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Geochemistry of Rock Units at the Potential Repository Level, Yucca Mountain, Nevada

Zell E. Peterman[a,*], Paul L. Cloke[b]

[a]U.S. Geological Survey, MS 963 Box 25046 DFC, Denver, CO, 80225, USA

[b]Science Applications International Corporation, MS 423 1261 Town Center Drive, Las Vegas, NV, 89144, USA

Abstract

The compositional variability of the phenocryst-poor member of the 12.8-million-year Topopah Spring Tuff at the potential repository level was assessed by duplicate analysis of 20 core samples from the cross drift at Yucca Mountain, Nevada. Previous analyses of outcrop and core samples of the Topopah Spring Tuff showed that the phenocryst-poor rhyolite, which includes both lithophysal and nonlithophysal zones, is relatively uniform in composition. Analyses of rock samples from the cross drift, the first from the actual potential repository block, also indicate the chemical homogeneity of this unit excluding localized deposits of vapor-phase minerals and low-temperature calcite and opal in fractures, cavities, and faults. The possible influence of vapor-phase minerals and calcite and opal coatings on rock composition at a scale sufficiently large to

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[*]Corresponding author.
Fax: (303) 236-4930
E-mail address: zpeterman@cs.com

incorporate these heterogeneously distributed deposits was evaluated and is considered to be relatively minor. Therefore, the composition of the phenocryst-poor member of the Topopah Spring Tuff is considered to be adequately represented by the analyses of samples from the cross drift. The mean composition as represented by the 10 most abundant oxides in weight percent or grams per hundred grams is: SiO_2, 76.29; Al_2O_3, 12.55; FeO, 0.14; Fe_2O_3, 0.97; MgO, 0.13; CaO, 0.50; Na_2O, 3.52; K_2O, 4.83; TiO_2, 0.11; and MnO, 0.07.

1. Introduction

A 2.6-km-long cross drift across the potential repository block was completed in April 1997 (Fulcher *et al.*, 2000) to provide direct access to the rock units in which emplacement drifts may be constructed (Fig. 1) for the potential high-level radioactive waste repository at Yucca Mountain, Nevada. Core samples from drill holes in the cross drift were analyzed for major and trace elements to characterize the geochemistry of these rocks. Although many chemical analyses of core from surface-based drilling and from outcrop samples exist (Lipman, 1965; Lipman *et al.*, 1966; Broxton *et al.*, 1989; Flood *et al.*, 1989; Schuraytz *et al.*, 1989; Peterman and Futa, 1996; Peterman *et al.*, 1996), the analyses reported herein are the first such data from the underground workings at Yucca Mountain.

The evaluation of a site for construction of an underground geologic repository requires an understanding of the present-day geological, hydrological, and geochemical environments and processes, how these have changed in the past, and how they might change in the future. In developing generic criteria for geologic disposal, the Committee on Radioactive Waste Management (National Research Council, 1978, p. 1) emphasized the importance of the geochemistry of potential host rocks and contained fluids as well as the impact of construction on these parameters. Chapman and McKinley (1987, p. 145-146) further emphasized the importance of host rock geochemistry to past and future water-rock interaction processes with regard to the buffering of water chemistry and the retardation of radionuclides. At Yucca Mountain the dissolution of or reaction with volcanic glass (White *et al.*, 1980) and with zeolites in altered tuffs (Bish *et al.*, 1984) are important controls on the chemical evolution of water percolating through the volcanic rocks.

To address these processes associated with water-rock interaction that will occur in proximity to emplacements drifts, definitive and reliable data on chemical composition of the host rock for the potential repository at Yucca Mountain are required. Such data will be used for geochemical modeling of rock alteration and secondary mineral deposition during initial heating and later cooling of the potential repository emplacement drifts. The corollary to alteration of the host rock and deposition of secondary minerals is the modification of the chemical composition of water that may enter the potential repository emplacement drifts and react with the waste packages and with invert material such as crushed rock or concrete.

2. Lithostratigraphy

Stuckless and Dudley (this issue) describe the geohydrology of the Yucca Mountain area, including the regional stratigraphy. The 12.8-Ma (Sawyer *et al.*, 1994) Topopah Spring Tuff, the host rock for the potential repository, is part of the Paintbrush Group of volcanic rocks. An informal lithostratigraphic division of the Paintbrush Group (modified from Buesch *et al.*, 1996) is given in Table 1. In the vicinity of the potential repository, the Topopah Spring Tuff reaches a maximum thickness of approximately 350 m (U.S. Department of Energy, 2000). It is a multiple flow, compound cooling unit as shown by repetition of vapor-phase and lithophysal zones, and by the presence of densely welded zones that overlie porous vapor-phase zones (Lipman *et al.*, 1966, p. F7). In addition to the depositional and cooling features, the Topopah Spring Tuff is compositionally zoned with a phenocryst-poor (crystal-poor) rhyolite member composing the lower two-thirds to three-quarters of the unit with an overlying member grading from rhyolite to quartz latite in which the abundance of phenocrysts increases upward (Lipman *et al.*, 1966, p. F11). Similar compositional variations occur in the overlying but thinner Tiva Canyon Tuff (Peterman and Futa, 1996; Peterman *et al.*, 1996) for which the stratigraphic divisions are given in Table 1. The emplacement drifts of the potential repository would be in the middle nonlithophysal (Tptpmn), the lower lithophysal (Tptpll), and the lower nonlithophysal (Tptpln) zones of the phenocryst-poor rhyolite member of the Topopah Spring Tuff.

The compositional variability of the Topopah Spring Tuff reflects pre-eruption chemical zonation in the magma chamber (Lipman *et al.*, 1966) in that the last material erupted would have been the quartz latitic magma derived from the lower part of the chamber. Strontium and neodymium isotope ratios of bulk rock and phenocrysts indicate that assimilation of Precambrian crust in addition to fractional crystallization contributed to the chemical diversity of the Paintbrush Group magmas (Noble and Hedge, 1969; Farmer *et al.*, 1991; Peterman *et al.*, 1991; Peterman and Futa, 1996; Peterman *et al.*, 1996).

All of the lithostratigraphic zones contain abundant fractures typically spaced centimeters to meters apart. Many of the fractures formed upon cooling or crystallization of the rock or during subsequent tectonic stresses, and the fractured rock is neither chemically nor mineralogically different from the adjacent unfractured rock. Some fractures were pathways for vapor movement during cooling of the tuffs and may contain vapor-phase minerals, mainly silica minerals and feldspars, or may have been corroded by the high-temperature vapor. Many of the fractures, including some of those with vapor-phase minerals, contain low-temperature assemblages of calcite ($CaCO_3$) and opal ($SiO_2 \cdot nH_20$) that precipitated from downward-percolating water (Paces *et al.*, 1998; Neymark and

Paces, 2000). In addition to the fractures, some of the lithophysal cavities and porous partings contain epigenetic deposits of calcite and opal as well as vapor-phase minerals.

3. Sampling and analysis

Following construction of the cross drift (Fulcher *et al.,* 2000), 2-m-deep coreholes spaced on 50-m centers were drilled horizontally from the left rib (left-hand side of the tunnel facing to the southwest) to determine physical properties and *in situ* moisture potential of the rocks. Multiple intervals of core from each hole, each approximately 5 to 7 cm long, were sealed in cans immediately after drilling to preserve moisture contained in the rocks. One sealed core sample was obtained from each of 20 selected coreholes drilled in the cross drift and prepared for analysis. Core samples containing vapor-phase minerals or low-temperature fracture and cavity calcite and opal deposits were not selected for analysis. The samples were from Stations 10+00 to 25+00 located 1,000 to 2,500 m from the intersection of the cross drift and the main drift of the Exploratory Studies Facility (Fig. 2).

