction with the aluminum results, suggest that minor amounts of colloidal material might have been present in the Day 70 solutions for these two samples.

Silicon concentrations (Table 24 and Fig. 3) for the GU-3 samples show the expected pattern of increase with reaction time, and reach values slightly more than 100 ppm after 48 days. Outcrop samples reached 84 ppm in 48 days at 150°C (Oversby, 1984a). The Fran Ridge drill core samples reached 66 and 69 ppm in 48 days. During the experiments with outcrop samples, the silicon was still increasing fairly rapidly with time for the interval between 31 and 48 days, suggesting that steady-state concentrations would be controlled by cristobalite (122 ppm). It is probable that lower sample surface area, resulting in lower reaction rates, caused the lower silicon in the outcrop experiments in comparison with the drill core samples. Low surface area may also explain the initial low silicon values for the GU-3 1096-ft sample (Table 12).

The 78-ft sample from UE-25h#1 appears to be a different case. The rate of increase of silicon in solution with time is slow, suggesting a steady-

state value lower than that of cristobalite solubility. Comparison of data for the untreated 78-ft sample with that for the pretreated sample shows initially higher silicon for the sample that had not been rinsed in J-13 water. Silicon concentration then decreases for longer reaction times, suggesting precipitation. The original pulse of silicon is probably caused by rapid dissolution of fine particles. The lowering of silicon as a function of reaction time suggests that precipitation has occurred. The data suggest a solubility limit of about 65 to 70 ppm for silicon in solutions in contact with the rock at 150°C.

Data for calcium (Table 25 and Fig. 4) and magnesium (Table 26) are consistent with results for outcrop samples (Oversby, 1984a). Magnesium data for Day 70 are higher (Table 14) than the 48-day results for the two samples that had higher Day 70 aluminum and iron (GU-3 1096 and UE-25h#1, 78 ft).

Potassium data (Table 27 and Fig. 5) for the samples from GU-3 and the pretreated Fran Ridge sample are consistent with the results in Table 15, and are much lower than results obtained with outcrop samples (Oversby, 1984a). The Fran Ridge sample that was not pretreated gives much higher

Figure 3. Silicon concentration as a function of reaction time for Topopah Spring tuff and J-13 water at 150°C.

Figure 4. Calcium concentration as a function of reaction time for Topopah Spring tuff and J-13 water at 150°C.

Figure 5. Potassium concentration as a function of reaction time for Topopah Spring tuff and J-13 water, at 150°C.

potassium in solution, especially for the shorter reaction times. This suggests supersaturation with potassium due to dissolution of fine particles of alkali feldspar, followed by precipitation or ion exchange of potassium in solution with the solid phases. Alternatively, there may be small amounts of a soluble potassium-bearing phase in the rock that is removed during the pretreatment step.

Sodium concentrations (Table 28) for pretreated samples are similar to or slightly higher than J-13 values. Previous results have given sodium data that are slightly lower than the J-13

concentration (Table 16 and Oversby, 1984a). Sodium is one of the more difficult elements to analyze by ICP, and shows rather large variability. The apparent differences in sodium concentrations may not be significant in terms of solution reactions. The Fran Ridge sample that was not pretreated gives significantly higher sodium for the short reaction times, supporting the theory that dissolution of alkali feldspar is responsible for the high potassium above as well as the high sodium. Data for lithium (Table 29) are indistinguishable from the starting J-13 concentration.

Table 17. Anion concentrations (mg/l), alkalinity (meq/l), and pH for pretreatment solutions, second series.

