Title: Mineralogic Variation in Drill Holes
USW NRG-6, NRG-7/7a, SD-7, SD-9, SD-12,
and UZ#14:
New Data from 1996-1997 Analyses

Author(s): S.J. Chipera
D.T. Vaniman
D.L. Bish
J.W. Carey

Submitted to: Yucca Mountain Site Characterization
Project Office Report

Deliverable No. SP321BM4

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED *ng*

Los Alamos
NATIONAL LABORATORY

MASTER

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. The Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

**Mineralogic Variation in Drill Holes
USW NRG-6, NRG-7/7a, SD-7, SD-9, SD-12, and UZ#14:
New Data from 1996 - 1997 Analyses**

S. J. Chipera, D. T. Vaniman, D. L. Bish, and J. W. Carey

Earth and Environmental Sciences Division

Los Alamos National Laboratory

Deliverable No. SP321BM4

Due Date: 05-JUN-1997

Abstract:

New quantitative X-ray diffraction (QXRD) mineralogic data have been obtained for samples from drill holes NRG-6, NRG-7/7a, SD-7, SD-9, SD-12, and UZ#14. In addition, new QXRD analyses were obtained on samples located in a strategic portion of drill hole USW H-3. These data improve our understanding of the mineral stratigraphy at Yucca Mountain, and they further constrain the 3-D Mineralogic Model of Yucca Mountain. The closer sample spacing used in these drill holes (average spacing of ~4.5 meters with closer spacing in variable areas), in contrast to the sample spacing in older drill cores (>15 meters), allows for a better understanding of the mineralogical variations and distribution with depth at Yucca Mountain. Some of the unexpected findings include the occurrence of the zeolite chabazite in the vitric zone of USW SD-7, broad overlap of vitric and zeolitic horizons (over vertical ranges up to 70 m), and the previously unrecognized importance of the bedded tuffs beneath the Calico Hills Formation as a subunit with generally more extensive zeolitization than the Calico Hills Formation in the southern part of the potential repository area. Reassessment of data from drill hole USW H-5 suggests that the zeolitization of this bedded unit occurs in the northwestern part of the repository exploration block as well. Further analyses of the same interval in USW H-3, however, have not permitted the same conclusion to be reached for the southwestern part of the repository block because of the much poorer quality of the cuttings in H-3 compared with those from H-5.

Unexpected occurrences of the zeolite stellerite in USW UZ#14 prompted the re-examination of occurrences of other minor zeolites, particularly erionite. Erionite, a carcinogenic zeolite, has been noted in the bulk rock in drill core from USW UZ#14 where it occurs in abundances of up to 34 weight percent in a 3.3 meter thick layer within the bedded unit immediately underlying the lower vitrophyre of the Topopah Spring Tuff. It is very possible that erionite exists within this bedded unit in some of the earlier drill holes at Yucca Mountain but has been overlooked due to the large sample intervals used when sampling those drill cores. UZ#14 is the second drill hole in which stellerite has been observed in the bulk rock

within the host rock unit, although stellerite has been observed to line fractures in numerous other drill cores at Yucca Mountain.

X-ray fluorescence (XRF) chemical data for drill holes USW SD-7, 9, and 12 show that the zeolitic horizons provide a >10 million year record of retardation of Sr transport, although the data also show that simplistic models of one-dimensional downward flow in the unsaturated zone (UZ) are inadequate. Complex interstratification of zeolites and glass, with highly variable profiles between drill cores, point to remaining problems in constructing detailed mineral stratigraphies. However, the new data in this report provide important information for constructing bounding models of zeolite stratigraphy for transport calculations.

I. INTRODUCTION

Yucca Mountain, located in southwestern Nevada, is being investigated to determine its suitability to host the first high-level nuclear waste repository in the United States (Fig. 1). The studies of Yucca Mountain and the surrounding area are part of the Yucca Mountain Site Characterization Project, directed by the Yucca Mountain Site Characterization Office (YMSCO) of the U.S. Department of Energy, Nevada Operations Office. In order to provide a sound basis for performance modeling (e.g., radionuclide transport and thermal response models), it is important to understand the mineral content and distribution within the mountain. Bish and Chipera (1989) compiled a summary of mineral distributions with depth for drill holes at Yucca Mountain that had been analyzed by X-ray diffraction (XRD). However, their results were based on data from drill holes that were not drilled under today's quality assurance (QA) program and the drill holes were sampled at greater spacing than currently practiced. Drill hole UE-25 UZ#16 was one of the first holes drilled under the present QA program, and it provided the first core obtained by dry drilling, using air (Chipera *et al.*, 1995b). The close spacing used in UE-25 UZ#16 sampling was designed to examine textural/lithologic subunits to determine whether there are relations between mineralogic and textural/lithologic features in the rock. The close spacing yielded some valuable and unexpected results, including the presence of the zeolite stellerite in bulk-rock samples of the devitrified Topopah Spring Tuff where it had only been observed previously in fractures. In addition, thin zeolitic beds were identified that would have been missed by the past larger sample spacing. Cumulatively, these thin zeolitic beds intercalated with vitric material may be of particular significance in performance modeling for Yucca Mountain. Figure 1 shows the locations of the drill holes that have been analyzed at Yucca Mountain along with their QA-status. The analyses included in this report help to fill in gaps between analyzed drill holes and provide quality data with which the non-QA data may be compared.

A previous report entitled "Preliminary Three-Dimensional Model of Yucca Mountain" (Chipera *et al.*, 1997) was formulated using older non-Q data, data from UE-25 UZ#16, and data from analyzed portions of USW SD-7, 9, and 12 (Chipera *et al.*, 1996). The present study

Figure 1: Map of Yucca Mountain showing the locations of the drill holes mentioned in the text.

provides additional data from deeper units (to total depth, T.D.) in SD-7, 9, and 12 as well as new data for the Topopah Spring Tuff in SD-7 and SD-12. Because of the time and funding constraints, complete analysis of the Topopah Spring Tuff in SD-12 was not possible. However, the unanalyzed section may be completed as a part of future studies to better understand hazardous mineral distributions. Complete analyses from surface to T.D. are also now available for NRG-6 and NRG-7/7A, along with new data for USW UZ#14 to 432 m depth. These new data will be used to revise and update the 3-D Mineralogic Model of Yucca Mountain. The need for a complete and accurate 3-D Mineralogic Model of Yucca Mountain, based on a representative areal sample distribution, is driven by several concerns arising from site characterization. For example, despite the Project's long-standing concept of the role of stacked zeolite horizons as barriers to radionuclide migration between the potential repository horizon and the water table and direct evidence for some form of zeolitic barrier above the water table in every drill hole examined to date (e.g., Vaniman *et al.*, 1984), there continues to be a common misconception that "holes" exist at Yucca Mountain where no zeolitic barriers occur between the potential repository and the water table. This misconception is unsupported by available data. Furthermore, the view that significant zeolite holes exist demonstrates the critical need for an accurate quantitative 3-D model of mineral distributions, widely accessible to Project participants, for accurate visualization of site properties. The utility of the new mineralogic data presented in this report, coupled with the 3-D Mineralogic Model, is also evident in addressing at least four other aspects of site characterization and assessment:

1) Linkages between mineralogy and fluid flow

Mineralogy is often a very important parameter in defining the hydrologic behavior of rock masses. For example, vitric nonwelded tuffs and zeolitized tuffs can have very similar porosities but different hydraulic conductivities (Loeven, 1993). Likewise, smectite intervals, even in thin occurrences, can give aquitard characteristics to porous intervals that would otherwise be very transmissive when saturated. The discovery of broadly overlapped vitric and zeolitic horizons emphasizes the importance of understanding the detailed mineralogy beneath the repository horizon.

2) Linkages between mineralogy and waste transport

Zeolitic horizons have long been and still remain an important factor in models of radionuclide transport at Yucca Mountain. A 3-D transport modeling capability has already been developed using a basic 3-D model of zeolite horizons that was not based on the Integrated Site Model (Robinson *et al.*, 1995). In this earlier study, zeolite horizons were defined based on assumed arbitrary cutoffs of zeolite percentage. The existing Mineralogic Model incorporates zeolite and other mineral percentages as the basic distributed property,

allowing mineral volumes to be defined as needed for specific performance studies. Data from the present study will improve the accuracy of the 3-D Mineralogic Model, facilitating more representative modeling of transport. For example, knowledge of the zeolite distribution in the broadly overlapped vitric to zeolitic transition zone is crucial to accurate transport modeling as even small volumes of zeolites are important in transport.

3) Mineral distributions and thermal stability

Hydrous minerals and water-bearing glasses can be affected by repository-induced heating and can in turn serve to moderate heat accumulation within the rock mass. Other minerals, particularly silica polymorphs, may be structurally affected or may control the aqueous silica concentrations of fluids migrating under thermal loads, resulting in silica dissolution or precipitation and rock-property modification at distal locations along the thermal gradient. The effects of thermal alteration by emplaced waste will likely be most pronounced in and just above the basal vitrophyre of the Topopah Spring Tuff, directly underlying the repository host rock. This vitrophyre is variably altered across Yucca Mountain, with devitrification-associated heulandite penetrating its highly irregular upper surface (Levy and O'Neil, 1989). Clinoptilolite and other zeolites (e.g., erionite in drill hole USW UZ#14) often occur in the basal vitrophyre. In the eastern part of Yucca Mountain, the nonwelded base of the Topopah Spring Tuff and all of the underlying Calico Hills Formation are extensively zeolitized (clinoptilolite $\pm$ mordenite). In the southwestern part of Yucca Mountain, the few core samples available suggest that much of this interval is essentially vitric and unaltered. Existing data suggest an alteration front may have been associated with past rises in the static water level (SWL), but the nature of this zeolitic/vitric transition and the implications for past fluctuations in the SWL were poorly constrained until the recent analyses of core samples from within the potential repository block. The nature of the lateral and vertical transitions between zeolitized and vitric portions of the Calico Hills Formation is of fundamental importance to understanding the potential for thermal alteration or dehydration of existing zeolites and possible formation of new zeolites and/or clays from heated glass (Vaniman and Bish, 1995). Results presented in this report show that the transition zone is quite variable across Yucca Mountain, in some places spanning a depth range of over 70 m.

4) Mineral distributions and health hazards

Distributions of crystalline silica polymorphs continue to have an important impact on determining the use of respirator protection by tunnel boring machine operators and others working during mining and drilling operations in the Exploratory Studies Facility (ESF). The Topopah Spring Tuff has highly variable ratios of the crystalline silica polymorphs and an

accurate knowledge of the distributions of these minerals in three dimensions will help in planning for mitigation of dust inhalation hazards.

Some ESF operations, such as the East-West Drift, may extend to depths in the Topopah Spring Tuff at the bottom of the lower non-lithophysal zone (Ttpnl) and below, where erionite may be encountered. Erionite is a natural fibrous zeolite that occurs in the rocks at Yucca Mountain and is listed as a known human carcinogen by recognized international agencies such as the International Agency for Research on Cancer (IARC). No safe exposure levels have been established for erionite and no federal health and safety standards are in place that specifically regulate exposure to erionite (aside from 29CFR1910, the Hazard Communications Standard). Although U.S. regulatory agencies do not specifically address erionite, its morphology and IARC classification strongly suggest that it be treated no less carefully than asbestos. Furthermore, Nevada state OSHA regulations specify that if an international agency such as IARC lists a material as carcinogenic, the material shall be considered by Nevada OSHA to be carcinogenic and shall be treated as such.

Erionite was first confirmed by XRD in Yucca Mountain tuffs in a fracture from drill hole UE-25a#1 at 395-m depth (1296.2 feet) on February 14, 1985 (Bish and Vaniman, 1985). A description of the techniques specially developed shortly thereafter at Los Alamos to detect very small quantities of erionite in mixtures with other minerals is reported in Bish and Chipera (1987; 1991) and Bish *et al.* (1995). When erionite was first identified in tuffs at Yucca Mountain, its health effects were not well known, and erionite was not listed by regulatory agencies. Since that time, YMSCP scientists have learned considerably more about the occurrence and distribution of erionite at Yucca Mountain and about the health effects of erionite.

Our ongoing effort to determine the distribution of erionite using specially developed X-ray diffraction techniques has proved very successful. All documented occurrences of erionite at Yucca Mountain are consistent and show that erionite, when it occurs, is restricted to the transition zone in the lower Topopah Spring Tuff where alteration occurs a few meters above, within, and a few meters below the basal vitrophyre. Erionite has not been identified outside this zone at Yucca Mountain. However, it is important to note that until recently it was believed that erionite occurrence at Yucca Mountain was restricted to fractures above the vitrophyre, and the high concentrations of erionite in the matrix below the vitrophyre in USW UZ#14 were totally unexpected. It is also important to note that restricted sampling intervals used in the past on the YMSCP, with samples often taken at greater than 15-m (50-ft) intervals, do not allow the Project to conclude that erionite does *not* occur in earlier sampled drill holes.

II. METHODS

The mineralogy of drill core samples from drill holes USW NRG-6, NRG-7/7a, SD-7, SD-9, SD-12, and UZ#14, as well as selected cuttings from USW H-3, was determined by quantitative XRD methods. Sampling of the cores was performed with a maximum sample spacing of ~8 m (26 ft) and an average sample spacing of 4.7 m (15.4 ft). Smaller spacing was often used when significant textural/stratigraphic features were observed in the core. This sample spacing is much closer than in our previous studies of non-QA core, in which the average spacing between samples was typically >15 m and often >40 m (Bish and Chipera, 1989).

To prepare the samples for X-ray powder diffraction (XRD) analyses, a small portion of each sample (~0.8 g) was mixed with 1.0- μm corundum (Al_2O_3) internal standard in the ratio 80% sample to 20% corundum by weight. Each sample was then ground under acetone or alcohol in an automatic Brinkmann Micro-Rapid mill (fitted with an agate mortar and pestle) for at least 10 minutes. This produced a sample with an average particle size of less than 5 μm and ensured thorough mixing of sample and internal standard. The fine particle size is necessary to ensure adequate particle statistics and to reduce primary extinction and other sample-related effects (Klug and Alexander, 1974; Bish and Reynolds, 1989). The adequacy of grinding times and techniques has been confirmed utilizing a Horiba CAPA-500 automatic particle-size-distribution analyzer calibrated with Duke Scientific glass microspheres.

All diffraction patterns were obtained on a Siemens D500 X-ray powder diffractometer using $\text{CuK}\alpha$ radiation, incident- and diffracted-beam Soller slits, and a Kevex Si(Li) solid-state detector from at least $2-50^\circ 2\theta$, using 0.02° steps, and counting for at least 2s/step. Mineral identification was accomplished by comparing observed patterns with patterns of pure standards, published patterns from the Joint Committee on Powder Diffraction Standards (JCPDS 1986), or calculated mineral patterns obtained from the program POWD10 (Smith *et al.*, 1982).

The quantitative XRD analyses for this report employed the internal standard or "matrix-flushing" method of Chung (1974) using synthetic 1.0- μm corundum as the internal standard (Bish and Chipera, 1988; 1989; Chipera and Bish, 1995; and Chipera *et al.*, 1995b). This method requires that reference intensity ratios (RIRs) be determined before sample analysis. It is important to note that these methods of data collection and analysis are not conducive to identifying phases present below ~0.5 wt %, and potentially important trace phases may be present in the samples. X-ray diffraction analyses for the detection of low levels of erionite use procedures specially developed at Los Alamos for the YMSCP. For these analyses, all sample mounts were sufficiently long to accept the X-ray beam fully at the lowest angle of interest, $\sim 6^\circ 2\theta$. X-ray runs were conducted twice on each sample. Samples were first examined from 2° to $36^\circ 2\theta$, with a step size of 0.02° and count times of at least 2 s per step, to

characterize the total mineralogy. They were then run from at least 6° to $9^\circ 2\theta$, with a step size of 0.02° and count times of between 180 and 999 s per step to improve the peak-to-background ratio in the region of the major erionite X-ray reflection (100) at about $7.67^\circ 2\theta$. All samples were analyzed in either an ethylene-glycol or 100% RH water-saturated atmosphere to expand any smectite in the samples. This treatment shifts the smectite 001 reflection to lower 2θ values away from the position of the strongest erionite reflection.

Bish and Chipera (1987; 1991) showed that erionite coexisting with clinoptilolite can be detected in amounts below 0.05 wt% using XRD. They prepared numerous mixtures of erionite in clinoptilolite ranging from 0.05 to 20.0 wt% erionite. Mixtures containing less than 0.05 wt% (500 ppm) erionite were not prepared because of uncertainties involved in weighing and homogenizing very small amounts of erionite with large amounts of clinoptilolite. It was found that erionite in relatively pure clinoptilolite can be readily detected down to 0.25 wt% using average run conditions, and amounts down to 0.05 wt% can be detected using long count-time runs. Because of diffraction from smectite, the detection limits of erionite in clinoptilolite are significantly worse when smectite is present, but glycolation of the sample allows increased resolution of the clinoptilolite/erionite reflections by shifting the smectite peaks to lower 2θ values. In samples that do not contain clinoptilolite or smectite, the limit of detection for erionite is below 0.05%, down to as low as 150 ppm for some samples.

Lower-limit-of-detection calculations were conducted on samples from USW SD-7. A peak is considered observed if it is at least three times the standard deviation (σ_b) of the background intensity at a given 2θ position, where the standard deviation of background intensity is the square root of the background counts accumulated in t seconds (C_b). The lower limit of detection (LLD) in intensity is then $3\sigma_b$ or $3\sqrt{C_b}$. For the analyses used in this paper, a minimum detectable integrated intensity (MDII) for erionite was calculated by assuming a triangular peak profile with a full-width at half-maximum (FWHM) of $\sim 0.14^\circ 2\theta$ (typical measured FWHM for erionite). The MDII is equal to the minimum detectable peak intensity times the FWHM or $3\sigma_b \times 0.14$. The MDII is then compared with the intensity obtained for a known abundance of erionite in an erionite-clinoptilolite standard mixture (e.g., 2.5 wt% erionite in 97.5 wt% clinoptilolite) to determine the LLD of erionite in that sample. The LLD for a given sample is a function of the count time per 2θ -step and of the background counts, which vary significantly primarily due to the presence or absence of smectite. Typical LLDs vary from 150 to 350 ppm for samples analyzed at 999 s/step, and from 300 to 500 ppm for samples analyzed at 360 s/step.

Chemical data for a subset of USW SD-7, 9, and 12 samples were obtained from splits of the alumina-crucible or tungsten-carbide shatterbox-ground powders that were used for XRD analysis. Chemical compositions were determined using a Rigaku 3064 X-ray fluorescence

spectrometer (XRF) and fundamental parameters matrix correction procedures (User's Guide to XRF-11 Software for Fundamental Parameters, Criss Software, Inc.). Samples were prepared by drying the powder for 4 hours at 110°C, equilibrating at ambient conditions for 24 hours, and then weighing sample and lithium tetraborate flux in a 1:9 ratio into a graphite crucible. Samples were fused for 35 minutes in a 1150°C furnace. Loss on ignition (LOI) was determined by heating an aliquot of the dried powder for 30 minutes at 1000°C. No attempt was made to distinguish between H_2O^+ and H_2O^- or any other volatile components in the samples. Major and minor elements analyzed included Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, and P. In addition, the trace elements Ba, Rb, Sr, V, Cr, Zn, Y, Zr, Nb, and Ni were also analyzed.

Chemical data on vitrophyre, smectite, and erionite-bearing samples from USW UZ#14 were obtained through instrumental neutron activation analysis (INAA). Samples were analyzed at the trace-element geochemistry laboratory of Washington University, St. Louis, MO, using methods described in Korotev (1991).

III. RESULTS and DISCUSSION

Quantitative XRD results for drill holes USW NRG-6, NRG-7/7a, SD-7, SD-9, SD-12, and UZ#14 are portrayed graphically in Figures 2-9, and are included in tabular form in Appendices I-VII. Data for USW NRG-6 were collected previously, but they were not published or incorporated into the 3-D Mineralogic Model of Yucca Mountain. These data are included in this report because NRG-6 provides Q-level core and adds valuable information on the composition of the Topopah Spring Tuff and overlying nonwelded Paintbrush Group units at the north end of the exploration block.

Drill holes NRG-6 and NRG-7/7a are shallow, but they provide excellent sample coverage within upper Paintbrush tuffs and, in particular, within the highly variable Paintbrush Group units between the Tiva Canyon and Topopah Spring Tuffs. Interestingly, in contrast to the lower vitric zone in the Topopah Spring Tuff, little zeolite was observed within these upper units. The alteration product of the glass in the upper Paintbrush tuffs appears to be primarily smectite which occurs throughout the vitric zone but is especially abundant at both the top and bottom margins. The lack of zeolite contrasts with the same vitric unit in UE-25 UZ#16 where a 1-meter thick bed containing ~18 wt% heulandite was observed close to the base of this unit (Chipera *et al.*, 1995b). Although the average sampling interval used was greater than 1 meter, a bedded zeolite unit would not have been missed since the sampling methodology in these holes involved sampling every significant observable textural and/or stratigraphic feature to determine if it was also reflected in the mineralogy.

The transition from glassy to zeolitic tuff below the potential repository horizon is well defined by our analyses of the USW SD-7, SD-9, SD-12, and UZ#14 samples. This transition

Figure 2: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole USW NRG-6.

Figure 3: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole USW NRG-7/7a.

Figure 4: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole USW SD-7.

Figure 5: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole USW SD-9.

Figure 6: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole USW SD-12.

Figure 7: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole USW UZ#14.

Figure 8: Results of quantitative XRD analyses showing with greater detail the distribution of zeolites and glass through the vitric-to-zeolitic portion of drill hole USW UZ#14.

Figure 9: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole USW H-3.

occurs in the vitric nonwelded base of the Topopah Spring Tuff in USW SD-9 and in a widely dispersed interval ranging from near the bottom of the vitric nonwelded base of the Topopah Spring Tuff throughout the Calico Hills Formation in USW SD-12 and USW SD-7. The data corroborate the sequence seen in other drill holes at Yucca Mountain, with the added benefit that the very close sample spacing in these drill holes provides a much more detailed picture of the variability in the transition from glass to zeolite. The top of the Topopah Spring Tuff vitrophyre shows the same thin horizon of significant smectite and clinoptilolite as in other drill holes (e.g., UE-25 UZ#16). The bottom of the vitrophyre in USW SD-9 is just 2 m above the top of the prominent zeolitic sequence. However, the close sample spacing across the vitric-to-zeolitic transition in all four of these cores shows complex interlayering of vitric and zeolite-altered horizons within the base of the vitric nonwelded portions of the basal Topopah Spring Tuff (USW SD-9 and UZ#14) and/or the Calico Hills Formation (USW SD-7 and SD-12), emphasizing the importance of obtaining closely spaced samples in horizons near the host rock.

Results for four additional USW H-3 cuttings samples, encompassing the lower Topopah Spring vitrophyre, the Calico Hills Formation, and the transition zone at the very top of the Prow Pass formation, are superimposed on the older data in Figure 9 and in Appendix VII. These four samples help to fill in the ~70-meter gap in USW H-3 across the critical vitric-to-zeolitic transition zone within the Calico Hills Formation where the Project presently has no data. Unfortunately, very little mineralogical data exist for this transition in the western portion of Yucca Mountain. The samples were carefully hand-picked from cuttings to select what appeared to be the first occurrences of distinctive alteration lithologies going down-hole. The principal goal of this study was to determine whether the bedded tuff at the base of the Calico Hills Formation (Tactb) was zeolitized in USW H-3 as it is in USW H-5. Only traces of zeolite were found, but other mineralogical anomalies, such as the very high feldspar content, indicate that the cuttings selected are not truly representative of the bulk rock. Unfortunately, the cuttings in USW H-3 are essentially sand-sized throughout this interval, they are heavily contaminated with materials from higher in the hole, and some sample sizes are small (<0.2 g). Thus their utility in determining mineral stratigraphy is severely compromised.

Figure 10 shows glass and total zeolite abundance diagrams for the three SD drill holes. For comparison among the three drill holes, sample depths have been normalized to elevation (meters above sea level). As can be seen from Figure 10, stratigraphy "rises" to the south whereas the static water level (SWL) drops to the south. The Calico Hills Formation has been completely zeolitized (*i.e.*, there is no remnant glass) in the northernmost hole (USW SD-9). Here the first vestige of the major unsaturated zone (UZ) zeolitic horizon at 436.4 m depth (865.9 m elevation) and the deepest preservation of nonwelded glass at 444.3 m depth (858.0 m elevation) are separated by only ~8 m. The dispersion of this transition is much greater in

Figure 10: Comparison of the vitric to zeolitic transition in drill holes USW SD-7, 9, and 12. Drill hole data have been normalized to elevation (m above sea level) to facilitate the comparisons.

the southern holes. The first evidence of the major UZ zeolitic horizon in USW SD-12 occurs at 421.0 m depth (902.7 m elevation) and the deepest preservation of nonwelded glass is at 490.8 m depth (dispersion of the vitric-to-zeolitic horizon across ~70 m). Disregarding an outlier of 1% clinoptilolite at 411.7 m depth, the first intersection of the major UZ zeolitic horizon in USW SD-7 occurs at 444.2 m depth (918.9 m elevation) and the loss of nonwelded glass occurs at 482.0 m depth (dispersion of the vitric-to-zeolitic transition across ~38 m). If the outlier of clinoptilolite at 411.7 m in USW SD-7 is included, the dispersion of the vitric-to-zeolitic transition in this core is ~70 m, comparable to the range in USW SD-12 (also ~70 m). However, the isolation of this outlier from the major zeolitized portion makes it doubtful that there is any genetic relation between it and the major zeolitized interval of the Calico Hills Formation in this core.

Of particular interest in the vitric interval is the observation of the zeolite mineral chabazite in concentrations of up to 9 wt% in 13 samples from USW SD-7 and in one sample from USW SD-12. The occurrence of chabazite in the bulk rock is somewhat unusual since it previously has been found only in limited abundances in fractures associated with vitric zones. Moreover, these earlier-discovered fracture occurrences are all below the static water level (Carlos *et al.*, 1995a,b). Chabazite may exist in the bulk rock in other drill holes, but it may not have been discovered previously because of the limited sampling that was conducted in the vitric regions where chabazite would occur (sample spacings in previous studies were typically greater than 8 m in this interval, whereas present sample spacings average ~4 m in this interval). Chabazite in USW SD-7 occurs both at the top of the lower Topopah Spring Tuff vitrophyre and within the nonwelded Calico Hills Formation. The occurrence of chabazite provides information on the geochemical conditions that existed during its formation. Chipera *et al.* (1995a) used representative chemical formulas and estimated thermodynamic data to model the conditions under which the various zeolite species at Yucca Mountain formed. Chemical analyses of modern Yucca Mountain water using present-day silica activities were found to plot within the predicted clinoptilolite stability field. A stability field for chabazite occurred only for groundwater compositions that were significantly more potassic than present Yucca Mountain groundwater. Decreases in aqueous silica and sodium activities and increases in temperature also enhance the stability field for chabazite.

