GEOCHEMICAL HOMOGENEITY OF TUFFS AT THE POTENTIAL REPOSITORY LEVEL, YUCCA MOUNTAIN, NEVADA

Zell E. Peterman
U.S. Geological Survey,
MS 963, Box 25046 Denver Federal Center,
Denver, CO 80225

Paul Cloke
Science Applications International Corp.
1180 Town Center Drive, MS 423
Las Vegas, NV 89144

I. INTRODUCTION

In a potential high-level radioactive waste repository at Yucca Mountain, Nevada, radioactive waste and canisters, drip shields protecting the waste from seepage and from rock falls, the backfill and invert material of crushed rock, the host rock, and water and gases contained within pores and fractures in the host rock together would form a complex system commonly referred to as the near-field geochemical environment.[1] Materials introduced into the rock mass with the waste that are designed to prolong containment collectively are referred to as the Engineered Barrier System, and the host rock and its contained water and gases compose the natural system. The interaction of these component parts under highly perturbed conditions including temperatures well above natural ambient temperatures will need to be understood to assess the performance of the potential repository for long-term containment of nuclear waste. The geochemistry and mineralogy of the rock mass hosting the emplacement drifts must be known in order to assess the role of the natural system in the near-field environment.[2,3] Emplacement drifts in a potential repository at Yucca Mountain would be constructed in the phenocryst-poor member of the Topopah Spring Tuff which is composed of both lithophysal and nonlithophysal zones.[4] The chemical composition of the phenocryst-poor member has been characterized by numerous chemical analyses of outcrop samples and of core samples obtained by surface-based drilling.[5] Those analyses have shown that the phenocryst-poor member of the Topopah Spring Tuff is remarkably uniform in composition both vertically and laterally. To verify this geochemical uniformity and to provide rock analyses of samples obtained directly from the potential repository block, major and trace elements were analyzed in core samples obtained from drill holes in the cross drift,[6] which was driven to provide direct access to the rock mass where emplacement drifts would be constructed.[7]

II. WORK DESCRIPTION

Coreholes 2 m long spaced on 50-m centers were drilled horizontally in the 2.6-km-long cross drift primarily to determine density, porosity, and moisture contents. Multiple intervals of core approximately 5 to 7 cm long from each core hole were sealed in cans immediately after recovery to preserve moisture. One sealed sample from each of twenty coreholes was selected for major and trace element analyses (Figure 1). Cores

Table 1. Mean composition of the phenocryst-poor member of the Topopah Spring Tuff in the cross drift. σ_x is standard deviation, SDOM is standard deviation of the mean, and Min and Max are the mean values plus and minus 2 times SDOM for each element.

Analyte	Mean	σ_x	SDOM	Min	Max
	Weight percent				
SiO_2	76.29	0.318	0.101	76.09	76.49
Al_2O_3	12.55	0.142	0.045	12.46	12.64
FeO	0.13	0.047	0.015	0.10	0.16
Fe_2O_3	0.97	0.070	0.022	0.93	1.01
MgO	0.12	0.020	0.006	0.11	0.13
CaO	0.50	0.027	0.008	0.48	0.52
Na_2O	3.52	0.109	0.035	3.45	3.59
K_2O	4.83	0.062	0.020	4.79	4.87
TiO_2	0.109	0.004	0.001	0.107	0.111
ZrO_2	0.016	0.001	0.000	0.015	0.017
P_2O_5	<0.05	---	---	---	---
MnO	0.068	0.008	0.002	0.063	0.073
Cl	0.017	0.004	0.001	0.014	0.020
F	0.038	0.008	0.003	0.033	0.043
S	<0.05	---	---	---	---
CO_2	0.011	0.003	0.001	0.009	0.01
H_2O-	0.24	0.072	0.023	0.19	0.29
H_2O+	0.40	0.090	0.029	0.34	0.46
SUM	99.81				
	Micrograms per gram				
Rb	188	5.3	1.7	185	191
Sr	25	3.4	1.1	23	27
Y	32	2.9	0.9	30	34
Zr	116	3.8	1.2	114	118
Nb	25	1.1	0.3	24	26
Ba	55	6.8	2.1	51	59
La	51	5.5	1.7	48	54
Ce	84	5.1	1.6	81	87

with vapor-phase minerals and low-temperature calcite and opal coatings were avoided. The core samples were prepared for analysis following standard procedures for crushing, pulverization, and splitting. Duplicate analyses of major and trace elements were conducted using energy–dispersive and wavelength dispersive X-ray fluorescence analyses (EDXRF and WDXRF, respectively), inductively coupled plasma mass spectrometry (ICPMS), and gravimetric and wet-chemical methods.[8] Quality control consisted of blind analyses of duplicates of the samples and of five splits each of two U.S. Geological Survey rock standards, RGM-1[9] and GSP-2[10].

