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September 2004

Mineralogic Model (MM3.0) Report

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2. Type of Mathematical Model			
☒ Process Model ☐ Abstraction Model ☐ System Model			
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This model provides the project with a representation of mineral abundances within the model area for use in groundwater flow and transport modeling.			
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	<p>assessed to be N/A Reference Only. This action resolves the use of TBV-3731 in this document. The input status of software code STRATAMODEL V4.1.1 has been changed to N/A Qualified Software. This action resolves TBV-3758.</p> <p>The use of DTN: LA9910JC831321.001 has been changed to corroborative as documented in Table 4.1 on page 26. This action resolves TBV-3657 in this document. Other minor editorial changes also have been made.</p> <p>Section 6.4.2, “Magnitude of Increased Uncertainty with Exclusion of TBV Data,” was deleted, as there are no longer any TBVs.</p> <p>Section 8.5, “Output Data, Listed by Data Tracking Number,” was added.</p> <p>Pages affected by this ICN are: Section 1, pp. 11, 18 Section 2, p. 21 Section 4, p. 26 Section 5, pp. 29-30 Section 6, pp. 31, 37, 63, 70 Section 7, p. 75 Section 8, pp. 77-80</p> <p>The changes in this document do not affect any of the figures. Due to reproductive limitations, please refer to MDL-NBS-GS-000003 Rev. 00 ICN 01 to examine the figures.</p> <p>An AP-2.14Q review was not conducted on this document because the changes only affected data qualification and verification issues. No changes were made that would affect the technical product output.</p>
REV 01	<p>The purpose of Revision 01 is to revise the report to bring it into procedural compliance and address regulatory integration team review comments. This revision addresses qualification of unqualified data cited as direct inputs, identification and addressing the acceptance criteria, the models level of importance and model validation. Condition reports (CRs) addressed include CR-2052, -2082, and -2752.</p> <p>Changes to this version are too extensive to be indicated by change bars. Entire model documentation was revised. Side bars are not used because the changes were too extensive to use Step 5.8f)1) per AP-SIIL.10Q, REV 02, ICN 06.</p>

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ACRONYMS AND ABBREVIATIONS

3-D	three-dimensional
ASCII	American Standard Code for Information Interchange
BSC	Bechtel SAIC Company, LLC
DIRS	document input reference system
DQR	Data Qualification Report
DOE	U.S. Department of Energy
DTN	data tracking number
LANL	Los Alamos National Laboratory
NRC	Nuclear Regulatory Commission
TBV	to be verified
TDMS	technical data management system
TSPA	total system performance assessment
USGS	U.S. Geological Survey
XRD	X-ray diffraction
YMRP	Yucca Mountain Review Plan

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1. PURPOSE

The purpose of this report is to provide a three-dimensional (3-D) representation of the mineral abundance within the geologic framework model domain. The mineralogic model enables project personnel to estimate mineral abundances at any position, within the model region, and within any stratigraphic unit in the model area. The model provides the abundance and distribution of 10 minerals and mineral groups within 22 stratigraphic sequences or model layers in the Yucca Mountain area. The uncertainties and limitations associated with this model are discussed in Section 6.4. Model validation accomplished by corroboration with data not cited as direct input is discussed in Section 7.

The primary user of the mineralogic model output is the *Heat Capacity Analysis Report* (BSC 2004 [DIRS 170003]). The *Heat Capacity Analysis Report* uses as direct input the mineral abundance values averaged for each of the 10 mineral groups by the mineralogic model layer to calculate the rock grain heat capacity. Then, the following model reports use these heat capacity values: *In-drift Natural Convection and Condensation Model Report* (BSC 2004 [DIRS 164327]), *Drift Degradation Analysis* (BSC 2004 [DIRS 166107]), *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862]), *Igneous Intrusion Impacts on Waste Packages and Waste Forms* (BSC 2004 [DIRS 168960]), *Dike/Drift Interactions* (BSC 2004 [DIRS 170028]), and *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 169565]).

In addition, two near-field environment and transport model reports, *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2004 [DIRS 169866]) and *Drift-Scale THC Seepage Model* (BSC 2004 [DIRS 169856]), cite the USW SD-9 borehole mineral abundance data as direct input. The data are discrete measurement values used to construct the mineralogic model and are not the representation of the 3-D product output. The borehole mineral abundance data are then used to calculate mineral volume fractions and surface areas.

Version 3.0 of the mineralogic model was developed from mineralogic data obtained from borehole samples. It consists of matrix mineral abundances as a function of x (easting), y (northing), and z (elevation), referenced to the stratigraphic framework defined in Version 3.1 of the geologic framework model. The stratigraphy is shown in Table 1-1. The significance of the mineralogic model for key aspects of site characterization and performance assessment is explained in subsequent sections.

The planning document for this model report is *Technical Work Plan for: The Integrated Site Model, Rev 05* (BSC 2004 [DIRS 169635]). The report was prepared in accordance with procedure AP-SIII.10Q, *Models*.

This report documents the qualification of data cited as direct input and the validation by corroboration with data not cited as direct input, in response to comments generated by regulatory integration team reviewers. There have been no changes to the product output (DTN: LA9908JC831321.001) since the last revision. Constraints and limitations of the mineralogic model are discussed in Sections 6.4 and 8.1.

The mineralogic model is one of three components of an integrated site model scope of work, which provides a consistent volumetric portrayal of the rock layers, rock properties, and

mineralogy of the Yucca Mountain site. The other components are the geologic framework model and the rock properties model. The lateral boundaries of the three component models are shown in Figure 1-1.

1.1 MINERALOGY AND HYDROLOGIC PROPERTIES

The hydrologic properties and behavior of rock units can be correlated with mineralogy (Loeven 1993 [DIRS 101258], pp. 15 to 26). Loeven shows that nonwelded vitric tuffs and zeolitized tuffs can have very different hydraulic conductivities. The use of the observed correlation between mineralogic and hydrologic data can provide a means of improving the accuracy and confidence of both hydrologic and mineralogic models. For example, in some areas, high-confidence mineralogic data can improve estimates of hydrologic properties; and in other areas, high-confidence hydrologic data can improve estimates of mineral abundance. Where hydraulic conductivity in zeolites is known to a high level of confidence, that knowledge can be used to obtain more accurate estimates of zeolitic abundance in samples of zeolites and non-welded tuffs for which hydraulic conductivity is known.

1.2 MINERALOGY AND RADIONUCLIDE TRANSPORT

Zeolitic horizons have long been an important factor in models of radionuclide transport at Yucca Mountain. Zeolites are capable of sorbing many cationic radionuclides (Johnstone and Wolfsberg 1980 [DIRS 109037], pp. 112 to 117, Tables A1, A2, A3). The mineralogic model incorporates zeolite and other mineral weight percentages as the basic distributed property, allowing the volumes of minerals present, represented as weight percentages of rock mass, to be defined explicitly in a spatial manner.

Table 1-1. Correlation Chart for Model Stratigraphy

Stratigraphic Unit ^{a, d}						Abbreviation ^a	RHH ^b	Geologic Framework Model Unit ^h	Mineralogic Model Unit
Group	Formation	Member	Zone	Subzone					
Alluvium and Colluvium						Qal, Qc	Tiva and Post-Tiva	Alluvium (only)	
Timber Mountain Group						Tm			
Rainier Mesa Tuff						Tmr			
Paintbrush Group						Tp			
		Post-tuff unit "x" bedded tuff				Tpbt6			
		Tuff unit "x" ^c				Tpki (informal)			
		Pre-tuff unit "x" bedded tuff				Tpbt5			
Tiva Canyon Tuff						Tpc			
		Crystal-Rich Member				Tpcr			
			Vitric zone			Tpcrv			
				Nonwelded subzone		Tpcrv3			

Table 1-1. Correlation Chart for Model Stratigraphy (Continued)

Stratigraphic Unit ^{a, d}						Abbreviation ^a	RHH ^b	Geologic Framework Model Unit ^h	Mineralogic Model Unit
Group	Formation	Member	Zone	Subzone					
				Moderately welded subzone		Tpcrv2	Tiva and Post-Tiva		
				Densely welded subzone		Tpcrv1			
				Nonlithophysal subzone		Tpcrn			
				Subvitrophyre transition subzone		Tpcrn4			
				Pumice-poor subzone		Tpcrn3			
				Mixed pumice subzone		Tpcrn2			
				Crystal transition subzone		Tpcrn1			
				Lithophysal zone		Tpcrl			
				Crystal transition subzone		Tpcrl1			
				Crystal-Poor Member		Tpcp	Tpcp		Sequence 22 (Layer 26) Alluvium– Tpc_un
				Upper lithophysal zone		Tpcpul			
				Spherulite-rich subzone		Tpcpul1			
				Middle nonlithophysal zone		Tpcpmn			
				Upper subzone		Tpcpmn3			
				Lithophysal subzone		Tpcpmn2			
				Lower subzone		Tpcpmn1			
				Lower lithophysal zone		Tpcpll			
				Hackly-fractured subzone		Tpcpllh			
				Lower nonlithophysal zone		Tpcpln			
				Hackly subzone		Tpcplnh			
				Columnar subzone		Tpcplnc	TpcLD		
				Vitric zone		Tpcpv			
				Densely welded subzone		Tpcpv3	Tpcpv3	Sequence 21 (Layer 25) Tpcpv3–Tpcpv2	
				Moderately welded subzone		Tpcpv2	Tpcpv2		
				Nonwelded subzone		Tpcpv1	Tpcpv1	Sequence 20 (Layer 24) Tpcpv1–Tpdrv2	
				Pre-Tiva Canyon bedded tuff		Tpbt4	Tpbt4		
				Yucca Mountain Tuff		Tpy	Yucca		
				Pre-Yucca Mountain bedded tuff		Tpbt3	Tpbt3_dc		
				Pah Canyon Tuff		Tpp	Pah		
				Pre-Pah Canyon bedded tuff		Tpbt2	Tpbt2		
				Topopah Spring Tuff		Tpt			
				Crystal-Rich Member		Tptr			
				Vitric zone		Tptrv			
				Nonwelded subzone		Tptrv3	Tptrv3		
				Moderately welded subzone		Tptrv2	Tptrv2		