3.1 Sample preparation

The core samples were air dried, broken with a hammer into pieces approximately 5 cm or smaller and crushed in a small jaw crusher to pieces approximately 1 cm or smaller. The crushed sample was weighed (typically 200 to 400 g) and split by cone and quartering to yield a subsample of approximately 100 grams (± 15 grams). The 100-gram split was pulverized in a rotary mill with hardened steel rings and puck for 2 minutes to yield nominal 200-mesh material. The 2-minute pulverization time was based on experience for minimizing overgrinding and potential iron contamination. The pulverized material was mixed by rolling 10 times on paper and then gathered as a conical pile in the center. Aliquots were taken by randomly scooping small amounts from around the pile with a spatula, leaving approximately 50 grams in reserve.

3.2 Analysis

Five aliquots of each sample were used for analysis of different elements by different methods. One aliquot was analyzed by energy-dispersive X-ray fluorescence (XRF) on packed powders for the selected trace elements Rb, Sr, Y, Zr, Nb, Ba, La, and Ce. A second aliquot and a third as a duplicate were analyzed by wavelength-dispersive XRF on prepared glass wafers for the major elements Si, Al, Fe (total), Mg, Ca, Na, K, Ti, P, and Mn. The fourth aliquot and a fifth as a duplicate were analyzed for ferrous Fe, Cl, F, S, inorganic C (reported as CO_2), and H_2O+ and H_2O- by various methods described by Arbogast (1996).

3.3 Quality control

To monitor precision and accuracy of analyses, five splits each of two USGS rock standards, RGM-1 and GSP-2, were submitted as blind samples along with the cross drift core samples. Analyses of these standards and a comparison with the USGS-recommended values (Smith, 1995; Gunderson, 1998) are given in Tables 2 and 3. The precision of the five replicate analyses of the two standards is considered to be acceptable as shown by the standard deviations for the oxides and elements. The agreement of the analyses with the recommended values also is acceptable considering the standard deviations of both the mean and the recommended values.

4. Results and discussion

Chemical analyses of duplicate samples from 20 cores in the cross drift (Table 4) indicate that the phenocryst-poor member of the Topopah Spring Tuff is compositionally uniform at the scale sampled regardless of stratigraphic zone (lithophysal or nonlithophysal). This uniformity is illustrated on a chemical rock classification diagram of total alkalis plotted against silica where the means of the duplicate analyses cluster tightly in the rhyolite field (Figure 3). Previous analyses of both phenocryst-poor rhyolite and phenocryst-rich quartz latite members of the Topopah Spring Tuff define the elliptical area in Figure 3 (Broxton *et al.*, 1989; unpublished USGS analyses).

The compositional variability of the cross drift samples was statistically assessed using the standard Fisher (F) test described by Youden (1951). This variability was determined by comparing the variance (square of the standard deviation) calculated from the 20 pairs of duplicate analyses with the variance calculated from the 20 mean values of the duplicate pairs of analyses. The compositions of the core samples are so similar that the analytical precision can be estimated by assuming that the analyses represent the same material. Thus, the analytical variance was calculated for each of the major oxides in Table 4 following the procedure described by Youden (1951, p. 17). Also, the means of the duplicate analyses were used to calculate the sample variance (the term sample is used in this paragraph as the subset of a population) by standard techniques. The value for F is the ratio of the sample variance to the analytical variance (Youden, 1951, p. 20-21) and is calculated as follows:

$$F = [\Sigma(x_m - \mu)^2/(n_m-1)]/\ \Sigma(x_a - x_b)^2/n$$

Where x_m = means of duplicate analyses

μ = overall mean of the analyses

n_m = number of samples (20)

x_a and x_b are the duplicate analyses

n = total number of analyses (40)

The critical value for F at a significance level of 0.05 (5 percent probability) for comparing the sample variance with the analytical variance is approximately

1.84 (Kanji, 1999, Table 3, p. 164). Thus, if the calculated F value for an oxide is 1.84 or less, the probability that sample variability exceeds analytical uncertainty is only 5 percent, and the variability can be attributed to analytical precision with 95 percent confidence (Youden, 1951, p. 20-21). If the critical F value is exceeded, real variability among samples in excess of analytical uncertainty is indicated. For the analyses of cross drift samples, the F values range from 1.34 to 25.9. The variability of only two oxides, SiO_2 (F=1.48) and TiO_2 (F=1.34), can be explained solely by analytical uncertainty. The larger F values, indicating real variability among samples, are for CaO (25.9), Na_2O (24.7), MnO (23.7), and F (21.3). The concentrations of Cl (4.69) and the oxides Al_2O_3 (5.37), Fe_2O_3 as total iron (8.31), MgO (11.7), and K_2O (11.9) have intermediate F values and smaller variability among samples. However, even the oxide with the largest statistical variability among samples, CaO, has a relatively small absolute variation (Table 4). The mean CaO concentration is 0.50 weight percent and the standard deviation is 0.03 (Table 6) whereas the standard deviation for the duplicates is 0.005. Thus, the standard deviation of the sample distribution for CaO is about 6 times the standard deviation of the duplicate analyses.

Normative mineral compositions (Table 5) were calculated from the means of each pair of duplicate analyses using the Igpet99 program (Carr, 1999). For samples for which the oxide or elemental concentrations were below detection, the values for the detection limits were used in the calculations. Thus, normative pyrite and apatite are calculated based on detectability limits of S and P_2O_5 of

0.05 weight percent. The abundances of the normative quartz and feldspars closely approximate the abundances of silica polymorphs and feldspars actually in the rocks (Bish and Vaniman, 1985, p. 6). However, hydrous phases such as biotite are not represented in the normative calculations, and the constituents that would form biotite are proportioned between the anhydrous minerals orthoclase and hypersthene in the normative calculations. The leucocratic nature of the phenocryst-poor rhyolite member of the Topopah Spring Tuff is shown by the sum of normative quartz and feldspars (orthoclase, albite, and anorthite), which ranges from 95 to 97 percent of the total rock (Table 5). The mean normative plagioclase composition for the 20 samples is albite with an anorthite content of 6.1 percent (Table 5).

Lipman *et al.* (1966, p. F42) used normative minerals to compare the composition of the Topopah Spring Tuff to the experimentally determined granite system of quartz, orthoclase, albite, and water of Tuttle and Bowen (1958). The normative mineral proportions in the tuff defined a trend characterized by nearly constant albite/orthoclase ratios but increasing quartz contents from quartz latite to rhyolite. The normative compositions of the more evolved rhyolites (largest normative quartz concentrations) coincided with the cotectic defined at 0.6±0.1 kilobars of water pressure. Lipman *et al.* (1966) also noted that the rhyolite analyses should be a good approximation of the composition of the magmatic liquid because of the low phenocryst content.

Normative quartz and the albite/orthoclase ratio for the analyses of cross drift samples (Table 5) are plotted on a binary depiction of the granite system (Figure 4) along with analyses of both phenocryst-rich and phenocryst-poor members reported by Lipman *et al.* (1966). The analyses of cross drift samples are similar to those of Lipman *et al.* (1966) for the phenocryst-poor member. The trend of all analyses projects onto the cotectic line between 0.5 and 1 kb of water pressure and a corresponding temperature range of 770° to 720°C. Subsequently, Lipman (1971, p. 438) estimated crystallization temperatures of the rhyolite at 700º±50ºC using the compositions of iron-titanium oxides. The two temperature estimates are in agreement.