A fracture below the vitric zone from USW SD-12 at 500.4 m (1641.7 ft) depth was found to be filled with smectite. This smectite was further characterized by XRD and was identified as an interstratified dioctahedral illite/smectite composed of ~40% collapsed layers. Characterization was conducted by comparing the X-ray pattern obtained from an oriented ethylene-glycol-solvated sample mount with patterns calculated using the computer program NEWMOD (Reynolds and Reynolds, 1987). Although the interstratification in the smectite could be interpreted to suggest that it was formed at somewhat elevated temperature, the lack of

ordering between the collapsed and expanded layers indicates that this smectite formed at temperatures below ~100°C (Hower and Altaner, 1983).

Generalized mineral distribution at Yucca Mountain

Clinoptilolite and mordenite are the most abundant zeolites at Yucca Mountain. Major continuous intervals of clinoptilolite occur in all drill holes, generally in association with nonwelded tuff intervals from ~100-150 m above the water table to ~500 m below. Heulandite is fairly common at Yucca Mountain but is lumped with clinoptilolite in XRD analyses since the two minerals are isostructural. Mordenite often occurs along with clinoptilolite but is less abundant in drill holes farther to the south and is virtually absent in bulk-rock samples from drill hole USW GU-3/G-3. The zeolite analcime occurs as a prograde alteration product at greater depths, but the depths of analcime occurrence are so great that little interaction with waste is likely. The locations of zeolitic intervals are strongly controlled by tuff stratigraphy; zeolites formed from the glasses of nonwelded and bedded intervals which reside between those portions of the tuffs that devitrified to form feldspars and silica minerals soon after emplacement. These zeolitic intervals and their effects on Np transport have been modeled recently by Robinson *et al.* (1995).

Until recently, chabazite was known only as a rare zeolite at Yucca Mountain. However, samples from the Calico Hills Formation in USW SD-7 contain up to 9 wt% chabazite in this zeolitized interval, occurring principally in a clinoptilolite + chabazite zone of ~14 m thickness, above a clinoptilolite + mordenite zone (Chipera *et al.*, 1996). In addition to clinoptilolite, mordenite, analcime, and minor chabazite, restricted occurrences of a few other zeolites have been found at Yucca Mountain. Stellerite is common in fractures of the Topopah Spring Tuff and is particularly common in both fractures and matrix of the Topopah Spring Tuff in drill holes UE-25 UZ#16 and USW UZ#14. Phillipsite is a rare zeolite at Yucca Mountain and has been found only in the zone of alteration above the water table at the top of the lower vitrophyre of the Topopah Spring Tuff (Carlos *et al.*, 1991; 1995a; 1995b). Until recently, erionite was also believed to occur only in fractures at the top of the Topopah Spring Tuff lower vitrophyre until it was found in significant quantities (up to 34%) in a 3-m thick sequence in the bulk rock underlying the Topopah Spring Tuff lower vitrophyre in drill core USW UZ#14.

Smectite is ubiquitous in low abundances throughout Yucca Mountain. XRD analyses show that smectite occurs in virtually all analyzed samples, typically in amounts <2%. Smectite + illite abundances rise at depth, particularly in the northern and central portions of the block where a fossil geothermal system occurs. Above the water table there are two mappable zones of up to 75% smectite in the Paintbrush Tuff, one within the vitric nonwelded section above the Topopah Spring Tuff and one at the top of the basal vitrophyre of the Topopah Spring Tuff. These smectites typically have non-expandable illite contents of 10-20%. Well beneath the

water table (depths >1000 m), rocks affected by the ancient (~10.7 Ma) geothermal system contain abundant smectite/illite but with a much higher illite content (~80-90%: Bish, 1989). Illitic clays have a higher layer charge than smectites, reducing their effective cation-exchange capacity. However, the illitic clays occur at such great depths that they are of little importance for transport modeling at Yucca Mountain.

The common silica polymorphs at Yucca Mountain include quartz, cristobalite, and tridymite. In addition, opal-CT is usually found in association with sorptive zeolites. Tridymite occurs primarily above the potential repository horizon, particularly in those parts of the Topopah Spring and Tiva Canyon Tuffs where vapor-phase crystallization is common. This distribution, as well as the common formation of tridymite in lithophysal cavities, is evidence of the vapor-phase growth of tridymite. Pseudomorphs of quartz after tridymite in deep fractures and cavities provide evidence of the instability of tridymite under low-temperature aqueous conditions. Tridymite occurrences have been interpreted as a possible limit on past maximum rises in the water table at Yucca Mountain (Levy, 1991). Cristobalite is not restricted to vapor-phase formation; instead, it is found in virtually every sample above the water table and in significant quantities in several zones just beneath the water table. The preservation of cristobalite in rocks above the water table is in accord with studies showing that an aqueous fluid is necessary for the rapid recrystallization of cristobalite to quartz (Ernst and Calvert, 1969). Opal-CT occurs both above and below the water table. Opal-CT and cristobalite are combined as one mineral group in the preliminary model because they are often almost indistinguishable in XRD analyses. Furthermore, these phases are the least stable of the silica minerals and generate comparable silica activities in aqueous solution.

Distribution of Erionite

Of the 6 drill holes analyzed in this report, erionite was only detected in drill core USW UZ#14. Table 1 lists the samples specifically analyzed for erionite along with the abundances detected. All documented occurrences of erionite at Yucca Mountain are consistent and show that erionite occurrence is restricted to the transition zone in the lower Topopah Spring Tuff where alteration occurs a few meters above, within, and a few meters below the basal vitrophyre. Erionite analyses therefore tended to focus on this region. However, additional analyses were conducted for samples from UZ#14 in the upper Paintbrush vitric zone which appears to be an environment similar to those in which erionite has been found previously in the lower Topopah Spring Tuff vitrophyre (altered glass, with significant smectite and trace zeolite). No erionite, however, was observed in these additional UZ#14 samples.

Figure 8 shows the distribution of erionite determined by XRD in samples from drill hole USW UZ#14. Erionite occurs in abundances of up to 34 weight percent over a limited depth

Table 1. Samples specifically examined for erionite.

Sample	Type	Wt% Erionite	Calculated Detection Limit	Sample	Type	Wt% Erionite	Calculated Detection Limit
USW SD-7				USW NRG-7/7a			
1156.7/1156.9	Bulk	---	185 ppm	1411.5/1411.8	Bulk	---	N.D.
1169.9/1170.0	Bulk	---	185 ppm	1416.4/1416.8	Bulk	---	N.D.
1175.1/1175.4	Fract.	---	N.D.	1451.2/1451.3	Bulk	---	N.D.
1179.5/1179.7	Bulk	---	185 ppm	1459.3/1459.5	Bulk	---	N.D.
1181.6/1182.0	Bulk	---	285 ppm	1463.5/1464.0	Bulk	---	N.D.
1187.0/1187.1	Bulk	---	220 ppm	1470.0/1470.2	Bulk	---	N.D.
1191.1/1191.3	Bulk	---	280 ppm	1475.0/1475.4	Bulk	---	N.D.
1245.5/1246.0	Fract.	---	N.D.	1481.1/1481.2	Bulk	---	N.D.
1278.6/1278.7	Bulk	---	245 ppm	1485.5/1485.7	Bulk	---	N.D.
1338.5/1338.7	Bulk	---	245 ppm	1492.0/1492.2	Bulk	---	N.D.
1391.0/1391.2	Bulk	---	220 ppm	1495.9/1496.2	Bulk	---	N.D.
USW SD-9				USW UZ#14			
1431.7/1431.9	Bulk	---	N.D.	Upper Paintbrush Vitric Zone			
1434.4/1434.5	Bulk	---	N.D.	71.0/71.4	Bulk	---	N.D.
1440.1/1440.2	Bulk	---	N.D.	261.6/262.0	Bulk	---	N.D.
1447.8/1448.0	Bulk	---	N.D.	278.3/278.5	Bulk	---	N.D.
1457.2/1457.6	Bulk	---	N.D.	286.4/286.7	Bulk	---	N.D.
1460.6/1460.8	Bulk	---	N.D.	Lower Topopah Spring Tuff			
1465.9/1466.1	Bulk	---	N.D.	Vitrophyre			
2140.5/2140.9	Bulk	---	N.D.	1277.4/1277.7	Bulk	---	N.D.
USW SD-12				1298.6/1299.1	Bulk	---	N.D.
1309.3/1309.5	Bulk	---	N.D.	1358.6/1358.8	Bulk	---	N.D.
1320.6/1321.0	Bulk	---	N.D.	1361.8/1361.9	Bulk	2 ± 1	
1333.2/1333.4	Bulk	---	N.D.	1362.6/1363.0	Bulk	17 ± 3	
1342.1/1342.2	Bulk	---	N.D.	1364.4/1364.6	Bulk	34 ± 7	
1351.9/1352.2	Bulk	---	N.D.	1365.8/1366.0	Bulk	17 ± 3	
1361.9/1362.0	Bulk	---	N.D.	1370.1/1370.3	Bulk	5 ± 1	
1371.4/1371.5	Bulk	---	N.D.	1370.3/1370.7	Bulk	7 ± 1	
1381.1/1381.3	Bulk	---	N.D.	1371.8/1372.0	Bulk	2 ± 1	
1388.0/1388.2	Bulk	---	N.D.	1372.7/1372.9	Bulk	~0.26	
1399.2/1399.3	Bulk	---	N.D.	1375.2/1375.4	Bulk	---	N.D.
				1387.0/1387.2	Bulk	---	N.D.
				1398.5/1398.7	Bulk	---	N.D.
				1414.9/1415.1	Bulk	---	N.D.
				1417.6/1417.8	Bulk	---	N.D.

--- = not detected

N.D. = not determined

range of approximately 3.4 m (11.1 ft), from 414.0 to 418.2 m depth (1361.8 to 1372.9 ft), in the moderately welded subzone beneath the Topopah Spring Tuff lower vitrophyre. The data in this zone show that erionite abundance is greatest at the top of this zone, decreasing significantly toward the bottom of the zone. Whether this distribution has a genetic implication is unknown, although the greater abundance at the top of the zone may be related to the proximity to the glassy vitrophyre. Visual examination of this interval indicates that it begins at the bottom of the densely welded lower vitrophyre (about 415.1 m, 1362 ft depth) and is most prominently developed in the moderately welded subzone (Tptpv2), dying out in the nonwelded vitric tuffs (about 418.5 m, 1373 ft depth) at the base of the Topopah Spring Tuff. Beneath this, a more typical vitric-to-clinoptilolite transition occurs. Textural relations in the USW UZ#14 samples suggest that erionite formed after clinoptilolite. Comparable alteration, producing such large amounts of erionite, has not been observed in any other drill core. However, it is important to note that the restricted sampling intervals used in the past on the YMSCP, with samples often taken at 15-m (50-ft) intervals, do not allow the Project to conclude that erionite does *not* occur in earlier sampled drill holes.

The INAA data for erionite-bearing samples from USW UZ#14 can be compared with data for the unaltered vitrophyre to determine the geochemical environment and the extent of chemical exchange involved in zeolitization. The alkali and alkaline-earth elements have proven particularly useful in estimating the amount of exchange involved in zeolitization. Table 2 summarizes these data for the vitrophyre, for a smectite concentrate, and for the erionite-rich tuff beneath the vitrophyre. The smectite sample is a relatively pure mineral separate from sample LANL#1876p1 (396.0-m depth). The mineral compositions of the vitrophyre sample (LANL#1714p1, 88% glass, 414.2-m depth) and of the erionite-rich sample (LANL#1715p1, 34% erionite, 415.9-m depth) are listed in Appendix VI.

Table 2: Alkali and alkaline-earth elements in samples from USW UZ#14.

	Na ₂ O %	K ₂ O %	CaO %	Rb ppm	Sr ppm	Cs ppm	Ba ppm
vitrophyre	2.81	4.60	0.80	177	136	11	45
smectite	0.13	0.26	2.70	22	488	19	14
erionite/ heulandite	0.70	2.13	4.20	143	625	29	43

If one assumes that the vitrophyre is a good compositional analog to the vitric tuff that altered to create the smectite- and zeolite-rich samples, the data in Table 2 indicate strong depletions of Na and moderate depletions of K in zeolites (erionite/heulandite) resulting from

alteration of glass, with associated strong Ca enrichment. Changes in Rb, Cs, and Ba are minor, but both the smectite and the zeolitic tuff are enriched in Sr. Although volume corrections for alteration will affect these trends somewhat, these corrections are minor compared with the amount of change seen in Na, K, Ca, and Sr. Figure 11 shows the chondrite-normalized lanthanide-element patterns for these three samples. Particularly notable is the absence of a Ce anomaly in the vitrophyre sample, the positive Ce anomaly in the erionite-rich sample, and the negative Ce anomaly in the smectite sample. Cerium segregates from the other lanthanide elements only under oxidizing conditions, in which Ce is 4+ and the other lanthanides are 3+. Comparable Ce anomalies have been found at the top of the Calico Hills Formation in USW SD-9, suggesting that accumulation of oxidized Ce in the upper parts of zeolitized intervals is less a function of erionite formation than it is a general feature of the upper parts of zeolitized horizons.

Chemical Analysis of the Vitric-to-Zeolitic Transition Zone in USW SD-7, 9, and 12

Whole-rock chemical data for USW SD-7, 9, and 12 samples as a function of depth are provided in Appendices VIII-X. The data in Appendices VIII-X correlate well with mineralogy. As expected, there is a direct correlation between abundant zeolite occurrences (>25% zeolites) and LOI (water). In addition, zeolites show a strong direct correlation with Ca and Mg, and an inverse correlation with Na and K. It is worth noting, however, that the relatively zeolite-poor (14% clinoptilolite) sample at 500.4 m depth in SD-12, within the zone of otherwise abundant zeolitization, is exceptionally Ca- and Mg-rich, reflecting the abundant crystalline detritus of the pre-Calico Hills Formation bedded tuff (Tactb) rather than a high zeolite content for this sample. Thus chemical information alone can not be used to infer alteration mineralogy without corroborating XRD information.

Evidence of the bulk-rock interaction with groundwater can be seen in the Sr data. The vitric and devitrified rhyolitic tuffs contain very little Sr, but there is a strong correlation between Sr abundance and sorptive phases (especially clinoptilolite/heulandite) in certain portions of the zeolitic horizons. Figures 12-14 relate zeolite abundance to the Sr concentration across the vitric-to-zeolitic transition for drill holes USW SD-7, 9, and 12. From the data presented in Figures 12-14, it is evident that Sr has been stripped from the downward-percolating groundwater by the sorptive zeolites. This effect is particularly apparent in drill hole USW SD-12 (Figure 14). Significant concentrations of Sr occur at the three spots in Figure 12 at (A) the top of the pervasively-zeolitized but low-zeolite-abundance zone extending from the base of the Topopah Spring Tuff through the Calico Hills Formation; (B) within the high-zeolite-abundance interval of the bedded tuffs beneath the Calico Hills Formation (Tactb); and (C) at the top of the high-zeolite-abundance zone at the bottom of the Prow Pass Tuff. In occurrences (A) and (C), it is evident that Sr has been removed from the downward-percolating groundwater

Figure 11: Chondrite-normalized lanthanide-element patterns for samples of erionite/heulandite, vitrophyre, and smectite from USW UZ#14.

Figure 12: Calcite and cumulative zeolite abundances compared with Sr content in USW SD-7.

Figure 13: Cumulative zeolite abundances compared with Sr content in USW SD-9.

Figure 14: Comparison of cumulative zeolite abundances with Sr content in USW SD-12.

by the sorptive zeolites. As downward-flowing groundwater encountered these two zeolite-altered horizons, the upper portion of each zeolite sequence stripped Sr from solution, leaving little if any Sr in the groundwater as it proceeded through the remainder of the zeolite sequence. Evidence for effective Sr sorption in situation (A), where zeolite abundances are only 2-3%, emphasizes the very effective interaction of even small amounts of zeolite with groundwater at Yucca Mountain. Situation (B), within the bedded tuffs beneath the Calico Hills Formation, is more complex. Here the greatest Sr content is ~80 m below the Sr concentration zone of situation (A). The occurrence of a high Sr concentration at situation (B) simply reflects the more mafic and feldspathic composition of a portion of the bedded tuff below the Calico Hills Formation (Tachb). It is important to know the initial compositional variation among units to recognize those variations caused by transport, as opposed to original stratigraphic variations.

The Vitric-to-Zeolitic Transition and Possible Paleo-Water Tables

Changes in past elevations in SWL have implications for potential changes in repository-to-SWL distance under possibly wetter climates in the future. One of the potential mineralogic indicators of past elevations in SWL beneath the exploration block is the distance between the top of the first major zeolitized horizon and the present SWL. Figure 15, modified from Chipera *et al.* (1995b), summarizes some estimates of this distance from various drill holes around Yucca Mountain. Ideally, a direct correlation between the occurrence of the top of this horizon of abundant zeolitization and an ancient SWL would be seen in all drill holes as a surface occurring at a relatively fixed elevation above the present SWL. However, there are several reasons (Levy, 1991) for this not to be the case:

- (1) Even if the SWL were to rise, abundant zeolitization would not occur to the height of saturation if appropriate parent material (porous, nonwelded vitric tuff) were not present.
- (2) More than one event of rise in the SWL can result in variable elevations of the zeolitization horizon because of possible tectonic offsets in parts of the exploration block between the timing of ancient and more recent rises in the SWL.
- (3) The present SWL is relatively flat beneath the exploration block but rises sharply to the north and west (Ervin *et al.*, 1993). Similar variable elevations may have occurred in an ancient SWL, but not necessarily in the same locations as in the present SWL.
- (4) Zeolitization can occur in unsaturated rocks, especially in situations of possible capillary draw, perched water, or lateral transmission from features that may be significant sources of recharge during pluvial episodes.
- (5) Widely spaced sample collections, and in particular the need to rely on cuttings or intermittent core/sidewall samples in all USW H- and WT-series holes, place large uncertainties on the estimates of the top of the zeolitized horizon (generally at least ± 10 m). The contact between vitric and zeolitic rocks is also gradational, adding a further uncertainty in the location

Figure 15: Elevations (m) above present SWL of the top of the most abundantly zeolitized horizon in drill cores at Yucca Mountain.

of the zeolitization front (e.g., the ~70 m overlap of glass and zeolites in SD-12 and the ~35 m overlap in SD-7 noted in this report).

Given these caveats, there remains a significant number of drill cores with zeolitization horizons about 106-135 m above the present SWL (Fig. 15). Unfortunately, all of these cores are closely clustered in one central area and are thus of uncertain regional significance. The search for ancient SWLs will require the examination of multiple lines of evidence. Combined studies of structural indications of fault displacements of the zeolitization horizon, of glass preservation, and of other mineral distributions (e.g., tridymite) have been interpreted to indicate that past rises in the SWL may have been as high as the vitric/zeolitic transition in the past but, since that time, have been no higher than ~60 m (Levy, 1991). Studies of Sr-isotopes in calcite at Yucca Mountain suggest a possible ancient SWL ~85 m above the present SWL (Marshall *et al.*, 1993). Hydrologic modeling suggests a maximum SWL rise of 130 m (Czarnecki, 1985). At present, it appears the modeled SWL maximum rise of 130 m may be closest to inferences of past SWL from zeolite occurrences. However, other constraints such as tridymite distributions continue to cast doubt on the utility of zeolite occurrences as measures of past water-table rise.

Levy (1991) pointed out that the localities with almost no drill-core data, in the central and southern part of the exploration block, are critical to this question, for it is here that the vitric-to-zeolitic transition of the Calico Hills Formation occurs. Drill cores USW SD-12 and USW SD-7 provide important data for filling this gap, but the data are sufficiently complex to leave some questions unresolved. The zeolite abundance data from USW SD-12 suggest a maximum past water-table rise of 106 m, but persistence of tridymite at greater depth could be interpreted to limit this rise to a timespan of less than $\sim 10^6$ yr (Levy, 1991; Fig. 6). Similarly, the zeolite abundance data from USW SD-7 suggest a maximum past water-table rise of 211 m, yet persistence of tridymite at depth could limit this rise to <127 m (Fig. 4). Clearly the mineral occurrences that might be interpreted as indicators of past water-table elevations yield conflicting interpretations and adequate interpretations must explain all of the conflicting data.

It should be remembered that the horizon of concern is that of the vitric-to-zeolitic transition, and one may as readily define a possible surface of past water-table rise based on the deepest preservation of abundant ($\geq 10\%$) nonwelded glass as on the shallowest occurrence of abundant zeolites. Using the depth of abundant glass as a criterion, a different set of "past water table elevations" can be defined as shown in Figure 16. Divergences between the zeolite-based (Fig. 15) and glass-based (Fig. 16) model surfaces are in some cases caused by the inadequacies of dealing with widely-spaced analyses of cuttings (e.g., ~34 m in USW H-5), but the more recent data show a real and large overlap of glassy and zeolitic samples across a dispersed vitric-to-zeolitic transition (~35 m in USW SD-7). In the most extreme example, the vitric-to-zeolitic transition in USW SD-12 is dispersed over a vertical range of ~70 m if the

Figure 16: Elevations (m) above present SWL of the bottom of the deepest abundant nonwelded glass in the unsaturated zone for drill cores at Yucca Mountain.

slightly to moderately zeolitized samples of the Calico Hills Formation and the Topopah Spring Tuff are considered (note that these occurrences of $\leq 10\%$ zeolite were not included when determining the top of the zeolitized horizon in Figure 15). This consideration is of more than passing interest, because the abundance at which zeolites become effective in sorption is an important factor to be considered in performance calculations. The Sr data indicate that the ~70 m of slightly zeolitized tuff in USW SD-12 can be effective in sorbing those alkaline earth radionuclides for which clinoptilolite is highly selective. Although the sorption of complex transuranics by clinoptilolite is minor (Robinson *et al.*, 1995), potentially greater permeability of partially zeolitized tuffs, in contrast to those that are fully zeolitized, may permit dispersed access of radionuclide-bearing solutions to zeolite surfaces. This is a most important factor, suggesting that the lithologic barriers beneath a repository horizon may not be simply categorized as devitrified, vitric, and zeolitic but should include another hybrid lithology that is made up of intercalated vitric and zeolitic materials.

IV. CONCLUSIONS

Drill holes USW NRG-6, NRG-7/7a, SD-7, SD-9, SD-12, and UZ#14 provide an important addition to previous core determinations of mineral distributions at Yucca Mountain. Previous concepts of mineral distributions (Bish and Chipera, 1989) have largely been borne out by the results from these drill holes. However, closer sample spacing has provided a more exact determination of mineral stratigraphy, particularly the transition/alteration of vitric intervals to zeolites. Moreover, the occurrence of chabazite in the vitric zone, the broad overlap of vitric and zeolitic horizons (over vertical ranges up to 70 m), the significant abundance of erionite in UZ#14, and the previously unrecognized importance of the bedded tuffs beneath the Calico Hills Formation as a subunit with unique zeolitization properties, all emphasize that we lack a complete understanding of mineral distributions at Yucca Mountain, even in close proximity to the host rock, and that "surprises" will still be encountered. The data obtained in drill holes USW SD-7, SD-9, SD-12, and UZ#14, put additional constraints on maximum and minimum zeolite abundances and on the three-dimensional stratigraphy derived from these data. The additional information obtained from these cores will improve the 3-D mineralogic models needed for adequate performance assessments of Yucca Mountain.

Although quantitative XRD analyses from drill holes USW NRG-6, NRG-7/7a, SD-7, SD-9, SD-12 and UZ#14 will soon be incorporated into the 3-D mineralogic model, additional analyses in new core and the non-Q data will still be required to exert statistical control when extrapolating the model to the west and to the south where we have extremely limited mineralogic data, even when the non-Q drill cores are included. Currently the Project is planning new drill holes, however, they plan to conduct only limited core sampling. Although this approach will reduce drilling costs, the utility of these holes in improving the knowledge of

mineral distributions at Yucca Mountain is doubtful. Cuttings can provide some useful information but the poor quality of cuttings in USW H-3 shows that problems in collecting quality cuttings, either from the poor sampling of particular lithologies or from drilling technique, can lead to very limited value of the material obtained. The costs of poorer quality versus costs of core collection should be considered carefully in future drilling.

ACKNOWLEDGMENTS

This work was supported by the Yucca Mountain Site Characterization Project as part of the Civilian Radioactive Waste Management Program of the U. S. Department of Energy. We are grateful to S. Levy for helpful review comments.

REFERENCES

- Bish, D. L. (1989) Evaluation of past and future alterations in tuff at Yucca Mountain, Nevada, based on the clay mineralogy of drill cores USW G-1, G-2, and G-3. Los Alamos National Laboratory report LA-10667-MS, 40p.
- Bish, D. L., and D. T. Vaniman (1985) Mineralogic summary of Yucca Mountain, Nevada. Los Alamos National Laboratory report LA-10543-MS, 55p.
- Bish, D. L., and S. J. Chipera (1987) Detection of trace amounts of erionite in samples using X-ray powder diffraction and profile refinement. Proceedings of the Clay Minerals Society 24th Annual Meeting, Socorro, New Mexico, 32.
- Bish, D. L., and S. J. Chipera (1988) Problems and solutions in quantitative analysis of complex mixtures by X-ray powder diffraction, in *Advances in X-Ray Analysis*, C. S. Barrett, J. V. Gilfrich, R. Jenkins, J. C. Russ, J. W. Richardson, Jr., and P. K. Predecki, Eds. (Plenum Press, New York) Vol. 31, 295-308.
- Bish, D. L., and S. J. Chipera (1989) Revised mineralogic summary of Yucca Mountain, Nevada, Los Alamos National Laboratory report LA-11497-MS, 68p.
- Bish, D. L., and S. J. Chipera (1991) Detection of trace amounts of erionite using X-ray powder diffraction: Erionite in tuffs of Yucca Mountain Nevada, and Central Turkey, *Clays and Clay Minerals* **39**, 437-445.
- Bish, D. L., and R. C. Reynolds, Jr. (1989) Sample preparation for X-ray diffraction, in *Modern Powder Diffraction*, D. L. Bish and J. E. Post, Eds. (Mineralogical Society of America, Washington, D.C.) Vol. 20, 73-99.
- Bish, D. L., S. J. Chipera, G. D. Guthrie, and D. T. Vaniman (1995) Letter Report: The occurrence and distribution of erionite in drill holes at Yucca Mountain, Nevada Milestone LA4058.
- Carlos, B. A., D. L. Bish, and S. J. Chipera (1991) Fracture-lining minerals in the lower Topopah Spring Tuff at Yucca Mountain. In *Proc. 2nd Annual High-Level Radioactive Waste Management Conf., Las Vegas, Nevada*, Amer. Nuclear Soc., Inc., La Grange Park, Illinois, 486-493.
- Carlos, B. A., S. J. Chipera, D. L. Bish, and R. Raymond (1995a) Distribution and chemistry of fracture-lining zeolites at Yucca Mountain, Nevada. Natural Zeolites '93: Occurrence, Properties, Use, D.W. Ming and F.A. Mumpton, eds. International Committee on Natural Zeolites, Brockport, NY, 547-563.
- Carlos, B. A., S. J. Chipera, and D. L. Bish (1995b) Distribution and chemistry of fracture-lining zeolites at Yucca Mountain, Nevada: Los Alamos National Laboratory Report LA-12977-MS, 92p.
- Chipera, S. J., and D. L. Bish (1995) Multi-reflection RIR and intensity normalizations for quantitative analyses: Applications to feldspars and zeolites, *Powder Diffraction* **10**, 47-55.