Table 1-1. Correlation Chart for Model Stratigraphy (Continued)

Stratigraphic Unit ^{a, d}						Abbreviation ^a	RHH ^a	Geologic Framework Model Unit ^h	Mineralogic Model Unit
Group	Formation	Member	Zone	Subzone					
				Densely welded subzone		Tptrv1		Tptrv1	Sequence 19 (Layer 23) Tptrv1
				Nonlithophysal zone		Tptrn			
				Dense subzone		Tptrn3			
				Vapor-phase corroded subzone		Tptrn2		Tptrn	
				Crystal transition subzone		Tptrn1			
				Lithophysal zone		Tptrl			
				Crystal transition subzone		Tptrl1		Tptrl	Sequence 18 (Layer 22)
				Crystal-Poor Member		Tptp			
				Lithic-rich zone		Tptpf or Tptrf		Tptf	Tptrn-Tptf
				Upper lithophysal zone		Tptpul		Tptpul	Sequence 17 (Layer 21) Tptpul
							RHHtop		
				Middle nonlithophysal zone		Tptpmn			
				Nonlithophysal subzone		Tptpmn3			
				Lithophysal bearing subzone		Tptpmn2			Sequence 16 (Layer 20)
				Nonlithophysal subzone		Tptpmn1		Tptpmn	Tptpmn
				Lower lithophysal zone		Tptpll		Tptpll	Sequence 15 (Layer 19) Tptpll
				Lower nonlithophysal zone		Tptpln		Tptpln	Sequence 14 (Layer 18) Tptpln
							RHH		
				Vitric zone		Tptpv			
				Densely welded subzone		Tptpv3		Tptpv3	Sequence 13 ^e
				Moderately welded subzone		Tptpv2		Tptpv2	(Layers 16 & 17) Tptpv3-Tptpv2
				Nonwelded subzone		Tptpv1		Tptpv1	
				Pre-Topopah Spring bedded tuff		Tpbt1		Tpbt1	Sequence 12 (Layer 15) Tptpv1 - Tpbt1
				Calico Hills Formation		Ta		Calico	Sequence 11 ^f (Layers 11, 12, 13, 14) Tac
				Bedded tuff		Tacbt		Calicobt	Sequence 10 (Layer 10) Tacbt
				Crater Flat Group		Tc			
				Prow Pass Tuff		Tcp			

Table 1-1. Correlation Chart for Model Stratigraphy (Continued)

Stratigraphic Unit ^{a, d}						Abbreviation ^a	RHH ^p	Geologic Framework Model Unit ^h	Mineralogic Model Unit
Group	Formation	Member	Zone	Subzone					
				Prow Pass Tuff upper vitric nonwelded zone		(Tcuv) ^d		Prowuv	Sequence 9 (Layer 9) Tcuv
				Prow Pass Tuff upper crystalline nonwelded zone		(Tcup) ^d		Prowuc	
				Prow Pass Tuff moderately densely welded zone		(Tcupd) ^d		Prowmd	
				Prow Pass Tuff lower crystalline nonwelded zone		(Tcupl) ^d		Prowlc	Sequence 8 (Layer 8) Tcup–Tcupl
				Prow Pass Tuff lower vitric nonwelded zone		(Tcuplv) ^d		Prowlv	
				Pre-Prow Pass Tuff bedded tuff		(Tcupbt) ^d		Prowbt	
				Bullfrog Tuff		Tcb			
				Bullfrog Tuff upper vitric nonwelded zone		(Tcbuv) ^d		Bullfroguv	Sequence 7 (Layer 7) Tcuplv–Tcbuv
				Bullfrog Tuff upper crystalline nonwelded zone		(Tcbuc) ^d		Bullfroguc	
				Bullfrog Tuff welded zone		(Tcbumd) ^d		Bullfrogmd	
				Bullfrog Tuff lower crystalline nonwelded zone		(Tcbcl) ^d		Bullfrogcl	Sequence 6 (Layer 6) Tcbuc–Tcbcl
				Bullfrog Tuff lower vitric nonwelded zone		(Tcbclv) ^d		Bullfroglv	
				Pre-Bullfrog Tuff bedded tuff		(Tcbbt) ^d		Bullfrogbt	
				Tram Tuff		Tct			
				Tram Tuff upper vitric nonwelded zone		(Tctuv) ^d		Tramuv	Sequence 5 (Layer 5) Tcbclv–Tctuv
				Tram Tuff upper crystalline nonwelded zone		(Tctuc) ^d		Tramuc	
				Tram Tuff moderately-densely welded zone		(Tctumd) ^d		Trammd	
				Tram Tuff lower crystalline nonwelded zone		(Tctcl) ^d		Tramcl	Sequence 4 (Layer 4) Tctuc–Tctcl
				Tram Tuff lower vitric nonwelded zone		(Tctlv) ^d		Tramlv	Sequence 3 (Layer 3) Tctlv–Tctbt
				Pre-Tram Tuff bedded tuff		(Tctbt) ^d		Trambt	
				Lava and flow breccia (informal)		Tll			Sequence 2 (Layer 2) Tund
				Bedded tuff		Tllbt			
				Lithic Ridge Tuff		Tr			
				Bedded tuff		Tlrbt			

Table 1-1. Correlation Chart for Model Stratigraphy (Continued)

Stratigraphic Unit ^{a, d}						Abbreviation ^a	RHH ^b	Geologic Framework Model Unit ^h	Mineralogic Model Unit
Group	Formation	Member	Zone	Subzone					
		Lava and flow breccia (informal)				TII2			
		Bedded tuff				TIIbt			
		Lava and flow breccia (informal)				TII3			
		Bedded tuff				TII3bt			
		Older tuffs (informal)				Tt			
			Unit a (informal)			Tta			
			Unit b (informal)			Ttb			
			Unit c (informal)			Ttc			
		Sedimentary rocks and calcified tuff (informal)				Tca			
		Tuff of Yucca Flat (informal)				Tyf	Tund		
Pre-Tertiary sedimentary rock							Paleozoic	Sequence 1 (Layer 1) Paleozoic ^g	
	Lone Mountain Dolomite					Slm			
	Roberts Mountain Formation					Srm			

NOTE: Shaded rows indicate header lines for subdivided units.

^a Source: DTN: MO9510RIB00002.004 (DIRS 103801).

^b Source: CRWMS M&O 1997 (DIRS 100223), pp. 43 to 50.

^c Correlated with the rhyolite of Comb Peak (Buesch et al. 1996 [DIRS 100106], Table 2).

^d For the purposes of the geologic framework model, Version3.1, each formation in the Crater Flat Group was subdivided into six zones based on the requirements of the users of the geologic framework model. The subdivisions are upper vitric (uv), upper crystalline (uc), moderately to densely welded (md), lower crystalline (lc), lower vitric (lv), and bedded tuff (bt) (Buesch and Spengler 1999 [DIRS 107905], pp. 62 to 63).

^e Sequence 13 (Tptpv3–Tptpv2) is subdivided into two layers of equal thickness.

^f Sequence 11 (Tac) is subdivided into four layers of equal thickness.

^g Sequence 1 (Paleozoic) represents a lower bounding surface.

^h Source: DTN: MO9901MWDGFM31.000 (DIRS 103769).

RHH = repository host horizon

Sources: DTN: MO9901MWDGFM31.000 (DIRS 103769); Rautman and McKenna 1998 (DIRS 107442), Section 2. Output DTN: LA9908JC831321.001.

Figure 1-1. Location Map of Yucca Mountain, Nevada, Showing Location of Exploratory Studies Facility, Cross-Block Drift, and Area of Integrated Site Model with Boundaries of Component Models

1.3 MINERAL DISTRIBUTIONS AND REPOSITORY PERFORMANCE

The mineralogic model also addresses the effects of repository-induced heating on hydrous mineral components at the site. Hydrous minerals, such as zeolites and clays, and volcanic glass are particularly susceptible to reactions caused by repository-induced heating (Levy 1991 [DIRS 100053]). These reactions can produce or absorb water; yield changes in porosity, permeability, and retardation characteristics; and moderate heat flux within the rock mass (Vaniman and Bish 1995 [DIRS 101496], pp. 533 to 546). Other minerals, particularly silica polymorphs, may undergo phase transitions or may control the aqueous silica concentrations of fluids migrating under thermal loads, resulting in silica dissolution or precipitation, redistribution of silica, and modification of rock properties (Levy 1991 [DIRS 100053]). All of these effects must be considered in three dimensions to adequately address the impact of various repository-loading strategies on the repository performance. The mineralogic model allows numerical modeling of reactions involving the breakdown of glass to zeolites and smectite, the breakdown of clinoptilolite and mordenite to analcime, and the transformation and redistribution of silica polymorphs.