Mean major-element compositions for samples of the phenocryst-poor Topopah Spring Tuff from the cross drift agree closely with mean compositions for 17 samples from borehole UE-25 UZ#16 and for 105 outcrop samples from the Yucca Mountain area (U.S. Department of Energy, 1998, Tables 6.1-3 and 6.1-4), except for MgO (Table 6). Although the mean MgO concentrations agree between the cross drift samples and samples from borehole UE-25 UZ#16, 0.12±0.02 weight percent and 0.12±0.08 weight percent, respectively, the mean MgO concentration of 0.03±0.07 weight percent for the 105 outcrop samples is significantly less than both of the other mean values. The reason for this difference is not known. The mean CaO concentration is slightly larger in the outcrop samples, probably because of inclusion of small amounts of calcite in the surface rocks as a result of pedogenic processes. Mean trace-element concentrations of the cross drift samples and of the UE-25 UZ#16 samples also agree closely (Table 6).

4.1 Heterogeneities

The chemical analyses of the cross drift samples do not include the possible compositional influence of localized deposits of vapor-phase minerals and low-temperature calcite and opal because these minerals were avoided in sample selection. The chemical uniformity of the cross drift samples implies that the high-temperature processes that redistributed material during and shortly after deposition of the ash-flow tuffs, such as devitrification, vapor-phase corrosion, and vapor-phase deposition, did not significantly alter the composition of the phenocryst-poor member of the Topopah Spring Tuff at the scale sampled. Direct characterization of rock compositions at a scale that would incorporate localized vapor-phase mineral and low-temperature calcite and opal abundances would require large, multi-ton bulk samples. Although this scale of sampling wasn't done during construction of the tunnels, the effects of these mineralogical heterogeneities on large-scale compositions can be estimated using additional information as described in the following.

Calcite and opal deposits are not abundant in the potential repository rocks (Paces *et al.*, 1998; Neymark and Paces, 2000). The most comprehensive estimate of calcite in these rocks is derived from normative calcite concentrations calculated from CO_2 analyses of 1.5-m intervals of drill cuttings from borehole USW WT-24. These calculations range from 0.002 to 1.8 weight percent (mean is 0.24 weight percent) normative calcite in the phenocryst-poor member of the Topopah Spring Tuff (J.B. Paces, U.S. Geological Survey, personal communication, June 11, 2000). The mean normative calcite concentrations in the lithostratigraphic zones for USW WT-24 are: Tptpul, 0.14; Tptpmn, 0.45; Tptpll, 0.028; and Tptpln, 0.042, all in weight percent. In comparison, the mean normative calcite concentration for the phenocryst-poor rhyolite represented by the cross drift samples is 0.025 weight percent based on the mean CO_2 concentration of 0.011 percent with a standard deviation of 0.003 (Table 6). Given the large uncertainty, this mean value is comparable to the mean USW WT-24 calcite concentrations of Tptpll (0.028 weight percent) and Tptpln (0.042 weight percent) but less than the values for Tptpul (0.14 weight percent) and Tptpmn (0.45 weight percent). Because the cuttings from USW WT-24 represent continuous sampling through the lithostratigaphic zones, the analyses are more representative at a larger scale than the analyses of cross drift samples which were selected to avoid secondary calcite and opal. For a larger scale representation of the chemical composition of Tptpmn, CaO and CO_2 could be increased from the mean values in Table 6 by adding 0.24 and 0.19 weight percent, respectively, on the basis of the USW WT-24 normative calcite values. Similarly, the CaO and CO_2 concentrations for Tptpul could be increased by 0.06 and 0.05 weight percent, respectively. Thus, the large-scale concentrations for CaO and CO_2 in Tptpmn would be 0.74 and 0.20 weight percent, respectively, and in Tptpul, 0.56 and 0.06 weight percent, respectively. These are small adjustments and are relatively inconsequential for the large-scale rock compositions of the potential repository units.

The possible influence of opal on silica concentrations at a large scale can be evaluated on the basis of the normative calcite concentrations discussed above. Although the calcite/opal ratio of low-temperature fracture and cavity coating deposits in the phenocryst-poor Topopah Spring Tuff has not been accurately determined, examination of numerous deposits indicates that a conservative ratio may be about 10 to 1. Thus, the largest mean calcite concentration (0.45 percent for Tptpmn) would correspond to about 0.045 percent silica (SiO_2). Given the mean SiO_2 concentration of 76.3±0.32 weight percent for the cross drift samples (Table 6), even this maximum value of 0.045 percent SiO_2 would be an insignificant addition to the bulk-rock composition at the larger scale of the phenocryst-poor member.

Vapor-phase minerals in lithophysal cavities and partings include tridymite, alkali feldspar, amphibole, pseudobrookite, manganese garnet, biotite, and specular hematite (Carlos, 1985; Carlos *et al.*, 1995). The most abundant of these in rhyolitic tuffs are the silica polymorphs and alkali feldspar (Smith, 1960, p. 152), and these minerals compose more than 95 percent of the phenocryst-poor rhyolite (Bish and Vaniman, 1985). Vapor-phase corrosion and vapor-phase deposition are common processes during the early post-depositional history of ash-flow sheets (Smith, 1960; Ross and Smith, 1961). These processes may approximate a closed-system redistribution of material within the lithostratigraphic zones in which the processes are operative. Hence, the compositional influence of vapor-phase minerals on the large-scale rock compositions would be small. More direct estimates of overall rock composition would require measurements of the abundances of silica minerals and feldspars, especially in the lithophysal zones. Such measurements are not currently available.

5.0 Conclusions

Major and minor element analyses of duplicate samples from 20 cores in the phenocryst-poor member of the Topopah Spring Tuff from the cross drift, the first analyses from the actual block of the potential repository at Yucca Mountain, indicate that the rocks are chemically uniform at the scale sampled, excluding any localized mineral heterogeneities. A statistical assessment of the chemical analyses indicated that the variability of SiO_2 and TiO_2 in the 20 samples is within the analytical uncertainty for these oxides, and the compositional variability of the other oxides and elements is very small. The slight variations in compositions are independent of the locations of samples with respect to lithostratigraphic zone in the phenocryst-poor member of the Topopah Spring Tuff. Normative mineral compositions are consistent with those previously reported (Lipman *et* *al.*, 1966) and plot close to the minima on the granite system of Tuttle and Bowen (1958).

The influence of localized mineral heterogeneities such as vapor-phase minerals and low-temperature calcite and opal deposits on large-scale rock compositions probably is very small. The influence of calcite deposits on large-scale rock compositions is inconsequential based on normative calcite determinations from USW WT-24 drill cuttings. Associated opal deposits do not influence large-scale compositions of silica for any lithostratigraphic zone because the abundance of opal is so minor. The possible influence on overall rock compositions of vapor-phase minerals, predominantly silica and feldspar, in lithophysal cavities and partings cannot be quantitatively assessed because the abundance of vapor-phase minerals in the lithophysal zones has not been determined. However, consideration of these zones as probable closed systems during the processes of vapor-phase corrosion and vapor-phase deposition implies that these deposits would not affect the large-scale compositions. Therefore, the analyses of samples from the cross drift cores reported here are considered to adequately represent the composition of the phenocryst-poor member of the Topopah Spring Tuff in the repository block.

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Table 1. Proposed stratigraphic divisions of the Paintbrush Group (Buesch et al., 1996). Subdivisions of formations into members and zones are informal.