Sample No.	Fluoride	Chloride	Nitrate	Sulfate	Alkalinity	pH
<u>Rinse solutions</u>						
J-13 control	1.3	7.5	13.1	18.7	2.10	8.33
<u>GU-3 1072.5</u>						
12 day	1.3	7.5	13.7	19.0	2.34	8.37
20 day	1.3	7.7	14.2	19.3	2.46	8.56
36 day	1.3	7.4	14.2	18.7	2.25	8.39
48 day	1.3	7.3	12.1	18.7	2.29	8.47
<u>GU-3 1096.0</u>						
12 day	1.4	7.6	13.1	18.7	2.25	8.40
20 day	1.4	7.7	17.4	19.0	2.29	8.54
36 day	1.4	7.5	12.1	19.0	2.33	8.56
48 day	1.4	8.1	16.8	18.7	2.51	nm ^a
<u>UE-25h#1 78.2</u>						
12 day	1.3	7.5	17.4	20.7	2.25	8.41
20 day	1.3	7.5	15.3	20.3	2.36	8.53
36 day	1.3	7.5	12.3	20.7	2.43	8.59
48 day	1.3	7.6	20.0	20.7	2.25	8.48
<u>Cooked rinse solutions</u>						
<u>GU-3 1072.5</u>						
12 day	8.6	14.6	12.1	18.7	2.01	8.24
20 day	8.8	14.2	11.5	18.7	2.00	8.22
36 day	8.6	14.0	11.5	19.0	1.94	8.05
48 day	4.5	7.0	11.1	19.1	2.06	8.28
<u>GU-3 1096.0</u>						
12 day	7.2	11.8	21.6	20.0	2.01	8.28
20 day	9.8	14.4	11.0	19.0	2.05	8.36
36 day	9.7	14.4	12.2	19.0	2.11	8.29
48 day	7.2	7.3	12.7	19.3	2.09	8.30
<u>UE-25h#1 78.2</u>						
12 day	1.6	7.2	13.7	19.0	2.10	8.25
20 day	1.3	6.9	11.5	18.7	2.15	8.13
36 day	1.3	6.9	12.2	19.0	2.12	8.32
48 day	2.6	7.0	11.1	19.0	2.16	8.40

^a Not measured.

Table 18. Cation concentrations in rinse solutions, mg/l.

	Al	B	Si	Ca	Mg	K	Na	Li	Analysis date
<u>J-13 average</u>	0.014	0.132	27.1	12.7	1.92	5.11	45	0.044	
<u>GU-3 1072.5</u>									
12 day	0.011	—	28.4	7.26	1.80	12.1	50	0.049	3/07/84
	0.051	—	26.9	8.68	1.88	11.0	48	0.045	3/23/84
20 day	0.013	—	27.9	7.10	1.74	12.3	50	0.047	3/07/84
	0.061	—	26.9	8.71	1.87	11.2	48	0.045	3/23/84
36 day	0.087	—	27.0	8.77	1.87	11.3	48	0.046	3/23/84
48 day	0.002	—	28.1	6.96	1.77	11.9	51	0.049	3/07/84
	0.066	—	26.6	8.48	1.86	11.1	47	0.045	3/23/84
<u>GU-3 1096.0</u>									
12 day	<0.01	—	28.3	8.05	1.80	11.8	52	0.049	3/07/84
	0.045	—	27.4	9.38	1.87	10.8	49	0.046	3/23/84
	0.038	—	27.5	10.6	1.83	10.9	55	0.052	4/09/84
20 day	0.005	—	28.1	7.44	1.71	11.1	50	0.047	3/07/84
	0.024	—	27.1	9.47	1.82	10.3	49	0.045	3/23/84
	0.028	—	27.7	10.9	1.81	11.2	56	0.052	4/09/84
36 day	0.008	—	27.7	7.63	1.69	11.3	50	0.047	3/07/84
	0.064	—	27.1	9.26	1.83	10.2	47	0.044	3/23/84
	0.056	—	27.4	10.6	1.79	10.6	54	0.051	4/09/84
48 day	0.005	—	27.6	7.21	1.69	11.4	49	0.046	3/07/84
	0.067	—	26.0	9.20	1.79	10.8	47	0.044	3/23/84
<u>UE-25h#1 78.2</u>									
12 day	0.018	—	28.2	8.88	2.03	12.4	48	0.049	3/07/84
20 day	0.007	—	28.1	8.61	2.01	12.9	49	0.050	3/07/84
	0.061	—	27.6	10.3	2.14	12.6	48	0.049	3/23/84
	0.056	—	27.9	11.5	2.10	12.2	53	0.055	4/09/84
36 day	0.014	—	28.3	8.26	1.97	12.7	49	0.051	3/07/84
	0.057	—	27.6	10.1	2.11	12.5	47	0.049	3/23/84
48 day	0.029	—	27.7	11.4	2.03	12.4	54	0.054	4/09/84
	0.047	0.154	26.5	9.83	2.00	11.8	48	0.046	6/22/84

Table 19. Cation concentrations in cooked rinse solutions, mg/l.