1.4 PREDICTION OF MINERAL DISTRIBUTIONS AND REPOSITORY DESIGN

Guidelines for repository performance address concerns over mineral stability in systems exposed to repository conditions (Section 4.2). Previous studies of thermal effects (Buscheck and Nitao 1993 [DIRS 109028], pp. 847 to 867) relevant to assessment of mineral stability have not been able to assess solid phase transformations (e.g., transitions between silica polymorphs) or hydrous-mineral dehydration/rehydration because of a lack of 3-D mineralogic data. Version 3.0 of the mineralogic model allows the formulation of thermal models to indicate much more precisely the maximum possible thermal loads that are consistent with maintaining relatively low temperatures for zeolite-rich zones, and it provides the abundances of silica polymorphs that are susceptible to phase transformations adjacent to the repository. Modeling developed in *Drift-Scale THC Seepage Model* (BSC 2004 [DIRS 169856]) couples the 3-D mineralogic model with mineral-reaction and heat-flow data making it possible to model thermal limits with fewer assumptions.

2. QUALITY ASSURANCE

Development of this model report and the supporting modeling activities have been determined to be subject to the Yucca Mountains Project's quality assurance program, as indicated in the *Technical Work Plan for: The Integrated Site Model* (BSC 2004 [DIRS 169635], Section 8.1, Work Package ARTM01). Approved quality assurance procedures identified in the technical work plan have been used to conduct and document the activities described in this model report. Section 8.4 of the technical work plan also identifies the methods used to control the electronic management of data during model documentation activities.

This model report provides representations of selected mineral abundances referenced to the stratigraphic framework, which are important to the demonstration of compliance with the postclosure performance objectives prescribed in 10 CFR 63.113 [DIRS 156605]. This model report addresses nuclides transport for infiltration through the Lower Natural Barrier and Upper Natural Barrier, which are classified in the *Q-List* (BSC 2004 [DIRS 168361]) as Safety Category "SC," because they are important to waste isolation, as defined in AP-2.22Q, *Classification Analysis and Maintenance of the Q-List*. The report contributes to the analysis and modeling data used to support performance assessment; the conclusions do not directly impact engineered features important to safety, as defined in AP-2.22Q.

Table 2-1. Model Development Documentation for Mineralogic Model

Model	Planning Document	Scientific Notebook Procedure	Scientific Notebook
Mineralogic Model Version 3.0	BSC 2004 [DIRS 169635]	LANL-YMP-QP-03.5 AP-SIII.1Q	LA-EES-1-NBK-99-001 (CRWMS M&O registry no. SN-LANL-SCI-190-V1) (Carey 1999 [DIRS 138525])

CRWMS=Civilian Radioactive Waste Management System; M&O=Management and Operating Contractor.

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3. USE OF SOFTWARE

3.1 QUALIFIED SOFTWARE

The mineralogic model was constructed using STRATAMODEL modeling software (STRATAMODEL V. 4.1.1, STN: 10121-4.1.1-00 [DIRS 153238]), an industry-standard software produced by Landmark Graphics Corporation, Houston, Texas. STRATAMODEL has the capability to integrate many different parameters to generate a multidisciplinary 3-D model. The software has been determined to be appropriate and adequate for its intended use in 3-D mineralogic modeling and no other software applications or computational methods were considered for this modeling effort. The software is under configuration management control (Table 3-1), and its qualification status is provided by the software baseline report.

Table 3-1. Quality Assurance Information for Model Software

CPU Platform	CPU Operating System	Software Name	Version	Qualification Procedure	Software Tracking Number (STN)
Silicon Graphics Inc.	IRIX 6.5	STRATAMODEL	4.1.1	AP-SI.1Q	10121-4.1.1-00

During the construction and use of the mineralogic model, it is stored on internal computer disks, backup tapes, and compact disks. The electronic files for Version 3.0 were submitted to the Technical Data Management System (TDMS) in American Standard Code for Information Interchange (ASCII) format. All files necessary to reconstruct the mineralogic model are available in the TDMS in product output DTN: LA9908JC831321.001, including data, interpretive data, parameter files, and instructions. Reconstruction of Version 3.0 requires STRATAMODEL software Version 4.1.1 or higher. ASCII format files containing all model results are also provided in the TDMS for use in the other software used in downstream modeling.

STRATAMODEL was used to maximize the potential for multiple uses of the mineralogic model. Transport codes, which incorporate thermal and geochemical effects, used on the Yucca Mountain Project are compatible with STRATAMODEL. STRATAMODEL also embodies the preferred methods for interpolation of mineral abundances between drill holes and in stratigraphic coordinates. In addition, the data in STRATAMODEL can be directly analyzed using geostatistical software.

Information from the geologic framework model, versions 3.1 (DTN: MO9901MWDGFM31.000 [DIRS 103769]) and 3.0 (DTN: MO9804MWDGFM03.001 [DIRS 109050]), was used in construction of Version 3.0 of the mineralogic model (Section 4.1.2). The qualification status of these models is provided in the DIRS database.

3.2 OTHER SOFTWARE

Microsoft Excel 97 was used during the course of the model validation activity to assist in organizing, managing, manipulating, comparing, and displaying data and information and computing standard statistical measures. This product is commercial, off-the-shelf software used to perform support activities; it was not used as the controlled source of information for the

analysis, as defined in LP-SI.11Q-BSC, *Software Management*. Microsoft Excel 97 is not, therefore, required to be qualified under these procedures.

Microsoft Excel 97 was used to organize mineral abundances by borehole and depth. Standard, cell-based arithmetic Excel operations were used temporarily to check for and identify duplicate sample data (by depth) and to order values by model sequence for comparisons during model validation. Standard, cell-based arithmetic operations also were used to average multiple values from model sequences for the validation comparisons. This computation is immediately verifiable by visual inspection.

4. INPUTS

Inputs for Version 3.0 of the mineralogic model consist of water table and stratigraphic surfaces from Versions 3.0 and 3.1 of the geologic framework model and *quantitative* X-ray diffraction (XRD) analyses of mineral abundances.

4.1 DIRECT INPUT

A list of direct data inputs is provided in Table 4-1, and their qualification status is provided in the Automated Technical Data Tracking database. Four input DTNs (LA9910JC832321.001 [DIRS 113496], LADV831321AQ97.001 [DIRS 107142], LADV831321AQ97.007 [DIRS 113499], and MO0101XRDDRILC.001 [DIRS 169517]) are qualified in this report (Appendices A, B, and C). Information showing the relationship of the sources and related qualification activities for output DTN: LA9908JC831321.001 are provided in Appendix D. Unqualified and qualified data from DTN: LADB831321AN98.002 (DIRS 109003) that were used as input to construct the model are now all qualified and contained in DTNs MO0101XRDMINAB.001 (DIRS 163796), MO0101XRDDRILC.001 (DIRS 169517), MO0101XRDDRILC.002 (DIRS 163795), and MO0106XRDDRILC.003 (DIRS 163797) (Table 4-1). Figure 4-1 shows the location of the boreholes from which derived mineralogic data was used in the construction of the mineralogic model. A brief discussion of the data is provided in the following subsections.

4.1.1 Mineralogic Data

The mineralogic model depends directly on quantitative X-ray diffraction (XRD) analyses. XRD offers the most direct and accurate analytical method for determining mineral abundance, because the data are fundamentally linked to crystal structure. Other methods based on down-hole logs or chemical or spectral properties from which mineral identities can be inferred are subject to much greater uncertainty. The development of quantitative XRD for application to core and cuttings analysis at Yucca Mountain (Bish and Chipera 1988 [DIRS 103130], pp. 295 to 308; Chipera and Bish 1995 [DIRS 105075], pp. 47 to 55) resulted in the development of a modeling software input data file of mineral abundances (in product output DTN: LA9908JC831321.001) as a function of map position and depth at Yucca Mountain.

The primary mineralogic direct data listed in Table 4-1 are quantitative XRD data used for constructing the mineralogic model. The selection of these data sets represents all available mineral abundances based on quantitative XRD analyses. A typical inherent analytical uncertainty associated with XRD analysis may be relatively low for high mineral abundances (feldspar, 60.45 ± 5.13) but, can be relatively higher in the case of low mineral abundances (cristobalite + opal CT, 8.07 ± 5.51). All data are expressed as weight percent and are used as reported in these files, with the following exceptions. Where a mineral was detected but in only trace abundance (i.e., much less than 1 percent) the result is reported in the tables as “Trc.” or “Tr.” In these cases, a uniform numeric value of 0.1 percent was assigned to each trace occurrence in order to have real (but appropriately small) numeric values in the mineralogic model. In some instances, depending on the mineralogic makeup of the sample, approximate or upper-limit values, such as “~1 percent” or “< 2 percent,” are reported in the data package. In

these cases, the ~ or < symbol was dropped, and the numeric value was used in the mineralogic model. These values are a conservative estimate based on the XRD analysis.

4.1.2 Stratigraphic Surfaces

The stratigraphic framework for Version 3.0 of the mineralogic model was constructed from stratigraphic surfaces obtained as ASCII-format export files from Version 3.1 of the geologic framework model (DTN: MO9901MWDGFM31.000 [DIRS 103769]). This was the most current stratigraphic framework available at the time the mineralogic model was constructed. Since the model construction, a later version of the geologic framework model (DTN: MO0012MWDGFM02.002 [DIRS 153777]) has been issued. The newer geologic framework model made corrections to the thickness of the repository host horizon model layer and to an anomalous flexure in the extreme northern edge of the model. The repository host horizon is not a mineralogic model sequence/layer. Therefore, these changes have little if any, impact on the mineralogic model, and the use of Version 3.1 of the geologic framework model is acceptable.