Formation	Member	Zone	Lithostratigraphic Unit
Tiva Canyon Tuff (Tpc)	Tpcr	Tpcrv	Quartz latite, crystal rich, vitric
		Tpcrn	Quartz latite, crystal rich, nonlithophysal
		Tpcrl	Quartz latite, crystal rich, lithophysal
	Tpcp	Tpcpul	Rhyolite, crystal poor, upper lithophysal
		Tpcpmn	Rhyolite, crystal poor, middle nonlithophysal
		Tpcpll	Rhyolite, crystal poor, lower lithophysal
		Tpcpln	Rhyolite, crystal poor, lower nonlithophysal
		Tpcpv	Rhyolite, crystal poor, vitric
Yucca Mountain Tuff (Tpy)			Rhyolitic ash flow tuff
Pah Canyon Tuff (Tpp)			Rhyolitic ash flow tuff
Topopah Spring Tuff (Tpt)	Tptr	Tptrv	Quartz latite, crystal rich, vitric
		Tptrn	Quartz latite, crystal rich, nonlithophysal
		Tptrl	Quartz latite, crystal rich, lithophysal
	Tptp	Tptpul	Rhyolite, crystal poor, upper lithophysal
		Tptpmn	Rhyolite, crystal poor, middle nonlithophysal
		Tptpll	Rhyolite, crystal poor, lower lithophysal
		Tptpln	Rhyolite, crystal poor, lower nonlithophysal
		Tptpv	Rhyolite, crystal poor, vitric

Table 2

Replicate chemical analyses of USGS Rock Standard RGM-1 and comparison with recommended values (weight percent). The dashes (---) signify not analyzed or not reported, and the symbol < designates below the detection limit indicated.

	C-146536	C-146542	C-146548	C-146554	C-146560	Mean	Standard Deviation	Recommended Value[a]	Standard Deviation[a]
SiO_2	72.5	73.0	73.1	72.6	72.8	72.80	0.255	73.4	0.53
Al_2O_3	13.7	13.7	13.7	13.7	13.7	13.70	0.000	13.7	0.19
FeO	1.50	0.90	1.40	1.10	1.00	1.18	0.259	1.27	0.05
Fe_2O_3	0.17	0.86	0.28	0.63	0.72	0.53	0.292	0.50	0.01
$[Fe_2O_3]_{TOT}$[b]	1.84	1.86	1.84	1.85	1.83	1.84	0.011	1.91	0.05
MgO	0.23	0.24	0.25	0.23	0.23	0.24	0.009	0.28	0.03
CaO	1.19	1.19	1.20	1.18	1.18	1.19	0.008	1.15	0.07
Na_2O	3.96	3.96	3.99	3.96	4.00	3.97	0.019	4.07	0.15
K_2O	4.30	4.32	4.32	4.31	4.33	4.32	0.011	4.30	0.10
TiO_2	0.28	0.28	0.28	0.27	0.28	0.28	0.004	0.27	0.02
P_2O_5	0.07	0.07	0.07	0.07	0.07	0.07	0.000	---	---
MnO	0.04	0.04	0.04	0.04	0.04	0.04	0.000	0.036	0.004
CO_2	<0.01	0.01	0.01	<0.01	<0.01	0.01	0.000	---	---
Cl	0.06	0.06	0.06	0.06	0.06	0.06	0.003	0.051	0.005
F	0.04	0.03	0.04	0.03	0.03	0.03	0.002	0.034	0.003
S	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	---	---	---
H_2O-	0.30	0.20	0.20	0.20	0.20	0.22	0.045	---	---
H_2O+	0.80	0.80	0.70	0.80	0.70	0.76	0.055	---	---
SUM	99.14	99.66	99.64	99.18	99.35	99.40		99.06	

[a] From Smith (1995)

[b] Total iron calculated as Fe_2O_3 and not included in SUM

Table 3

Replicate chemical analyses of USGS Rock Standard GSP-2 and comparison with recommended values (weight percent). The dashes (---) signify not analyzed or not reported.

	C-146539	C-146545	C-146551	C-146557	C-146563	Mean	Standard Deviation	Recommended Value[a]	Standard Deviation[a]
SiO_2	66.3	66.5	66.4	66.4	66.5	66.42	0.084	66.6	0.80
Al_2O_3	14.9	14.9	14.9	14.9	14.9	14.90	0.000	14.9	0.20
$[Fe_2O_3]_{TOT}$[b]	4.86	4.86	4.86	4.88	4.88	4.87	0.011	4.90	0.16
MgO	0.93	0.91	0.91	0.93	0.93	0.92	0.011	0.96	0.03
CaO	2.08	2.09	2.09	2.09	2.09	2.09	0.004	2.10	0.06
Na_2O	2.68	2.69	2.71	2.70	2.70	2.70	0.011	2.78	0.09
K_2O	5.40	5.37	5.38	5.39	5.38	5.38	0.011	5.38	0.14
TiO_2	0.67	0.67	0.67	0.67	0.67	0.67	0.000	0.66	0.02
P_2O_5	0.31	0.31	0.31	0.31	0.32	0.31	0.004	0.29	0.02
MnO	0.04	0.04	0.04	0.04	0.04	0.04	0.000	---	---
CO_2	0.16	0.15	0.15	0.13	0.14	0.15	0.011	---	---
Cl	0.04	0.04	0.04	0.04	0.04	0.04	0.001	---	---
F	0.37	0.47	0.45	0.36	0.38	0.41	0.048	---	---
S	0.06	0.06	0.07	0.05	0.05	0.06	0.008	---	---
H_2O-	0.20	0.20	0.20	0.10	0.20	0.18	0.045	---	---
H_2O+	0.80	0.70	0.70	0.80	0.80	0.76	0.055	---	---
SUM	99.80	99.95	99.88	99.79	100.02	99.89		98.57	

[a] From Gunderson (1998)

[b] Total iron as Fe_2O_3

Table 4

Geochemistry of the phenocryst-poor rhyolite of the Topopah Spring Tuff. The number following CS is distance in meters into the cross drift, and the suffix letters a and b designate duplicate splits. The dashes (---) signify not analyzed and the symbol < designates below the detection limit indicated.

	Sample number and lithostratigraphic zone													
	CS1000a	CS1000b	CS1050a	CS1050b	CS1150a	CS1150b	CS1200a	CS1200b	CS1300a	CS1300b	CS1350a	CS1350b	CS1400a	CS1400b
	Tptpul	Tptpul	Tptpmn	Tptpmn	Tptpmn	Tptpmn	Tptpmn	Tptpmn	Tptpmn	Tptpmn	Tptpmn	Tptpmn	Tptpmn	Tptpmn
	Major oxides and elements, weight percent													
SiO_2	76.2	76.5	76.5	76.2	76.5	76.6	76.7	76.7	76.3	76.4	76.2	76.1	76.0	76.5
Al_2O_3	12.4	12.6	12.4	12.4	12.5	12.5	12.5	12.6	12.4	12.4	12.5	12.4	12.4	12.5
FeO	<0.05	0.1	<0.05	<0.05	0.1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.2	0.2
Fe_2O_3	1.00	0.88	0.99	0.99	0.90	1.01	1.02	1.02	1.00	0.99	1.04	0.99	0.77	0.78
MgO	0.14	0.14	0.14	0.15	0.12	0.13	0.11	0.13	0.12	0.14	0.11	0.10	0.15	0.14
CaO	0.49	0.51	0.51	0.51	0.50	0.50	0.51	0.50	0.50	0.50	0.50	0.50	0.51	0.52
Na_2O	3.37	3.36	3.35	3.36	3.50	3.48	3.50	3.46	3.48	3.52	3.56	3.50	3.39	3.39
K_2O	4.87	4.88	4.78	4.80	4.80	4.80	4.86	4.83	4.78	4.78	4.81	4.82	4.75	4.78
TiO_2	0.11	0.11	0.11	0.11	0.10	0.10	0.11	0.11	0.10	0.10	0.11	0.10	0.11	0.11
P_2O_5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
MnO	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.09	0.09	0.05	0.05
Cl	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.03
F	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.05
S	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
CO_2	0.01	0.01	0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.01	0.01	0.02	<0.01	0.01	0.01
H_2O-	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.3	0.2	0.2	0.2	0.3	0.2
H_2O+	0.4	0.4	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.4	0.3	0.6	0.6	0.5
SUM	99.51	99.91	99.71	99.44	99.83	99.95	100.12	100.07	99.41	99.56	99.49	99.45	99.31	99.75
	Trace elements, in micrograms/gram													
Rb	188	---	187	---	183	---	185	---	183	---	186	---	189	---
Sr	20	---	30	---	28	---	20	---	23	---	27	---	31	---
Y	32	---	32	---	35	---	30	---	34	---	31	---	34	---
Zr	113	---	111	---	116	---	113	---	119	---	112	---	117	---
Nb	23	---	25	---	25	---	25	---	25	---	23	---	25	---
Ba	50	---	50	---	52	---	59	---	49	---	50	---	60	---
La	38	---	55	---	48	---	45	---	57	---	44	---	57	---
Ce	77	---	92	---	87	---	85	---	87	---	82	---	85	---

Table 4 (continued)
Geochemistry of the phenocryst-poor rhyolite of the Topopah Spring Tuff. The number following CS is distance in meters into the cross drift, and the suffix letters a and b designate duplicate splits. The dashes (---) signify not analyzed and the symbol < designates below the detection limit indicated.