- Chipera, S. J., D. L. Bish, and B. A. Carlos (1995a) Equilibrium modeling of the formation of zeolites in fractures at Yucca Mountain, Nevada. Natural Zeolites '93: Occurrence, Properties, Use, D.W. Ming and F.A. Mumpton, eds. International Committee on Natural Zeolites, Brockport, NY, 565-577.
- Chipera, S. J., D. T. Vaniman, B. A. Carlos, and D. L. Bish (1995b) Mineralogic variation in drill core UE-25 UZ#16, Yucca Mountain, Nevada. Los Alamos National Laboratory report, LA-12810-MS, 39p.
- Chipera, S. J., D. T. Vaniman, and D. L. Bish (1996) Zeolite abundances and the vitric-to-zeolitic transition in drill holes USW SD-7, 9, and 12, Yucca Mountain, Nevada. Los Alamos YMP Milestone Report #LA4240, LA-EES-1-TIP-96-005, 20p.
- Chipera, S. J., K. Carter-Krogh, D. T., Vaniman, D. L. Bish, and J. W. Carey (1997) Preliminary three-dimensional mineralogic model of Yucca Mountain, Nevada. Los Alamos National Laboratory YMP Deliverable No: SP321AM4.
- Chung, F. H. (1974) Quantitative interpretation of X-ray diffraction patterns of mixtures. I. Matrix-flushing method for quantitative multicomponent analysis, *Journal of Applied Crystallography* 7, 519-525.
- Czarnecki, J. B. (1985) Simulated effects of increased recharge on the ground-water flow system of Yucca Mountain and vicinity, Nevada-California, U. S. Geol. Survey Water Resources Invest. Report. 84-4344.
- Ernst, W. G., and S. E. Calvert (1969) An experimental study of the recrystallization of porcelanite and its bearing on the origin of some bedded cherts, *American Journal of Science*, 267A, 114-133.
- Ervin, E. M., R. R. Luckey, and D. J. Burkhardt (1993) Summary of revised potentiometric-surface map for Yucca Mountain and vicinity, Nevada, In *High Level Radioactive Waste Management*, Amer. Nuc. Soc. and Amer. Soc. Civil Eng., Proc. 4th Ann. Internat. Conf., Las Vegas, Nevada, 1554-1558.
- Hower, J., and S. P. Altaner (1983) The petrologic significance of illite/smectite, *Clay Minerals Society*, 20th Annual Meeting, Buffalo, New York, 40.
- JCPDS (1986) *Mineral Powder Diffraction File Data Book* (International Centre for Diffraction Data, Swarthmore, Pennsylvania).
- Klug, H. P., and L. E. Alexander (1974) *X-ray Diffraction Procedures for Polycrystalline and Amorphous Materials* (John Wiley & Sons, Inc., New York).
- Korotev, R. L. (1991) Chemical stratigraphy of two regolith cores from the Central Highlands of the Moon. In *Proceedings of the 21st Lunar and Planetary Science Conference*, Lunar and Planetary Institute, V. L. Sharpton and G. Ryder, eds., Houston, TX, 229-289.
- Levy, S. S. (1984) Petrology of samples from drill holes USW H-3, H-4, and H-5, Yucca Mountain, Nevada, Los Alamos National Laboratory report, LA-9706-MS, 77p.

- Levy, S. S. (1991) Mineralogic alteration history and paleohydrology at Yucca Mountain, Nevada, In *High Level Radioactive Waste Management*, Amer. Nuc. Soc. and Amer. Soc. Civil Eng., Proc. 2nd Internat. Conf., Las Vegas, Nevada, 477-485.
- Levy, S. S., and J. R. O'Neil (1989) Moderate-temperature zeolitic alteration in a cooling pyroclastic deposit, *Chemical Geology* **76**, 321-326.
- Loeven, C. (1993) A summary and discussion of hydrologic data from the Calico Hills nonwelded hydrogeologic unit at Yucca Mountain, Nevada. Los Alamos National Report LA-12376-MS, 102p.
- Marshall, B. D., Z. E. Peterman, and J. S. Stuckless (1993) Strontium Isotopic evidence for a higher water table at Yucca Mountain, In *High Level Radioactive Waste Management*, Amer. Nuc. Soc. and Amer. Soc. Civil Eng., Proc. 4th Ann. Internat. Conf., Las Vegas, Nevada, 1948-1952.
- Reynolds, R. C., Jr., and R. C. Reynolds III (1987) Description of program NEWMOD for the calculation of the one-dimensional X-ray diffraction patterns of mixed-layered clays; FORTRAN 77 Version NEWMOD 1.01, R.C. Reynolds, Jr., 8 Brook Dr., Hanover, New Hampshire.
- Robinson, B. A., A. V. Wolfsberg, G. A. Zyvoloski, and C. W. Gable (1995) An unsaturated zone flow and transport model of Yucca Mountain. Los Alamos National Laboratory Milestone #3468.
- Smith, D. K., M. C. Nichols, and M. E. Zolensky (1982) POWD10, a FORTRAN IV program for calculating X-ray powder diffraction patterns - Version 10, Pennsylvania State University, College of Earth and Mineral Sciences report.
- Vaniman, D. T., and D. L. Bish (1995) The Importance of zeolites in the potential high-level radioactive waste repository at Yucca Mountain, Nevada, Natural Zeolites '93: Occurrence, Properties, Use, D.W. Ming and F.A. Mumpton, eds. International Committee on Natural Zeolites, Brockport, NY, 533-546.
- Vaniman, D., D. Bish, D. Broxton, F. Byers, G. Heiken, B. Carlos, E. Semarge, F. Caporuscio, and R. Gooley (1984) Variations in authigenic mineralogy and sorptive zeolite abundance at Yucca Mountain, Nevada, based on studies of drill cores USW GU-3 and G-3, Los Alamos National Laboratory report LA-9707-MS, 71p.

QUALITY ASSURANCE

The LANL tracking number for this report is LA-EES-1-TIP-97-010.
The Data Tracking number for this report is LADV831321AQ97.001.

Previous Data Tracking Numbers for Data Referenced in This Report:

LASC831321DQ96.001 [Chipera, SJ, Vaniman, DT, and Bish, DL (1996) Zeolite abundances and the vitric-to-zeolitic transition in drill holes USW SD-7, 9, and 12, Yucca Mountain, Nevada. Los Alamos National Laboratory Report LA-EES-1-TIP-96-005, 20p.]

LASC831321DQ96.002 [DTN for the Los Alamos Min-Pet Summary and Synthesis report]

LA000000000110.002 and LA000000000111.002 [Bish, DL, and Chipera, SJ (1989) Revised mineralogic summary of Yucca Mountain, Nevada. Los Alamos National Laboratory Report LA-11497-MS, 68p.]

LA000000000086.002 [quantitative XRD portion of the report by Chipera, SJ, Vaniman, DT, Carlos, BA, and Bish, DL (1995) Mineralogic variation in drill core UE-25 UZ-16, Yucca Mountain, Nevada. Los Alamos National Laboratory Report LA-12810-MS, 39p.]

Computer Software Used in this Report:

XRD Data were obtained on the LANL EES-1 Siemens D500 X-ray powder diffractometers using the commercial software package—DIFFRAC5000.
LANL YMP release label = DIFFRAC5000-01-00-00.

Integrated peak intensities were obtained using the program GRAPHINT.
LANL YMP release label = GRAPHINT-01-00-00.

QUANT (version 5.04) had been qualified under the software QA requirements of the earlier QA program which included auxiliary software.
LANL YMP release label = QUANT-01-00-00.

The latest modifications to QUANT (producing version 5.05) were conducted in accordance with the QA program emplaced 31-JAN-1994 and are documented in TWS-EES-1-1-92-03, pages 54–70.

Note Book / Log Book Entries Relevant to this Report:

TWS-EES-1-2-93-6	Pages 39-150
LA-EES-1-NBK-95-011	Pages 3-27, 53-64, 114-128, 131-137
TWS-EES-1-3-89-17	Pages 47-80
TWS-EES-1-8/86-57	Pages 50-81
TWS-EES-1-7/86-35	Pages 64-91
TWS-EES-1-1-90-1	Pages 122-139
LA-EES-1-NBK-95-007	Pages 4-46

Figure Captions:

- Figure 1: Map of Yucca Mountain, Nevada, showing the locations of the drill holes mentioned in the text.
- Figure 2: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole NRG-6.
- Figure 3: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole NRG-7/7A.
- Figure 4: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole USW SD-7.
- Figure 5: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole USW SD-9.
- Figure 6: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole USW SD-12.
- Figure 7: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole USW UZ#14.
- Figure 8: Results of quantitative XRD analyses showing with greater detail the distribution of zeolites and glass through the vitric-to-zeolitic portion of drill hole USW UZ#14.
- Figure 9: Results of quantitative XRD analyses showing abundances of minerals and glass for drill hole USW H-3.
- Figure 10: Comparison of the vitric to zeolitic transition in drill holes USW SD-7, 9, and 12. Drill hole data has been normalized to elevation (m above sea level) to facilitate the comparisons.
- Figure 11: Chondrite-normalized lanthanide-element patterns for samples of erionite/heulandite, vitrophyre, and smectite from USW UZ#14.
- Figure 12: Calcite and cumulative zeolite abundances compared with Sr content in USW SD-7.
- Figure 13: Cumulative zeolite abundances compared with Sr content in USW SD-9.
- Figure 14: Cumulative zeolite abundances compared with Sr content in USW SD-12.
- Figure 15: Elevations (m) above present SWL of the top of the most abundantly zeolitized horizon in drill cores at Yucca Mountain.
- Figure 16: Elevations (m) above present SWL of the bottom of the deepest abundant nonwelded glass in the unsaturated zone for drill cores at Yucca Mountain.

APPENDICES

Appendix I: Quantitative XRD results for samples from drill hole USW NRG-6.

Appendix II: Quantitative XRD results for samples from drill hole USW NRG-7/7A.

Appendix III: Quantitative XRD results for samples from drill hole USW SD-7.

Appendix IV: Quantitative XRD results for samples from drill hole USW SD-9.

Appendix V: Quantitative XRD results for samples from drill hole USW SD-12.

Appendix VI: Quantitative XRD results for samples from drill hole USW UZ#14.

Appendix VII: Quantitative XRD results for samples from drill hole USW H-3.

Appendix VIII: Chemical analyses for drill hole USW SD-7.

Appendix IX: Chemical analyses for drill hole USW SD-9.

Appendix X: Chemical analyses for drill hole USW SD-12.

Appendix I. Quantitative XRD results for drill core USW NRG-6.

Sample	LANL #	Depth (m)	Smect-ite	Tridy-mite	Cristob-alite	Quartz	Feld-spar	Glass	Hem-atite	Mica	Horn-blende	Calcite	Total
Tiva Canyon Tuff			0 - 48.3 m										
2.1/2.2	1289p1	0.7	2 ± 1	12 ± 1	24 ± 3	2 ± 1	57 ± 8	—	1 ± 1	—	—	—	98 ± 9
24.2/24.5	1290p1	7.5	3 ± 1	5 ± 1	32 ± 2	1 ± 1	58 ± 8	—	1 ± 1	—	—	—	100 ± 8
49.8/50.0	1291p1	15.2	3 ± 1	4 ± 1	33 ± 2	1 ± 1	58 ± 8	—	Trc.	—	—	—	99 ± 8
67.2/67.4	1292p1	20.5	4 ± 1	6 ± 1	30 ± 2	2 ± 1	58 ± 8	—	1 ± 1	—	—	—	101 ± 8
92.2/92.9	1293p3	28.3	3 ± 1	4 ± 1	30 ± 2	4 ± 1	58 ± 8	—	Trc.	—	—	—	99 ± 8
124.1/124.3	1294p1	37.9	Trc.	2 ± 1	34 ± 2	1 ± 1	58 ± 8	—	1 ± 1	—	—	—	96 ± 8
139.4/139.6	1295p1	42.6	21 ± 6	—	12 ± 1	—	25 ± 4	42 ± 7	—	—	—	—	100 ± 7
157.8/158.1	1296p1	48.2	19 ± 6	—	Trc.	—	4 ± 1	77 ± 6	—	—	—	—	100 ± 6
bedded tuffs			48.3 - 53.3 m										
163.3/163.6	1297p1	49.9	9 ± 3	—	1 ± 1	Trc.	7 ± 1	83 ± 3	—	—	—	—	100 ± 3
169.2/169.5	1298p1	51.7	18 ± 5	—	2 ± 1	3 ± 1	17 ± 2	59 ± 5	—	Trc.	1 ± 1	—	100 ± 6
Pah Canyon Tuff			53.3 - 67.3 m										
178.0/178.3	1299p1	54.4	9 ± 3	—	1 ± 1	—	11 ± 2	79 ± 3	—	Trc.	—	—	100 ± 4
200.5/201.0	1300p1	61.3	4 ± 1	—	1 ± 1	1 ± 1	20 ± 3	73 ± 3	—	1 ± 1	—	—	100 ± 4
209.0/209.5	1301p1	63.9	2 ± 1	—	1 ± 1	1 ± 1	19 ± 3	76 ± 3	—	Trc.	—	1 ± 1	100 ± 4
219.0/219.3	1302p1	66.8	3 ± 1	—	Trc.	—	9 ± 1	88 ± 1	—	Trc.	—	—	100 ± 1
bedded tuffs			67.3 - 75.2 m										
223.7/224.2	1303p1	68.3	5 ± 2	—	1 ± 1	3 ± 1	13 ± 2	77 ± 3	—	1 ± 1	—	—	100 ± 3
230.0/230.6	1304p1	70.3	38 ± 11	—	1 ± 1	1 ± 1	8 ± 1	51 ± 11	1 ± 1	—	—	—	100 ± 11
235.0/235.4	1305p1	71.8	5 ± 2	—	Trc.	1 ± 1	12 ± 2	81 ± 3	—	1 ± 1	—	—	100 ± 3
237.0/237.4	1306p1	72.4	22 ± 7	—	Trc.	1 ± 1	24 ± 3	50 ± 7	1 ± 1	2 ± 1	—	—	100 ± 8
Topopah Spring Tuff			75.2 m - bottom										
251.0/251.5	1307p1	76.7	11 ± 3	—	1 ± 1	3 ± 1	13 ± 2	69 ± 4	1 ± 1	2 ± 1	—	—	100 ± 4
258.5/258.8	1308p1	78.9	Trc.	—	—	1 ± 1	6 ± 1	93 ± 1	Trc.	—	—	—	100 ± 1
260.1/260.3	1309p1	79.3	Trc.	—	1 ± 1	—	15 ± 2	80 ± 2	2 ± 1	2 ± 1	—	—	100 ± 3
263.6/263.8	1310p1	80.4	—	4 ± 1	19 ± 11	2 ± 1	73 ± 10	—	Trc.	3 ± 1	—	—	101 ± 15
266.1/266.2	1311p1	81.1	—	3 ± 1	21 ± 12	1 ± 1	72 ± 10	—	1 ± 1	2 ± 1	—	—	100 ± 16
287.7/288.1	1396p1	87.8	—	9 ± 1	15 ± 1	—	69 ± 10	—	1 ± 1	1 ± 1	—	—	95 ± 10
308.5/308.8	1397p1	94.1	—	3 ± 1	14 ± 1	1 ± 1	75 ± 11	—	1 ± 1	1 ± 1	—	—	95 ± 11

Appendix I. Quantitative XRD results for drill core USW NRG-6 (continued).

Sample	LANL #	Depth (m)	Smect-ite	Tridy-mite	Cristob-alite	Quartz	Feld-spar	Glass	Hem-atite	Mica	Horn-blende	Calcite	Total
327.2/327.5	1398p1	99.8	—	12 ± 1	9 ± 4	—	76 ± 11	—	2 ± 1	1 ± 1	—	—	100 ± 12
346.8/347.2	1399p1	105.8	1 ± 1	8 ± 1	9 ± 4	—	80 ± 11	—	1 ± 1	1 ± 1	—	—	100 ± 12
366.1/366.3	1400p1	111.7	2 ± 1	10 ± 1	12 ± 1	—	74 ± 10	—	1 ± 1	1 ± 1	—	—	100 ± 10
386.6/386.8	1401p1	117.9	2 ± 1	12 ± 1	9 ± 4	—	75 ± 11	—	1 ± 1	1 ± 1	—	—	100 ± 12
408.4/408.7	1402p1	124.6	3 ± 1	13 ± 1	11 ± 1	—	69 ± 10	—	1 ± 1	Trc.	—	—	97 ± 10
427.8/428.2	1403p1	130.5	5 ± 2	15 ± 2	12 ± 2	Trc.	64 ± 9	—	1 ± 1	Trc.	—	—	97 ± 10
447.2/447.5	1404p1	136.4	11 ± 3	22 ± 2	11 ± 2	2 ± 1	55 ± 8	—	1 ± 1	Trc.	—	—	102 ± 9
465.0/465.5	1405p1	141.9	4 ± 1	18 ± 2	17 ± 2	3 ± 1	55 ± 8	—	1 ± 1	Trc.	—	—	98 ± 9
480.8/481.1	1406p1	146.6	4 ± 1	9 ± 1	24 ± 2	6 ± 1	54 ± 8	—	1 ± 1	Trc.	—	—	98 ± 8
498.1/498.7	1407p1	152.0	1 ± 1	10 ± 1	21 ± 2	8 ± 1	55 ± 8	—	1 ± 1	Trc.	—	—	96 ± 8
512.2/512.7	1408p1	156.3	4 ± 1	17 ± 2	12 ± 2	8 ± 1	56 ± 8	—	1 ± 1	Trc.	—	—	98 ± 9
516.6/516.9	1409p1	157.6	2 ± 1	11 ± 1	18 ± 2	1 ± 1	63 ± 9	—	1 ± 1	Trc.	—	—	96 ± 9
531.4/531.8	1410p1	162.1	4 ± 1	8 ± 1	28 ± 3	2 ± 1	53 ± 7	—	1 ± 1	Trc.	—	—	96 ± 8
550.7/551.0	1411p1	167.9	4 ± 1	10 ± 1	20 ± 2	9 ± 1	55 ± 8	—	1 ± 1	Trc.	—	—	99 ± 8
569.1/569.4	1412p1	173.6	4 ± 1	8 ± 1	24 ± 2	9 ± 1	54 ± 8	—	1 ± 1	Trc.	—	—	100 ± 8
589.2/589.5	1413p1	179.7	3 ± 1	7 ± 1	20 ± 2	13 ± 1	54 ± 8	—	1 ± 1	Trc.	—	—	98 ± 8
609.0/609.4	1414p1	185.8	3 ± 1	6 ± 1	16 ± 1	18 ± 1	54 ± 8	—	1 ± 1	Trc.	—	—	98 ± 8
633.0/633.4	1415p1	193.1	3 ± 1	6 ± 1	21 ± 2	16 ± 1	54 ± 8	—	1 ± 1	Trc.	—	1 ± 1	102 ± 9
653.2/653.6	1416p1	199.2	3 ± 1	6 ± 1	21 ± 2	13 ± 1	54 ± 8	—	Trc.	Trc.	—	—	97 ± 8
666.9/667.3	1417p1	203.4	5 ± 2	4 ± 1	18 ± 1	18 ± 1	52 ± 7	—	1 ± 1	Trc.	—	—	98 ± 8
686.0/686.4	1418p1	209.2	3 ± 1	5 ± 1	14 ± 1	20 ± 2	54 ± 8	—	Trc.	—	—	—	96 ± 8
706.2/706.7	1491p1	215.4	3 ± 1	3 ± 1	29 ± 2	7 ± 1	54 ± 8	—	1 ± 1	Trc.	—	—	97 ± 8
726.5/726.9	1420p1	221.6	2 ± 1	4 ± 1	31 ± 2	4 ± 1	54 ± 8	—	1 ± 1	—	—	—	96 ± 8
745.4/745.8	1421p1	227.3	3 ± 1	1 ± 1	29 ± 2	10 ± 1	54 ± 8	—	Trc.	Trc.	—	—	97 ± 8
766.7/767.2	1422p1	233.8	2 ± 1	5 ± 1	17 ± 1	17 ± 1	55 ± 8	—	2 ± 1	Trc.	—	—	98 ± 8
786.6/786.9	1423p1	239.9	3 ± 1	2 ± 1	33 ± 2	3 ± 1	57 ± 8	—	1 ± 1	—	—	—	99 ± 8
800.3/800.5	1424p1	244.0	3 ± 1	3 ± 1	27 ± 2	10 ± 1	55 ± 8	—	—	Trc.	—	—	98 ± 8
805.5/805.7	1425p1	245.6	2 ± 1	3 ± 1	32 ± 2	4 ± 1	54 ± 8	—	1 ± 1	—	—	—	96 ± 8
826.5/827.0	1426p1	252.1	3 ± 1	5 ± 1	17 ± 1	19 ± 1	55 ± 8	—	1 ± 1	Trc.	—	—	100 ± 8
845.3/845.5	1427p1	257.7	1 ± 1	2 ± 1	16 ± 1	22 ± 2	56 ± 8	—	1 ± 1	Trc.	—	—	98 ± 8

[illegible]

Appendix II. Quantitative XRD results for drill core USW NRG-7/7a.

Sample	Depth (m)	LANL #	Smect-ite	Clino-ptilolite	Morden-ite	Tridy-mite	Cristob-alite	Opal-CT	Quartz	Feld-spar	Glass	Hem-atite	Mica	Kaolin-ite	Total
Tiva Canyon Tuff		0 - 32.3 m													
19.3/19.5	5.9	#2040p1	—	—	—	3 ± 1	29 ± 2	—	6 ± 1	62 ± 9	—	Trc.	—	—	100 ± 9
39.4/39.5	12.0	#2043p1	1 ± 1	—	—	4 ± 1	31 ± 2	—	—	61 ± 9	—	Trc.	Trc.	—	97 ± 9
59.7/60.0	18.3	#2044p1	—	—	—	2 ± 1	33 ± 2	—	—	60 ± 8	—	1 ± 1	—	—	96 ± 8
71.2/71.5	21.8	#2045p1	29 ± 9	—	—	—	14 ± 1	—	Trc.	28 ± 4	29 ± 9	Trc.	—	—	100 ± 10
90.5/90.7	27.6	#2046p1	6 ± 2	—	—	—	Trc.	—	Trc.	3 ± 1	91 ± 2	—	—	—	100 ± 2
Yucca Mountain Tuff		32.3 - 53.7 m													
109.1/109.3	33.3	#2047p1	4 ± 1	—	—	—	—	—	—	Trc.	96 ± 1	—	—	—	100 ± 1
130.5/130.7	39.8	#2048p1	2 ± 1	—	—	—	18 ± 1	—	—	20 ± 3	59 ± 3	1 ± 1	—	—	100 ± 3
161.3/161.4	49.2	#2049p1	11 ± 3	—	—	—	1 ± 1	—	1 ± 1	7 ± 1	80 ± 3	—	—	—	100 ± 3
Pah Canyon Tuff		53.7 - 85.3 m													
181.6/181.7	55.4	#2050p1	2 ± 1	—	—	—	1 ± 1	—	1 ± 1	13 ± 2	82 ± 2	—	1 ± 1	—	100 ± 3
203.5/203.8	62.1	#2051p1	Trc.	—	—	—	Trc.	—	1 ± 1	15 ± 2	83 ± 2	Trc.	1 ± 1	—	100 ± 2
222.7/223.0	68.0	#2052p1	—	—	—	—	Trc.	—	1 ± 1	16 ± 2	81 ± 2	Trc.	2 ± 1	—	100 ± 2
245.3/245.7	74.9	#2053p1	8 ± 2	—	—	—	Trc.	—	1 ± 1	10 ± 1	80 ± 2	Trc.	1 ± 1	—	100 ± 3
263.0/263.1	80.2	#2054p1	7 ± 2	—	—	—	2 ± 1	—	3 ± 1	8 ± 1	80 ± 2	Trc.	Trc.	—	100 ± 3
263.9/264.1	80.5	#2055p1	64 ± 19	—	—	—	—	—	1 ± 1	8 ± 1	26 ± 19	1 ± 1	—	—	100 ± 19
Topopah Spring Tuff		85.3 - 456.6 m													
281.1/281.2	85.7	#2056p1	1 ± 1	—	—	—	Trc.	—	2 ± 1	18 ± 3	77 ± 3	1 ± 1	1 ± 1	—	100 ± 4
293.9/294.2	89.7	#2057p1	—	—	—	—	—	5 ± 1	1 ± 1	7 ± 1	86 ± 2	1 ± 1	—	—	100 ± 2
297.3/297.6	90.7	#2058p1	Trc.	—	—	—	1 ± 1	—	—	19 ± 3	77 ± 3	2 ± 1	1 ± 1	—	100 ± 3
302.8/303.0	92.4	#2059p1	—	2 ± 1	—	4 ± 1	15 ± 1	—	1 ± 1	66 ± 9	9 ± 9	1 ± 1	1 ± 1	1 ± 1	100 ± 9
321.5/321.7	98.1	#2060p1	—	—	—	5 ± 1	16 ± 1	—	—	73 ± 10	—	1 ± 1	1 ± 1	—	96 ± 10
340.8/342.1	104.3	#2061p1	—	—	—	20 ± 2	9 ± 4	—	—	69 ± 10	—	1 ± 1	1 ± 1	—	100 ± 11
361.7/361.3	110.1	#2062p1	—	—	—	7 ± 1	12 ± 1	—	—	76 ± 11	—	1 ± 1	1 ± 1	—	97 ± 11
385.4/385.5	117.5	#2063p1	Trc.	—	—	6 ± 1	12 ± 1	—	—	77 ± 11	—	1 ± 1	1 ± 1	—	97 ± 11
408.3/408.5	124.5	#2064p1	1 ± 1	—	—	9 ± 1	12 ± 1	—	—	71 ± 10	—	1 ± 1	1 ± 1	—	95 ± 10
430.9/431.1	131.4	#2065p1	3 ± 1	—	—	12 ± 1	9 ± 5	—	—	78 ± 11	—	1 ± 1	1 ± 1	—	104 ± 12
451.6/451.7	137.7	#2066p1	3 ± 1	—	—	14 ± 1	11 ± 1	—	—	70 ± 10	—	1 ± 1	Trc.	—	99 ± 10
473.5/473.6	144.4	#2067p1	3 ± 1	—	—	14 ± 1	12 ± 1	—	1 ± 1	68 ± 10	—	2 ± 1	1 ± 1	—	101 ± 10
487.9/488.2	148.8	#2068p1	7 ± 2	—	—	20 ± 2	12 ± 2	—	1 ± 1	62 ± 9	—	1 ± 1	Trc.	—	103 ± 10

Appendix II. Quantitative XRD results for drill core USW NRG-7/7a (continued).