The water table surface was extracted from Version 3.0 of the geologic framework model (DTN: MO9804MWDGFM03.001 [DIRS 109050]). This surface was the most current at the time of the model construction. The current water table surface (DTN: GS010608312332.001 [DIRS 155307]) is not used, because the surface is shown for illustration purposes only. Therefore, the use of the older surface has no impact to the product output of this report. The creation of the stratigraphic framework required modification of the ASCII-format export files as described in Section 6.2.1.

4.2 CRITERIA

The general requirements to be satisfied by the total system performance assessment (TSPA) are stated in 10 CFR 63.114 [DIRS 156605]. Technical requirements to be satisfied by the TSPA are identified in the *Yucca Mountain Project Requirements Document* (Canori and Leitner 2003 [DIRS 166275]). The acceptance criteria that will be used by the U.S. Nuclear Regulatory Commission (NRC) to determine whether the technical requirements have been met are identified in the *Yucca Mountain Review Plan, Final Report* (YMRP) (NRC 2003 [DIRS 163274]). An evaluation of acceptance criteria against the information in this model report determined that criteria 1.5.3 discussed in the technical work plan should not be addressed and that criteria from Section 2.2.1.3.3 should be addressed. The acceptance criteria identified in Section 2.2.1.3.3.3 of the YMRP are included below. In cases where subsidiary criteria are listed in the YMRP for a given criterion, only the subsidiary criteria addressed by this model report are listed. Where a subcriterion includes several components, only some of those components may be addressed. How these components are addressed is summarized in Section 8.2.

2.2.1.3.3: Quantity and Chemistry of Water Contacting Engineered Barriers and Waste Forms

Acceptance Criterion 1: System Description and Model Integration Are Adequate.

- (5) Sufficient technical bases and justification are provided for TSPA assumptions and approximations for modeling coupled

thermal-hydrologic-mechanical-chemical effects on seepage and flow, the waste package chemical environment, and the chemical environment for radionuclide release. The effects of distribution of flow on the amount of water contacting the engineered barriers and waste forms are consistently addressed, in all relevant abstractions.

- (8) Adequate technical bases are provided, including activities such as independent modeling, laboratory or field data, or sensitivity studies, for inclusion of any thermal-hydrologic-mechanical-chemical couplings and features, events, and processes.

Acceptance Criterion 2: *Data are Sufficient for Model Justification.*

- (1) Geological, hydrological, and geochemical values used in the license application are adequately justified. Adequate description of how the data were used, interpreted, and appropriately synthesized into the parameters is provided.

Acceptance Criterion 3: *Data Uncertainty is Characterized and Propagated Through the Model Abstraction.*

- (1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate.
- (4) Adequate representation of uncertainties in the characteristics of the natural system and engineered materials is provided in parameter development for conceptual models, process-level models, and alternative conceptual models. The U.S. Department of Energy may constrain these uncertainties using sensitivity analyses or conservative limits. For example, the U.S. Department of Energy demonstrates how parameters used to describe flow through the engineered barrier system bound the effects of backfill and excavation-induced changes.

4.3 CODES, STANDARDS, AND REGULATIONS

No codes, standards, or regulations were used in the mineralogic model other than those previously cited in this report.

Table 4-1. Direct Data Input

Data Description	Data Tracking Number (DTN)	DIRS Number
Mineralogy, borehole UE-25 a#1	MO0101XRDDRILC.002, Table S01026_001	DIRS 163795
Mineralogy, borehole UE-25 b#1	MO0101XRDMINAB.001, Table S01023_001	DIRS 163796
Mineralogy, borehole UE-25 p#1	MO0101XRDDRILC.001, Table S01025_002	DIRS 169517
Mineralogy, borehole UE-25 UZ#16	LA000000000086.002, Table S97218_001 LAJC831321AQ98.005, Table S98436_002	DIRS 107144 DIRS 109004
Mineralogy, borehole USW G-1	MO0101XRDMINAB.001, Table S01023_002	DIRS 163796
Mineralogy, borehole USW G-2	MO0101XRDDRILC.002, Table S01026_002	DIRS 163795
Mineralogy, borehole USW G-3/GU-3	MO0101XRDMINAB.001, Tables S01023_003 and S01023_005	DIRS 163796
Mineralogy, borehole USW G-4	MO0101XRDMINAB.001, Table S01023_004	DIRS 163796
Mineralogy, borehole USW H-3	MO0101XRDDRILC.001, Table S01025_003 LADV831321AQ97.001, Table S97466_007	DIRS 169517 DIRS 107142
Mineralogy, borehole USW H-4	MO0101XRDDRILC.001, Table S01025_004	DIRS 169517
Mineralogy, borehole USW H-5	MO0101XRDDRILC.001, Table S01025_005 LADV831321AQ97.007, Table S98070_005 LA9910JC831321.001	DIRS 169517 DIRS 113499 DIRS 113496
Mineralogy, borehole USW H-6	MO0106XRDDRILC.003, Table S01074_001	DIRS 163797
Mineralogy, borehole USW NRG-6	LADV831321AQ97.001, Table S97466_001 LASC831321AQ96.002, Table S97226_001	DIRS 107142 DIRS 109042
Mineralogy, borehole USW NRG-7a	LADV831321AQ97.001, Table S97466_002	DIRS 107142
Mineralogy, borehole USW SD-6	LASC831321AQ98.003, Table S98170_001 LADV831321AQ99.001, Table S99203_001	DIRS 109043 DIRS 109044
Mineralogy, borehole USW SD-7	LADV831321AQ97.001, Table S97466_003 LAJC831321AQ98.005, Table S98436_001	DIRS 107142 DIRS 109004
Mineralogy, borehole USW SD-9	LADV831321AQ97.001, Table S97466_004 LAJC831321AQ98.005, Table S98436_004	DIRS 107142 DIRS 109004
Mineralogy, borehole USW SD-12	LADV831321AQ97.001, Table S97466_005 LAJC831321AQ98.005, Table S98436_003	DIRS 107142 DIRS 109004
Mineralogy, borehole USW UZ-14	LADV831321AQ97.001, Table S97466_006 LASC831321AQ96.002, Table S97226_002	DIRS 107142 DIRS 109042
Mineralogy, borehole USW UZN-31	LASL831322AQ97.001, Table S97601_005	DIRS 109045
Mineralogy, borehole USW UZN-32	LASL831322AQ97.001, Table S97601_006	DIRS 109045
Mineralogy, borehole USW WT-1	MO0101XRDDRILC.001, Table S01025_006	DIRS 169517
Mineralogy, borehole USW WT-2	MO0101XRDDRILC.001, Table S01025_007	DIRS 169517

Table 4-1. Direct Data Input (Continued)

Data Description	Data Tracking Number (DTN)	DIRS Number
Mineralogy, borehole USW WT-24	LASC831321AQ98.001, Table S98084_001 LADV831321AQ99.001, Table S99203_002	DIRS 109047 DIRS 109044
Stratigraphic surfaces, ASCII export files, GFM3.1	MO9901MWDGFM31.000	DIRS 103769
Water table from GFM3.0	MO9804MWDGFM03.001	DIRS 109050

NOTES: For simplification, a shortened version of the borehole identifier is used when referring to boreholes in the text, figures, and tables (e.g., "UE-25 a#1" is simplified to "a#1").

DTNs LA9910JC831321.001 [DIRS 113496], MO0101XRDDRILC.001 [DIRS 169517], LADV831321AQ97.001 [DIRS 107142], and LADV831321AQ97.007 [DIRS 113499] are qualified in Appendices A-C of this report.

DIRS=Document Input Reference System; GFM=geologic framework model

Source: DTN: MO9901MWDGFM31.000 (DIRS 103769). Output DTN: LA9908JC831321.001.

Figure 4-1. Locations of Boreholes Used in Mineralogic Model 3.0

5. ASSUMPTIONS

The assumption used to build the mineralogic model is methodological and geological; therefore, it is an inherent part of the discussion in Section 6. The assumption for model development is presented here.

Mineral abundances at one location within a model stratigraphic unit have a value that is correlated with a spatially nearby value. This assumption is based on three geologic principles. Vertical succession of rock layers can be established using the Principles of Superposition and Original Horizontality (Jackson 1997 [DIRS 109119], pp. 361 and 362). These two principles establish the fact that geologic depositional events result in a succession of horizontal layers of sediments stacked one upon another. In the case of Yucca Mountain, successive volcanic eruptions deposited a succession of volcanic rocks. Vertical succession allows the separation of the average values of mineral analyses based on model layers or sequences. The Principle of Original Lateral Continuity (Jackson 1997 [DIRS 109119], p.361) is applied not only in the construction of the model, but also in the validation. This principle states that sediment will be deposited in a layer that not only is flat, but also extends for a considerable distance in all directions. In other words, the layer is laterally continuous. Vertical continuity within each layer or sequence allows the average mineral abundance values to be determined by layers or sequences. No additional confirmation of this assumption is required.

This assumption is the basis for the following methodological approaches:

- Modeling in stratigraphic coordinates (Section 6.2.3)
- Calculation of mineral distributions using an inverse distance weighting method (Section 6.2.4)
- Model validation by corroboration with independent data (Section 7).

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6. MODEL DISCUSSION

6.1 CHANGES FROM PREVIOUS VERSIONS TO VERSION 3.0

Version 3.0 of the mineralogic model incorporates several enhancements, which improve the model's ability to represent the site mineralogy. Version 3.0 incorporates stratigraphy from geologic framework model Version 3.1 and is constructed on a 200-ft (61-m) north-south and east-west grid. Version 3.0 represents a complete revision of earlier versions, and the resulting model supersedes all previous versions. This version provides values for the entire region of geologic framework model Version 3.1: 547,000–584,000 ft (166,726–178,003 m) easting and 738,000–787,000 ft (224,942–239,878 m) northing, Nevada State Plane coordinates.