	Sample number and lithostratigraphic zone													
	CS1450a Tptpll	CS1450b Tptpll	CS1500a Tptpll	CS1500b Tptpll	CS1750a Tptpll	CS1750b Tptpll	CS1800a Tptpll	CS1800b Tptpll	CS1950a Tptpll	CS1950b Tptpll	CS2000a Tptpll	CS2000b Tptpll	CS2100a Tptpll	CS2100b Tptpll
						Oxides, in weight percent								
SiO_2	76.3	75.9	76.5	76.6	76.4	76.7	75.8	75.8	76.3	76.5	76.4	77.1	75.4	75.5
Al_2O_3	12.5	12.5	12.5	12.4	12.6	12.6	12.9	12.9	12.5	12.5	12.5	12.6	12.9	12.9
FeO	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.1	0.1	<0.05	0.1	<0.05	0.1
Fe_2O_3	1.02	1.03	0.97	0.99	1.00	1.00	1.00	1.00	0.94	0.90	1.04	0.92	1.03	0.90
MgO	0.10	<0.10	0.12	<0.10	0.10	0.10	0.11	<0.10	0.11	0.10	<0.10	<0.10	<0.10	<0.10
CaO	0.41	0.42	0.50	0.51	0.51	0.51	0.49	0.49	0.50	0.50	0.53	0.53	0.50	0.50
Na_2O	3.66	3.60	3.45	3.49	3.53	3.53	3.66	3.67	3.49	3.51	3.60	3.55	3.68	3.68
K_2O	4.87	4.83	4.81	4.82	4.79	4.84	4.96	4.97	4.78	4.79	4.83	4.84	5.01	5.00
TiO_2	0.11	0.11	0.10	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.11	0.11	0.11
P_2O_5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
MnO	0.07	0.07	0.07	0.07	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.07	0.07
Cl	0.02	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.01	0.01
F	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.06	0.06	0.03	0.03
S	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
CO_2	0.01	<0.01	0.01	0.01	0.01	0.01	0.01	0.01	<0.01	0.01	0.02	0.02	<0.01	0.01
H_2O-	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.1
H_2O+	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.3	0.3	0.4	0.3	0.1
SUM	99.70	99.12	99.67	99.64	99.75	100.11	99.56	99.67	99.55	99.63	99.68	100.50	99.25	99.01
						Trace elements, in micrograms/gram								
Rb	188	---	187	---	189	---	198	---	186	---	186	---	203	---
Sr	23	---	22	---	23	---	27	---	29	---	26	---	25	---
Y	31	---	31	---	36	---	27	---	34	---	33	---	26	---
Zr	120	---	110	---	116	---	120	---	115	---	119	---	116	---
Nb	26	---	23	---	25	---	24	---	25	---	27	---	25	---
Ba	52	---	52	---	48	---	55	---	52	---	51	---	61	---
La	52	---	55	---	52	---	56	---	45	---	56	---	56	---
Ce	86	---	84	---	85	---	84	---	76	---	86	---	82	---

Table 4 (continued)
Geochemistry of the phenocryst-poor rhyolite of the Topopah Spring Tuff. The number following CS is distance in meters into the cross drift, and the suffix letters a and b designate duplicate splits. The dashes (---) signify not analyzed and the symbol < designates below the detection limit indicated.

	Sample number and lithostratigraphic zone											
	CS2150a Tptpll	CS2150b Tptpll	CS2250a Tptpll	CS2250b Tptpll	CS2350a Tptpln	CS2350b Tptpln	CS2400a Tptpln	CS2400b Tptpln	CS2450a Tptpln	CS2450b Tptpln	CS2500a Tptpln	CS2500b Tptpln
					Oxides and, in weight percent							
SiO_2	76.1	76.4	75.7	76.3	75.9	76.6	76.5	76.0	75.8	76.3	76.6	76.8
Al_2O_3	12.6	12.6	12.4	12.5	12.3	12.5	12.6	12.6	12.6	12.7	12.6	12.6
FeO	<0.05	0.1	<0.05	<0.05	0.2	0.2	<0.05	0.1	0.1	0.1	0.2	0.2
Fe_2O_3	1.05	0.98	1.09	1.10	0.92	0.91	1.04	0.92	0.96	0.97	0.83	0.84
MgO	0.10	0.11	0.13	0.14	<0.10	<0.10	0.17	0.17	<0.10	<0.10	<0.10	<0.10
CaO	0.51	0.51	0.47	0.47	0.48	0.49	0.54	0.54	0.54	0.55	0.50	0.51
Na_2O	3.42	3.42	3.45	3.47	3.58	3.63	3.37	3.37	3.63	3.66	3.70	3.70
K_2O	4.85	4.84	4.78	4.84	4.79	4.81	4.85	4.81	4.74	4.76	4.78	4.78
TiO_2	0.11	0.11	0.11	0.11	0.11	0.10	0.11	0.11	0.11	0.11	0.11	0.11
P_2O_5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
MnO	0.06	0.06	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07
Cl	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
F	0.05	0.04	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04	0.05	0.05
S	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
CO_2	0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
H_2O-	0.3	0.2	0.3	0.2	0.2	0.2	0.4	0.5	0.2	0.3	0.1	0.2
H_2O+	0.6	0.5	0.5	0.5	0.4	0.5	0.1	0.5	0.3	0.4	0.3	0.2
SUM	99.78	99.89	99.06	99.75	99.00	100.07	99.81	99.75	99.11	99.99	99.86	100.08
					Trace elements, in micrograms/gram							
Rb	187	---	195	---	180	---	189	---	183	---	183	---
Sr	28	---	21	---	22	---	27	---	27	---	23	---
Y	37	---	35	---	32	---	35	---	33	---	29	---
Zr	116	---	118	---	118	---	121	---	126	---	114	---
Nb	25	---	25	---	25	---	26	---	25	---	25	---
Ba	57	---	56	---	52	---	58	---	78	---	56	---
La	48	---	58	---	52	---	44	---	55	---	50	---
Ce	82	---	87	---	72	---	82	---	95	---	86	---

Table 5

Normative minerals for the phenocryst-poor rhyolite of the Topopah Spring Tuff. The number following CS is the distance In meters into the cross drift. The dashes (---) signify not calculated.