	Al	B	Si	Ca	Mg	K	Na	Li	Analysis date
<u>J-13 average</u>	0.014	0.132	27.1	12.7	1.92	5.11	45	0.044	
<u>GU-3 1072.5</u>									
12 day	2.63	—	76.8	1.16	0.029	8.8	53	0.062	3/07/84
	2.80	—	75.6	2.08	0.047	8.6	52	0.059	3/23/84
	2.67	—	73.2	2.15	0.045	8.4	54	0.063	4/09/84
	2.75	0.166	74.4	2.06	0.040	7.3	55	0.057	6/22/84
20 day	2.65	—	77.7	1.11	0.028	8.7	56	0.063	3/07/84
	2.76	—	74.3	1.89	0.049	7.7	51	0.037	3/23/84
	2.69	—	73.3	2.00	0.047	7.2	54	0.063	4/09/84
	2.75	0.170	74.4	1.87	0.046	6.8	54	0.056	6/22/84
36 day	2.72	—	79.1	1.13	0.034	3.6	56	0.064	3/07/84
	2.76	—	74.7	1.99	0.056	8.0	51	0.058	3/23/84
	2.67	—	73.2	2.13	0.055	7.4	56	0.063	4/09/84
	2.71	0.171	72.2	1.97	0.059	7.2	55	0.057	6/22/84
48 day	2.68	—	78.5	1.03	0.027	8.9	54	0.063	3/07/84
	2.80	—	76.1	1.94	0.047	8.6	53	0.060	3/23/84
	2.69	—	74.2	1.97	0.045	7.9	54	0.064	4/09/84
	2.77	0.171	75.4	1.90	0.041	7.3	55	0.057	6/22/84
<u>GU-3 1096.0</u>									
12 day	1.83	—	79.6	2.32	0.031	9.7	57	0.061	3/07/84
	1.91	—	77.0	3.56	0.043	9.1	52	0.057	3/23/84
	1.80	—	74.3	3.87	0.040	8.6	57	0.062	4/09/84
	1.88	0.166	76.3	3.63	0.037	8.3	56	0.056	6/22/84
20 day	1.74	—	78.1	2.41	0.028	9.4	55	0.060	3/07/84
	1.79	—	74.4	3.87	0.053	9.2	52	0.056	3/23/84
	1.73	—	73.2	4.16	0.051	8.3	56	0.061	4/09/84
36 day	1.80	—	79.1	2.48	0.029	10.1	57	0.062	3/07/84
	1.85	—	75.8	3.78	0.044	8.6	52	0.056	3/23/84
	1.82	—	75.7	4.26	0.043	9.0	58	0.064	4/09/84
	1.88	0.168	75.4	3.93	0.040	8.0	57	0.056	6/22/84
48 day	1.75	—	77.8	2.50	0.034	9.3	54	0.060	3/07/84
	1.76	—	73.9	4.17	0.040	8.8	56	0.063	4/09/84
	1.79	0.165	74.8	4.07	0.035	8.0	57	0.056	6/22/84
<u>UE-25h#1 78.2</u>									
12 day	3.14	—	66.6	1.83	0.026	12.0	51	0.062	3/07/84
	3.41	—	65.6	3.08	0.041	11.7	53	0.061	3/23/84
	3.17	—	62.4	3.12	0.038	10.7	54	0.063	4/09/84
	3.35	0.203	64.6	3.03	0.038	9.9	54	0.058	6/22/84
20 day	3.10	—	66.9	1.97	0.031	12.3	53	0.064	3/07/84
	3.26	—	64.3	2.99	0.063	11.5	50	0.059	3/23/84
	3.15	—	63.8	3.16	0.061	11.4	52	0.065	4/09/84
	3.26	0.204	64.6	3.08	0.062	10.1	54	0.059	6/22/84
36 day	3.13	—	66.5	1.83	0.023	11.7	53	0.062	3/07/84
	3.37	—	64.7	2.99	0.044	11.0	50	0.059	3/23/84
	3.26	—	64.3	3.19	0.045	10.4	53	0.065	4/09/84
	3.31	0.207	63.7	3.06	0.053	9.7	53	0.057	6/22/84
48 day	3.04	—	65.5	1.86	0.030	12.2	51	0.061	3/07/84
	3.26	—	63.7	2.90	0.037	11.5	50	0.058	3/23/84
	3.20	—	64.1	3.20	0.037	11.6	55	0.066	4/09/84
	3.19	0.197	61.9	2.90	0.032	9.9	53	0.057	6/22/84