A synopsis of changes between versions of the mineralogic model is as follows:

- **Preliminary mineralogic model**—The initial model was developed in a stratigraphic framework taken from integrated site model Version 1.0.
- **Mineralogic model Version 1.0**—The stratigraphic framework was upgraded to Version 2.0 of the integrated site model. New mineralogic data from boreholes H-3, NRG-6, NRG-7a, SD-7, SD-9, SD-12, UZ-14, and UZN-32 were incorporated.
- **Mineralogic model Version 1.1**—New mineralogic data from borehole WT-24 were incorporated.
- **Mineralogic model Version 2.0**—The stratigraphic framework was upgraded to Version 3.0 of the geologic framework model. The grid resolution was refined from 800 ft to 200 ft (244 m to 61 m). Borehole H-6 was incorporated. New data from boreholes SD-6, SD-7, SD-12, UZ#16, and WT-24 were included. The modeled mineral classes were expanded from 6 to 10. Mineralogic modeling was conducted in stratigraphic coordinates (see Section 6.2.3 for further explanation). The stratigraphic framework used for the mineralogic framework was simplified from 31 to 22 sequences.
- **Mineralogic model Version 3.0**—The stratigraphic framework was upgraded to Version 3.1 of the geologic framework model. New data from boreholes SD-6 and WT-24 were included. Tptpv3–Tptpv2 sequence was subdivided into two layers. The area covered by the mineralogic model was expanded to include the entire area of Version 3.1 of the geologic framework model. The procedure for mineralogic modeling in stratigraphic coordinates was significantly improved, resulting in a more internally consistent representation of mineralogy and stratigraphy.

An additional layer was created in Version 3.0 of the mineralogic model by subdividing the Tptpv3–Tptpv2 sequence (sequence 13) into two layers of equal thickness, partly to better represent the zone of intense smectite and zeolite alteration at the boundary between Tptpln (sequence 14) and Tptpv3. In some places, samples from this altered zone occur at the base of Tptpln as defined in Version 3.1 of the geologic framework model, and these samples were adjusted in elevation to fall in the upper part of Tptpv3.

The areal boundaries of Version 3.0 of the mineralogic model were extended to cover the entire region covered by Version 3.1 of the geologic framework model. Although this extension includes areas where borehole data are sparse, project personnel requested that the mineralogic model be available for the entire region. The region of better-supported mineralogic values is identified within this larger region.

The mineralogic data for Version 3.0 of the mineralogic model and the previous versions were obtained from quantitative XRD analyses of cores and cuttings from boreholes at Yucca Mountain. Inclusion of the new data from boreholes SD-6 and WT-24 has resulted in a significant improvement of the model because these boreholes provide information from the northern and western parts of the site, where boreholes are scarce or the samples available are largely cuttings.

6.2 METHODOLOGY

The mineralogic model is a static representational model based on geologic principles and constructed with industry standard software. Alternative models and the use of alternate conceptual methodologies were determined in the technical work plan (BSC 2004 [DIRS 169635], Section 2.2.2) to be not applicable and, therefore, not considered. The methodology used to calculate the mineral distributions, an inverse-distance-weighting function, was considered adequate for the intended use of the model. The benefits and limitations of this function are discussed in Section 6.2.4. Similarly, no literature searches were done, and other, additional background information is not provided in this report.

The basic components of the 3-D mineralogic model are a stratigraphic framework, mineralogic data from boreholes, and 3-D geologic modeling software. The stratigraphic framework was obtained from Version 3.1 of the geologic framework model (DTN: MO9901MWDGFM31.000). The sources of mineralogic data (listed in Table 4-1) contain quantitative XRD data from boreholes. The 3-D geologic modeling was conducted with the software STRATAMODEL. STRATAMODEL performs distance-weighted interpolations of borehole data within stratigraphic units specified by the framework to produce a volumetric distribution of the rock properties associated with each stratigraphic horizon.

The modeling process consists of four sequential steps:

1. Modification of ASCII-format export files from Version 3.1 of the geologic framework model: Missing values near faults were supplied by interpolation.
2. Creation of the stratigraphic framework: Stratigraphic surfaces from Version 3.1 of the geologic framework model were joined in three dimensions to create a stratigraphic framework.
3. Incorporation of mineralogic data from specific boreholes: Quantitative XRD analyses of mineral abundance as a function of geographic position (borehole location) and sample elevation were placed within the 3-D stratigraphic framework.

4. Calculation of mineralogic distribution data for the entire 3-D model with the use of a deterministic, inverse-distance-weighting function: Measured mineralogic data at each borehole were used to predict mineral abundances at all locations in the model.

Each modeling step is documented in a scientific notebook (Carey 1999 [DIRS 138525]) and is discussed in detail in the following subsections.

6.2.1 Modification of Version 3.1 of the Geologic Framework Model Files

The Version 3.1 geologic framework model ASCII-format export files used to create the stratigraphic framework for the mineralogic model lack elevation values at some grid nodes and along fault traces. These omissions occur only in the ASCII-format export files, not in Version 3.1 of the geologic framework model. Therefore, before the creation of the stratigraphic framework, the Version 3.1 geologic framework model ASCII-format files were modified to fill in values near major faults.

To create the stratigraphic framework, STRATAMODEL requires values for all grid nodes. In order to provide the missing values at these points in a controlled and reasonable manner, elevations for undefined grid nodes were interpolated from adjacent grid points by means of the Stratamap function in STRATAMODEL. For example, if the values adjacent to an undefined grid node were 600 m and 700 m, the interpolated value would be 650 m. Each Version 3.1 geologic framework model surface included several thousand extrapolated values per grid with a total of 45,756 grid nodes (186 by 246 nodes). The operation of the Stratamap function was checked to ensure that the elevations of the original data points had not been adjusted and that the interpolated values accurately represented the faulted regions. The checks were done numerically, by visual comparison of the grids, and by checking to see that contacts of Version 3.1 of the geologic framework model within boreholes, as represented within STRATAMODEL, were correct. The interpolated data are available in product output DTN: LA9908JC831321.001.

6.2.2 Creation of Stratigraphic Framework

The stratigraphic framework for the mineralogic model was created from the Version 3.1 geologic framework model stratigraphy Table 1-1. Version 3.1 of the geologic framework model results was obtained as exported ASCII-format files with data listed at the 200-ft (61-m) grid spacings. The grid used in the mineralogic model has the same 200-ft (61-m) grid spacing as Version 3.1 of the geologic framework model and consists of 186 by 246 grid nodes. The areal extent is 65.7 sq. mi. (170 km²).

The stratigraphic framework for the mineralogic model was created with a subset of 22 of the 52 stratigraphic surfaces in Version 3.1 of the geologic framework model. An example of a Version 3.1 geologic framework model surface, that of the Tiva Canyon Tuff vitric zone nonwelded subzone (Tpcpv1), is illustrated in Figure 6-1 (elevations in meters are shown in the color key). The surface is notable for the fine resolution of topography, including faults such as the Solitario Canyon fault to the west. The 22 stratigraphic surfaces were linked via STRATAMODEL into a stratigraphic framework to define 22 volumetric *sequences*, as shown in Table 1-1 and illustrated in Figures 6-2 and 6-3. (Note: Figures 6-2 and 6-3 can be used as a

guide for locating the position of sequences in other figures.) Many of the sequences in Version 3.0 of the mineralogic model incorporate several stratigraphic units as shown in Table 1-1 and Figure 6-4 in which each sequence is labeled with the units forming its upper and lower surfaces.

The modeling in the mineralogic model was conducted in stratigraphic coordinates so that the mineralogic data were constrained to their proper stratigraphic units. As a result, mineralogic and stratigraphic data are consistent and all mineral data are located in the correct stratigraphic unit. A detailed comparison of Version 3.1 geologic framework model stratigraphic assignments versus mineralogy for each of the borehole samples was conducted for every observation used in the mineralogic model. This analysis was based on mineralogic composition of the borehole sample. In several places, this analysis resulted in reassignment of samples to the mineralogically correct stratigraphic unit. As a result, this version of the mineralogic model is more consistent with the geologic framework model than previous versions.

The 22 sequences listed in Table 1-1 were defined to keep the mineralogic model as simple as possible and to accurately define zeolitic, vitric, and repository host units at Yucca Mountain. Sequence 22, the uppermost sequence, includes all stratigraphic units above Tpcpv because these units share a common devitrification mineralogy dominated by feldspar plus silica minerals. The next sequence (sequence 21) consists of a Tiva Canyon vitrophyre unit composed of two subzones (Tpcpv3 and Tpcpv2), combined in the mineralogic model because they share a similar abundance of welded glass. The hydrogeologic Paintbrush nonwelded unit (PTn) is represented by sequence 20, which extends from the nonwelded subzone of the lower vitric zone of the Tiva Canyon Tuff to the upper vitric zone of the Topopah Spring Tuff. It includes six stratigraphic units occurring between the top of Tpcpv1 and the base of Tptrv2. These six units are similar in having variable proportions of glass plus smectite that cannot be captured within the larger scale of the mineralogic model; therefore, these six units were combined into sequence 20. The remaining Topopah Spring Tuff below sequence 20 is represented as eight sequences in the mineralogic model, representing the upper vitrophyre, the upper quartz-latite to rhyolite transition, the four lithophysal and nonlithophysal units, and units of welded and nonwelded glass at the base. The welded glass unit at the base, which includes Tptpv3 and Tptpv2, is represented as a single sequence in the mineralogic model (sequence 13). However, the sequence is subdivided into two equal-thickness layers. As described in Section 6.1, the uppermost layer was used, in part, to represent the “altered zone,” or region of intense smectite and zeolite alteration that occurs in many boreholes at the contact of Tptpln and Tptpv3. Stratigraphic units Tptpv1 and Tpbt1 were combined into a single sequence in the mineralogic model (sequence 12) because of their similar character in many boreholes and because Tpbt1 is generally thin and not well represented in the mineralogic data.