Table 2. Mean trace element contents of the phenocryst-poor member of the Topopah Spring Tuff in the cross drift. Only one sample returned a copper value greater than the detection limit.

Element	Mean	σ_x	SDOM	Min	Max
	Micrograms per gram				
Ag	<1	---	---	---	---
As	5.4	1.9	0.60	4.1	6.6
Ba	51.3	12.1	3.83	43.7	59.0
Be	3.4	0.1	0.03	3.4	3.5
Bi	0.06	0.03	0.01	0.04	0.08
Cd	0.07	0.03	0.01	0.05	0.09
Ce	70.8	5.84	1.85	67.1	74.5
Co	0.23	0.05	0.02	0.19	0.26
Cr	8.7	2.9	0.92	6.9	10.6
Cs	4.2	0.3	0.09	4.0	4.4
Cu	13.7	---	---	---	---
Ga	15.6	0.50	0.16	15.3	16.0
La	34.2	3.31	1.05	32.1	36.3
Li	25.1	8.9	2.82	19.4	30.7
Mo	2.21	0.95	0.30	1.61	2.82
Nb	20.6	1.4	0.45	19.7	21.5
Ni	1.4	0.3	0.11	1.2	1.6
Pb	27.2	1.1	0.36	26.5	27.9
Rb	185.6	8.8	2.78	180.0	191.1
Sb	0.33	0.06	0.02	0.29	0.37
Sc	2.45	0.10	0.03	2.39	2.51
Sr	27.1	3.3	1.06	25.0	29.2
Th	26.0	1.4	0.45	25.1	26.9
Tl	1.10	0.21	0.07	1.0	1.2
U	3.92	0.30	0.10	3.73	4.11
V	1.3	0.6	0.20	0.9	1.7
Y	30.1	3.06	0.97	28.2	32.1
Zn	35.9	4.3	1.35	33.2	38.6

III. RESULTS

Statistical analyses of the major and trace element concentrations show the compositional uniformity of samples from the cross drift (Table 1). The trace elements in Table 1 were determined by EDXRF analyses of packed powders, and the larger suite of trace elements was determined by ICPMS (Table 2). For the trace elements Rb, Sr, Y, Nb, and Ba, typically there is good agreement between methods (Tables 1 and 2). For La and Ce, however, the EDXRF values are substantially larger than the ICPMS values. These differences may relate to lack of complete sample dissolution for the ICPMS analyses because rare-earth elements such as La and Ce may occur in refractory trace minerals that are difficult to dissolve. Consequently, the EDXRF values for La and Ce are preferred.

In evaluating the compositional variability of the phenocryst-poor member of the Topopah Spring Tuff sampled in the cross drift, the variations of major elements among samples were compared with the analytical precision for the same elements estimated from the duplicate analyses.[6] This evaluation showed that the variability in SiO_2 and TiO_2 among the 20 samples is within analytical uncertainty. The variability of the other elements exceeds analytical error, although the range is relatively small. For example, CaO shows one of the larger variabilities in excess of analytical error, but the standard deviation is only six times the analytical error. Table 1 lists both sigma (σ_x) and standard deviation of the mean (SDOM, σ_x divided by the square root of the number of analyses). The last two columns in Table 1, Min and Max, are the mean values minus and plus 2 times SDOM, respectively. The statistical implications of the Min and Max values are that if the same number of samples from the cross drift were collected and analyzed again using the same criteria, the new mean values would be in the Min-Max ranges (Table 1) 19 times out of 20 (95 percent confidence level). The trace elements determined by ICPMS analyses (Table 2) show the same limited variability as the major and trace elements in Table 1.