Table 20. Anion concentrations (mg/l), alkalinity (meq/l), and pH for final samples.

Sample No.	Fluoride	Chloride	Nitrate	Sulfate	Alkalinity	pH
GU-3 1072.5						
12 day	3.7	8.5	9.9	19.1	1.95	8.59
20 day	3.5	6.4	15.8	17.1	1.81	8.77
36 day	3.8	6.7	26.7	17.0	1.22	8.98
48 day	4.0	8.0	8.7	17.8	1.25	9.03
GU-3 1096.0						
12 day	8.2	6.5	9.4	18.4	1.86	8.34
20 day	6.2	6.5	14.2	17.4	1.98	8.67
36 day	6.8	6.9	22.7	17.8	1.58	8.89
48 day	8.0	8.5	8.9	18.4	1.55	8.93
UE-25h#1 78.2 with prt						
12 day	2.7	8.1	9.6	18.8	1.91	8.64
20 day	2.8	6.3	11.9	16.7	2.28	7.99
36 day	2.8	6.9	26.3	17.5	2.60	9.21
48 day	2.7	7.8	8.7	17.9	1.58	9.19
UE-25h#1 78.2 without prt						
12 day	3.4	9.3	9.8	20.8	2.32	8.64
20 day	3.4	7.3	17.5	19.0	2.05	9.17
36 day	3.5	7.9	33.9	19.2	1.60	9.12
48 day	3.5	9.0	8.9	19.6	1.91	8.95

Table 21. Aluminum concentration, mg/l.

Run duration (days)	GU-3 1072.5	GU-3 1096.0	UE-25h#1 78.2		Analysis date
			With prt	Without prt	
12	0.54	0.72	1.41	1.91	3/21/84
12	0.59	0.75	1.41	1.95	4/09/84
20	0.43	0.49	0.56	1.52	3/21/84
20	0.42	0.50	0.54	1.46	4/09/84
20			0.55		6/22/84
36	0.32	0.33	0.82	0.74	6/19/84
48			0.83	0.46	6/19/84
48	0.34	0.42			6/20/84

Table 22. Boron concentration, mg/l.

Run duration (days)	GU-3 1072.5	GU-3 1096.0	UE-25h#1 78.2		Analysis date
			With prt	Without prt	
20			0.207		6/22/84
36	0.174	0.174	0.237	0.327	6/19/84
48			0.235	0.287	6/19/84
48	0.166	0.170			6/20/84

Table 23. Iron concentration, mg/l.

Run duration (days)	GU-3 1072.5	GU-3 1096.0	UE-25h#1 78.2		Analysis date
			With prt	Without prt	
12	0.026	0.018	0.023	0.061	3/21/84
12	0.038	0.022	0.027	0.076	4/09/84
20	0.018	0.011	0.006	0.021	3/21/84
20	0.018	0.009	<0.003	0.018	4/09/84
20			0.009		6/22/84
36	0.041	0.015	0.028	0.077	6/19/84
48			0.020	0.017	6/19/84
48	0.019	0.067			6/20/84

Table 24. Silicon concentration, mg/l.

Run duration (days)	GU-3 1072.5	GU-3 1096.0	UE-25h#1 78.2		Analysis date
			With prt	Without prt	
12	86.8	89.1	60.3	79.7	3/21/84
12	85.4	89.3	59.7	78.4	4/09/84
20	88.9	87.4	61.9	77.9	3/21/84
20	90.3	90.3	62.2	77.2	4/09/84
20			62.4		6/22/84
36	92.2	94.8	66.0	75.2	6/19/84
48			69.0	66.0	6/19/84
48	102	105			6/20/84

Table 25. Calcium concentration, mg/l.