The Calico Hills Formation and the underlying bedded tuff are represented by sequences 11 and 10, respectively. The Calico Hills Formation was further subdivided into four layers. The layers have distinct mineralogic abundances in the mineralogic model and were created to allow modeling of variable zeolitization with depth in the Calico Hills Formation.

Output DTN: LA9908JC831321.001.

Figure 6-1. Shaded Relief View of Tpcpv1, Nonwelded Subzone of Vitric Zone of Tiva Canyon Tuff

000130DC_MM_05.ai

Output DTN: LA9908JC831321.001.

Figure 6-2. North-South Cross Section Through the Repository, Illustrating Sequences Used in Version 3.0 of the Mineralogic Model, Excluding the Paleozoic Sequence

Output DTN: LA9908JC831321.001.

Figure 6-3. East-West Cross Section Through the Repository, Illustrating Sequences Used in Version 3.0 of the Mineralogic Model, Excluding the Paleozoic Sequence

6-8

In Version 3.1 of the geologic framework model, the Prow Pass Tuff, Bullfrog Tuff, and Tram Tuff are each represented by six stratigraphic units (a total of 18 units). In the mineralogic model, these 18 units were combined into a total of four zeolitic or vitric and three devitrified nonzeolitic sequences. These sequences reflect the characteristic alternation at this depth between units that can be readily zeolitized and those that have devitrified to feldspar plus silica minerals and in which zeolitization does not occur. The uppermost, first zeolitic sequence is defined by the upper vitric subunit of the Prow Pass Tuff (Tcpu_v). The word “vitric” and the symbol “v” are used in Version 3.1 of the geologic framework model to describe originally vitric units, even when these units may now be zeolitic.

The upper vitric or zeolitic sequence in the Prow Pass Tuff is followed by a nonzeolitic sequence representing the devitrified center of the Prow Pass Tuff (Tcpu_c–Tcpu_l). It includes the upper crystalline, middle densely welded, and lower crystalline subunits. The second zeolitic sequence includes the lower vitric portion of the Prow Pass Tuff (Tcpu_v), the bedded tuff of the Prow Pass Tuff (Tcpu_b), and the upper vitric subunit of the Bullfrog Tuff (Tcbu_v). This sequence is identified as Tcpu_v–Tcbu_v. The second nonzeolitic sequence consists of the devitrified Bullfrog Tuff and combines three subunits (Tcbu_c, Tcbu_{md}, and Tcbu_l). The third zeolitic sequence, labeled Tcbu_v–Tctu_v, includes the lower vitric and bedded tuff of the Bullfrog Tuff in addition to the upper vitric unit of the Tram Tuff. The final nonzeolitic sequence, Tctu_c–Tctu_l, includes the devitrified center of the Tram Tuff (Tctu_c, Tctu_{md}, and Tctu_l). The final zeolitic sequence is the base of the Tram Tuff (Tctu_v and Tctu_b). Units older than the Tram Tuff are undifferentiated as Tund and have a variable zeolitic character.

The lowermost sequence in the mineralogic model is the Paleozoic sequence, making a total of 22 sequences. However, there are 26 distinct layers in the mineralogic model, including the subdivision of Tptpv3–Tptpv2 into two layers and the Calico Hills Formation into four layers. The model contains 45,756 (186 by 246) grid nodes, which with 26 layers brings the total number of cells in the model to 1,189,656. Each cell contains 16 values, including percentage abundance for 10 mineral groups listed in Section 6.2.3, cell volume, cell location (x, y), elevation (z), sequence number, and layer number. Any cell in the model can be queried to obtain any of these values. Figure 6-2 illustrates a north-south cross section and Figure 6-3 illustrates an east-west cross section through Yucca Mountain, showing the distributions and thicknesses of the sequences used as the framework of the mineralogic model (Table 1-1).

To assess the differences between the geologic framework model Version 3.1 stratigraphy and the Mineralogic Model 3.0 sequences a comparison was made at all of the boreholes from which mineralogic data were obtained for the model. Because the boreholes are not located precisely at grid nodes, some differences between the predicted and actual elevations of contacts were expected. There is no impact to the mineralogic model, because mineralogic composition was the primary parameter used to adjust stratigraphic location of sample values. The elevations of the contacts between stratigraphic units were found to be within 3.3 ft (1 m) to 49 ft (15 m) of the Version 3.1 geologic framework model values detailed in a scientific notebook (Carey 1999 [DIRS 138525], pp. 10 to 12, 199 to 221). These relatively low differences in contact elevations indicate a good comparison between the stratigraphy and mineralogic model sequences.

6.2.3 Incorporation of Mineralogic Data from Boreholes

Mineralogic data, including core samples and cuttings, are available for 24 boreholes in the form of data files providing the mineralogy as a function of sample depth or elevation. The cuttings were used in the mineralogic model based on the assumption presented in Section 5. Elevations assigned to cutting samples were the midpoints of the depth ranges from which the cuttings were collected. The borehole locations are shown on the map in Figure 6-5. Ten minerals groups or classes were incorporated in Version 3.0 of the mineralogic model:

- Smectite + illite
- Sorptive zeolites (the sum of clinoptilolite, heulandite, mordenite, chabazite, erionite, and stellerite)
- Tridymite
- Cristobalite + opal-CT
- Quartz
- Feldspars
- Volcanic glass
- Nonsorptive zeolite (analcime)
- Mica
- Calcite.

The mineralogy (weight percent present for each of the 10 mineral groups), stratigraphy, and elevations of the samples collected from each of the 24 boreholes included in the mineralogic model are provided in a STRATAMODEL data input file in product output DTN: LA9908JC831321.001. Because boreholes UZN-31 and UZN-32 are separated by only 74 ft (23 m), the mineralogical data from these boreholes were combined into a single borehole file (Carey 1999 [DIRS 138525], pp. 187 to 188). The model grid spacing is 200 ft., which is a larger distance than the distance between the two boreholes. Therefore, the data from the two boreholes can be combined without impact to the mineralogic model. A total of 23 borehole files were used in Version 3.0 of the mineralogic model.

The borehole data files were imported into a process that involved mapping the elevations of the mineralogic samples onto the stratigraphic elevations obtained from Version 3.1 of the geologic framework model. The mineralogic model was constructed with the use of the numeric mean of all of the mineralogic data within a given sequence at each borehole. Inevitably, there were some discrepancies between elevations in the mineralogic data and the elevations predicted by STRATAMODEL and Version 3.1 of the geologic framework model. These discrepancies included mineralogic data from a given stratigraphic unit being assigned to the incorrect sequence in STRATAMODEL.

There were three causes of these discrepancies:

1. The boreholes are not located at grid nodes. The elevations calculated by STRATAMODEL for the stratigraphic contacts at the boreholes are based on an average of the nearest four grid nodes. The calculated value was in error where the average value differed from the true value because of uneven topography near the borehole. These occurrences are identified in Appendix E as “too close to boundary.”
2. There are regions of some stratigraphic units where Version 3.1 of the geologic framework model does not precisely reproduce observed borehole contacts. In addition, three boreholes that were used in the mineralogic model were not used in the construction of Version 3.1 of the geologic framework model (a#1, UZN-31, and UZN-32) and one borehole in which only part of the stratigraphy was used (UZ-14). The geologic framework model stratigraphy provides contact information only for units below Tptpv2 in UZ-14. These discrepancies are similar in character to discrepancies described in No. 1, and are also identified in Appendix E as “too close to boundary.”
3. There were a few places in which STRATAMODEL predicted the absence of a sequence at a particular borehole. This occurred where the surface defining the sequence was absent. For example, at borehole H-4, Tpcpv3 is absent; therefore, the entire sequence Tpcpv3–Tpcpv2 was not present in the mineralogic model at H-4. There was also one location (WT-1) in which faulting caused the apparent removal of sequences in the mineralogic model. These discrepancies are identified in Appendix E as “removed; unit X not present in mineralogic model,” in which case the mineralogic sample was removed from the model.

In correcting for these discrepancies, there are two possible approaches: (1) assume the correct elevations but possibly incorrect assignments of mineralogy to stratigraphy, or (2) assume the correct mineralogy associated with a mineral-stratigraphic unit but possibly incorrect elevations for the mineralogic data. The latter approach is known as modeling in stratigraphic coordinates and is based on the geologic principles presented in Section 5. The geologic principles result in the concept of vertical succession whereby mineralogic composition can be used as the basis for forming model sequences. This approach was used in the construction of Version 3.0 of the mineralogic model. The advantages of the stratigraphic coordinate system are that all mineralogic data are correctly associated with a sequence and that the stratigraphic relationship of data from differing boreholes is preserved. Therefore, mineralogic data were assigned to the correct sequence by small adjustments to apparent elevations, where needed.