Sample	Depth (m)	LANL #	Smect-ite	Clino-ptilolite	Morden-ite	Tridymite	Cristobalite	Opal-CT	Quartz	Feldspar	Glass	Hematite	Mica	Kaolin-ite	Total
507.1/507.4	154.7	#2069p1	5 ± 2	—	—	21 ± 2	10 ± 2	—	5 ± 1	60 ± 8	—	1 ± 1	Trc.	—	102 ± 9
528.4/528.7	161.1	#2070p1	4 ± 1	—	—	14 ± 1	18 ± 2	—	5 ± 1	58 ± 8	—	1 ± 1	Trc.	—	100 ± 8
551.3/551.5	168.1	#2071p1	4 ± 1	—	—	10 ± 1	18 ± 2	—	7 ± 1	57 ± 8	—	Trc.	Trc.	—	96 ± 8
569.4/569.7	173.6	#2072p1	5 ± 2	—	—	12 ± 1	15 ± 2	—	11 ± 1	57 ± 8	—	1 ± 1	Trc.	—	101 ± 9
594.8/595.0	181.4	#2073p1	2 ± 1	—	—	9 ± 1	19 ± 2	—	13 ± 1	55 ± 8	—	1 ± 1	—	—	99 ± 8
615.2/615.4	187.6	#2119p1	3 ± 1	—	—	8 ± 1	22 ± 2	—	6 ± 1	57 ± 8	—	1 ± 1	Trc.	—	97 ± 8
634.7/634.8	193.5	#2074p1	4 ± 1	—	—	4 ± 1	29 ± 2	—	7 ± 1	55 ± 8	—	1 ± 1	Trc.	—	100 ± 8
658.9/659.4	201.0	#2075p1	3 ± 1	—	—	11 ± 1	15 ± 2	—	17 ± 1	56 ± 8	—	1 ± 1	Trc.	—	103 ± 8
678.0/678.3	206.7	#2076p1	3 ± 1	—	—	4 ± 1	20 ± 2	—	17 ± 1	53 ± 7	—	Trc.	—	—	97 ± 7
699.3/699.5	213.2	#2077p1	4 ± 1	—	—	4 ± 1	18 ± 1	—	15 ± 1	57 ± 8	—	1 ± 1	Trc.	—	99 ± 8
724.5/724.7	220.9	#2078p1	4 ± 1	—	—	5 ± 1	16 ± 1	—	16 ± 1	59 ± 8	—	1 ± 1	Trc.	—	101 ± 8
745.9/746.3	227.5	#2079p1	3 ± 1	—	—	6 ± 1	16 ± 1	—	20 ± 2	57 ± 8	—	1 ± 1	Trc.	—	103 ± 8
767.9/768.1	234.1	#2080p1	3 ± 1	—	—	3 ± 1	21 ± 2	—	16 ± 1	55 ± 8	—	1 ± 1	Trc.	—	99 ± 8
791.5/792.0	241.4	#2081p1	3 ± 1	—	—	1 ± 1	22 ± 2	—	18 ± 1	52 ± 7	—	Trc.	Trc.	—	96 ± 7
815.3/815.5	248.6	#2082p1	4 ± 1	—	—	2 ± 1	26 ± 2	—	13 ± 1	57 ± 8	—	Trc.	Trc.	—	102 ± 8
837.3/837.6	255.3	#2083p1	3 ± 1	—	—	5 ± 1	9 ± 3	—	29 ± 2	56 ± 8	—	1 ± 1	Trc.	—	103 ± 9
860.1/860.3	262.2	#2084p1	3 ± 1	—	—	Trc.	24 ± 2	—	17 ± 1	53 ± 7	—	—	Trc.	—	97 ± 7
881.8/882.0	268.8	#2085p1	4 ± 1	—	—	7 ± 1	16 ± 1	—	18 ± 1	55 ± 8	—	1 ± 1	Trc.	—	101 ± 8
903.0/903.3	275.3	#2086p1	3 ± 1	—	—	3 ± 1	14 ± 1	—	23 ± 2	54 ± 8	—	Trc.	Trc.	—	97 ± 8
924.9/925.1	282.0	#2087p1	2 ± 1	—	—	—	6 ± 2	—	35 ± 2	55 ± 8	—	Trc.	Trc.	—	98 ± 9
950.8/951.2	289.9	#2088p1	3 ± 1	—	—	1 ± 1	9 ± 3	—	33 ± 2	54 ± 8	—	Trc.	Trc.	—	100 ± 9
973.4/973.6	296.8	#2089p1	2 ± 1	—	—	8 ± 1	11 ± 1	—	24 ± 2	54 ± 8	—	1 ± 1	Trc.	—	100 ± 8
995.4/995.7	303.5	#2090p1	3 ± 1	—	—	4 ± 1	20 ± 2	—	17 ± 1	57 ± 8	—	Trc.	Trc.	—	101 ± 8
1005.0/1005.5	306.5	#2091p1	3 ± 1	—	—	2 ± 1	17 ± 1	—	21 ± 2	55 ± 8	—	Trc.	Trc.	—	98 ± 8
1028.0/1028.2	313.4	#2092p1	1 ± 1	—	—	1 ± 1	24 ± 2	—	15 ± 1	56 ± 8	—	1 ± 1	—	—	98 ± 8
1050.2/1050.5	320.2	#2093p1	2 ± 1	—	—	6 ± 1	22 ± 2	—	14 ± 1	54 ± 8	—	Trc.	Trc.	—	98 ± 8
1076.3/1076.5	328.1	#2094p1	1 ± 1	—	—	2 ± 1	12 ± 1	—	27 ± 2	54 ± 8	—	Trc.	Trc.	—	96 ± 8
1099.7/1100.1	335.3	#2095p1	2 ± 1	—	—	2 ± 1	10 ± 1	—	32 ± 2	55 ± 8	—	Trc.	Trc.	—	101 ± 8
1123.2/1123.3	342.4	#2096p1	—	—	—	4 ± 1	13 ± 1	—	27 ± 2	55 ± 8	—	Trc.	Trc.	—	99 ± 8
1146.7/1146.9	349.6	#2097p1	2 ± 1	—	—	7 ± 1	13 ± 1	—	21 ± 2	56 ± 8	—	1 ± 1	Trc.	—	100 ± 8
1164.2/1164.7	355.0	#2098p1	1 ± 1	—	—	5 ± 1	22 ± 2	—	14 ± 1	56 ± 8	—	Trc.	Trc.	—	98 ± 8
1186.7/1187.4	361.9	#2099p1	1 ± 1	—	—	3 ± 1	11 ± 1	—	29 ± 2	57 ± 8	—	Trc.	Trc.	—	101 ± 8
1205.9/1206.2	367.6	#2100p1	2 ± 1	—	—	2 ± 1	10 ± 1	—	30 ± 2	57 ± 8	—	Trc.	Trc.	—	101 ± 8

Appendix II. Quantitative XRD results for drill core USW NRG-7/7a (continued).

Sample	Depth (m)	LANL #	Smect-ite	Clino-ptilolite	Morden-ite	Tridy-mite	Cristob-alite	Opal-CT	Quartz	Feld-spar	Glass	Hem-atite	Mica	Kaolin-ite	Total
1227.7/1228.5	374.4	#2101p1	2 ± 1	—	—	2 ± 1	9 ± 3	—	30 ± 2	54 ± 8	—	Trc.	Trc.	—	97 ± 9
1250.0/1250.1	381.0	#2102p1	2 ± 1	—	—	3 ± 1	10 ± 1	—	29 ± 2	54 ± 8	—	1 ± 1	Trc.	—	99 ± 8
1273.9/1274.0	388.3	#2103p1	2 ± 1	—	—	3 ± 1	11 ± 1	—	29 ± 2	56 ± 8	—	Trc.	Trc.	—	101 ± 8
1294.6/1294.8	394.7	#2104p1	2 ± 1	—	—	—	8 ± 3	—	33 ± 2	57 ± 8	—	Trc.	Trc.	—	100 ± 9
1318.5/1318.9	402.0	#2105p1	2 ± 1	—	—	—	13 ± 1	—	30 ± 2	56 ± 8	—	1 ± 1	Trc.	—	102 ± 8
1340.1/1340.3	408.5	#2106p1	2 ± 1	—	—	Trc.	18 ± 1	—	23 ± 2	55 ± 8	—	Trc.	Trc.	—	98 ± 8
1359.7/1360.0	414.5	#2107p1	2 ± 1	—	—	—	16 ± 1	—	27 ± 2	53 ± 7	—	Trc.	Trc.	—	98 ± 7
1370.1/1370.4	417.7	#2108p1	2 ± 1	—	—	—	20 ± 2	—	24 ± 2	51 ± 7	—	Trc.	Trc.	—	97 ± 8
1379.9/1380.4	420.7	#2109p1	2 ± 1	—	—	4 ± 1	23 ± 2	—	13 ± 1	54 ± 8	—	Trc.	Trc.	—	96 ± 8
1391.9/1392.4	424.4	#2110p1	2 ± 1	1 ± 1	—	1 ± 1	16 ± 1	—	25 ± 2	53 ± 7	—	Trc.	Trc.	—	98 ± 8
1402.0/1402.1	427.4	#2111p1	2 ± 1	2 ± 1	—	2 ± 1	23 ± 2	—	15 ± 1	52 ± 7	—	Trc.	Trc.	—	96 ± 8
1409.5/1409.6	429.6	#2112p1	—	—	—	4 ± 1	20 ± 2	—	21 ± 2	51 ± 7	—	—	Trc.	—	96 ± 8
1411.5/1411.8	430.3	#2113p1	21 ± 6	29 ± 3	1 ± 1	—	—	35 ± 10	1 ± 1	18 ± 3	—	—	Trc.	—	105 ± 12
1416.4/1416.8	431.8	#2114p1	4 ± 1	1 ± 1	1 ± 1	—	—	5 ± 1	1 ± 1	9 ± 1	79 ± 2	—	Trc.	—	100 ± 2
1425.8/1425.9	434.6	#2115p1	Trc.	—	—	—	—	3 ± 1	Trc.	4 ± 1	93 ± 1	—	Trc.	—	100 ± 1
1437.0/1437.2	438.1	#2116p1	—	1 ± 1	—	—	—	3 ± 1	1 ± 1	6 ± 1	89 ± 2	—	Trc.	—	100 ± 2
1451.2/1451.3	442.4	#1880p1	—	—	—	—	—	—	1 ± 1	3 ± 1	96 ± 1	—	Trc.	—	100 ± 1
1459.3/1459.5	444.9	#1881p1	3 ± 1	1 ± 1	—	—	—	5 ± 1	1 ± 1	6 ± 1	84 ± 2	—	Trc.	—	100 ± 2
1463.5/1464.0	446.2	#1882p1	5 ± 2	2 ± 1	—	—	—	4 ± 1	Trc.	4 ± 1	85 ± 2	—	Trc.	—	100 ± 3
1470.0/1470.2	448.1	#1883p1	8 ± 2	5 ± 1	—	—	—	5 ± 1	—	4 ± 1	78 ± 2	—	Trc.	—	100 ± 3
1475.0/1475.4	449.7	#1884p1	8 ± 2	71 ± 6	—	—	—	24 ± 5	1 ± 1	1 ± 1	—	—	—	—	105 ± 8
1481.1/1481.2	451.5	#1885p1	2 ± 1	77 ± 6	—	—	—	23 ± 5	1 ± 1	2 ± 1	—	—	Trc.	—	105 ± 8
1485.5/1485.7	452.8	#1886p1	2 ± 1	79 ± 6	—	—	—	18 ± 4	2 ± 1	6 ± 1	—	—	Trc.	—	107 ± 7
1492.0/1492.2	454.8	#1888p1	Trc.	78 ± 6	1 ± 1	—	—	16 ± 4	3 ± 1	7 ± 2	—	—	Trc.	—	105 ± 8
Calico Hills Formation			455.0 m - bottom												
1495.9/1496.2	456.0	#1887p1	2 ± 1	67 ± 6	2 ± 1	—	—	14 ± 4	5 ± 1	13 ± 3	—	—	Trc.	—	103 ± 8
1499.4/1499.7	457.1	#2117p1	1 ± 1	80 ± 6	—	—	—	13 ± 3	2 ± 1	8 ± 2	—	—	—	—	104 ± 7
1513.0/1513.4	461.3	#2118p1	Trc.	84 ± 6	—	—	—	7 ± 2	4 ± 1	7 ± 2	—	—	Trc.	—	102 ± 7
Bottom			461.3 m												

Appendix III. Quantitative XRD results for drill core USW SD-7.

Sample	Depth (m)	LANL #	Smect-ite	Clino-ptilolite	Morden-ite	Chab-azite	Tridy-mite	Cristob-alite	Opal-CT	Quartz	Feld-spar	Glass	Hem-atite	Mica	Other	Total
Tiva Canyon Tuff (Tpc)		15.2 - 111.6 m														
Topopah Spring Tuff (Tpt)		111.6 - 411.8 m														
369.3/369.7	112.7	2532p1	15 ± 5	-	-	-	11 ± 1	10 ± 1	-	1 ± 1	59 ± 8	-	2 ± 1	Trc.	-	98 ± 10
386.1/386.2	117.7	2533p1	8 ± 2	-	-	-	12 ± 1	19 ± 2	-	4 ± 1	54 ± 8	-	1 ± 1	Trc.	-	98 ± 9
387.0/387.1	118.0	2534p1	Trc.	-	-	-	9 ± 1	20 ± 2	-	3 ± 1	63 ± 9	-	1 ± 1	Trc.	-	96 ± 9
388.1/388.2	118.3	2535p1	-	-	-	-	2 ± 1	15 ± 1	-	1 ± 1	76 ± 11	-	2 ± 1	1 ± 1	-	97 ± 11
392.1/392.3	119.6	2536p1	-	-	-	-	2 ± 1	16 ± 1	-	-	79 ± 11	-	1 ± 1	1 ± 1	-	99 ± 11
397.5/397.6	121.2	2537p1	-	-	-	-	5 ± 1	14 ± 1	-	-	73 ± 10	-	1 ± 1	1 ± 1	-	94 ± 10
415.9/416.1	126.8	2538p1	Trc.	-	-	-	8 ± 1	12 ± 1	-	Trc.	79 ± 11	-	1 ± 1	1 ± 1	-	101 ± 11
438.6/438.9	133.8	2539p1	1 ± 1	-	-	-	13 ± 1	11 ± 1	-	-	73 ± 10	-	1 ± 1	Trc.	-	99 ± 10
462.8/463.1	141.2	2540p1	1 ± 1	-	-	-	16 ± 2	11 ± 1	-	1 ± 1	70 ± 10	-	1 ± 1	Trc.	Trc. ¹	100 ± 10
487.8/487.9	148.7	2541p1	3 ± 1	-	-	-	20 ± 2	10 ± 2	-	Trc.	67 ± 9	-	1 ± 1	Trc.	-	101 ± 10
511.8/512.0	156.1	2542p1	4 ± 1	-	-	-	21 ± 2	9 ± 4	-	1 ± 1	63 ± 9	-	1 ± 1	Trc.	-	99 ± 10
533.3/533.5	162.6	2543p1	4 ± 1	-	-	-	11 ± 1	26 ± 3	-	1 ± 1	54 ± 8	-	1 ± 1	Trc.	-	97 ± 9
556.8/557.4	169.9	2544p1	2 ± 1	-	-	-	12 ± 1	21 ± 2	-	1 ± 1	63 ± 9	-	1 ± 1	Trc.	-	100 ± 9
582.5/582.6	177.6	2545p1	4 ± 1	-	-	-	5 ± 1	34 ± 3	-	1 ± 1	55 ± 8	-	1 ± 1	Trc.	-	100 ± 9
607.3/607.5	185.2	2546p1	4 ± 1	-	-	-	9 ± 1	25 ± 2	-	7 ± 1	53 ± 7	-	Trc.	Trc.	-	98 ± 7
631.5/631.7	192.5	2547p1	3 ± 1	-	-	-	4 ± 1	32 ± 2	-	5 ± 1	55 ± 8	-	Trc.	Trc.	-	99 ± 8
656.4/656.6	200.1	2548p1	2 ± 1	-	-	-	-	11 ± 1	-	33 ± 2	53 ± 7	-	Trc.	Trc.	-	99 ± 7
682.5/683.1	208.2	2549p1	4 ± 1	-	-	-	2 ± 1	25 ± 2	-	15 ± 1	53 ± 7	-	Trc.	Trc.	-	99 ± 7
703.8/704.3	214.7	2550p1	3 ± 1	-	-	-	2 ± 1	35 ± 2	-	4 ± 1	53 ± 7	-	-	Trc.	-	97 ± 7
725.1/725.7	221.2	2551p1	5 ± 2	-	-	-	4 ± 1	31 ± 2	-	5 ± 1	52 ± 7	-	-	Trc.	-	97 ± 8
749.3/749.6	228.5	2552p1	3 ± 1	-	-	-	4 ± 1	35 ± 2	-	2 ± 1	52 ± 7	-	Trc.	Trc.	-	96 ± 7
775.2/775.8	236.5	2553p1	5 ± 2	-	-	-	3 ± 1	34 ± 2	-	3 ± 1	52 ± 7	-	-	Trc.	-	97 ± 8
800.3/800.5	244.0	2554p1	3 ± 1	-	-	-	2 ± 1	35 ± 2	-	3 ± 1	54 ± 8	-	Trc.	Trc.	-	97 ± 8
825.0/825.7	251.7	2555p1	4 ± 1	-	-	-	5 ± 1	20 ± 2	-	18 ± 1	53 ± 7	-	Trc.	Trc.	-	100 ± 7
848.1/848.4	258.6	2556p1	4 ± 1	-	-	-	5 ± 1	14 ± 1	-	24 ± 2	54 ± 8	-	Trc.	Trc.	-	101 ± 8
875.7/876.0	267.0	2557p1	3 ± 1	-	-	-	4 ± 1	34 ± 2	-	4 ± 1	53 ± 7	-	1 ± 1	Trc.	-	99 ± 8
898.4/898.6	273.9	2558p1	4 ± 1	-	-	-	3 ± 1	25 ± 2	-	11 ± 1	52 ± 7	-	1 ± 1	Trc.	-	96 ± 8
924.4/924.7	281.8	2559p1	5 ± 2	-	-	-	8 ± 1	23 ± 2	-	11 ± 1	55 ± 8	-	Trc.	Trc.	-	102 ± 9
946.0/946.4	288.5	2560p1	5 ± 2	-	-	-	3 ± 1	12 ± 1	-	29 ± 2	55 ± 8	-	Trc.	Trc.	-	104 ± 9
966.2/966.9	294.7	2561p1	5 ± 2	-	-	-	3 ± 1	12 ± 1	-	26 ± 2	51 ± 7	-	Trc.	Trc.	-	97 ± 8

Appendix III. Quantitative XRD results for drill core USW SD-7 (continued).

Sample	Depth (m)	LANL #	Smect-ite	Clino- ptilolite	Morden- ite	Chab- azite	Tridy- mite	Cristob- alite	Opal- CT	Quartz	Feld- spar	Glass	Hem- atite	Mica	Other	Total
974.3/974.5	297.0	2562p1	6 ± 2	—	—	—	3 ± 1	22 ± 2	—	18 ± 1	51 ± 7	—	1 ± 1	Trc.	—	101 ± 8
993.4/994.3	303.1	2563p1	3 ± 1	—	—	—	10 ± 1	9 ± 3	—	24 ± 2	55 ± 8	—	1 ± 1	Trc.	—	102 ± 9
1013.5/1014.3	309.2	2564p1	2 ± 1	—	—	—	3 ± 1	23 ± 2	—	17 ± 1	54 ± 8	—	1 ± 1	Trc.	—	100 ± 8
1032.1/1032.3	314.6	2565p1	4 ± 1	—	—	—	3 ± 1	21 ± 2	—	19 ± 1	56 ± 8	—	Trc.	Trc.	—	103 ± 8
1053.5/1054.2	321.3	2566p1	3 ± 1	—	—	—	7 ± 1	11 ± 1	—	26 ± 2	52 ± 7	—	1 ± 1	Trc.	—	100 ± 8
1073.0/1073.6	327.2	2567p1	3 ± 1	—	—	—	1 ± 1	20 ± 2	—	20 ± 2	53 ± 7	—	Trc.	Trc.	—	97 ± 8
1091.9/1092.2	332.9	2568p1	3 ± 1	—	—	—	—	18 ± 1	—	25 ± 2	55 ± 8	—	Trc.	Trc.	—	101 ± 8
1115.1/1115.4	340.0	2569p1	4 ± 1	—	—	—	—	19 ± 1	—	22 ± 2	53 ± 7	—	Trc.	Trc.	—	98 ± 7
1133.3/1133.4	345.5	2014p1	5 ± 2	—	—	—	1 ± 1	20 ± 2	—	18 ± 1	53 ± 7	—	Trc.	Trc.	—	97 ± 8
1156.7/1156.9	352.6	2015p1	7 ± 2	—	—	—	—	16 ± 1	—	23 ± 2	50 ± 7	—	Trc.	Trc.	—	96 ± 8
1161.5/1161.6	354.1	2016p1	4 ± 1	—	—	—	1 ± 1	10 ± 1	—	30 ± 2	53 ± 7	—	Trc.	Trc.	—	98 ± 7
1165.0/1165.1	355.1	2017p1	6 ± 2	—	—	—	—	18 ± 1	—	24 ± 2	52 ± 7	—	Trc.	Trc.	—	100 ± 8
1169.9/1170.0	356.6	2018p1	6 ± 2	—	—	—	—	11 ± 1	—	29 ± 2	51 ± 7	—	Trc.	Trc.	—	97 ± 8
1175.1/1175.4	358.3	2019p1	6 ± 2	—	—	—	—	16 ± 1	—	25 ± 2	51 ± 7	—	Trc.	Trc.	—	98 ± 8
1179.5/1179.7	359.6	2020p1	5 ± 2	—	—	1 ± 1	—	18 ± 1	—	21 ± 2	51 ± 7	—	Trc.	Trc.	—	96 ± 8
1181.6/1182.0	360.3	2021p1	7 ± 2	—	—	1 ± 1	2 ± 1	17 ± 1	—	20 ± 2	49 ± 7	—	Trc.	Trc.	—	96 ± 8
1187.0/1187.1	361.8	2022p1	59 ± 18	—	—	5 ± 1	—	—	22 ± 6	1 ± 1	15 ± 2	—	—	—	—	102 ± 19
1191.1/1191.3	363.1	2023p1	19 ± 6	38 ± 3	—	5 ± 1	—	—	25 ± 7	7 ± 1	14 ± 2	—	—	Trc.	—	108 ± 10
1193.4/1193.5	363.8	2024p1	6 ± 2	—	—	—	—	—	21 ± 6	1 ± 1	15 ± 2	57 ± 6	—	Trc.	—	100 ± 7
1201.7/1201.9	366.3	2025p1	1 ± 1	—	—	—	—	—	17 ± 5	1 ± 1	14 ± 2	67 ± 5	—	Trc.	—	100 ± 6
1213.5/1213.7	369.9	2026p1	1 ± 1	—	—	—	—	—	17 ± 4	1 ± 1	12 ± 2	69 ± 4	—	Trc.	—	100 ± 5
1230.7/1230.9	375.2	2027p1	1 ± 1	—	—	—	—	—	12 ± 3	2 ± 1	9 ± 1	76 ± 3	—	Trc.	—	100 ± 3
1245.5/1246.0	379.8	2028p1	Trc.	—	—	—	—	—	10 ± 2	1 ± 1	9 ± 1	80 ± 2	—	Trc.	—	100 ± 2
1260.2/1260.3	384.1	2029p1	Trc.	—	—	—	—	—	9 ± 2	1 ± 1	7 ± 1	83 ± 2	—	Trc.	—	100 ± 2
1278.6/1278.9	389.8	2030p1	1 ± 1	—	—	—	—	—	18 ± 5	1 ± 1	13 ± 2	67 ± 5	—	Trc.	—	100 ± 6
1298.8/1299.0	395.9	2031p1	2 ± 1	—	—	—	—	—	14 ± 4	1 ± 1	12 ± 2	71 ± 4	—	Trc.	Trc. ¹	100 ± 5
1299.7/1299.8	396.2	2468p1	1 ± 1	—	—	—	—	—	8 ± 2	1 ± 1	8 ± 1	82 ± 2	—	Trc.	—	100 ± 3
1321.5/1321.6	402.8	2032p1	Trc.	—	—	—	—	—	4 ± 1	2 ± 1	7 ± 1	87 ± 1	—	Trc.	—	100 ± 2
1338.5/1338.7	408.0	2033p1	Trc.	—	—	—	—	—	2 ± 1	1 ± 1	3 ± 1	94 ± 1	—	Trc.	—	100 ± 2
1350.5/1350.7	411.7	2034p1	Trc.	1 ± 1	—	—	—	—	16 ± 5	5 ± 1	20 ± 3	52 ± 6	—	Trc.	6 ± 1 ²	100 ± 6

Appendix III. Quantitative XRD results for drill core USW SD-7 (continued).