	Sample number and lithostratigraphic zone										
	CS1000 Tptpul	CS1050 Tptpmn	CS1150 Tptpmn	CS1200 Tptpmn	CS1300 Tptpmn	CS1350 Tptpmn	CS1400 Tptpmn	CS1450 Tptpll	CS1500 Tptpll	CS1750 Tptpll	CS1800 Tptpll
					Normative, in weight percent						
Q (quartz)	37.14	37.45	36.88	36.89	36.75	36.25	37.37	35.72	36.93	36.59	34.56
or (orthoclase)	28.84	28.31	28.37	28.66	28.25	28.48	28.19	28.66	28.48	28.48	29.37
ab (albite)	28.37	28.36	29.46	29.37	29.47	29.72	28.46	30.57	29.29	29.80	30.91
an (anorthite)	1.89	1.94	1.97	2.02	1.97	1.97	1.92	1.50	2.02	2.02	1.84
C (corundum)	1.01	0.99	0.86	0.85	0.78	0.73	1.05	0.76	0.80	0.85	0.84
hy (hypersthene)	0.35	0.37	0.32	0.30	0.32	0.27	0.37	0.25	0.27	0.25	0.27
mt (magnetite)	---	---	0.02	---	---	---	0.31	---	---	---	---
il (ilmenite)	0.20	0.14	0.19	0.14	0.14	0.18	0.21	0.14	0.14	0.14	0.14
hem (hematite)	0.91	0.93	0.92	0.96	0.94	0.96	0.56	0.97	0.92	0.94	0.94
ap (apatite)	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
hl (halite)	0.03	0.02	0.02	0.02	0.03	0.03	0.05	0.03	0.02	0.02	0.03
zr (zircon)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
fl (fluorite)	0.07	0.07	0.05	0.05	0.05	0.05	0.09	0.07	0.05	0.05	0.07
pr (pyrite)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
ru (rutile)	0.01	0.05	---	0.05	0.04	0.02	---	0.05	0.05	0.05	0.05
SUM	99.06	98.87	99.30	99.55	98.98	98.90	98.82	98.96	99.21	99.43	99.26
100*an/(ab+an)	6.2	6.4	6.3	6.4	6.3	6.2	6.3	4.7	6.5	6.3	5.6
Q+or+ab+an	96.24	96.06	96.68	96.94	96.44	96.42	95.94	96.45	96.72	96.89	96.68
ab/or	0.98	1.00	1.04	1.02	1.04	1.04	1.01	1.07	1.03	1.05	1.05

Table 5 (continued)

Normative minerals for the phenocryst-poor rhyolite of the Topopah Spring Tuff. The number following CS is the distance In meters into the cross drift. The dashes (---) signify not calculated.

	Sample number and lithostratigraphic zone										
	CS1950 Tptpll	CS2000 Tptpll	CS2100 Tptpll	CS2150 Tptpll	CS2250 Tptpll	CS2350 Tptpln	CS2400 Tptpln	CS2450 Tptpln	CS2500 Tptpln	Mean	Standard Deviation
					Normative, in weight percent						
Q (quartz)	36.82	36.53	33.91	36.92	36.60	36.06	37.10	35.66	36.02	36.41	0.90
or (orthoclase)	28.31	28.60	29.61	28.66	28.42	28.37	28.54	28.07	28.25	28.55	0.37
ab (albite)	29.47	30.15	31.07	28.79	29.13	30.40	28.37	30.74	31.16	29.65	0.93
an (anorthite)	1.89	1.90	1.97	1.87	1.74	1.77	2.09	2.14	1.87	1.92	0.14
C (corundum)	0.89	0.76	0.72	1.07	0.94	0.65	1.09	0.75	0.68	0.85	0.13
hy (hypersthene)	0.27	0.25	0.25	0.27	0.35	0.25	0.42	0.25	0.25	0.30	0.05
mt (magnetite)	0.02	---	---	---	---	0.34	---	0.05	0.37	0.19	0.17
il (ilmenite)	0.21	0.18	0.20	0.18	0.14	0.21	0.20	0.21	0.21	0.18	0.03
hem (hematite)	0.91	0.95	0.94	0.99	1.04	0.67	0.95	0.92	0.57	0.89	0.13
ap (apatite)	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.00
hl (halite)	0.03	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.01
zr (zircon)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.00
fl (fluorite)	0.07	0.11	0.05	0.09	0.07	0.09	0.07	0.07	0.09	0.07	0.02
pr (pyrite)	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.00
ru (rutile)	---	0.03	0.01	0.02	0.05	---	0.01	---	---	0.04	0.02
SUM	99.13	99.73	98.99	99.13	98.75	99.08	99.11	99.13	99.74	99.30	---
100*an/(ab+an)	6.0	5.9	6.0	6.1	5.6	5.5	6.9	6.5	5.7	6.07	0.48
Q+or+ab+an	96.49	97.18	96.56	96.24	95.89	96.60	96.10	96.61	97.30	96.52	0.38
ab/or	1.04	1.05	1.05	1.00	1.02	1.07	0.99	1.10	1.10	1.04	0.03

Table 6

Comparison of average chemical compositions of the phenocryst-poor rhyolite of the Topopah Spring Tuff. Values for the cross drift samples are the means of analyses in Table 4. The dashes (---) signify not analyzed or not reported, and the symbol (<) designates below the detection limit indicated.

	Cross Drift Samples (this report)		17 Samples, UE-25 UZ#16 (DOE, 1998)		105 Outcrop Samples (DOE, 1998)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
			Major oxides and elements, in weight percent			
SiO_2	76.29	0.318	76.92	0.31	75.64	0.58
Al_2O_3	12.55	0.142	12.74	0.17	12.37	0.18
FeO	0.13	0.047	---	---	---	---
Fe_2O_3	0.97	0.070	1.00	0.02	0.98	0.04
MgO	0.12	0.020	0.12	0.08	0.03	0.07
CaO	0.50	0.027	0.46	0.02	0.73	0.28
Na_2O	3.52	0.109	3.44	0.25	3.44	0.25
K_2O	4.83	0.062	5.05	0.06	4.86	0.10
TiO_2	0.109	0.004	0.10	0.01	0.10	0.01
ZrO_2	0.016	0.001	---	---	---	---
P_2O_5	<0.05	---	---	---	---	---
MnO	0.068	0.008	0.068	0.004	0.06	0.01
Cl	0.017	0.004	---	---	---	---
F	0.038	0.008	---	---	---	---
S	<0.05	---	---	---	---	---
CO_2	0.011	0.003	---	---	---	---
H_2O-	0.24	0.072	---	---	---	---
H_2O+	0.40	0.090	---	---	---	---
SUM	99.81		99.90		98.21	---
			Trace elements, in micrograms per gram			
Rb	188	5.3	185	6	---	---
Sr	25	3.4	29	8	---	---
Y	32	2.9	29	9	---	---
Zr	116	3.8	126	11	---	---
Nb	25	1.1	20	8	---	---
Ba	55	6.8	---	---	---	---
La	51	5.5	---	---	---	---
Ce	84	5.1	---	---	---	---

Figures

1. Shaded relief map showing the location of the Exploratory Studies Facility and the cross drift at Yucca Mountain, Nevada.

2. Generalized geologic section of Yucca Mountain along the cross drift showing locations of boreholes (solid squares) from which core samples were collected (adapted from U.S. Department of Energy, 2000, Fig. 4.7-5). The cross drift intersects the Exploratory Studies Facility at ESF Station 19+92. Cross drift stations are designated in hundreds and tens of meters such that Station 16+00, for example, is 1,600 meters from the intersection with the ESF. Lithostratigraphic units are defined in Table 1. Qal refers to Quaternary alluvium.

3. Chemical analyses of samples of the crystal-poor member of the Topopah Spring Tuff plotted on the International Union of Geological Sciences classification diagram for igneous rocks based on SiO_2 and Na_2O +K_2O (Le Maitre, 1989). The field for the Topopah Spring Tuff that extends into the trachyte field includes samples historically referred to as quartz latites (Broxton *et al.*, 1989; unpublished USGS analyses). Quartz latitehttp://www.crateandbarrel.com/customer/default.asp will be used in this report for consistency with previous studies.

4. Normative compositions of samples from the Topopah Spring Tuff plotted on a binary depiction of the ternary granite system albite-orthoclase-quartz. The loci of the granite minima is defined by the ratio of albite to orthoclase and by the corresponding quartz concentration at different pressures and temperatures (Rollinson, 1993, p. 87).