In addition, a detailed comparison of mineralogy and stratigraphy revealed some inconsistencies between stratigraphic and mineralogic assignments. For example, a sample near a contact, with mineralogy characteristic of a devitrified tuff, may have been placed in a vitric/zeolitic tuff when the data files were imported into STRATAMODEL. In this case, the sample elevation was adjusted to assign the mineralogy to the adjacent devitrified stratigraphic sequence.

The details of the adjustments for each borehole are provided in Appendix E, Table E-1.

6.2.4 Calculation of Mineral Distributions

The final stage of the mineralogic model construction in STRATAMODEL is the distribution of the mineralogic data in three dimensions using the geologic principles presented in Section 5. This estimation can be accomplished by a number of methods, including geometric, distance-weighting, and geostatistical methods. In Version 3.0 of the mineralogic model, a distance-weighting method was used to estimate mineral distributions. The geologic Principle of Lateral Continuity allows for this type of estimation (Section 5). Geostatistical calculations were not conducted in this version of the model, but the data in Version 3.0 of the mineralogic model could be used for such calculations to provide a statistical framework for transport calculations.

The 3-D mineral distributions were calculated using an inverse-distance-weighting function that operates solely within sequences (i.e., mineral abundances in a given sequence were calculated solely from mineralogic data within that sequence):

$$W(r,R) = (1-r/R)^2(R/r)^X \quad (\text{Eq. 6-1})$$

where

W = weighting function

r = distance between the interpolated point and a known value

R = search radius

X = power factor.

This weighting function is provided by the STRATAMODEL software and yields, essentially, a $1/r^X$ weighting of the mineralogic data. At small values of r, the weighting function is approximately equal to $(R/r)^X$, which is the same as a simple inverse weighting function, $(1/r)^X$ multiplied by a normalization factor, R^X . The advantage of the STRATAMODEL function is apparent at values of r that approach R: the STRATAMODEL weighting function goes to 0, while a simple inverse weighting function retains non-zero weighting at R. In other words, the STRATAMODEL weighting function provides a smooth transition in weighting between values of r less than R to values greater than R, but the simple inverse weighting function yields an abrupt transition from non-zero weights ($r < R$) to zero weights ($r > R$). In calculating the mineral abundance at a specified location, the weights are normalized so that the sum of the weight is equal to 1.

In Version 3.0 of the mineralogic model, a power factor of $X=4$ was used. The choice of $X=4$ was made based on an analysis of the mineralogic data as documented in a scientific notebook (Carey 1999 [DIRS 138525], pp. 222 to 246). Three possible choices were investigated in detail: $X=2$, $X=4$, and $X=6$. The advantage of $X=4$ was most apparent in the analysis of the predicted zeolite distribution in the Calico Hills Formation (sequence 11; see Figures 6-11 through 6-15). A choice of $X=2$ allowed too much influence from distant boreholes such that substantial non-zero values of zeolite were predicted in the southwest region of the model. Such predictions differed from a basic mineralogic-data analysis, which indicated that there should be consistently low values of zeolite in the southwest. A choice of $X=6$ yielded low predicted values of zeolite in the southwest but also predicted very localized control of mineralogy. For example, the transition zone between zeolitic and non-zeolitic Calico Hills Formation was very narrow. This high degree of local control was not consistent with the mineralogic analysis. The choice of $X=4$

allowed for sufficient local control to yield low abundances of zeolite in the southwest, while avoiding severe localization of predicted values.

The search radius, *R*, is also an important parameter and was set at 26,247 ft (8,000 m) to allow the mineralogic data to fill all of the model space in the Version 3.1 geologic framework model.

6.3 RESULTS AND DISCUSSION

The results for Version 3.0 of the mineralogic model are illustrated in cross sections and in map views of individual surfaces. Black areas on the map view figures indicate regions where a sequence is missing due to faulting or erosion. The location and extent of the north-south and east-west cross sections are shown in Figure 6-5 in relation to the repository. The mineralogic stratigraphy is labeled on cross sections provided in Figures 6-2 and 6-3.

6.3.1 Model Limits and Illustration of Results

In Figures 6-5 to 6-26 a color-coded key lists mineral abundance values in weight percent. Figure 6-5 shows the distribution of boreholes on which the mineralogic model is based. Colors in the background to this figure are keyed to the abundance of volcanic glass in sequence 20 (PTn unit). The sources of the mineralogic data are confined to the central portion of the model area; the mineralogic model results are poorly constrained outside of the subregion indicated by the black box in Figure 6-5. Also shown in Figure 6-5 are regions in which sequence 20 is absent as indicated by linear black areas. These regions occur in linear zones near faults, where the mineralogic model resolution of fault geometry is poor. Accurate mineralogic results should not be expected adjacent to faults. Sequence 20 is also absent in broad areas where it has been removed by erosion as indicated by broad black areas. Figure 6-5 illustrates the relatively small, central area in which mineralogic data are abundant, relative to the broader extent of the geologic framework model. This limitation should be kept in mind in considering the visualizations generated from the mineralogic model.

6.3.2 Sorptive Zeolite Distribution

Zeolite abundance is shown in Figure 6-6 as a range of colors from dark blue (0 percent) to red (20 percent or greater). Sorptive zeolites at Yucca Mountain play an important role in models of radionuclide retardation and thermohydrology and in repository design. Sorptive zeolites occur in variable amounts below the repository host horizon in four distinct stratigraphic groups separated by nonzeolitic intervals. The repository host horizon, as shown in Table 1-1, includes part of sequence 17 and all of sequences 14, 15, and 16. Zeolite distributions are displayed in Figures 6-7 and 6-8. Cross-sectional keys to sequence names and numbers are provided on Figures 6-2 and 6-3. The distribution of sorptive zeolites is closely related to the internal stratigraphy of the tuffs (also see Section 6.2.2). Sorptive zeolites occur within the upper vitric, basal vitric, and basal bedded tuff units of each formation of the Crater Flat Group (Tram Tuff, Bullfrog Tuff, and Prow Pass Tuff). The devitrified center of each formation in the Crater Flat Group lacks zeolites. The net result is a sequence of alternating zeolitic and nonzeolitic rocks. The highest stratigraphic level at which extensive zeolitization of vitric units occurs varies across the geographic extent of the mineralogic model. In the south and west, the first occurrence of abundant zeolites below the repository host horizon is in the lower vitric unit of the Prow Pass

Tuff (sequence 7). Toward the north and east, the first occurrence of abundant zeolites extends into the bedded tuff below the Calico Hills Formation (sequence 10), into the Calico Hills Formation (sequence 11), and ultimately to the lower vitric units of the Topopah Spring Tuff (Ttpv1, Ttpv2, and Ttpv3; sequences 12 and 13) (Figure 6-7). The position of the water table relative to zeolitized rocks is shown in Figures 6-9 and 6-10. These cross sections were truncated at the water table, which rises in elevation toward the north and the west. In the north-south cross section, zeolite-rich rocks separate the proposed repository host horizon (sequences 14, 15, 16 and part of 17) from the water table at all locations (Figure 6-9). Note the common occurrence of moderate-abundance zeolite units at the tops of the zeolite-rich units. In the east-west cross section, zeolites also occur between the repository host horizon and the water table, except in several down-dropped blocks to the east of the repository. These zeolite-free regions develop where faulting drops the Topopah Spring Tuff below the water table.

The progressive development of zeolitization from northeast to southwest is illustrated in a series of map views through the Calico Hills Formation (Tac; Sequence 11) and into the upper vitric Prow Pass Tuff (Tcupv; Sequence 9); see Figures 6-11 through 6-16. The transition zone between regions of high (greater than 5 percent) and low (0 to 5 percent) zeolite abundance is an important feature to model accurately because it may be a zone of enhanced radionuclide sorption below the repository. The presence of the zeolites clinoptilolite and mordenite is associated with increased radionuclide sorptive capacity (Vaniman and Bish 1995 [DIRS 101496], pp. 537 to 538). However, the decreased permeability associated with zeolitization of moderately welded to nonwelded vitric tuff (Loeven 1993 [DIRS 101258], Table 6) may inhibit interaction between fluid-borne radionuclides and zeolites in the rock matrix. Within the transition zone, zeolites are present but the rock should be more permeable than completely zeolitized rock would be. This higher permeability may therefore allow the radionuclides better access to sorptive minerals.

The transition zone is not easily characterized. There is a striking reduction in zeolite abundance from east to west in the upper half of the Calico Hills Formation, across a north-south boundary that is well defined in the region of boreholes WT-2 and UZ#16 (Figures 6-11 and 6-12). The location and abruptness of this transition are very poorly constrained to the north and west of H-5 and moderately constrained to the south between WT-1 and G-3. In the lower half of the Calico Hills Formation (sequence 11), extensive zeolitization occurs in borehole SD-7 and moderate zeolitization occurs in SD-12 and H-6 (Figures 6-13 and 6-14). This leads to a complex transition zone, in which a high-zeolite “peninsula” extends westward from SD-7. The detailed sampling of SD-7 and SD-12 suggests a transition zone that may be quite heterogeneous both vertically and horizontally. In SD-7, sills of more than 25 percent zeolite alternate with largely vitric samples in the lower half of the Calico Hills Formation, suggesting an interfingering transition zone. In contrast, SD-12 shows a rather uniform development of increasing zeolitization with depth. These data indicate that the general reduction in zeolitization to the southwest may be strongly overprinted by patchy intervals of highly zeolitized Calico Hills Formation.

000130DC_MM_08.ai

Output DTN: LA9908JC831321.001.

Figure 6-5. Map View of Volcanic Glass Distribution in "PTn" Unit, Tpcpv1–Tptrv2 (Sequence 20) for Entire Version 3.0 of the Mineralogic Model

Output DTN: LA9908JC831321.001.