Sample	Depth (m)	LANL #	Smect-ite	Clino-tilloite	Morden-ite	Chab-azite	Tridy-mite	Cristob-alite	Opal-CT	Quartz	Feld-spar	Glass	Hem-atite	Mica	Other	Total
Pre-Tpt bedded tuff			411.8 - 421.0 m													
Calico Hills Formation (Ta)			421.0 - 477.7 m													
1391.0/1391.2	424.0	2035p1	1 ± 1	—	—	—	—	—	2 ± 1	3 ± 1	6 ± 1	85 ± 2	—	Trc.	3 ± 1 ²	100 ± 2
1421.1/1421.3	433.2	2297p1	Trc.	—	—	—	—	—	2 ± 1	1 ± 1	6 ± 1	91 ± 1	—	—	—	100 ± 2
1444.6/1444.8	440.4	2298p1	Trc.	—	—	—	—	—	2 ± 1	2 ± 1	6 ± 1	90 ± 1	—	—	—	100 ± 2
1467.4/1457.5	444.2	2299p1	Trc.	1 ± 1	—	Trc.	—	—	3 ± 1	3 ± 1	7 ± 1	86 ± 2	—	Trc.	—	100 ± 2
1471.5/1471.8	448.6	2300p1	Trc.	1 ± 1	—	Trc.	—	—	2 ± 1	4 ± 1	8 ± 1	85 ± 2	—	Trc.	—	100 ± 2
1493.2/1493.6	455.2	2301p1	11 ± 3	14 ± 1	—	3 ± 1	—	—	5 ± 1	4 ± 1	10 ± 2	53 ± 4	—	Trc.	—	100 ± 4
1493.2/1493.6b	455.2	2301p2	Trc.	45 ± 4	—	5 ± 1	—	—	26 ± 7	7 ± 1	14 ± 3	—	—	Trc.	—	97 ± 9
1513.9/1514.2	461.5	2302p1	2 ± 1	6 ± 1	—	1 ± 1	—	—	5 ± 1	4 ± 1	8 ± 1	74 ± 2	—	Trc.	—	100 ± 2
1517.3/1517.6	462.6	2303p1	5 ± 2	2 ± 1	—	1 ± 1	—	—	5 ± 1	7 ± 1	16 ± 2	63 ± 3	—	1 ± 1	—	100 ± 4
1519.1/1519.3	463.1	2304p1	Trc.	60 ± 5	—	9 ± 2	—	—	19 ± 4	5 ± 1	6 ± 1	—	—	Trc.	—	99 ± 7
1538.5/1538.6	469.0	2305p1	3 ± 1	14 ± 1	3 ± 1	2 ± 1	—	—	10 ± 2	4 ± 1	8 ± 1	56 ± 3	—	Trc.	—	100 ± 3
1560.1/1560.5	475.6	2306p1	5 ± 2	21 ± 2	6 ± 2	—	—	—	9 ± 2	3 ± 1	7 ± 1	49 ± 4	—	—	—	100 ± 4
Pre-Ta bedded-tuff			477.7 - 495.9 m													
1567.1/1567.3	477.7	2307p1	5 ± 2	68 ± 5	—	—	—	—	17 ± 4	4 ± 1	9 ± 2	—	—	Trc.	—	103 ± 7
1567.1/1567.3b	477.7	2307p2	1 ± 1	49 ± 5	—	—	—	—	33 ± 8	7 ± 1	10 ± 2	—	—	—	—	100 ± 10
1581.2/1581.5	482.0	2308p1	5 ± 2	49 ± 3	—	5 ± 1	—	—	8 ± 2	6 ± 1	12 ± 2	14 ± 4	—	1 ± 1	—	100 ± 5
1581.2/1581.8b	482.1	2308p2	1 ± 1	53 ± 5	—	—	—	—	37 ± 8	6 ± 1	5 ± 1	—	—	Trc.	—	102 ± 10
1597.1/1597.4	486.9	2309p1	3 ± 1	46 ± 4	—	—	—	—	25 ± 7	11 ± 1	19 ± 4	—	—	1 ± 1	—	105 ± 9
1601.5/1601.8	488.2	2310p1	3 ± 1	50 ± 4	—	—	—	—	15 ± 5	12 ± 1	22 ± 4	—	—	1 ± 1	—	103 ± 8
1618.1/1618.2	493.2	2311p1	7 ± 2	55 ± 4	—	—	—	—	12 ± 4	5 ± 1	24 ± 5	—	—	Trc.	Trc. ¹	103 ± 8
1622.6/1622.9	494.7	2312p1	8 ± 2	54 ± 5	—	—	—	—	25 ± 7	4 ± 1	13 ± 3	—	—	—	—	104 ± 9
Prow Pass Tuff (Tcp)			495.9 - 660.7 m													
1636.5/1636.8	498.9	2313p1	7 ± 2	46 ± 4	—	—	—	—	35 ± 9	2 ± 1	12 ± 2	—	—	—	—	102 ± 10
1647.7/1647.9	502.3	2314p1	1 ± 1	—	—	—	4 ± 1	35 ± 2	—	3 ± 1	51 ± 7	—	1 ± 1	—	—	95 ± 8
1666.6/1666.8	508.0	2315p1	2 ± 1	—	—	—	1 ± 1	7 ± 2	—	30 ± 2	55 ± 8	—	2 ± 1	Trc.	—	97 ± 9
1688.2/1688.4	514.6	2316p1	2 ± 1	—	—	—	3 ± 1	2 ± 1	—	33 ± 2	56 ± 8	—	1 ± 1	Trc.	—	97 ± 8
1718.7/1718.9	523.9	2317p1	2 ± 1	—	—	—	5 ± 1	2 ± 1	—	32 ± 2	55 ± 8	—	1 ± 1	Trc.	—	97 ± 8
1741.0/1741.3	530.7	2318p1	1 ± 1	—	—	—	6 ± 1	3 ± 1	—	28 ± 2	57 ± 8	—	1 ± 1	Trc.	—	96 ± 8
1765.9/1766.3	538.4	2319p1	1 ± 1	—	—	—	2 ± 1	7 ± 2	—	29 ± 2	59 ± 8	—	Trc.	Trc.	—	98 ± 9
1787.1/1787.2	544.7	2320p1	1 ± 1	—	—	—	—	15 ± 1	—	25 ± 2	58 ± 8	—	Trc.	Trc.	—	99 ± 8

Appendix III. Quantitative XRD results for drill core USW SD-7 (continued).

Sample	Depth (m)	LANL #	Smect-ite	Clino-ptilolite	Morden-ite	Chab-azite	Tridy-mite	Cristob-alite	Opal-CT	Quartz	Feld-spar	Glass	Hem-atite	Mica	Other	Total
1796.7/1797.0	547.7	2321p1	2 ± 1	—	—	—	—	16 ± 1	—	19 ± 1	61 ± 9	—	Trc.	Trc.	—	98 ± 9
1824.6/1824.9	556.2	2322p1	2 ± 1	—	—	—	—	26 ± 2	—	12 ± 1	57 ± 8	—	Trc.	Trc.	—	97 ± 8
1843.4/1843.7	562.0	2323p1	3 ± 1	—	—	—	—	30 ± 2	—	7 ± 1	57 ± 8	—	Trc.	Trc.	—	97 ± 8
1867.5/1868.1	569.4	2324p1	2 ± 1	35 ± 2	—	—	—	21 ± 2	—	6 ± 1	39 ± 7	—	—	Trc.	—	103 ± 8
1893.8/1894.1	577.3	2325p1	5 ± 2	29 ± 3	—	—	—	—	36 ± 12	3 ± 1	29 ± 5	—	—	—	Trc. ¹	102 ± 14
1913.4/1914.9	583.7	2326p1	4 ± 1	42 ± 4	3 ± 1	—	—	—	28 ± 9	4 ± 1	23 ± 5	—	—	—	—	104 ± 11
1938.5/1938.7	590.9	2327p1	1 ± 1	53 ± 6	6 ± 2	—	—	—	20 ± 6	5 ± 1	20 ± 4	—	—	—	—	105 ± 10
1962.8/1963.1	598.4	2328p1	2 ± 1	60 ± 6	5 ± 2	—	—	—	14 ± 4	4 ± 1	20 ± 5	—	—	—	—	105 ± 9
1988.6/1989.0	606.2	2329p1	3 ± 1	54 ± 7	12 ± 4	—	—	—	18 ± 5	3 ± 1	15 ± 4	—	—	Trc.	—	105 ± 10
2010.2/2010.5	612.8	2330p1	1 ± 1	82 ± 6	—	—	—	—	12 ± 3	Trc.	10 ± 2	—	—	—	—	105 ± 7
2021.3/2021.6	616.2	2331p1	2 ± 1	68 ± 5	—	—	—	—	19 ± 5	2 ± 1	14 ± 3	—	—	—	—	105 ± 8
2035.1/2035.3	620.4	2332p1	2 ± 1	56 ± 7	10 ± 3	—	—	—	16 ± 5	3 ± 1	18 ± 4	—	—	—	—	105 ± 10
2043.8/2044.0	623.0	2333p1	2 ± 1	61 ± 7	7 ± 2	—	—	—	14 ± 4	2 ± 1	18 ± 4	—	—	—	—	104 ± 9
2062.6/2062.8	628.7	2334p1	1 ± 1	49 ± 8	17 ± 5	—	—	—	17 ± 5	3 ± 1	17 ± 5	—	—	—	—	104 ± 12
2082.8/2083.1	634.9	2335p1	1 ± 1	53 ± 8	15 ± 5	—	—	—	15 ± 4	2 ± 1	17 ± 5	—	—	—	—	103 ± 11
2094.2/2094.6	638.4	2336p1	1 ± 1	39 ± 9	30 ± 8	—	—	—	13 ± 4	4 ± 1	17 ± 6	—	—	—	—	104 ± 14
2109.6/2109.9	643.1	2337p1	1 ± 1	53 ± 9	18 ± 6	—	—	—	13 ± 4	2 ± 1	19 ± 5	—	—	—	—	106 ± 13
2133.7/2133.9	650.4	2338p1	1 ± 1	60 ± 9	16 ± 5	—	—	—	11 ± 3	2 ± 1	14 ± 4	—	—	—	—	104 ± 12
2159.6/2159.8	658.3	2339p1	2 ± 1	52 ± 8	15 ± 5	—	—	—	12 ± 3	5 ± 1	18 ± 5	—	—	—	—	104 ± 11
2159.5/2159.8	658.3	2339p2	3 ± 1	51 ± 7	14 ± 5	—	—	—	15 ± 4	4 ± 1	16 ± 4	—	—	—	—	103 ± 10
Pre-Tcp bedded tuff			660.7 - 664.5 m													
2179.2/2179.4	664.3	2340p1	4 ± 1	34 ± 2	—	—	—	—	2 ± 1	7 ± 1	50 ± 9	—	—	2 ± 1	—	99 ± 9
2179.2/2179.4	664.3	2340p2	7 ± 2	33 ± 2	—	—	—	Trc.	—	4 ± 1	53 ± 9	—	—	3 ± 1	—	100 ± 10
2180.0/2180.2	664.5	2341p1	Trc.	—	—	—	—	5 ± 2	—	34 ± 2	56 ± 8	—	1 ± 1	1 ± 1	—	97 ± 9
2180.0/2180.2	664.5	2341p2	1 ± 1	—	—	—	—	5 ± 2	—	40 ± 2	51 ± 7	—	1 ± 1	1 ± 1	—	99 ± 8
Bullfrog Tuff (Tcb)			664.5 - 786.2 m													
static water level			665.7 m													
2201.7/2201.9	671.1	2342p1	1 ± 1	—	—	—	—	19 ± 1	—	18 ± 1	62 ± 9	—	1 ± 1	1 ± 1	—	102 ± 9
2201.7/2201.9	671.1	2342p2	3 ± 1	—	—	—	—	20 ± 2	—	18 ± 1	59 ± 8	—	1 ± 1	1 ± 1	—	102 ± 8
2225.3/2225.4	678.3	2343p1	2 ± 1	—	—	—	—	19 ± 1	—	18 ± 1	59 ± 8	—	1 ± 1	1 ± 1	—	100 ± 8
2225.3/2225.4	678.3	2343p2	3 ± 1	—	—	—	—	17 ± 1	—	19 ± 1	62 ± 9	—	1 ± 1	2 ± 1	—	104 ± 9
2250.8/2251.0	686.1	2344p1	2 ± 1	—	—	—	—	19 ± 1	—	16 ± 1	63 ± 9	—	1 ± 1	2 ± 1	—	103 ± 9

Appendix III. Quantitative XRD results for drill core USW SD-7 (continued).

Sample	Depth (m)	LANL #	Smectite	Clinoptilolite	Mordenite	Chabazite	Tridymite	Cristobalite	Opal-CT	Quartz	Feldspar	Glass	Hematite	Mica	Other	Total
2275.1/2275.3	693.5	2345p1	2 ± 1	—	—	—	—	19 ± 1	—	20 ± 2	56 ± 8	—	1 ± 1	1 ± 1	—	99 ± 8
2302.3/2302.6	701.8	2346p1	2 ± 1	—	—	—	—	18 ± 1	—	19 ± 1	61 ± 9	—	1 ± 1	1 ± 1	—	102 ± 9
2324.4/2324.7	708.6	2347p1	2 ± 1	—	—	—	—	21 ± 2	—	18 ± 1	60 ± 8	—	1 ± 1	1 ± 1	—	103 ± 8
2350.4/2350.8	716.5	2348p1	2 ± 1	—	—	—	—	19 ± 1	—	21 ± 2	56 ± 8	—	Trc.	1 ± 1	—	99 ± 8
2358.2/2358.3	718.8	2349p1	2 ± 1	Trc.	—	—	—	16 ± 1	—	27 ± 2	56 ± 8	—	Trc.	1 ± 1	—	102 ± 8
2374.3/2374.5	723.7	2350p1	2 ± 1	—	—	—	—	14 ± 1	—	24 ± 2	60 ± 8	—	Trc.	1 ± 1	—	101 ± 8
2401.3/2402.5	732.3	2351p1	3 ± 1	—	—	—	—	12 ± 1	—	24 ± 2	62 ± 9	—	Trc.	2 ± 1	—	103 ± 9
2426.6/2426.8	739.7	2352p1	1 ± 1	—	—	—	—	16 ± 1	—	22 ± 2	59 ± 8	—	Trc.	1 ± 1	—	99 ± 8
2453.9/2454.1	748.0	2353p1	2 ± 1	—	—	—	—	13 ± 1	—	26 ± 2	58 ± 8	—	1 ± 1	1 ± 1	—	101 ± 8
2478.1/2478.5 ^a	755.4	2354p1	37 ± 11	17 ± 1	—	—	—	2 ± 1	—	6 ± 1	34 ± 5	—	1 ± 1	1 ± 1	Trc. ¹	98 ± 12
2478.1/2478.5	755.4	2354p2	5 ± 2	—	47 ± 15	—	—	—	—	11 ± 1	38 ± 14	—	—	Trc.	Trc. ¹	101 ± 21
2501.6/2501.9	762.6	2355p1	2 ± 1	49 ± 4	2 ± 1	—	—	—	19 ± 6	4 ± 1	26 ± 5	—	—	Trc.	Trc. ¹	102 ± 9
2524.7/2524.9	769.6	2356p1	2 ± 1	61 ± 5	4 ± 1	—	—	2 ± 1	—	3 ± 1	25 ± 6	—	—	1 ± 1	Trc. ¹	98 ± 8
2549.3/2549.5	777.1	2357p1	Trc.	57 ± 9	21 ± 6	—	—	—	—	3 ± 1	19 ± 6	—	—	1 ± 1	Trc. ¹	101 ± 12
2575.6/2575.9	785.1	2358p1	Trc.	55 ± 10	24 ± 7	—	—	4 ± 1	—	2 ± 1	15 ± 5	—	—	1 ± 1	—	101 ± 13
Pre-Tcb bedded tuff			786.2 - 792.8 m													
2595.8/2596.0	791.3	2359p1	5 ± 2	34 ± 5	14 ± 5	—	—	—	12 ± 4	10 ± 1	28 ± 7	—	—	1 ± 1	—	104 ± 11
Tram Tuff (Tct)			792.8 m - bottom													
2621.3/2621.7	799.1	2360p1	2 ± 1	43 ± 6	11 ± 3	—	—	—	20 ± 6	4 ± 1	21 ± 5	—	—	3 ± 1	—	104 ± 10
2649.8/2649.9	807.7	2361p1	2 ± 1	36 ± 5	12 ± 4	—	—	—	15 ± 5	7 ± 1	29 ± 7	—	—	3 ± 1	—	104 ± 11
2674.7/2675.0	815.3	2362p1	Trc.	43 ± 4	2 ± 1	—	—	—	20 ± 7	5 ± 1	30 ± 6	—	—	2 ± 1	—	102 ± 10
Bottom			815.3 m													

¹Hornblende

²Calcite

^aBreccia

Appendix IV. Quantitative XRD results for drill core USW SD-9.

Sample	Depth (m)	LANL #	Smect-ite	Clino-ptilolite	Morden-ite	Tridy-mite	Cristob-alite	Opal-CT	Quartz	Feld-spar	Glass	Hem-atite	Mica	Horn-blende	Total
Topopah Spring Tuff (Tpt) 77.9 - 446.3 m															
1364.0/1364.1	415.8	2469p1	Trc.	1 ± 1	-	3 ± 1	28 ± 2	-	11 ± 1	54 ± 8	-	-	Trc.	-	97 ± 8
1364.3/1364.4	415.9	2470p1	30 ± 9	17 ± 2	-	-	-	30 ± 9	1 ± 1	21 ± 3	1 ± 13	-	Trc.	Trc.	100 ± 13
1364.8/1365.2	416.1	2392p1	9 ± 3	3 ± 1	-	-	-	21 ± 5	1 ± 1	12 ± 2	54 ± 6	-	-	-	100 ± 6
1381.0/1381.3	421.0	2393p1	-	Trc.	-	-	-	6 ± 1	1 ± 1	5 ± 1	88 ± 1	-	Trc.	-	100 ± 2
1397.1/1397.2	425.9	2394p1	-	-	-	-	-	-	1 ± 1	3 ± 1	96 ± 1	-	Trc.	-	100 ± 1
1415.4/1415.5	431.4	2395p1	Trc.	-	-	-	-	5 ± 1	1 ± 1	4 ± 1	90 ± 1	-	-	-	100 ± 2
1421.5/1421.5	433.3	2396p1	Trc.	-	-	-	-	3 ± 1	1 ± 1	4 ± 1	92 ± 1	-	Trc.	-	100 ± 2
1425.5/1426.0	434.6	2397p1	5 ± 2	-	-	-	-	6 ± 1	1 ± 1	3 ± 1	85 ± 2	-	-	-	100 ± 3
1428.2/1428.4	435.4	2398p1	8 ± 2	-	-	-	-	9 ± 2	1 ± 1	4 ± 1	78 ± 3	-	Trc.	-	100 ± 3
1431.7/1431.9	436.4	1889p1	10 ± 3	3 ± 1	-	-	-	7 ± 2	1 ± 1	6 ± 1	73 ± 4	-	Trc.	-	100 ± 4
1434.4/1434.5	437.2	1890p1	1 ± 1	63 ± 5	-	-	-	18 ± 5	8 ± 1	14 ± 3	-	-	Trc.	-	104 ± 8
1440.1/1440.2	439.0	1891p1	3 ± 1	28 ± 2	-	-	-	8 ± 2	3 ± 1	4 ± 1	54 ± 3	-	Trc.	-	100 ± 3
1447.8/1448.0	441.4	1892p1	3 ± 1	4 ± 1	-	-	-	8 ± 2	3 ± 1	11 ± 2	71 ± 3	-	Trc.	-	100 ± 3
1457.2/1457.6	444.3	1893p1	1 ± 1	66 ± 5	1 ± 1	-	-	11 ± 3	3 ± 1	8 ± 2	10 ± 6	-	-	-	100 ± 6
1460.5/1460.8	445.3	1894p1	1 ± 1	73 ± 6	2 ± 1	-	-	19 ± 4	3 ± 1	7 ± 2	-	-	-	-	105 ± 8
Pre-Tpt bedded tuff 446.3 - 447.8 m															
1465.9/1466.1	446.9	1895p1	2 ± 1	80 ± 6	-	-	-	9 ± 2	3 ± 1	7 ± 2	-	-	-	-	101 ± 7
Calico Hills Formation (Ta) 447.8 - 539.2 m															
1486.3/1486.6	453.1	2238p1	Trc.	73 ± 6	1 ± 1	-	-	20 ± 5	3 ± 1	6 ± 1	-	-	Trc.	-	103 ± 8
1508.5/1508.8	459.9	2239p1	Trc.	68 ± 6	3 ± 1	-	-	16 ± 4	4 ± 1	10 ± 2	-	-	Trc.	-	101 ± 8
1527.1/1527.4	465.6	2240p1	8 ± 2	71 ± 6	-	-	-	19 ± 4	2 ± 1	5 ± 1	-	-	-	-	105 ± 8
1547.1/1547.4	471.6	2241p1	Trc.	66 ± 7	7 ± 2	-	-	18 ± 4	5 ± 1	9 ± 2	-	-	Trc.	-	105 ± 9
1566.9/1567.3	477.7	2242p1	Trc.	69 ± 8	7 ± 2	-	-	14 ± 4	4 ± 1	10 ± 2	-	-	Trc.	-	104 ± 9
1585.4/1585.6	483.3	2243p1	1 ± 1	58 ± 5	1 ± 1	-	-	16 ± 4	9 ± 1	15 ± 3	-	-	Trc.	-	100 ± 7
1605.0/1605.2	489.3	2244p1	1 ± 1	67 ± 8	11 ± 4	-	-	10 ± 2	4 ± 1	9 ± 2	-	-	Trc.	-	102 ± 9
1626.2/1626.3	495.7	2245p1	1 ± 1	71 ± 9	9 ± 3	-	-	15 ± 3	3 ± 1	5 ± 1	-	-	Trc.	-	104 ± 10
1647.9/1648.2	502.4	2246p1	Trc.	63 ± 12	23 ± 7	-	-	9 ± 2	3 ± 1	7 ± 2	-	-	Trc.	-	105 ± 14
1669.7/1669.9	509.0	2247p1	Trc.	63 ± 11	19 ± 5	-	-	13 ± 3	4 ± 1	5 ± 1	-	-	Trc.	-	104 ± 13
1689.8/1690.3	515.2	2248p1	Trc.	70 ± 9	12 ± 4	-	-	12 ± 3	3 ± 1	7 ± 2	-	-	Trc.	-	104 ± 11
1711.7/1711.9	521.8	2249p1	Trc.	70 ± 10	13 ± 4	-	-	13 ± 3	3 ± 1	5 ± 1	-	-	Trc.	-	104 ± 11
1729.6/1729.9	527.3	2250p1	Trc.	55 ± 9	16 ± 4	-	-	19 ± 5	4 ± 1	8 ± 2	-	-	Trc.	-	102 ± 11
1752.6/1753.0	534.3	2251p1	Trc.	43 ± 8	20 ± 5	-	-	16 ± 5	9 ± 1	17 ± 5	-	-	Trc.	-	105 ± 12

Sample	Depth (m)	LANL #	Smect-ite	Clin- ptilolite	Morden- ite	Tridy- mite	Cristob- alite	Opal- CT	Quartz	Feld- spar	Glass	Hem- atite	Mica	Horn- blende	Total
Pre-Ta bedded tuff		539.2 - 553.9 m													
1770.7/1770.9	539.8	2252p1	1 ± 1	48 ± 7	12 ± 4	—	—	16 ± 4	7 ± 1	14 ± 3	—	—	Trc.	—	98 ± 10
1777.8/1778.0	541.9	2253p1	Trc.	35 ± 4	6 ± 2	—	—	35 ± 10	10 ± 1	17 ± 3	—	—	1 ± 1	—	104 ± 11
1797.8/1798.1	548.1	2254p1	Trc.	50 ± 5	6 ± 2	—	—	5 ± 2	11 ± 1	28 ± 6	—	—	3 ± 1	—	103 ± 8
Prow Pass Tuff (Tcp)		553.9 m to bottom													
1821.1/1821.6	555.2	2255p1	8 ± 2	47 ± 4	—	—	—	33 ± 8	4 ± 1	11 ± 2	—	—	Trc.	—	103 ± 9
1840.4/1840.6	561.0	2256p1	2 ± 1	57 ± 5	—	—	—	26 ± 7	3 ± 1	15 ± 3	—	—	Trc.	—	103 ± 9
1864.6/1864.7	568.4	2257p1	—	Trc.	42 ± 8	—	—	40 ± 13	3 ± 1	24 ± 8	—	—	—	Trc.	109 ± 17
1866.2/1866.5	568.9	2258p1	6 ± 2	38 ± 7	20 ± 8	—	—	21 ± 6	3 ± 1	18 ± 5	—	—	—	—	106 ± 13
static water level		572.3 m													
1885.6/1886.0	574.9	2259p1	2 ± 1	—	—	—	3 ± 1	—	35 ± 2	57 ± 8	—	1 ± 1	Trc.	—	98 ± 8
1908.5/1908.8	581.8	2260p1	1 ± 1	—	—	—	3 ± 1	—	33 ± 2	59 ± 8	—	1 ± 1	Trc.	—	97 ± 8
1927.8/1928.3	587.7	2363p1	3 ± 1	—	—	—	8 ± 3	—	29 ± 2	62 ± 9	—	1 ± 1	1 ± 1	—	104 ± 10
1949.1/1949.4	594.2	2364p1	3 ± 1	—	—	—	7 ± 3	—	27 ± 2	64 ± 9	—	Trc.	Trc.	—	101 ± 10
1971.9/1972.2	601.1	2365p1	3 ± 1	—	—	—	18 ± 1	—	16 ± 1	63 ± 9	—	Trc.	Trc.	—	100 ± 9
1991.2/1991.4	607.0	2366p1	4 ± 1	—	—	—	29 ± 2	—	5 ± 1	58 ± 8	—	Trc.	Trc.	—	96 ± 8
1993.8/1994.0	607.8	2367p1	3 ± 1	—	—	—	32 ± 2	—	5 ± 1	57 ± 8	—	Trc.	Trc.	—	97 ± 8
2014.5/2015.1	614.2	2368p1	5 ± 2	31 ± 4	8 ± 3	—	—	35 ± 11	2 ± 1	23 ± 5	—	—	—	—	104 ± 13
2036.1/2036.5	620.7	2369p1	3 ± 1	42 ± 5	9 ± 3	—	—	21 ± 7	4 ± 1	26 ± 6	—	—	—	—	105 ± 11
2057.0/2057.3	627.1	2370p1	2 ± 1	48 ± 6	8 ± 3	—	—	21 ± 6	4 ± 1	19 ± 4	—	—	—	—	102 ± 10
2077.6/2078.0	633.4	2371p1	2 ± 1	57 ± 6	6 ± 2	—	—	15 ± 4	6 ± 1	18 ± 4	—	—	—	—	104 ± 9
2098.8/2099.0	639.8	2372p2	1 ± 1	47 ± 7	15 ± 4	—	—	22 ± 6	2 ± 1	14 ± 4	—	—	—	—	101 ± 11
2119.1/2119.3	646.0	2373p1	Trc.	43 ± 9	29 ± 8	—	—	14 ± 4	3 ± 1	17 ± 6	—	—	—	—	106 ± 14
2140.5/2140.9	652.5	2374p1	Trc.	56 ± 8	14 ± 4	—	—	14 ± 4	2 ± 1	16 ± 4	—	—	—	—	102 ± 11
2157.4/2157.6	657.6	2375p1	Trc.	50 ± 8	19 ± 6	—	—	12 ± 4	3 ± 1	20 ± 6	—	—	—	—	104 ± 12
2157.6/2157.7	657.7	2375p2	Trc.	48 ± 9	22 ± 6	—	—	26 ± 6	Trc.	4 ± 1	—	—	—	—	100 ± 12
2178.5/2179.0	664.2	2376p1	1 ± 1	49 ± 8	17 ± 5	—	—	16 ± 5	3 ± 1	18 ± 5	—	—	—	—	104 ± 12
2200.6/2201.3	671.0	2377p1	Trc.	43 ± 7	19 ± 5	—	—	19 ± 6	4 ± 1	20 ± 6	—	—	—	—	105 ± 12
2221.4/2222.0	677.3	2378p1	1 ± 1	62 ± 9	13 ± 4	—	—	17 ± 4	3 ± 1	9 ± 2	—	—	—	—	105 ± 11
bottom of hole		677.6 m													

Appendix V. Quantitative XRD results for drill core USW SD-12.