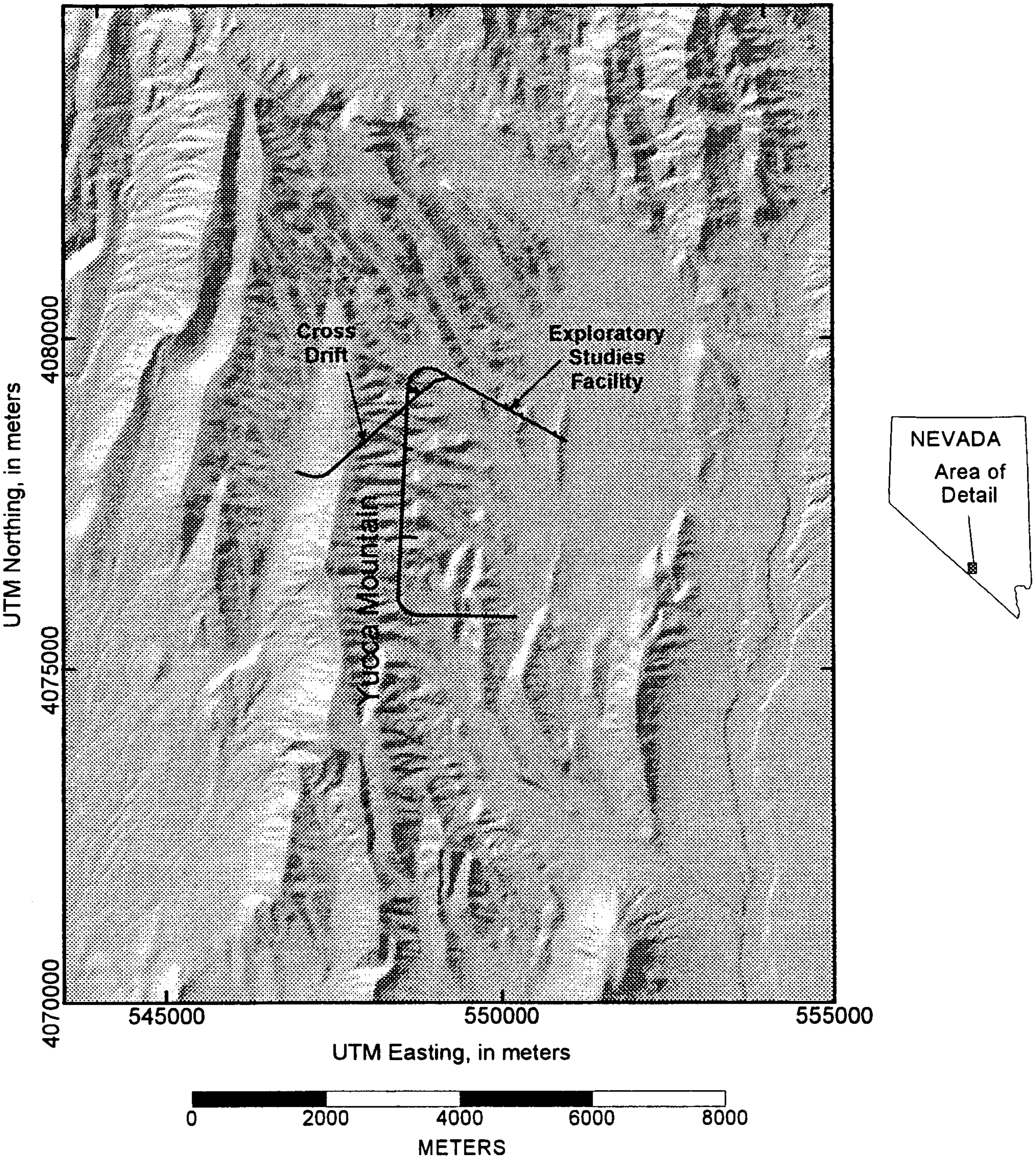

Cross
Drift
Exploratory
Studies
Facility
Yucca Mountain
UTM Northing, in meters
4080000
4075000
4070000
545000
550000
555000
UTM Easting, in meters
0
2000
4000
6000
8000
METERS
NEVADA
Area of
Detail