Table 3. Mean normative mineral contents of the phenocryst-poor rhyolite member of the Topopah Spring Tuff in the cross drift

Minerals	Mean	σ_x	SDOM	Min	Max
	Weight percent				
Quartz	36.41	0.899	0.201	36.01	36.81
Orthoclase	28.55	0.375	0.084	28.38	28.71
Albite	29.65	0.930	0.208	29.24	30.07
Anorthite	1.92	0.138	0.031	1.85	1.98
Corundum	0.85	0.133	0.030	0.79	0.91
Hypersthene	0.30	0.052	0.012	0.27	0.32
Magnetite	0.19	0.171	0.038	0.11	0.26
Ilmenite	0.18	0.031	0.007	0.16	0.19
Hematite	0.89	0.132	0.029	0.84	0.95
Apatite	<0.12	---	---	---	---
Halite	0.03	0.007	0.002	0.02	0.03
Zircon	0.03	0.000	0.000	0.03	0.03
Fluorite	0.07	0.018	0.004	0.06	0.08
Pyrite	<0.09	---	---	---	---
Rutile	0.04	0.017	0.004	0.03	0.04

The mineralogy of the densely welded and devitrified phenocryst-poor member of the Topopah Spring Tuff is dominated by silica polymorphs and alkali feldspar. The major rock-forming minerals and their abundances can be estimated from the chemical analyses by the calculation of normative minerals (Table 3). Bish and Vaniman[11] used calculated normative minerals as a check on their mineralogic determinations based on quantitative X-ray diffraction analyses, and they concluded that for the major rock-forming minerals, the normative mineral abundances are good approximations to the actual mineral abundances. The Max and Min values for combined quartz plus orthoclase plus albite plus anorthite are 95.5 and 97.6 percent which agree well with the determinations reported by Bish and Vaniman (p. 6)[11] for the phenocryst-poor member of the Topopah Spring Tuff.

IV. DISCUSSION

Duplicate major and trace element chemical analyses of 20 samples from the cross drift representing several lithostratigraphic zones confirm within the sampled interval the remarkable compositional uniformity of the phenocryst-poor member of the Topopah Spring Tuff. Localized deposits of vapor-phase minerals in lithophysal cavities and low-temperature calcite and opal coatings in fractures and cavities were avoided in sampling. However, because vapor-phase minerals are mostly silica polymorphs and alkali feldspar in approximately the same relative abundance as in the rocks, inclusion of such deposits in larger scale sampling likely would not change the bulk composition of the phenocryst-poor member of the Topopah Spring Tuff from that reported here. Inclusion of low-temperature calcite and opal coatings in large bulk samples could increase the CaO and CO_2 contents slightly, but the SiO_2 contents would not be appreciably affected.[6] Consequently, the major and trace element compositions of the host-rock units for the potential repository at Yucca Mountain are adequately represented by the chemical analyses summarized here.

V. ACKNOWLEDGMENTS

This study was completed by the U.S. Geological Survey, in cooperation with the Nevada Operations Office, U.S. Department of Energy, under Interagency Agreement DE-AI08-97NV12033. The major (Table 1) and trace element analyses (Table 2) were conducted by Joseph Taggart, Jr. (Mineral Resources Team) and Paul Lamothe (Crustal Imaging and Characterization Team), respectively. The trace element analyses reported in Table 1 were determined by Brian Marshall (Yucca Mountain Project Branch) by energy-dispersive X-ray fluorescence. The report was reviewed by Mark Peters (Los Alamos National Laboratory) and by Clay Hunter (USGS). We are grateful to all of these people.

VI. REFERENCES

---

[1] U.S. Department of Energy, , *Viability Assessment of a Repository at Yucca Mountain, Total System Performance Assessment,* p. 3-39 to 3-66, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, D.C. (1998).

[2] National Research Council, *Geological Criteria for Repositories for High-Level Radioactive Waste,* National Academy of Sciences, Washington D.C., 19 (1978).

[3] N.A. Chapman and I.G. McKinley, *The Geological Disposal of Nuclear Waste,* p. 145-146: John Wiley and Sons, New York (1998).