Sample	Depth (m)	LANL #	Smect-ite	Clino-ptilolite	Morden-ite	Tridy-mite	Cristob-alite	Opal-CT	Quartz	Feld-spar	Glass	Hem-atite	Mica	Other	Total
Topopah Spring Tuff (Tpt)			90.2 - 429.2 m												
320.2/320.5	97.7	2588p1	19 ± 6	2 ± 1 ¹	—	—	1 ± 1	—	2 ± 1	29 ± 4	46 ± 7	1 ± 1	Trc.	Trc. ^a	100 ± 7
324.9/325.3	99.2	2589p1	2 ± 1	—	—	—	Trc.	—	Trc.	14 ± 2	81 ± 2	2 ± 1	1 ± 1	—	100 ± 3
330.7/331.1	100.9	2590p1	Trc.	—	—	1 ± 1	15 ± 1	—	1 ± 1	41 ± 6	23 ± 6	Trc.	1 ± 1	18 ± 1 ^a	100 ± 6
331.1/332.5	101.3	2591p1	Trc.	—	—	4 ± 1	25 ± 2	—	5 ± 1	63 ± 9	—	1 ± 1	1 ± 1	—	99 ± 9
337.8/338.0	103.0	2592p1	1 ± 1	—	—	6 ± 1	15 ± 1	—	—	79 ± 11	—	2 ± 1	—	Trc. ^b	103 ± 11
356.7/357.0	108.8	2593p1	Trc.	—	—	5 ± 1	12 ± 1	—	—	74 ± 10	—	2 ± 1	1 ± 1	7 ± 1 ^a	101 ± 10
376.3/376.7	114.8	2594p1	Trc.	—	—	13 ± 1	9 ± 5	—	—	77 ± 11	—	1 ± 1	1 ± 1	—	101 ± 12
395.9/396.3	120.8	2595p1	—	—	—	14 ± 1	7 ± 3	—	Trc.	74 ± 10	—	1 ± 1	1 ± 1	Trc. ^b	97 ± 11
419.8/420.0	128.0	2596p1	2 ± 1	—	—	16 ± 2	10 ± 1	—	Trc.	74 ± 10	—	1 ± 1	Trc.	Trc. ^b	103 ± 10
443.3/443.8	135.3	2597p1	2 ± 1	—	—	24 ± 2	8 ± 4	—	1 ± 1	67 ± 9	—	1 ± 1	Trc.	—	103 ± 10
465.8/466.0	142.0	2598p1	4 ± 1	—	—	19 ± 2	13 ± 2	—	2 ± 1	61 ± 9	—	1 ± 1	Trc.	4 ± 1 ^a	104 ± 10
489.6/490.0	149.4	2599p1	4 ± 1	—	—	14 ± 1	21 ± 3	—	3 ± 1	55 ± 8	—	1 ± 1	Trc.	—	98 ± 9
517.4/517.8	157.8	2600p1	3 ± 1	—	—	9 ± 1	27 ± 3	—	1 ± 1	56 ± 8	—	1 ± 1	Trc.	—	97 ± 9
543.7/544.1	165.8	2601p1	4 ± 1	—	—	7 ± 1	30 ± 3	—	3 ± 1	55 ± 8	—	1 ± 1	Trc.	1 ± 1 ^a	101 ± 9
561.9/562.2	171.4	2602p1	5 ± 2	—	—	7 ± 1	28 ± 2	—	3 ± 1	54 ± 8	—	1 ± 1	Trc.	—	98 ± 9
580.7/580.8	177.0	2603p1	5 ± 2	—	—	6 ± 1	25 ± 2	—	9 ± 1	55 ± 8	—	1 ± 1	Trc.	—	101 ± 9
602.6/604.6	184.3	2604p1	4 ± 1	—	—	8 ± 1	23 ± 2	—	12 ± 1	55 ± 8	—	1 ± 1	Trc.	—	103 ± 8
629.7/630.1	192.1	2605p1	4 ± 1	—	—	5 ± 1	29 ± 2	—	6 ± 1	54 ± 8	—	Trc.	Trc.	—	98 ± 8
654.4/654.6	199.5	2606p1	3 ± 1	—	—	7 ± 1	19 ± 2	—	15 ± 1	56 ± 8	—	Trc.	Trc.	—	100 ± 8
679.5/679.9	207.2	2607p1	4 ± 1	—	—	2 ± 1	30 ± 2	—	8 ± 1	53 ± 7	—	—	Trc.	—	97 ± 7
706.0/706.1	215.2	2608p1	5 ± 2	—	—	4 ± 1	26 ± 2	—	11 ± 1	52 ± 7	—	—	Trc.	—	98 ± 8
733.0/733.3	223.5	2609p1	5 ± 2	—	—	3 ± 1	34 ± 2	—	5 ± 1	54 ± 8	—	Trc.	Trc.	1 ± 1 ^a	102 ± 9
759.8/760.1	231.7	2610p1	4 ± 1	—	—	4 ± 1	28 ± 2	—	9 ± 1	54 ± 8	—	Trc.	Trc.	—	99 ± 8
785.5/785.8	239.5	2611p1	3 ± 1	—	—	4 ± 1	34 ± 2	—	3 ± 1	54 ± 8	—	—	Trc.	—	98 ± 8
807.0/807.3	246.1	2012p1	4 ± 1	—	—	3 ± 1	27 ± 2	—	10 ± 1	53 ± 7	—	Trc.	Trc.	—	97 ± 7
831.4/831.7	253.5	2613p1	4 ± 1	—	—	3 ± 1	6 ± 2	—	33 ± 2	56 ± 8	—	Trc.	Trc.	—	102 ± 9
852.9/853.7	260.2	2614p1	4 ± 1	—	—	14 ± 1	16 ± 2	—	13 ± 1	55 ± 8	—	1 ± 1	Trc.	—	103 ± 8
881.1/881.5	268.7	2615p1	3 ± 1	—	—	3 ± 1	17 ± 1	—	23 ± 2	54 ± 8	—	Trc.	Trc.	—	100 ± 8
903.1/903.4	275.4	2616p1	5 ± 2	—	—	4 ± 1	25 ± 2	—	12 ± 1	54 ± 8	—	Trc.	Trc.	—	100 ± 9
929.9/930.2	283.5	2617p1	4 ± 1	—	—	7 ± 1	10 ± 1	—	24 ± 2	55 ± 8	—	Trc.	Trc.	—	100 ± 8
954.7/954.9	291.1	2618p1	3 ± 1	—	—	4 ± 1	22 ± 2	—	16 ± 1	54 ± 8	—	Trc.	Trc.	—	99 ± 8
979.7/980.0	298.7	2619p1	2 ± 1	—	—	3 ± 1	26 ± 2	—	11 ± 1	54 ± 8	—	1 ± 1	—	—	97 ± 8
1273.4/1273.45	388.1	2471p1	—	1 ± 1	—	2 ± 1	29 ± 2	—	7 ± 1	56 ± 8	—	1 ± 1	Trc.	1 ± 1 ^a	97 ± 9

Appendix V. Quantitative XRD results for drill core USW SD-12 (continued).

Sample	Depth (m)	LANL #	Smect-ite	Clino-ptilolite	Morden-ite	Tridy-mite	Cristob-alite	Opal-CT	Quartz	Feld-spar	Glass	Hem-atite	Mica	Other	Total
1309.3/1309.6	399.2	1866p1	Trc.	—	—	—	—	20 ± 5	1 ± 1	14 ± 2	65 ± 5	—	Trc.	—	100 ± 5
1319.0/1319.4	402.2	2472p1	Trc.	—	—	—	—	18 ± 5	1 ± 1	15 ± 2	66 ± 5	—	Trc.	—	100 ± 5
1320.6/1321.0	402.6	1867p1	Trc.	—	—	—	—	18 ± 5	1 ± 1	13 ± 2	68 ± 5	—	Trc.	—	100 ± 5
1333.2/1333.4	406.4	1868p1	2 ± 1	—	—	—	—	8 ± 2	1 ± 1	9 ± 1	80 ± 2	—	Trc.	—	100 ± 3
1342.1/1342.2	409.1	1869p1	Trc.	—	—	—	—	4 ± 1	1 ± 1	4 ± 1	91 ± 1	—	Trc.	—	100 ± 2
1351.9/1352.2	412.2	1870p1	Trc.	—	—	—	—	6 ± 1	1 ± 1	5 ± 1	88 ± 1	—	Trc.	—	100 ± 2
1361.9/1362.0	415.1	1871p1	—	—	—	—	—	3 ± 1	1 ± 1	4 ± 1	92 ± 1	—	Trc.	—	100 ± 2
1371.4/1371.5	418.0	1872p1	Trc.	—	—	—	—	2 ± 1	1 ± 1	4 ± 1	93 ± 1	—	Trc.	—	100 ± 2
1381.1/1381.3	421.0	1873p1	1 ± 1	2 ± 1	—	—	—	4 ± 1	1 ± 1	5 ± 1	87 ± 2	—	Trc.	—	100 ± 2
1388.0/1388.1	423.1	1874p1	Trc.	2 ± 1	—	—	—	5 ± 1	3 ± 1	8 ± 1	82 ± 2	—	Trc.	—	100 ± 2
1399.2/1399.3	426.5	1875p1	1 ± 1	3 ± 1	—	—	—	5 ± 1	5 ± 1	12 ± 2	74 ± 2	—	Trc.	—	100 ± 3
Pre-Tpt bedded tuff			429.2 - 430.0 m												
1408.0/1408.1	429.2	2708p1	8 ± 2	1 ± 1	—	—	—	3 ± 1	2 ± 1	9 ± 1	77 ± 2	Trc.	Trc.	—	100 ± 3
1410.5/1410.6	430.0	2709p1	2 ± 1	1 ± 1	—	—	—	3 ± 1	2 ± 1	7 ± 1	85 ± 2	Trc.	Trc.	Trc. ^b	100 ± 2
Calico Hills Formation (Ta)			430.0 - 487.5 m												
1439.9/1440.1	438.9	2261p1	—	1 ± 1	—	—	—	2 ± 1	2 ± 1	6 ± 1	89 ± 2	—	Trc.	—	100 ± 2
1458.7/1458.9	444.7	2262p1	Trc.	4 ± 1	—	—	—	2 ± 1	2 ± 1	5 ± 1	87 ± 2	—	Trc.	—	100 ± 2
1480.2/1480.5	451.3	2263p1	Trc.	4 ± 1	—	—	—	4 ± 1	4 ± 1	9 ± 1	79 ± 2	—	Trc.	—	100 ± 2
1500.8/1501.0	457.5	2264p1	1 ± 1	5 ± 1	—	—	—	4 ± 1	4 ± 1	7 ± 1	79 ± 2	—	Trc.	—	100 ± 2
1519.8/1520.1	463.3	2265p1	2 ± 1	5 ± 1	—	—	—	12 ± 3	6 ± 1	17 ± 2	58 ± 4	—	Trc.	—	100 ± 4
1540.9/1541.3	469.8	2266p1	2 ± 1	10 ± 1	—	—	—	9 ± 2	5 ± 1	10 ± 2	64 ± 3	—	Trc.	—	100 ± 3
1561.1/1561.3	475.9	2267p1	3 ± 1	3 ± 1	—	—	—	5 ± 1	3 ± 1	8 ± 1	78 ± 2	—	Trc.	—	100 ± 2
1581.3/1581.6	482.1	2268p1	2 ± 1	9 ± 1	—	—	—	5 ± 1	4 ± 1	7 ± 1	73 ± 2	—	Trc.	—	100 ± 2
Pre-Ta bedded tuff			487.5 - 502.4 m												
1600.0/1600.3	487.8	2269p1	4 ± 1	12 ± 1	—	—	—	5 ± 1	7 ± 1	10 ± 2	62 ± 2	—	Trc.	—	100 ± 3
1600.0/1600.3	487.8	2269p2	7 ± 2	51 ± 6	4 ± 2	—	—	30 ± 7	2 ± 1	8 ± 2	—	—	—	—	102 ± 10
1601.5/1601.8	488.2	2390p1	5 ± 2	68 ± 5	—	—	—	15 ± 3	4 ± 1	6 ± 1	—	—	—	—	98 ± 6
1609.9/1610.4	490.8	2391p1	3 ± 1	30 ± 2	—	—	—	7 ± 2	11 ± 1	11 ± 2	34 ± 3	—	Trc.	4 ± 1 ^c	100 ± 4
1620.4/1620.6	494.0	2270p1	4 ± 1	59 ± 5	—	—	—	18 ± 5	8 ± 1	14 ± 3	—	—	1 ± 1	1 ± 1 ^a	105 ± 8
1641.4/1641.7	500.4	2271p1	9 ± 3	14 ± 1	—	—	—	25 ± 11	8 ± 1	45 ± 7	—	—	1 ± 1	1 ± 1 ^a	103 ± 14
Prow Pass Tuff (Tcp)			502.4 - 653.8 m												
1656.3/1656.8	505.0	2272p1	7 ± 2	58 ± 5	—	—	—	23 ± 6	3 ± 1	13 ± 3	—	—	—	1 ± 1 ^a	105 ± 9
1680.7/1680.9	512.3	2273p1	2 ± 1	—	—	—	7 ± 2	—	35 ± 2	54 ± 8	—	2 ± 1	Trc.	—	100 ± 9

Appendix V. Quantitative XRD results for drill core USW SD-12 (continued).

Sample	Depth (m)	LANL #	Smect-ite	Clinoptilolite	Mordenite	Tridymite	Cristobalite	Opal-CT	Quartz	Feldspar	Glass	Hematite	Mica	Other	Total
1700.3/1700.6	518.3	2274p1	3 ± 1	—	—	2 ± 1	4 ± 1	—	34 ± 2	55 ± 8	—	1 ± 1	Trc.	—	99 ± 8
1720.1/1720.4	524.4	2275p1	2 ± 1	—	—	3 ± 1	2 ± 1	—	32 ± 2	56 ± 8	—	2 ± 1	Trc.	—	97 ± 8
1739.8/1740.2	530.4	2276p1	2 ± 1	—	—	3 ± 1	2 ± 1	—	32 ± 2	58 ± 8	—	1 ± 1	1 ± 1	—	99 ± 9
1760.0/1760.4	536.6	2277p1	3 ± 1	—	—	3 ± 1	2 ± 1	—	30 ± 2	60 ± 8	—	1 ± 1	Trc.	—	99 ± 8
1780.2/1780.4	542.7	2278p1	2 ± 1	—	—	—	10 ± 1	—	26 ± 2	60 ± 8	—	1 ± 1	Trc.	—	99 ± 8
1799.4/1800.0	548.6	2279p1	2 ± 1	—	—	3 ± 1	4 ± 1	—	31 ± 2	57 ± 8	—	1 ± 1	Trc.	—	98 ± 8
1821.2/1821.6	555.2	2280p1	Trc.	—	—	—	18 ± 1	—	21 ± 2	60 ± 8	—	1 ± 1	Trc.	—	100 ± 8
1840.6/1840.8	561.1	2281p1	5 ± 2	—	—	—	27 ± 2	—	9 ± 1	55 ± 8	—	2 ± 1	1 ± 1	—	99 ± 9
1860.0/1860.3	567.0	2282p1	2 ± 1	—	—	—	31 ± 2	—	5 ± 1	57 ± 8	—	1 ± 1	Trc.	—	96 ± 8
1874.4/1874.5	571.3	2283p1	6 ± 2	10 ± 1	5 ± 2	—	—	45 ± 17	4 ± 1	34 ± 6	—	—	—	Trc. ^b	104 ± 18
1891.6/1891.9	576.7	2284p1	5 ± 2	50 ± 6	10 ± 4	—	—	11 ± 3	6 ± 1	22 ± 5	—	—	—	—	104 ± 10
1911.8/1911.9	582.7	2285p1	5 ± 2	48 ± 5	4 ± 2	—	—	21 ± 6	5 ± 1	19 ± 4	—	—	—	—	102 ± 9
1929.7/1929.9	588.2	2286p1	3 ± 1	51 ± 6	6 ± 2	—	—	21 ± 6	4 ± 1	19 ± 4	—	—	—	Trc. ^b	104 ± 10
Static Water Level			593.8 m												
1950.0/1950.7	594.6	2287p1	3 ± 1	56 ± 6	5 ± 2	—	—	16 ± 5	4 ± 1	21 ± 5	—	—	—	Trc. ^b	105 ± 10
1972.1/1972.4	601.2	2379p1	2 ± 1	65 ± 5	—	—	—	15 ± 4	4 ± 1	19 ± 4	—	—	Trc.	—	105 ± 8
1990.7/1990.9	606.8	2380p1	3 ± 1	62 ± 5	2 ± 1	—	—	18 ± 5	4 ± 1	13 ± 3	—	—	—	—	102 ± 8
2010.6/2010.9	612.9	2381p1	1 ± 1	69 ± 6	3 ± 1	—	—	14 ± 4	2 ± 1	15 ± 3	—	—	—	—	104 ± 8
2029.3/2029.5	618.6	2382p1	2 ± 1	34 ± 8	30 ± 9	—	—	15 ± 5	3 ± 1	20 ± 6	—	—	—	—	104 ± 14
2050.7/2051.1	625.2	2383p1	2 ± 1	38 ± 8	28 ± 9	—	—	16 ± 5	2 ± 1	19 ± 6	—	—	—	—	105 ± 14
2072.1/2072.4	631.7	2384p1	2 ± 1	44 ± 9	25 ± 8	—	—	15 ± 4	1 ± 1	16 ± 5	—	—	—	—	103 ± 14
2092.7/2093.0	637.9	2385p1	2 ± 1	53 ± 8	16 ± 5	—	—	14 ± 4	1 ± 1	16 ± 4	—	—	—	—	102 ± 11
2120.2/2120.4	646.3	2386p1	2 ± 1	53 ± 9	20 ± 6	—	—	11 ± 3	3 ± 1	13 ± 4	—	—	—	—	102 ± 12
2142.6/2142.8	653.1	2387p1	1 ± 1	52 ± 8	16 ± 5	—	—	11 ± 3	2 ± 1	21 ± 6	—	—	—	—	103 ± 12
Bull Frog Tuff (Tcb)			653.8 m to Bottom												
2148.6/2148.9	655.0	2388p1	2 ± 1	—	—	—	13 ± 1	—	26 ± 2	56 ± 8	—	1 ± 1	—	—	98 ± 8
2163.0/2163.4	659.4	2389p1	—	—	—	—	6 ± 2	—	33 ± 2	59 ± 8	—	1 ± 1	1 ± 1	—	100 ± 9
bottom of hole			660.3 m												

¹ Zeolite, exact species uncertain but believed to be clinoptilolite.

^a Calcite.

^B Hornblende.

^C Chabazite.

100

Appendix VI. Quantitative XRD results for drill core USW UZ#14.

Sample	Depth (m)	LANL #	Smect-ite	Clino- ptilolite	Steller- ite	Erion- ite	Tridy- mite	Cristob- alite	Opal- CT	Quartz	Feld- spar	Glass	Hem- atite	Mica	Other	Total
Alluvium			0-12.2 m													
13.8/14.2	4.3	#1441p2	Trc.	-	-	-	22 ± 2	5 ± 3	-	-	73 ± 10	-	1 ± 1	Trc.	Trc. ¹	101 ± 11
31.9/32.2	9.8	#1442p1	2 ± 1	-	-	-	2 ± 1	34 ± 2	-	-	57 ± 8	-	Trc.	-	1 ± 1 ²	96 ± 8
Yucca Mountain Tuff			12.2-31.1 m													
48.9/49.2	15.0	#1443p2	Trc.	-	-	-	7 ± 1	30 ± 3	-	1 ± 1	60 ± 8	-	-	Trc.	-	98 ± 9
49.5/49.8	15.2	#1444p1	Trc.	-	-	-	7 ± 1	29 ± 2	-	Trc.	59 ± 8	-	-	Trc.	-	95 ± 8
54.9/55.4	16.9	#1445p1	Trc.	-	-	-	5 ± 1	32 ± 2	-	-	58 ± 8	-	-	-	-	95 ± 8
62.0/62.5	19.1	#1446p1	Trc.	-	-	-	2 ± 1	34 ± 2	-	1 ± 1	58 ± 8	-	-	-	-	95 ± 8
71.0/71.4	21.8	#1447p1	21 ± 6	-	-	-	-	-	-	Trc.	1 ± 1	78 ± 6	-	-	-	100 ± 6
76.3/76.7	23.4	#1448p1	18 ± 5	-	-	-	-	-	-	Trc.	Trc.	82 ± 5	-	-	-	100 ± 5
81.4/81.7	24.9	#1449p1	10 ± 3	-	-	-	-	1 ± 1	-	Trc.	10 ± 1	79 ± 3	-	-	-	100 ± 3
83.9/84.1	25.6	#1450p1	11 ± 3	-	-	-	-	1 ± 1	-	1 ± 1	8 ± 1	79 ± 3	-	-	-	100 ± 3
89.1/89.3	27.2	#1451p1	14 ± 4	1 ± 1	-	-	-	1 ± 1	-	1 ± 1	10 ± 1	73 ± 4	-	-	Trc. ¹	100 ± 4
92.5/92.6	28.2	#1452p1	22 ± 7	Trc.	-	-	1 ± 1	1 ± 1	-	5 ± 1	14 ± 2	57 ± 7	Trc.	-	-	100 ± 7
98.9/99.2	30.2	#1453p1	17 ± 5	-	-	-	-	1 ± 1	-	1 ± 1	19 ± 3	62 ± 6	-	Trc.	-	100 ± 6
101.6/102.0	31.1	#1454p1	28 ± 8	-	-	-	-	1 ± 1	-	Trc.	16 ± 2	54 ± 8	-	1 ± 1	-	100 ± 8
Pah Canyon Tuff			31.1-78.8 m													
104.4/104.6	31.9	#1455p1	21 ± 6	-	-	-	-	Trc.	-	Trc.	13 ± 2	66 ± 6	-	Trc.	-	100 ± 6
124.3/124.6	38.0	#1456p1	13 ± 4	-	-	-	-	1 ± 1	-	1 ± 1	16 ± 2	67 ± 4	1 ± 1	1 ± 1	-	100 ± 5
150.3/150.5	45.9	#1457p1	11 ± 3	-	-	-	-	Trc.	-	1 ± 1	17 ± 2	69 ± 4	1 ± 1	1 ± 1	-	100 ± 4
164.0/164.4	50.1	#1458p1	7 ± 2	-	-	-	-	1 ± 1	-	1 ± 1	16 ± 2	74 ± 3	-	1 ± 1	-	100 ± 3
183.9/184.0	56.1	#1459p1	5 ± 2	-	-	-	-	1 ± 1	-	2 ± 1	20 ± 3	71 ± 4	-	1 ± 1	-	100 ± 4
204.2/204.4	62.3	#1460p1	11 ± 3	-	-	-	-	1 ± 1	-	1 ± 1	17 ± 2	69 ± 4	-	1 ± 1	-	100 ± 4
224.2/224.5	68.4	#1461p1	11 ± 3	-	-	-	-	1 ± 1	-	1 ± 1	16 ± 2	70 ± 4	-	1 ± 1	-	100 ± 4
227.7/228.0	69.5	#1462p1	13 ± 4	-	-	-	-	2 ± 1	-	1 ± 1	17 ± 2	65 ± 4	-	2 ± 1	-	100 ± 5
239.1/239.4	73.0	#1463p1	17 ± 5	-	-	-	-	1 ± 1	-	1 ± 1	11 ± 2	70 ± 5	-	Trc.	-	100 ± 6
241.4/241.7	73.7	#1464p1	19 ± 6	-	-	-	-	1 ± 1	-	3 ± 1	20 ± 3	54 ± 6	-	3 ± 1	-	100 ± 7

Appendix VI. Quantitative XRD results for drill core USW UZ#14 (continued).