Fig. 1

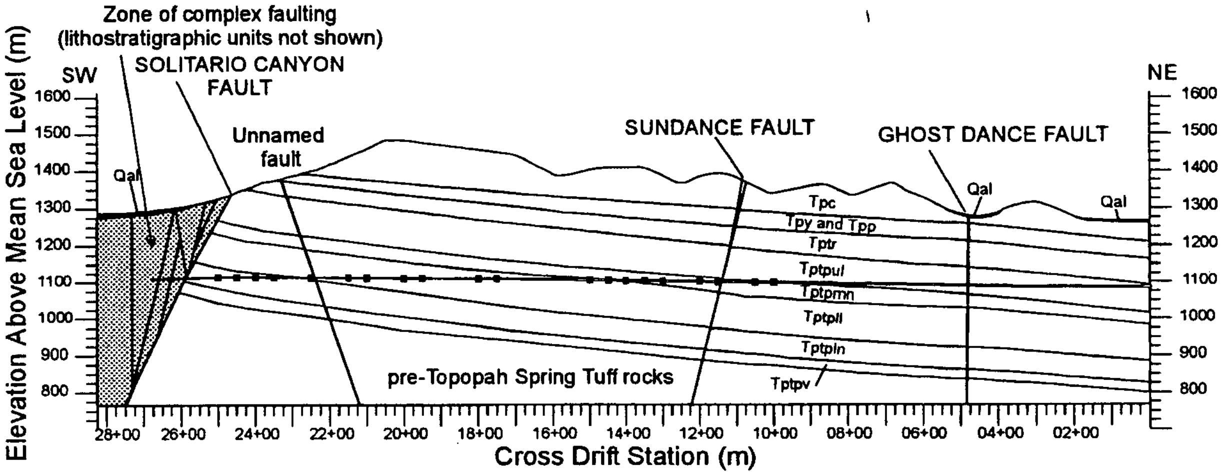
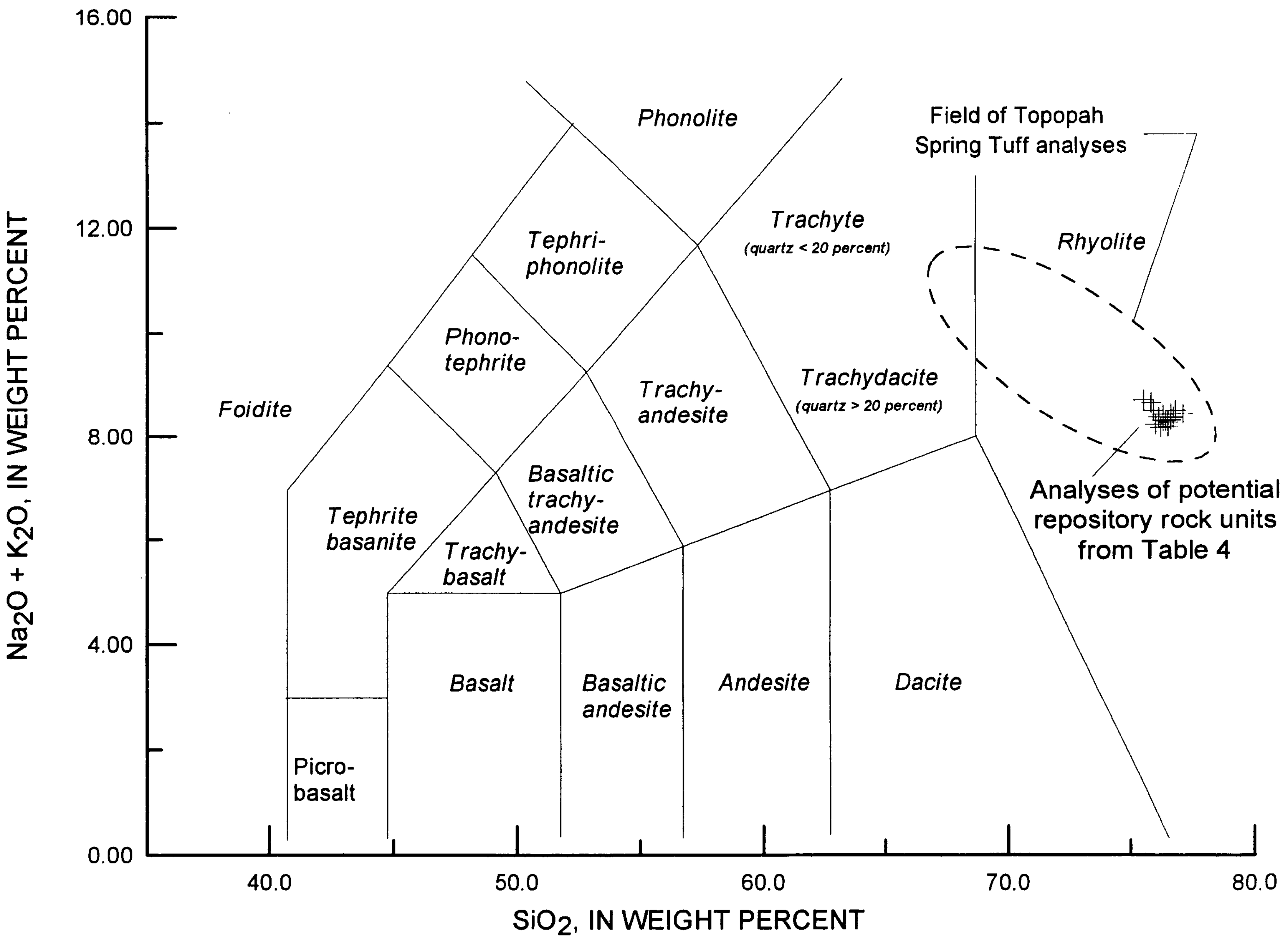
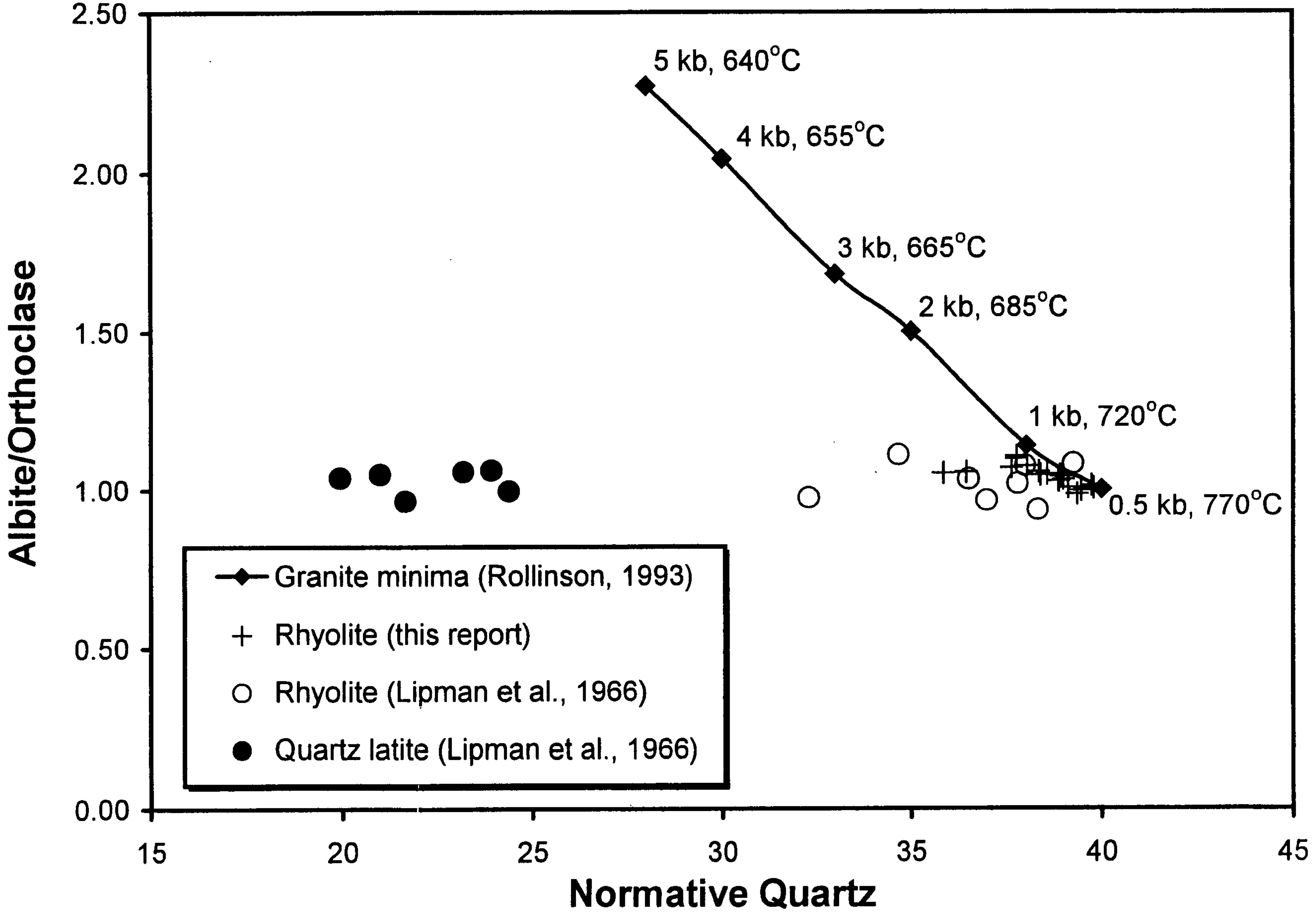

Zone of complex faulting
(lithostratigraphic units not shown)
SOLITARIO CANYON
FAULT
Unnamed
fault
SUNDANCE FAULT
GHOST DANCE FAULT
SW
NE
Qal
Qal
Qal
Tpc
Tpy and Tpp
Tptr
Tptpul
Tptpmn
Tptpll
Tptpln
Tptpv
pre-Topopah Spring Tuff rocks
Elevation Above Mean Sea Level (m)
1600
1500
1400
1300
1200
1100
1000
900
800
28+00
26+00
24+00
22+00
20+00
18+00
16+00
14+00
12+00
10+00
08+00
06+00
04+00
02+00
Cross Drift Station (m)

Fig. 2


16.00
12.00
8.00
4.00
0.00
Na$_2$O + K$_2$O, IN WEIGHT PERCENT
40.0
50.0
60.0
70.0
80.0
SiO$_2$, IN WEIGHT PERCENT
Phonolite
Foidite
Tephri-phonolite
Phono-tephrite
Tephrite basanite
Picro-basalt
Trachy-basalt
Basaltic trachy-andesite
Trachy-andesite
Trachyte (quartz < 20 percent)
Trachydacite (quartz > 20 percent)
Rhyolite
Basalt
Basaltic andesite
Andesite
Dacite
Field of Topopah Spring Tuff analyses
Analyses of potential repository rock units from Table 4



Albite/Orthoclase
2.50
2.00
1.50
1.00
0.50
0.00
15
20
25
30
35
40
45
Normative Quartz
5 kb, 640°C
4 kb, 655°C
3 kb, 665°C
2 kb, 685°C
1 kb, 720°C
0.5 kb, 770°C
Granite minima (Rollinson, 1993)
Rhyolite (this report)
Rhyolite (Lipman et al., 1966)
Quartz latite (Lipman et al., 1966)