Run duration (days)	GU-3 1072.5	GU-3 1096.0	UE-25h#1 78.2		Analysis date
			With prt	Without prt	
12	7.21	6.48	4.60	2.86	3/21/84
12	7.08	6.49	4.65	2.85	4/09/84
20	3.93	4.34	4.32	0.88	3/21/84
20	4.02	4.33	4.41	0.72	4/09/84
20			4.45		6/22/84
36	4.84	5.47	2.85	2.18	6/19/84
48			1.86	1.18	6/19/84
48	4.01	3.70			6/20/84

Table 26. Magnesium concentration, mg/l.

Run duration (days)	GU-3 1072.5	GU-3 1096.0	UE-25h#1 78.2		Analysis date
			With prt	Without prt	
12	0.110	0.073	0.091	0.100	3/21/84
12	0.116	0.076	0.094	0.111	4/09/84
20	0.031	0.033	0.039	0.024	3/21/84
20	0.039	0.036	0.039	0.029	4/09/84
20			0.034		6/22/84
36	0.081	0.049	0.054	0.056	6/19/84
48			0.051	0.041	6/19/84
48	0.061	0.107			6/20/84

Table 27. Potassium concentration, mg/l.

Run duration (days)	GU-3 1072.5	GU-3 1096.0	UE-25h#1 78.2		Analysis date
			With prt	Without prt	
12	3.4	3.8	6.8	9.4	3/21/84
12	3.5	4.0	7.0	9.3	4/09/84
20	2.5	2.7	6.2	5.9	3/21/84
20	2.3	3.2	6.2	6.0	4/09/84
20			5.5		6/22/84
36	0.7	1.9	3.0	2.8	6/19/84
48			2.9	5.0	6/19/84
48	1.8	2.3			6/20/84

Table 28. Sodium concentration, mg/l.

Run duration (days)	GU-3 1072.5	GU-3 1096.0	UE-25h#1 78.2		Analysis date
			With prt	Without prt	
12	49	49	47	57	3/21/84
12	45	46	45	53	4/09/84
20	44	47	46	52	3/21/84
20	42	42	43	49	4/09/84
20			48		6/22/84
36	46	48	48	56	6/19/84
48			47	47	6/19/84
48	46	47			6/20/84

Table 29. Lithium concentration, mg/l.

Run duration (days)	GU-3 1072.5	GU-3 1096.0	UE-25h#1 78.2		Analysis date
			With prt	Without prt	
12	0.039	0.042	0.031	0.040	3/21/84
12	0.044	0.046	0.036	0.045	4/09/84
20	0.039	0.039	0.034	0.032	3/21/84
20	0.043	0.043	0.038	0.035	4/09/84
20			0.034		6/22/84
36	0.037	0.038	0.024	0.029	6/19/84
48			0.022	0.030	6/19/84
48	0.037	0.037			6/20/84

Conclusions

Solution concentrations obtained from the reaction of Topopah Spring tuff samples taken from three vertical drill cores and the horizontal air-drilled hole at Fran Ridge with J-13 water at 150°C are similar for all samples except for somewhat lower silicon in one of the Fran Ridge samples. The data are consistent with results obtained from surface outcrop samples that have been pretreated to remove evaporite deposits for all elements except potassium, which is higher for the outcrop samples, and silicon, which is slightly lower for the outcrop samples. The lower silicon for outcrop samples may be a kinetic effect, with solubility controlled in the long term by cristobalite in all cases except the anomalous Fran Ridge sample.

There is no evidence for significant quantities of evaporite material in any of the drill core sam-

ples. This is particularly significant in the case of the air-drilled samples, since no drilling fluids that might remove such materials were used in obtaining those samples. The Fran Ridge core samples may contain very small amounts of alkali borate salts.

Some of the solution data show minor variability that is attributable to trace phases. Several samples indicate the presence of minor amounts of iron-manganese-aluminum material, which is identified in the room temperature rinse solutions. One sample appears to contain a source of fluoride, probably in the form of fluorite. The highest fluoride concentration found was less than 10 ppm. No other significant amounts of anions were found to be produced as a result of reaction of the rock with J-13 water.

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