Sample	Depth (m)	LANL #	Smectite	Clinoptilolite	Stellerite	Erionite	Tridymite	Cristobalite	Opal-CT	Quartz	Feldspar	Glass	Hematite	Mica	Other	Total
Topopah Spring Tuff			78.8-428.0 m													
261.6/262.0	79.9	#1465p1	10 ± 3	1 ± 1 ^a	—	—	—	1 ± 1	—	1 ± 1	17 ± 2	68 ± 4	—	2 ± 1	—	100 ± 4
278.3/278.5	84.9	#1466p1	19 ± 6	—	—	—	—	1 ± 1	—	1 ± 1	17 ± 2	58 ± 6	1 ± 1	3 ± 1	—	100 ± 7
279.7/280.7	85.6	#1467p1	12 ± 4	—	—	—	—	1 ± 1	—	1 ± 1	12 ± 2	73 ± 4	Trc.	1 ± 1	—	100 ± 5
282.5/282.8	86.2	#1468p1	Trc.	—	—	—	—	1 ± 1	—	—	15 ± 2	81 ± 2	2 ± 1	1 ± 1	—	100 ± 3
286.4/286.7	87.4	#1470p1	Trc.	Trc. ^a	—	—	4 ± 1	18 ± 1	—	1 ± 1	72 ± 10	—	Trc.	1 ± 1	—	96 ± 10
293.7/293.9	89.6	#1471p1	—	—	—	—	6 ± 1	19 ± 2	—	—	71 ± 10	—	1 ± 1	1 ± 1	—	98 ± 10
302.6/303.0	92.4	#1472p1	Trc.	—	—	—	7 ± 1	20 ± 2	—	Trc.	70 ± 10	—	1 ± 1	Trc.	—	98 ± 10
311.9/312.2	95.2	#1473p1	1 ± 1	—	—	—	13 ± 1	15 ± 2	—	1 ± 1	68 ± 10	—	1 ± 1	1 ± 1	—	100 ± 10
330.7/331.0	100.9	#1474p1	—	—	—	—	6 ± 1	16 ± 1	—	Trc.	74 ± 10	—	1 ± 1	1 ± 1	—	98 ± 10
349.5/349.8	106.6	#1475p1	Trc.	—	—	—	10 ± 1	11 ± 1	—	—	74 ± 10	—	1 ± 1	1 ± 1	—	97 ± 10
374.5/374.9	114.3	#1476p1	1 ± 1	—	—	—	9 ± 1	12 ± 1	—	Trc.	75 ± 11	—	2 ± 1	1 ± 1	—	100 ± 11
398.4/398.6	121.5	#1477p1	2 ± 1	—	2 ± 1 ^b	—	11 ± 1	11 ± 1	—	—	71 ± 10	—	1 ± 1	Trc.	—	98 ± 10
407.8/408.1	124.4	#1478p1	2 ± 1	—	1 ± 1 ^b	—	10 ± 1	13 ± 1	—	—	71 ± 10	—	1 ± 1	1 ± 1	—	99 ± 10
424.4/424.7	129.4	#1479p1	4 ± 1	—	Trc. ^b	—	11 ± 1	12 ± 1	—	Trc.	70 ± 10	—	1 ± 1	Trc.	—	98 ± 10
439.4/440.0	134.1	#1480p1	4 ± 1	—	—	—	20 ± 2	13 ± 2	—	1 ± 1	63 ± 9	—	Trc.	Trc.	—	101 ± 10
464.6/465.6	141.9	#1481p1	4 ± 1	—	—	—	14 ± 1	19 ± 2	—	3 ± 1	58 ± 8	—	1 ± 1	Trc.	—	99 ± 8
488.9/489.3	149.1	#1482p1	4 ± 1	—	—	—	6 ± 1	29 ± 2	—	3 ± 1	54 ± 8	—	1 ± 1	Trc.	—	97 ± 8
514.6/515.1	157.0	#1483p1	3 ± 1	—	1 ± 1 ^b	—	16 ± 2	20 ± 3	—	5 ± 1	55 ± 8	—	1 ± 1	Trc.	—	101 ± 9
537.4/537.9	164.0	#1484p1	3 ± 1	—	2 ± 1 ^b	—	6 ± 1	32 ± 3	—	3 ± 1	55 ± 8	—	1 ± 1	—	—	102 ± 9
560.8/561.3	171.1	#1485p1	3 ± 1	—	2 ± 1 ^b	—	7 ± 1	31 ± 3	—	3 ± 1	51 ± 7	—	1 ± 1	—	—	98 ± 8
582.6/583.6	177.9	#1486p1	4 ± 1	—	1 ± 1 ^b	—	8 ± 1	29 ± 3	—	2 ± 1	50 ± 7	—	1 ± 1	Trc.	—	95 ± 8
609.9/610.4	186.0	#1489p1	4 ± 1	—	1 ± 1 ^b	—	7 ± 1	28 ± 2	—	5 ± 1	53 ± 7	—	1 ± 1	—	—	99 ± 8
635.5/636.2	193.9	#1489p2	7 ± 2	—	5 ± 1	—	18 ± 2	19 ± 3	—	6 ± 1	42 ± 6	—	1 ± 1	Trc.	—	98 ± 7
656.3/656.9	200.2	#1490p1	2 ± 1	—	—	—	10 ± 1	17 ± 2	—	15 ± 1	54 ± 8	—	1 ± 1	—	—	99 ± 8
675.1/675.7	206.0	#1491p1	3 ± 1	—	—	—	5 ± 1	31 ± 2	—	5 ± 1	54 ± 8	—	1 ± 1	—	—	99 ± 8
695.6/696.0	212.1	#1493p1	5 ± 2	—	—	—	6 ± 1	32 ± 3	—	2 ± 1	52 ± 7	—	1 ± 1	—	—	98 ± 8
717.3/717.6	218.7	#1494p1	3 ± 1	—	—	—	5 ± 1	32 ± 2	—	4 ± 1	52 ± 7	—	1 ± 1	—	—	97 ± 8
738.0/738.5	225.1	#1497p1	3 ± 1	—	—	—	3 ± 1	29 ± 2	—	9 ± 1	53 ± 7	—	—	Trc.	—	97 ± 7
758.2/758.3	231.1	#1489p1	5 ± 2	—	—	—	4 ± 1	31 ± 2	—	5 ± 1	55 ± 8	—	Trc.	Trc.	—	100 ± 9
777.8/778.3	237.2	#1499p1	3 ± 1	—	—	—	4 ± 1	20 ± 2	—	16 ± 1	55 ± 8	—	1 ± 1	—	—	99 ± 8

Appendix VI. Quantitative XRD results for drill core USW UZ#14 (continued).

Sample	Depth (m)	LANL #	Smect-ite	Clino- ptilolite	Steller- ite	Erion- ite	Tridy- mite	Cristob- alite	Opal- CT	Quartz	Feld- spar	Glass	Hem- atite	Mica	Other	Total
797.4/797.8	243.2	#1500p1	4 ± 1	—	—	—	4 ± 1	33 ± 2	—	7 ± 1	54 ± 8	—	1 ± 1	Trc.	—	103 ± 8
817.7/818.0	249.3	#1501p1	5 ± 2	—	—	—	5 ± 1	32 ± 2	—	5 ± 1	50 ± 7	—	Trc.	Trc.	—	97 ± 8
837.7/838.1	255.5	#1502p1	3 ± 1	—	—	—	15 ± 2	16 ± 2	—	11 ± 1	51 ± 7	—	1 ± 1	Trc.	—	97 ± 8
860.2/860.5	262.3	#1503p1	4 ± 1	—	—	—	4 ± 1	11 ± 1	—	24 ± 2	59 ± 8	—	Trc.	Trc.	—	102 ± 8
881.5/881.8	268.8	#1504p1	4 ± 1	—	—	—	4 ± 1	13 ± 1	—	26 ± 2	53 ± 7	—	1 ± 1	Trc.	—	101 ± 8
902.0/902.8	275.2	#1505p1	2 ± 1	—	—	—	5 ± 1	23 ± 2	—	15 ± 1	56 ± 8	—	1 ± 1	Trc.	—	102 ± 8
923.8/924.4	281.8	#1506p1	3 ± 1	—	—	—	4 ± 1	15 ± 1	—	22 ± 2	58 ± 8	—	1 ± 1	Trc.	—	103 ± 8
945.4/945.5	288.2	#1507p1	3 ± 1	—	1 ± 1	—	7 ± 1	20 ± 2	—	14 ± 1	56 ± 8	—	1 ± 1	Trc.	—	102 ± 9
967.4/967.6	294.9	#1508p1	3 ± 1	—	—	—	3 ± 1	20 ± 2	—	19 ± 1	55 ± 8	—	Trc.	Trc.	—	100 ± 8
986.4/986.7	300.7	#1509p1	2 ± 1	—	1 ± 1	—	6 ± 1	27 ± 2	—	7 ± 1	53 ± 7	—	1 ± 1	Trc.	—	97 ± 8
1010.6/1011.1	308.2	#1510p1	4 ± 1	—	—	—	3 ± 1	27 ± 2	—	11 ± 1	52 ± 7	—	1 ± 1	Trc.	—	98 ± 8
1027.0/1027.2	313.1	#1511p1	3 ± 1	—	—	—	6 ± 1	20 ± 2	—	13 ± 1	53 ± 7	—	1 ± 1	Trc.	—	96 ± 8
1046.7/1047.0	319.1	#1512p1	3 ± 1	—	—	—	3 ± 1	31 ± 2	—	7 ± 1	53 ± 7	—	Trc.	Trc.	—	97 ± 7
1070.3/1070.9	326.4	#1513p1	3 ± 1	1 ± 1 ^a	—	—	6 ± 1	15 ± 1	—	22 ± 2	51 ± 7	—	1 ± 1	Trc.	—	99 ± 8
1091.1/1091.6	332.7	#1515p1	3 ± 1	—	—	—	3 ± 1	23 ± 2	—	14 ± 1	54 ± 8	—	1 ± 1	Trc.	—	98 ± 8
1113.3/1113.7	339.5	#1516p1	2 ± 1	—	—	—	5 ± 1	27 ± 2	—	9 ± 1	54 ± 8	—	1 ± 1	—	—	98 ± 8
1133.7/1134.1	345.7	#1517p1	3 ± 1	—	—	—	9 ± 1	18 ± 2	—	15 ± 1	54 ± 8	—	1 ± 1	Trc.	—	100 ± 8
1154.9/1155.3	352.1	#1518p1	4 ± 1	—	—	—	4 ± 1	16 ± 1	—	22 ± 2	57 ± 8	—	Trc.	Trc.	—	103 ± 8
1175.6/1175.7	358.4	#2008p1	7 ± 2	—	—	—	5 ± 1	24 ± 2	—	14 ± 1	52 ± 7	—	1 ± 1	Trc.	—	103 ± 8
1195.2/1195.3	364.3	#2009p1	9 ± 3	—	—	—	4 ± 1	22 ± 2	—	15 ± 1	49 ± 7	—	1 ± 1	Trc.	—	100 ± 8
1215.8/1216.0	370.6	#2010p1	4 ± 1	—	5 ± 1	—	2 ± 1	21 ± 2	—	17 ± 1	52 ± 7	—	1 ± 1	Trc.	—	102 ± 8
1234.8/1235.0	376.4	#2011p1	4 ± 1	—	6 ± 1	—	2 ± 1	22 ± 2	—	17 ± 1	51 ± 7	—	Trc.	Trc.	—	102 ± 8
1254.6/1254.7	382.4	#2012p1	4 ± 1	—	3 ± 1	—	3 ± 1	23 ± 2	—	14 ± 1	48 ± 7	—	1 ± 1	Trc.	—	96 ± 8
1264.6/1264.7	385.5	#2013p1	3 ± 1	2 ± 1	13 ± 3	—	1 ± 1	22 ± 2	—	13 ± 1	46 ± 6	—	—	Trc.	—	100 ± 7
1277.4/1277.7	389.4	I. Yang	15 ± 5	58 ± 5	—	—	—	—	20 ± 5	1 ± 1	6 ± 1	—	—	Trc.	—	100 ± 9
1298.6/1299.1	396.0	#1876p1	50 ± 15	32 ± 2	—	—	—	—	9 ± 2	2 ± 1	7 ± 1	—	—	Trc.	—	100 ± 15
1358.6/1358.8	414.2	#1714p1	4 ± 1	3 ± 1	—	—	—	—	1 ± 1	1 ± 1	3 ± 1	88 ± 2	—	Trc.	—	100 ± 2
1361.8/1361.9	415.1	#1877p1	8 ± 2	4 ± 1	—	2 ± 1	—	4 ± 1	—	5 ± 1	13 ± 2	64 ± 3	—	Trc.	—	100 ± 3
1362.6/1363.0	415.4	#1878p1	22 ± 7	10 ± 1	—	17 ± 3	—	—	—	1 ± 1	6 ± 1	44 ± 7	—	—	—	100 ± 8
1364.4/1364.6	415.9	#1715p1	9 ± 3	23 ± 2	—	34 ± 7	—	—	—	1 ± 1	12 ± 2	21 ± 8	—	Trc.	—	100 ± 8

Appendix VI. Quantitative XRD results for drill core USW UZ#14 (continued).

Sample	Depth (m)	LANL #	Smect-ite	Clinoptilolite	Stellerite	Erionite	Tridymite	Cristobalite	Opal-CT	Quartz	Feldspar	Glass	Hematite	Mica	Other	Total
1365.8/1366.0	416.4	#1716p1	5 ± 2	37 ± 3	—	17 ± 3	—	—	17 ± 4	4 ± 1	8 ± 1	12 ± 6	—	Trc.	—	100 ± 6
1370.1/1370.3	417.7	#1717p1	11 ± 3	23 ± 2	—	5 ± 1	—	—	10 ± 2	1 ± 1	8 ± 1	42 ± 4	—	—	—	100 ± 4
1370.3/1370.7	417.8	#1657p1	17 ± 5	14 ± 1	—	7 ± 1	—	—	3 ± 1	1 ± 1	4 ± 1	54 ± 5	—	Trc.	—	100 ± 5
1371.8/1372.0	418.2	#1718p1	14 ± 4	7 ± 1	—	2 ± 1	—	—	4 ± 1	1 ± 1	3 ± 1	69 ± 4	—	—	—	100 ± 5
1372.7/1372.9	418.5	#1879p1	8 ± 2	19 ± 1	—	Trc.	—	—	6 ± 1	1 ± 1	4 ± 1	62 ± 2	—	Trc.	—	100 ± 3
1375.2/1375.4	419.2	#1720p1	5 ± 2	8 ± 1	—	—	—	—	3 ± 1	1 ± 1	4 ± 1	79 ± 2	—	Trc.	—	100 ± 3
1387.0/1387.2	422.8	#1726p1	3 ± 1	14 ± 1	—	—	—	—	3 ± 1	Trc.	4 ± 1	76 ± 2	—	Trc.	—	100 ± 2
1398.5/1398.7	426.3	#1732p1	1 ± 1	77 ± 6	—	—	—	—	12 ± 3	3 ± 1	9 ± 2	—	—	Trc.	1 ± 1 ³	103 ± 7
Calico Hills Formation			428.0-533.4 m													
1414.9/1415.1	431.3	#1739p1	2 ± 1	66 ± 5	—	—	—	—	14 ± 4	5 ± 1	11 ± 2	—	—	Trc.	1 ± 1 ³	99 ± 7
1417.6/1417.8	432.1	#1746p1	2 ± 1	65 ± 5	—	—	—	—	13 ± 3	6 ± 1	12 ± 3	—	—	Trc.	1 ± 1 ³	99 ± 7
Prow Pass Tuff			533.4-631.5 m													
Static Water Level			597.4 m													
Bullfrog Tuff			631.5 m to Bottom													
Bottom of Drill Hole			672.7 m													

^aZeolite, exact species uncertain but believed to be clinoptilolite.

^bZeolite, exact species uncertain but believed to be stellerite, possibly with clinoptilolite.

¹Hornblende

²Calcite

³Mordenite

10/10/80

Appendix VII. Quantitative XRD results for USW H-3 drill cuttings (new data in bold type).

Sample ^a	Depth (m)	Smectite	Mica	Clino- ptilolite	Morden- ite	Tridy- mite	Quartz	Cristob- alite*	Alkali Feldspar	Glass	Hematite	Horn- blende	Calcite
Topopah Spring Tuff		123.1-424.3 m											
470-480	143.3-146.3	-	2 ± 1	-	-	13 ± 6	-	8 ± 3	77 ± 10	-	1 ± 1	-	-
520-530	158.5-161.5	-	-	-	-	Tr.	-	24 ± 5	76 ± 10	-	-	-	-
540-550	164.6-167.6	-	Tr.	-	-	21 ± 4	-	5 ± 3	73 ± 10	-	1 ± 1	-	-
610-620	185.9-189.0	-	-	-	-	Tr.	-	29 ± 5	71 ± 10	-	1 ± 1	-	-
740-750	225.6-228.6	~1	~1	-	-	-	4 ± 2	26 ± 5	68 ± 10	-	-	-	-
800-810	243.8-246.9	2 ± 1	~1	-	-	Tr.	2 ± 1	27 ± 5	69 ± 10	-	-	-	-
870-880	265.2-268.2	~1	Tr.	-	-	-	29 ± 4	3 ± 2	66 ± 10	-	-	-	-
930-940	283.5-286.5	~1	~1	-	-	-	14 ± 3	16 ± 4	69 ± 10	-	1 ± 1	-	-
990-1000	301.8-304.8	~1	-	-	-	4 ± 2	Tr.	23 ± 5	72 ± 10	-	-	-	-
1030-1040	313.9-317.0	~1	-	-	-	Tr.	3 ± 1	24 ± 5	72 ± 10	-	1 ± 1	-	-
1100-1110	335.3-338.3	~1	-	-	-	Tr.	2 ± 1	23 ± 5	74 ± 10	-	1 ± 1	-	-
1160-1170	353.6-356.6	~1	~1	-	-	-	2 ± 1	29 ± 5	67 ± 10	-	-	-	-
1270-1280	387.1-390.1	-	2 ± 1	-	-	-	2 ± 1	7 ± 4	19 ± 10	70 ± 20	-	-	-
1320-1330	402.3-405.4	-	-	-	-	-	2 ± 1	5 ± 3	23 ± 10	70 ± 20	-	-	-
1360-1370	414.5-417.6	Tr.	Tr.	-	-	-	Tr.	Tr.	3 ± 1	97 ± 1	-	-	-
Calico Hills Formation and pre-Ta bedded tuffs		424.3-453.2 m											
1440-1450	438.9-442.0	3 ± 1	Tr.	-	-	-	Tr.	5 ± 1	11 ± 1	81 ± 2	-	-	-
1480-1490	451.1-454.2	5 ± 2	5 ± 2	1 ± 1	-	-	3 ± 1	1 ± 1	47 ± 7	34 ± 8	-	1 ± 1	3 ± 1
Prow Pass Tuff		453.2-581.3 m											
1500-1510	457.2-460.2	2 ± 1	Tr.	1 ± 1	-	4 ± 1	12 ± 1	20 ± 2	50 ± 7	10 ± 8	1 ± 1	-	-
1550(SW)	472.4	Tr.	1 ± 1	2 ± 3	-	7 ± 3	10 ± 5	7 ± 3	70 ± 10	-	-	-	-
1655(SW)	504.5	Tr.	1 ± 1	2 ± 3	-	7 ± 3	7 ± 3	7 ± 3	75 ± 10	-	-	-	-
1700(SW)	518.2	Tr.	1 ± 1	2 ± 3	-	-	10 ± 5	15 ± 5	60 ± 10	15 ± 5	-	-	-
1800(SW)	548.6	2 ± 3	1 ± 1	60 ± 10	-	-	7 ± 3	-	30 ± 10	-	-	-	-
1900(SW)	579.1	7 ± 3	1 ± 1	75 ± 5	-	2 ± 3	2 ± 3	2 ± 3	15 ± 5	-	-	-	-
Bullfrog Tuff		581.3-755.1 m											
2400(SW)	731.5	-	1 ± 1	75 ± 5	-	-	2 ± 3	2 ± 3	15 ± 5	-	-	1 ± 1	-
2440(SW)	743.7	-	1 ± 1	35 ± 5	30 ± 10	-	2 ± 3	2 ± 3	30 ± 10	-	-	-	-
static water level		750.9 m											
Tram Tuff		755.1-1108.6 m											
2490(SW)	759.0	2 ± 3	1 ± 1	45 ± 5	25 ± 5	-	2 ± 3	-	20 ± 10	-	-	-	-

^a Sample numbers represent depth of sample in feet. SW = sidewall core sample from Levy (1984).

*Opal-CT present in zeolitic tuff is reported as cristobalite.

Appendix VIIIa. Major element XRF results (wt%) for drill hole USW SD-7 samples.

Sample	Depth (m)	LANL #	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Total
1278.6/1278.9	389.8	2030p1	75.24	0.097	12.35	0.96	0.069	nd	0.54	3.61	4.58	nd	2.84	100.37
1321.5/1321.6	402.8	2032p1	75.10	0.096	12.25	0.96	0.075	nd	0.52	3.51	4.89	nd	2.97	100.47
1350.5/1350.7	411.7	2034p1	71.55	0.098	11.82	0.94	0.065	nd	3.29	3.40	4.52	nd	4.33	100.08
1421.1/1421.3	433.2	2297p1	74.79	0.097	12.32	1.00	0.092	nd	0.57	3.35	4.69	nd	3.44	100.43
1467.4/1457.5	444.2	2299p1	74.37	0.094	12.13	0.99	0.061	nd	0.72	3.03	4.81	nd	3.68	99.96
1471.5/1471.8	448.6	2300p1	74.33	0.094	12.34	1.00	0.063	nd	0.83	3.03	4.67	nd	4.00	100.42
1493.2/1493.6	455.2	2301p1	69.22	0.111	14.08	1.20	0.065	nd	2.04	2.02	3.67	nd	7.71	100.30
1493.2/1493.6b	455.2	2301p2	73.40	0.087	10.62	0.88	0.052	nd	2.51	1.80	2.75	0.011	8.14	100.32
1513.9/1514.2	461.5	2302p1	72.76	0.095	12.16	1.00	0.062	nd	1.34	2.45	4.29	nd	6.09	100.34
1517.3/1517.6	462.6	2303p1	71.43	0.212	13.30	1.79	0.076	0.35	1.34	2.61	4.42	0.031	4.67	100.33
1519.1/1519.3	463.1	2304p1	70.94	0.070	10.56	0.80	0.050	0.18	2.98	1.18	2.38	nd	10.87	100.11
1538.5/1538.6	469.0	2305p1	72.74	0.075	11.79	0.88	0.052	0.16	1.53	2.04	4.02	nd	6.86	100.31
1560.1/1560.5	475.6	2306p1	71.13	0.072	11.96	0.88	0.050	0.27	2.09	1.61	3.47	nd	8.78	100.47
1567.1/1567.3	477.7	2307p1	69.35	0.109	11.55	1.09	0.034	0.47	3.01	0.92	2.47	nd	10.97	100.14
1567.1/1567.3b	477.7	2307p2	74.01	0.057	9.96	0.66	0.029	0.28	2.31	1.08	2.44	nd	9.05	100.04
1581.2/1581.5	482.0	2308p1	66.67	0.150	12.93	1.31	0.046	0.38	3.10	1.42	3.36	0.018	10.67	100.18
1581.2/1581.8b	482.0	2308p2	76.19	0.066	8.56	0.67	0.028	0.14	2.20	0.92	2.44	nd	8.74	100.04
1601.5/1601.8	488.2	2310p1	70.71	0.181	12.28	1.55	0.047	0.52	2.78	1.88	2.87	0.032	7.38	100.38
1622.6/1622.9	494.7	2312p1	70.63	0.137	12.00	1.40	0.061	0.54	2.35	1.40	3.00	0.025	8.67	100.34
1636.5/1636.8	498.9	2313p1	72.46	0.096	11.55	1.14	0.048	0.40	1.95	1.36	3.11	nd	7.97	100.19
1647.7/1647.9	502.3	2314p1	78.62	0.091	11.12	1.14	0.066	nd	0.39	2.65	5.36	nd	0.75	100.26
1688.2/1688.4	514.6	2316p1	75.91	0.112	12.82	1.32	0.079	nd	0.51	3.52	5.26	0.011	0.68	100.32
1741.0/1741.3	530.7	2318p1	74.96	0.117	13.15	1.37	0.079	nd	0.59	3.84	4.73	0.012	0.71	99.65
1796.7/1797.0	547.7	2321p1	75.28	0.113	13.18	1.33	0.051	nd	0.56	3.99	4.72	0.010	0.73	100.06
1843.4/1843.7	562.0	2323p1	75.07	0.112	13.14	1.38	0.086	nd	0.61	3.90	4.86	0.012	0.70	99.97
1867.5/1868.1	569.4	2324p1	73.58	0.129	12.74	1.42	0.085	0.12	1.02	3.51	4.27	0.015	3.05	100.03
1893.8/1894.1	577.3	2325p1	72.35	0.127	12.84	1.44	0.064	0.16	1.08	3.09	3.82	0.013	5.16	100.28
1913.4/1914.9	583.7	2326p1	71.54	0.130	12.58	1.44	0.091	0.17	0.98	2.92	4.18	0.019	6.26	100.43
1938.5/1938.7	590.9	2327p1	70.41	0.139	12.03	1.41	0.072	0.14	1.07	3.36	3.71	0.018	7.74	100.20
1962.8/1963.1	598.4	2328p1	69.12	0.151	12.51	1.52	0.072	0.15	1.06	3.70	3.53	0.021	8.44	100.39

Appendix VIIIa. Major element XRF results (wt%) for drill hole USW SD-7 samples (continued).

Sample	Depth (m)	LANL #	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Total
1988.6/1989.0	606.2	2329p1	69.79	0.118	12.33	1.36	0.036	0.17	1.04	3.57	3.12	0.011	8.92	100.53
2010.2/2010.5	612.8	2330p1	68.51	0.086	11.97	1.13	0.026	nd	1.02	3.87	3.21	nd	10.58	100.49
2021.3/2021.6	616.2	2331p1	71.03	0.097	11.48	1.30	0.031	nd	0.89	3.58	3.41	nd	8.70	100.61
2035.1/2035.3	620.4	2332p1	69.12	0.108	12.58	1.32	0.083	0.11	1.03	3.74	3.42	0.008	9.00	100.62
2062.6/2062.8	628.7	2334p1	69.44	0.108	12.30	1.47	0.143	nd	1.03	3.68	3.45	0.013	8.77	100.50
2094.2/2094.6	638.4	2336p1	69.08	0.118	12.26	1.82	0.153	nd	1.16	3.64	3.23	0.011	9.24	100.81
2133.7/2133.9	650.4	2338p1	68.66	0.106	12.33	1.25	0.025	nd	1.27	3.72	3.09	0.009	10.07	100.61
2159.6/2159.8	658.3	2339p1	68.71	0.144	12.95	1.68	0.120	0.26	1.34	3.43	3.29	0.026	9.07	101.11
2179.2/2179.4	664.3	2340p1	65.36	0.244	16.23	2.09	0.127	0.35	1.42	2.60	8.13	0.048	3.47	100.27
2180.0/2180.2	664.5	2341p1	77.38	0.119	11.85	1.19	0.082	nd	0.51	3.21	5.15	0.016	0.53	100.16
2201.7/2201.9	671.1	2342p1	74.87	0.159	13.48	1.52	0.078	0.12	0.70	3.47	5.43	0.023	0.63	100.62
2225.3/2225.4	678.3	2343p1	74.05	0.191	13.58	1.61	0.089	0.17	0.94	3.85	4.74	0.034	0.69	100.13

Analyses below the detection limit are designated as nd.