[4] D.C. Buesch, R.W. Spengler, T.C Moyer and J.K. Geslin, *Proposed Stratigraphic Nomenclature and Macroscopic Identification of Lithostratigraphic Units of the Paintbrush Group Exposed at Yucca Mountain, Nevada,* 47 p,, U.S. Geological Survey Open-File Report 94-469. (1996).

[5] U.S. Department of Energy, *Yucca Mountain Site Description,* Tables 6.1-3 and 6.1-4, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, D.C., (1998).

[6] Z.E. Peterman and P.C. Cloke, Geochemistry of rock units at the potential repository level, Yucca Mountain, Nevada: *Applied Geochemistry* (Accepted 12-15-2000).

[7] B. Fulcher, J. Eastland and J.B. Copeland, Building the east-west cross drift tunnel at Yucca Mountain: *Mining Engineering*, 52, 19-26. (2000).

[8] B. Arbogast, *Analytical Methods Manual for the Mineral Resource Surveys Program*, 248 p., U.S Geological Survey Open-File Report 96-525 (1966).

[9] D.B. Smith, Rhyolite, Glass Mountain, RGM-1: U.S. Geological Survey Certificate of Analysis, accessed August 8, 2000, at URL http://minerals.cr.usgs.gov/geochem/rhyolite.pdf (1995).

[10] L. Gunderson, Granodiorite, Silver Plume, Colorado, GSP-2: U.S. Geological Survey Certificate of Analysis, accessed August 8, 2000, at URL http://minerals.cr.usgs.gov/geochem/grano.pdf (1998).

[11] D.L. Bish and D.T. Vaniman, *Mineralogic summary of Yucca Mountain, Nevada,* 55 p., Los Alamos National Laboratory Report LA-10543-MS (1985).

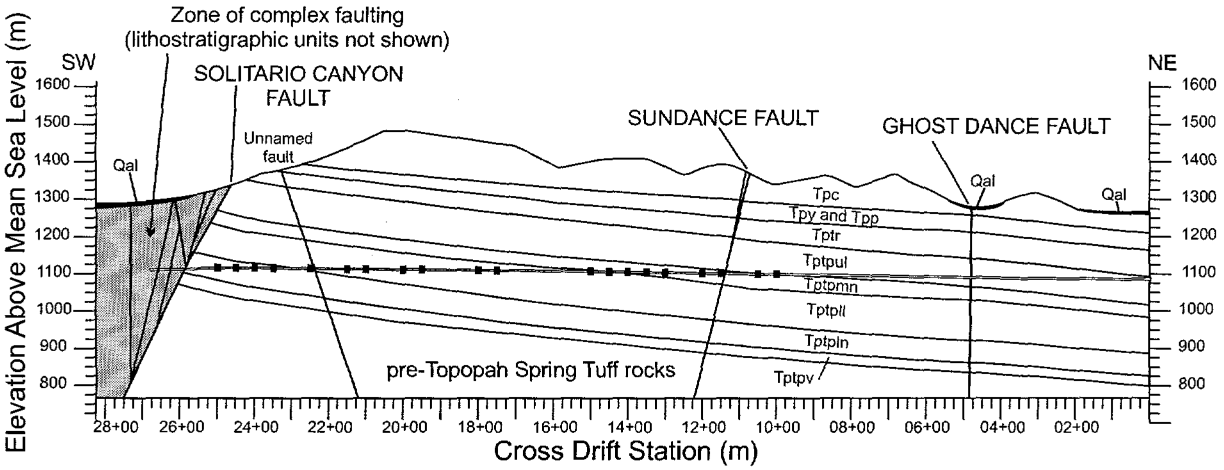

Figure 1. Generalized geologic section along the cross drift. Sample locations are shown by black squares. The following abbreviations designate geologic units: Qal, Quaternary alluvium;Tpc, Tiva Canyon Tuff; Tpy, Yucca Mountain Tuff; Tpp, Pah Canyon Tuff; Tptr, phenocryst-rich member of the Topopah Spring Tuff. The abbreviations Tptpul, Tptpmn, Tptpll, Tptpln,and Tptpv designate the phenocryst-poor member of the Topopah Spring Tuff with suffix letters indicating upper lithophysal (ul), middle nonlithophysal (mn), lower lithophysal (ll), lower nonlithophysal (ln), and vitric (v) zones. These designations are based on the informal lithostratigraphic classification of Buesch et al.[4]