Appendix VIIIb. Minor element XRF results (ppm) for drill hole USW SD-7 samples.

Sample	Depth (m)	LANL #	V	Cr	Ni	Zn	Rb	Sr	Y	Zr	Nb	Ba	Total Traces (wt %)
1278.6/1278.9	389.8	2030p1	164.4	11.0	31.8	58.0	165.6	35.2	34.1	122.1	25.5	84.9	0.09
1321.5/1321.6	402.8	2032p1	155.5	nd	40.8	57.6	183.8	28.6	31.4	122.4	14.6	75.3	0.09
1350.5/1350.7	411.7	2034p1	15.8	nd	10.1	52.7	154.7	96.8	19.9	120.8	21.4	105.4	0.07
1421.1/1421.3	433.2	2297p1	22.5	nd	10.1	55.1	176.0	160.4	19.5	125.7	19.1	56.2	0.08
1467.4/1457.5	444.2	2299p1	63.4	nd	37.5	47.4	176.5	38.4	31.2	123.4	17.9	65.9	0.07
1471.5/1471.8	448.6	2300p1	nd	nd	10.5	49.2	178.8	40.7	28.2	122.1	16.6	80.1	0.06
1493.2/1493.6	455.2	2301p1	nd	nd	nd	60.1	129.8	96.9	30.2	132.8	23.6	98.1	0.07
1493.2/1493.6b	455.2	2301p2	14.5	nd	nd	36.4	95.8	145.2	20.6	108.1	10.5	168.7	0.07
1513.9/1514.2	461.5	2302p1	nd	nd	95.2	43.8	171.4	95.8	29.5	120.3	29.5	112.9	0.08
1517.3/1517.6	462.6	2303p1	15.0	8.7	14.3	50.2	187.2	157.5	22.0	142.2	21.8	234.1	0.10
1519.1/1519.3	463.1	2304p1	12.8	nd	14.0	38.7	98.9	495.5	13.8	95.5	13.8	65.5	0.10
1538.5/1538.6	469.0	2305p1	147.3	nd	45.6	43.3	168.5	544.5	27.7	111.3	10.5	108.3	0.15
1560.1/1560.5	475.6	2306p1	nd	nd	nd	47.6	163.7	747.8	21.9	116.2	28.8	98.3	0.15
1567.1/1567.3	477.7	2307p1	23.3	nd	33.5	47.1	97.7	950.1	7.2	132.9	22.6	157.6	0.18
1567.1/1567.3b	477.7	2307p2	171.1	nd	43.7	37.3	98.1	745.5	21.5	103.2	8.9	89.4	0.16
1581.2/1581.5	482.0	2308p1	20.7	nd	15.6	47.5	143.2	247.7	15.0	126.7	23.3	306.6	0.11
1581.2/1581.8b	482.0	2308p2	nd	nd	nd	30.6	101.4	180.7	nd	72.8	15.3	210.4	0.07
1601.5/1601.8	488.2	2310p1	22.9	nd	10.6	40.3	107.6	358.3	15.4	138.8	nd	579.8	0.15
1622.6/1622.9	494.7	2312p1	nd	nd	58.3	55.8	108.5	124.4	50.3	158.3	25.5	447.5	0.12
1636.5/1636.8	498.9	2313p1	179.0	nd	26.3	63.1	99.5	72.5	43.1	150.0	29.2	205.9	0.11
1647.7/1647.9	502.3	2314p1	nd	nd	57.6	46.2	131.3	37.5	31.1	151.1	22.0	264.3	0.09
1688.2/1688.4	514.6	2316p1	nd	nd	9.9	63.8	184.8	57.9	45.0	180.5	23.2	282.4	0.10
1741.0/1741.3	530.7	2318p1	nd	nd	nd	64.6	165.2	65.1	36.7	194.3	26.9	228.9	0.09
1796.7/1797.0	547.7	2321p1	45.0	nd	30.3	69.5	171.8	66.3	31.3	179.3	20.3	257.5	0.11
1843.4/1843.7	562.0	2323p1	nd	nd	17.2	55.7	183.9	61.0	32.2	184.7	32.6	248.2	0.10
1867.5/1868.1	569.4	2324p1	nd	nd	82.3	48.8	113.3	114.9	37.0	177.7	25.1	260.9	0.10
1893.8/1894.1	577.3	2325p1	195.0	nd	23.5	70.4	130.9	93.8	27.3	168.0	27.2	230.0	0.12
1913.4/1914.9	583.7	2326p1	20.2	nd	nd	67.4	142.2	75.0	54.3	165.6	28.1	295.5	0.10
1938.5/1938.7	590.9	2327p1	35.2	nd	nd	58.5	140.6	81.4	31.1	162.6	19.5	264.9	0.10
1962.8/1963.1	598.4	2328p1	21.0	nd	27.6	68.1	147.8	83.9	29.9	168.9	28.0	286.6	0.10

Appendix VIIIb. Minor element XRF results (ppm) for drill hole USW SD-7 samples (continued).

Sample	Depth (m)	LANL #	V	Cr	Ni	Zn	Rb	Sr	Y	Zr	Nb	Ba	Total Traces (wt %)
1988.6/1989.0	606.2	2329p1	12.4	nd	21.5	64.6	133.8	53.9	29.7	156.8	24.4	175.1	0.08
2010.2/2010.5	612.8	2330p1	72.5	nd	37.2	53.6	163.8	45.9	29.6	149.4	21.9	105.5	0.08
2021.3/2021.6	616.2	2331p1	98.6	nd	47.7	59.9	142.6	49.3	44.6	144.3	21.9	152.6	0.09
2035.1/2035.3	620.4	2332p1	36.8	nd	22.3	68.0	141.0	52.3	28.4	152.9	29.7	259.0	0.10
2062.6/2062.8	628.7	2334p1	nd	nd	nd	63.3	138.1	49.6	64.2	161.9	18.1	352.0	0.10
2094.2/2094.6	638.4	2336p1	nd	nd	48.0	110.8	142.1	46.0	34.7	161.6	33.1	336.7	0.11
2133.7/2133.9	650.4	2338p1	nd	nd	29.5	71.2	145.0	59.0	22.9	151.1	24.3	170.1	0.08
2159.6/2159.8	658.3	2339p1	25.3	nd	14.3	68.9	129.1	99.5	29.1	161.3	22.0	281.5	0.10
2179.2/2179.4	664.3	2340p1	nd	nd	25.7	80.0	188.9	368.9	22.0	299.2	28.0	671.0	0.20
2180.0/2180.2	664.5	2341p1	nd	nd	23.4	52.5	162.4	112.2	33.6	170.7	20.7	518.1	0.13
2201.7/2201.9	671.1	2342p1	13.0	nd	nd	50.3	165.2	153.5	36.5	197.7	14.1	465.2	0.13
2225.3/2225.4	678.3	2343p1	66.8	nd	24.4	72.7	157.9	243.5	26.0	246.0	26.4	669.8	0.18

Analyses below the detection limit are designated as nd.

Appendix IXa. Major element XRF results (wt%) for drill hole USW SD-9 samples.

Sample	Depth (m)	LANL #	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Total
1397.1/1397.2	425.9	2394p1	74.72	0.096	12.42	0.94	0.068	nd	0.52	3.59	4.78	nd	3.19	100.39
1421.5/1421.5	433.3	2396p1	74.82	0.095	12.35	0.92	0.073	nd	0.59	3.14	5.04	nd	3.33	100.42
1425.5/1426.0	434.6	2397p1	71.08	0.091	16.22	0.91	0.078	nd	0.74	2.59	4.45	nd	3.97	100.25
1428.2/1428.4	435.4	2398p1	73.55	0.094	13.25	0.98	0.121	nd	0.89	2.51	4.40	nd	4.73	100.59
1431.7/1431.9	436.4	1889p1	72.60	0.104	13.55	1.06	0.114	nd	1.08	2.45	4.19	nd	5.21	100.43
1434.4/1434.5	437.2	1890p1	71.26	0.100	11.76	0.98	0.095	nd	2.04	2.24	3.70	nd	8.19	100.44
1440.1/1440.2	439.0	1891p1	72.49	0.091	12.40	0.94	0.085	nd	1.31	2.34	4.30	nd	6.46	100.46
1447.8/1448.0	441.4	1892p1	74.98	0.096	12.03	0.97	0.111	nd	0.81	2.66	4.75	nd	4.13	100.59
1457.2/1457.6	444.3	1893p1	68.86	0.089	11.98	0.89	0.067	nd	1.99	2.01	4.19	nd	10.36	100.51
1460.5/1460.8	445.3	1894p1	71.64	0.091	11.09	0.90	0.058	nd	1.71	1.88	4.15	nd	9.06	100.64
1465.9/1466.1	446.9	1895p1	68.62	0.099	12.67	1.03	0.072	nd	1.91	2.19	4.43	nd	9.17	100.26
1486.3/1486.6	453.1	2238p1	72.60	0.063	10.83	0.79	0.052	nd	1.33	2.03	4.28	nd	8.78	100.81
1508.5/1508.8	459.9	2239p1	71.56	0.071	11.30	0.85	0.061	nd	1.10	2.35	4.66	nd	8.50	100.52
1527.1/1527.4	465.6	2240p1	70.81	0.077	12.72	0.94	0.037	nd	1.19	2.14	3.89	nd	8.56	100.42
1547.1/1547.4	471.6	2241p1	72.17	0.070	11.37	0.87	0.030	nd	0.88	2.59	4.53	0.009	8.14	100.70
1585.4/1585.6	483.3	2243p1	72.31	0.076	12.16	0.89	0.079	nd	0.71	2.78	4.98	nd	6.84	100.88
1626.2/1626.3	495.7	2245p1	71.54	0.068	11.15	0.82	0.044	nd	0.72	2.74	4.58	nd	8.56	100.27
1669.7/1669.9	509.0	2247p1	71.38	0.070	11.33	0.84	0.042	nd	0.83	2.93	4.14	nd	9.08	100.71
1711.7/1711.9	521.8	2249p1	71.39	0.071	11.52	0.86	0.020	nd	0.84	2.80	4.26	nd	8.89	100.72
1752.6/1753.0	534.3	2251p1	73.14	0.079	11.55	0.88	0.051	nd	0.86	2.85	4.20	nd	6.99	100.68
1770.7/1770.9	539.8	2252p1	70.92	0.123	12.18	1.16	0.034	0.19	1.04	2.66	4.12	0.019	8.27	100.80
1797.8/1798.1	548.1	2254p1	71.61	0.144	12.41	1.26	0.043	0.19	1.52	2.97	4.00	0.037	6.01	100.36
1821.1/1821.6	555.2	2255p1	71.57	0.100	12.54	1.18	0.134	0.59	1.22	2.11	3.61	0.012	7.50	100.70
1840.4/1840.6	561.0	2256p1	71.11	0.095	12.34	1.15	0.053	0.12	1.08	2.13	5.18	nd	7.53	100.87
1864.6/1864.7	568.4	2257p1	78.47	0.076	8.81	0.91	0.075	nd	1.50	2.25	2.14	nd	6.81	101.11
1866.2/1866.5	568.9	2258p1	71.67	0.100	12.48	1.25	0.161	0.13	1.72	2.51	3.14	0.011	7.47	100.77
1885.6/1886.0	574.9	2259p1	76.07	0.107	13.08	1.30	0.074	nd	0.45	3.19	5.98	0.009	0.64	100.99

Analyses below the detection limit are designated as nd.

Appendix IXb. Minor element XRF results (ppm) for drill hole USW SD-9 samples.

Sample	Depth (m)	LANL #	V	Cr	Ni	Zn	Rb	Sr	Y	Zr	Nb	Ba	Total Traces (wt %)
1397.1/1397.2	425.9	2394p1	37.5	nd	36.0	43.2	188.2	15.5	38.0	120.6	29.3	65.7	0.07
1421.5/1421.5	433.3	2396p1	22.1	nd	33.4	72.5	188.9	15.4	23.7	118.7	20.3	nd	0.06
1425.5/1426.0	434.6	2397p1	nd	nd	38.6	50.8	175.2	17.9	24.1	301.5	23.6	321.9	0.12
1428.2/1428.4	435.4	2398p1	14.1	8.7	19.0	52.2	179.0	19.8	32.3	117.3	24.1	79.8	0.07
1431.7/1431.9	436.4	1889p1	11.0	9.9	10.4	60.4	164.3	22.0	21.6	128.4	21.9	51.2	0.06
1434.4/1434.5	437.2	1890p1	nd	nd	13.1	53.8	124.2	97.3	19.7	121.9	26.6	98.3	0.07
1440.1/1440.2	439.0	1891p1	nd	nd	nd	44.1	171.1	36.8	22.4	110.5	20.6	nd	0.05
1447.8/1448.0	441.4	1892p1	nd	nd	15.4	45.9	184.2	18.3	26.0	119.9	28.0	56.2	0.06
1457.2/1457.6	444.3	1893p1	nd	nd	30.9	43.4	184.7	36.4	18.3	111.6	32.3	83.6	0.07
1460.5/1460.8	445.3	1894p1	17.3	nd	nd	43.5	179.5	34.7	33.0	108.1	15.2	88.5	0.06
1465.9/1466.1	446.9	1895p1	11.4	nd	17.3	42.4	179.5	42.5	8.2	122.8	30.6	60.4	0.06
1486.3/1486.6	453.1	2238p1	nd	nd	20.6	36.1	173.8	33.8	26.9	77.1	16.7	93.8	0.06
1508.5/1508.8	459.9	2239p1	nd	nd	nd	48.3	185.8	33.9	22.1	88.0	18.4	103.1	0.06
1527.1/1527.4	465.6	2240p1	nd	nd	nd	63.6	159.6	29.2	33.2	92.1	31.7	55.9	0.06
1547.1/1547.4	471.6	2241p1	nd	8.3	nd	43.0	168.8	27.4	19.5	83.8	16.7	nd	0.04
1585.4/1585.6	483.3	2243p1	11.8	nd	nd	38.5	191.7	37.8	18.1	98.1	22.0	93.9	0.06
1626.2/1626.3	495.7	2245p1	nd	nd	nd	36.4	182.7	32.1	35.8	82.9	23.1	88.8	0.06
1669.7/1669.9	509.0	2247p1	nd	nd	30.9	43.5	179.2	31.1	35.2	85.8	13.6	88.4	0.06
1711.7/1711.9	521.8	2249p1	nd	nd	16.3	41.1	176.3	35.4	18.9	91.3	24.7	97.8	0.06
1752.6/1753.0	534.3	2251p1	13.0	nd	13.8	36.4	169.0	43.4	28.9	103.1	17.9	192.3	0.07
1770.7/1770.9	539.8	2252p1	nd	nd	nd	34.3	160.8	91.1	31.5	101.9	24.8	223.5	0.08
1797.8/1798.1	548.1	2254p1	17.5	nd	10.9	40.1	143.1	225.6	15.5	139.8	10.1	735.6	0.16
1821.1/1821.6	555.2	2255p1	21.9	nd	nd	58.9	121.7	79.3	29.9	160.3	19.9	612.7	0.13
1840.4/1840.6	561.0	2256p1	nd	nd	15.3	65.7	159.6	67.9	35.0	152.5	28.3	169.7	0.08
1864.6/1864.7	568.4	2257p1	nd	nd	nd	48.1	120.2	30.8	25.0	117.3	24.2	242.1	0.07
1866.2/1866.5	568.9	2258p1	nd	nd	14.8	64.9	122.7	85.0	17.3	167.8	34.9	448.4	0.11
1885.6/1886.0	574.9	2259p1	11.9	nd	20.2	73.9	189.1	53.4	28.2	178.9	19.5	220.8	0.10

Analyses below the detection limit are designated as nd.

Appendix Xa. Major element XRF results (wt%) for drill hole USW SD-12 samples.

Sample	Depth (m)	LANL #	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Total
1309.3/1309.6	399.2	1866p1	75.51	0.097	12.46	0.96	0.055	nd	0.51	3.85	4.29	nd	2.73	100.53
1333.2/1333.4	406.4	1868p1	74.16	0.098	12.49	0.94	0.083	nd	0.56	3.42	4.74	nd	3.09	99.64
1351.9/1352.2	412.2	1870p1	74.11	0.099	12.27	0.96	0.078	nd	0.52	3.41	4.86	nd	3.08	99.45
1371.4/1371.5	418.0	1872p1	74.42	0.098	12.18	0.95	0.070	nd	0.50	3.48	4.81	nd	3.03	99.60
1381.1/1381.3	421.0	1873p1	74.48	0.094	12.51	0.96	0.074	nd	0.67	3.33	4.62	nd	3.52	100.34
1388.0/1388.1	423.1	1874p1	74.40	0.089	12.23	0.94	0.077	nd	0.71	3.29	4.54	nd	3.45	99.81
1399.2/1399.3	426.5	1875p1	73.92	0.089	12.36	0.95	0.065	nd	0.81	3.27	4.50	nd	3.48	99.52
1439.9/1440.1	438.9	2261p1	74.13	0.091	12.19	0.98	0.062	nd	0.67	3.12	4.80	nd	3.46	99.57
1458.7/1458.9	444.7	2262p1	72.86	0.091	12.19	0.96	0.061	nd	0.97	2.94	4.50	nd	4.28	98.93
1480.2/1480.5	451.3	2263p1	73.45	0.095	12.13	1.07	0.056	0.10	0.95	2.81	4.51	nd	4.14	99.36
1500.8/1501.0	457.5	2264p1	73.81	0.072	11.92	0.90	0.051	nd	0.97	2.74	4.54	nd	4.52	99.57
1519.8/1520.1	463.3	2265p1	74.11	0.075	12.02	0.89	0.054	nd	0.97	2.73	4.50	nd	4.11	99.52
1540.9/1541.3	469.8	2266p1	73.33	0.079	11.91	0.90	0.055	nd	1.13	2.65	4.32	nd	5.31	99.74
1561.1/1561.3	475.9	2267p1	74.51	0.073	11.91	0.90	0.055	nd	0.73	2.77	4.75	nd	4.25	99.99
1581.3/1581.6	482.1	2268p1	74.09	0.074	12.10	0.89	0.054	nd	0.98	2.76	4.57	nd	5.03	100.60
1600.0/1600.2	487.7	2269p1	72.14	0.082	12.58	1.01	0.056	0.13	1.05	2.46	4.53	nd	5.65	99.75
1600.3	487.8	2269p2	72.74	0.067	11.48	0.83	0.036	nd	1.50	1.77	3.85	nd	6.75	99.08
1601.5/1601.8	488.2	2390p1	68.92	0.072	11.98	0.92	0.044	nd	1.57	2.24	3.74	nd	10.50	100.05
1609.9/1610.4	490.8	2391p1	70.98	0.099	11.95	1.01	0.050	0.12	1.51	2.40	3.80	0.010	8.73	100.75
1620.4/1620.6	494.0	2270p1	73.33	0.131	12.51	1.17	0.041	0.14	1.68	2.48	3.62	0.011	5.85	101.08
1641.4/1641.7	500.4	2271p1	65.77	0.438	15.04	3.65	0.057	0.97	3.00	2.67	3.54	0.144	3.54	99.07
1656.3/1656.8	505.0	2272p1	71.45	0.106	12.23	1.27	0.084	0.28	1.54	2.31	3.46	nd	6.31	99.16
1680.7/1680.9	512.3	2273p1	75.82	0.099	12.18	1.21	0.063	0.12	0.30	2.66	6.15	nd	0.73	99.42
1700.3/1700.6	518.3	2274p1	75.69	0.101	12.77	1.25	0.076	nd	0.42	3.01	5.80	0.010	0.63	99.85
1739.8/1740.2	530.4	2276p1	75.99	0.105	13.17	1.31	0.074	nd	0.54	3.65	4.92	0.010	0.61	100.48
1780.2/1780.4	542.7	2278p1	75.37	0.103	12.81	1.29	0.079	nd	0.51	3.81	4.98	0.009	0.53	99.59
1821.2/1821.6	555.2	2280p1	74.91	0.102	12.87	1.29	0.079	nd	0.50	3.81	4.92	nd	0.47	99.04
1860.0/1860.3	567.0	2282p1	74.28	0.117	13.01	1.40	0.082	0.10	0.56	3.38	5.37	0.014	0.69	99.10
1874.4/1874.5	571.3	2283p1	72.50	0.129	13.46	1.46	0.073	0.30	1.41	2.92	3.64	0.017	3.93	99.96
1891.6/1891.9	576.7	2284p1	67.82	0.148	14.23	1.65	0.076	0.27	1.91	2.87	3.64	0.023	6.43	99.15

Appendix Xa. Major element XRF results (wt%) for drill hole USW SD-12 samples (continued).

Sample	Depth (m)	LANL #	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	LOI	Total
1911.8/1911.9	582.7	2285p1	70.42	0.126	12.88	1.46	0.080	0.20	1.43	2.63	4.06	0.020	5.92	99.31
1929.7/1929.9	588.2	2286p1	71.03	0.138	12.55	1.39	0.131	0.17	1.27	3.05	4.00	0.021	5.73	99.59
1950.0/1950.7	594.6	2287p1	69.38	0.160	12.59	1.49	0.055	0.18	1.19	3.34	3.96	0.024	6.15	98.61

Analyses below the detection limit are designated as nd.

Appendix Xb. Minor element XRF results (ppm) for drill hole USW SD-12 samples.

Sample	Depth (m)	LANL #	V	Cr	Ni	Zn	Rb	Sr	Y	Zr	Nb	Ba	Total Traces (wt %)
1309.3/1309.6	399.2	1866p1	26.1	nd	8.3	41.8	179.0	24.7	30.0	115.4	17.0	52.4	0.060
1333.2/1333.4	406.4	1868p1	nd	nd	nd	44.2	180.8	58.3	35.9	113.4	19.5	73.1	0.063
1351.9/1352.2	412.2	1870p1	nd	nd	nd	41.8	181.2	35.4	26.6	108.1	21.7	73.2	0.058
1371.4/1371.5	418.0	1872p1	11.7	nd	14.7	28.0	178.9	22.5	34.5	112.5	19.5	59.5	0.058
1381.1/1381.3	421.0	1873p1	13.2	nd	10.8	40.7	182.1	247.4	31.3	130.4	16.7	38.9	0.086
1388.0/1388.1	423.1	1874p1	20.4	nd	8.1	39.4	174.9	155.2	31.6	119.5	17.8	45.9	0.074
1399.2/1399.3	426.5	1875p1	7.5	nd	12.5	37.1	169.8	65.4	25.6	109.4	19.4	43.7	0.059
1439.9/1440.1	438.9	2261p1	nd	nd	6.1	39.8	180.4	32.9	24.9	108.6	21.0	66.5	0.058
1458.7/1458.9	444.7	2262p1	nd	nd	nd	43.4	169.8	44.5	38.5	118.3	17.9	113.9	0.065
1480.2/1480.5	451.3	2263p1	9.3	nd	nd	38.4	188.5	51.0	30.9	92.8	20.3	125.0	0.066
1500.8/1501.0	457.5	2264p1	nd	nd	nd	38.0	180.5	40.0	34.5	91.8	10.3	57.0	0.054
1519.8/1520.1	463.3	2265p1	nd	nd	nd	41.1	187.6	41.8	23.9	88.9	23.8	142.8	0.065
1540.9/1541.3	469.8	2266p1	16.3	nd	18.8	39.1	178.5	37.1	23.1	92.5	23.1	113.7	0.065
1561.1/1561.3	475.9	2267p1	25.5	nd	10.6	38.5	192.2	26.7	21.0	84.7	21.7	nd	0.051
1581.3/1581.6	482.1	2268p1	11.2	nd	23.6	35.2	179.8	36.0	24.7	91.8	11.4	85.4	0.060
1600.0/1600.2	487.7	2269p1	20.7	nd	18.5	48.4	172.6	41.7	40.6	101.7	14.2	147.0	0.073
1600.3	487.8	2269p2	nd	nd	nd	32.8	156.0	47.3	7.9	82.0	27.5	nd	0.043
1601.5/1601.8	488.2	2390p1	nd	nd	30.0	40.9	145.3	68.3	nd	90.2	19.5	88.5	0.058
1609.9/1610.4	490.8	2391p1	nd	nd	17.1	35.8	162.6	86.7	20.6	103.0	16.3	289.4	0.086
1620.4/1620.6	494.0	2270p1	nd	nd	16.7	44.0	138.1	155.2	20.2	133.8	15.6	501.0	0.120
1641.4/1641.7	500.4	2271p1	81.8	15.2	12.4	70.8	127.5	490.1	23.9	234.0	11.6	1087.7	0.254
1656.3/1656.8	505.0	2272p1	44.3	nd	7.5	59.8	124.6	112.4	36.6	156.4	25.2	462.8	0.123
1680.7/1680.9	512.3	2273p1	12.3	nd	7.3	24.7	182.5	29.7	28.8	159.3	26.0	242.2	0.085
1700.3/1700.6	518.3	2274p1	17.9	nd	27.3	43.0	190.7	50.2	32.7	166.5	21.9	279.8	0.099
1739.8/1740.2	530.4	2276p1	13.5	nd	nd	64.1	167.6	56.7	39.3	171.6	28.5	297.7	0.100
1780.2/1780.4	542.7	2278p1	27.9	nd	21.5	56.3	169.5	57.6	31.9	174.2	27.8	249.8	0.099
1821.2/1821.6	555.2	2280p1	nd	nd	10.6	34.1	175.5	56.1	37.5	160.0	26.9	234.0	0.088
1860.0/1860.3	567.0	2282p1	7.0	nd	7.6	44.6	197.4	55.3	47.1	163.7	28.8	244.1	0.095
1874.4/1874.5	571.3	2283p1	nd	nd	nd	58.0	100.2	247.2	40.2	187.8	27.3	275.1	0.113
1891.6/1891.9	576.7	2284p1	20.9	12.9	nd	59.8	131.5	110.3	40.2	178.2	23.2	254.0	0.101

Appendix Xb. Minor element XRF results (ppm) for drill hole USW SD-12 samples (continued).

Sample	Depth (m)	LANL #	V	Cr	Ni	Zn	Rb	Sr	Y	Zr	Nb	Ba	Total Traces (wt %)
1911.8/1911.9	582.7	2285p1	nd	nd	7.1	48.8	142.5	74.0	33.9	159.3	24.1	239.5	0.087
1929.7/1929.9	588.2	2286p1	16.5	nd	nd	62.9	141.5	80.7	34.4	166.4	24.9	354.8	0.105
1950.0/1950.7	594.6	2287p1	nd	9.0	nd	64.6	153.2	88.3	31.4	174.1	24.8	234.6	0.094

Analyses below the detection limit are designated as nd.