Figure 6-6. Zeolite Distribution in North-South and East-West Cross Sections Through Center of Repository Block

Output DTN: LA9908JC831321.001.

Figure 6-7. Zeolite Distribution in North-South Cross Section Through the Repository Block

Output DTN: LA9908JC831321.001.

Figure 6-8. Zeolite Distribution in East-West Cross Section Through the Repository Block

Output DTN: LA9908JC831321.001.

Figure 6-9. Zeolite Distribution in North-South Cross Section Through the Repository Block and Above the Water Table

Output DTN: LA9908JC831321.001.

Figure 6-10. Zeolite Distribution in East-West Cross Section Through Repository Block and Above Water Table

The bedded tuff below the Calico Hills Formation (sequence 10, Tacbt) is zeolitized in boreholes SD-7, WT-2, SD-12, and H-5 (Figure 6-15). The transition zone to low zeolite abundance is confined to the southwest, around SD-6, H-3, and G-3. However, SD-6 contains about 15 percent smectite and perhaps should be viewed as a part of the zone of abundant sorptive mineralogy. There are no data for this unit at H-6.

The upper vitric Prow Pass Tuff (sequence 9, Tcpu) has a zeolite distribution similar to that of Tacbt, except that there are data at H-6 with abundant zeolites (Figure 6-16). In addition, SD-6 lacks both smectite and zeolites in sequence 9.

Zeolitization is complete throughout the mineralogic model in sequence 7, which includes the lower vitric and bedded tuffs of the Prow Pass Tuff and the upper vitric unit of the Bullfrog Tuff.

In general, the mineralogic model represents the transition zone as a rather sharp boundary modified by the local effects of particular boreholes. The southwest region as a whole is characterized by low zeolite abundances (less than 10 percent). Values near 0 percent in the Calico Hills Formation (sequence 11) are restricted to regions adjacent to nonzeolite-bearing boreholes such as G-3, H-3, and H-5. There is little control on the extrapolation of zeolite data in the northeast, northwest, and southeast regions of the mineralogic model. The predicted values of extensive zeolitization in the north are strongly influenced by boreholes such as G-2 and G-1. Either of the regions distant from these boreholes may be characterized by more moderate values of zeolitization.

The most abundant zeolites at Yucca Mountain are clinoptilolite and mordenite (Bish and Chipera 1989 [DIRS 101195], Appendix A). Major, stratigraphically continuous intervals of clinoptilolite occur in all boreholes, from about 330 ft to 500 ft (100 m to 150 m) above the water table to about 1,600 ft (500 m) below the water table. Heulandite is fairly common at Yucca Mountain but is combined with clinoptilolite in the XRD analyses because the two minerals have the same crystal structure. Mordenite often occurs along with clinoptilolite but is less abundant in boreholes to the south; for example, it is virtually absent in bulk-rock samples from borehole G-3. The nonsorptive zeolite analcime occurs as a higher temperature alteration product at greater depths, and its occurrence deepens stratigraphically from the Prow Pass Tuff in G-2 to the Tram Tuff in G-1 and older lavas in G-3. Except in the north, the depths of analcime occurrence are so great that little interaction with migrating radioactive waste is likely.

Until core samples from borehole SD-7 were analyzed, chabazite was known only as a rare zeolite at Yucca Mountain. However, samples from the Calico Hills Formation (sequence 11) in SD-7 contained significant amounts of chabazite (up to 9 percent) in an approximately 46-ft- (14-m-) thick zeolitized interval consisting principally of clinoptilolite + chabazite, overlying a clinoptilolite + mordenite zone (DTN: LADV831321AQ97.001 [DIRS 107142]). This occurrence indicates that the sorptive zeolite assemblages may be more complex at the southern end of the exploratory block than previously predicted.

Output: DTN: LA9908JC831321.001.

Figure 6-11. Zeolite Distribution in Map View of Upper Layer (Layer 14) of Calico Hills Formation (Tac, Sequence 11)

Output: DTN: LA9908JC831321.001.

Figure 6-12. Zeolite Distribution in Map View of Middle-Upper Layer (Layer 13) of Calico Hills Formation (Tac, Sequence 11)

Output: DTN: LA9908JC831321.001.

Figure 6-13. Zeolite Distribution in Map View of Middle-Lower Layer (Layer 12) of Calico Hills Formation (Tac, Sequence 11)

000130DC_MM_17.ai

Output: DTN: LA9908JC831321.001.

Figure 6-14. Zeolite Distribution in Map View of Lower Layer (Layer 11) of Calico Hills Formation (Tac, Sequence 11)

Output: DTN: LA9908JC831321.001.

Figure 6-15. Zeolite Distribution in Map View of Bedded Tuff of Calico Hills Formation (Tacbt, Sequence 10)

Output: DTN: LA9908JC831321.001

Figure 6-16. Zeolite Distribution in Map View of Upper Vitric Zone of Prow Pass Tuff (Tcuv, Sequence 9)

In addition to clinoptilolite, mordenite, analcime, and minor chabazite, localized occurrences of a few other zeolites were found at Yucca Mountain. Stellerite is common in fractures of the Topopah Spring Tuff and is particularly common in both the fractures and matrix of the Topopah Spring Tuff in borehole UZ#16. Stellerite extends into the lower devitrified portion of the Topopah Spring Tuff (sequences 14 and 15) in borehole UZ-14, spanning an interval in which perched water was observed during drilling. Phillipsite is a rare zeolite at Yucca Mountain that was found only in the altered zone above the water table at the top of the basal vitrophyre of the Topopah Spring Tuff (Carlos et al. 1995 [DIRS 101326], pp. 39, 47). Laumontite occurs in very small amounts (less than 4 percent) in deep, altered tuffs in borehole p#1 and perhaps in G-1 (Bish and Chipera 1989 [DIRS 101195]). Phillipsite and laumontite are so rare that it was not necessary to consider them in the estimation of zeolite volume for the mineralogic model.

Erionite is another rare zeolite at Yucca Mountain and was at first observed only in the altered zone at the top of the Topopah Spring Tuff basal vitrophyre. However, it has since been found in significant quantities (up to 34 percent) in drill core from a 10-ft- (3-m-) thick sequence in the bulk rock underlying the Topopah Spring Tuff basal vitrophyre in borehole UZ-14 and in trace amounts (1 percent) in a breccia zone in the south ramp of the Exploratory Studies Facility. Although the occurrence of erionite is rather sporadic and, where found, its abundance is typically low, it is a significant health concern due to its known carcinogenicity.

6.3.3 Smectite + Illite Distribution

Smectite is a swelling clay with a high cation-exchange capacity. Where present in significant amounts, it can act as a relatively impermeable barrier to fluid flow. It effectively sorbs many cationic species, such as Pu(V) in biocarbonate water, and is therefore an important factor in calculations of radionuclide retardation (Vaniman et al. 1996 [DIRS 111128]). Illites are clays with a higher layer charge than smectites, reducing their effective cation-exchange capacity and eliminating their impermeable character. At greater depths, illite develops as a prograde product of smectite alteration, particularly in the northern and central portions of the mineralogic model (Bish and Aronson 1993 [DIRS 100006], pp. 151 to 155).

Smectite + illite are present in low abundance throughout Yucca Mountain except in some thin horizons and at depth in the region of boreholes G-1 and G-2 (Figures 6-17 and 6-18). XRD analyses indicate smectite in virtually all analyzed samples, although typically in amounts less than 5 percent. Volumes of smectite + illite increase at depth, particularly in the fossil geothermal system. Above the water table, there are two zones of up to 75 percent smectite in the Paintbrush Group, one within the vitric nonwelded section above the Topopah Spring Tuff (PTn, sequence 20) and one at the top of the basal vitrophyre of the Topopah Spring Tuff (upper layer of sequence 13). These smectites typically have nonexpandable illite contents of 10 to 20 percent (Bish and Aronson 1993 [DIRS 100006], pp. 151 to 152). Well beneath the water table (depths greater than 3,300 ft (1,000 m) below ground surface), the ancient (approximately 10.7 million years ago) geothermal system generated abundant smectite + illite but with a much higher illite content (up to approximately 80–90 percent) (Bish and Aronson 1993 [DIRS100006], Figures 3 and 4, pp. 152 to 153). However, the illitic clays occur at such great depths that they are of little importance for transport modeling at Yucca Mountain.

6.3.4 Volcanic Glass Distribution

Volcanic glass is a highly reactive, metastable material that can react in the presence of water to form assemblages including zeolites and clays. The distribution of volcanic glass relative to the repository location is an important factor in evaluating possible repository-induced mineral reactions and assessing their impact on repository performance. Volcanic glass is almost entirely restricted to regions above the water table at Yucca Mountain (Figures 6-5, 6-19, and 6-20). The location of the water table is displayed in Figures 6-9 and 6-10. The most significant occurrences of volcanic glass are in the PTn unit (sequence 20), the lower vitrophyre of the Topopah Spring Tuff (top of sequence 13), and in vitric, zeolite-poor regions of the Calico Hills Formation (sequence 11) in the southwestern and western regions of the mineralogic model. The distribution of volcanic glass in the Calico Hills Formation is inversely correlated with zeolite abundance. In the transition zone between high- and low-abundance zeolite, volcanic glass and zeolite occur together.

6.3.5 Silica Polymorph Distribution

The common silica polymorphs at Yucca Mountain include quartz, cristobalite, opal-CT, and tridymite. These minerals could affect repository performance because of their chemical reactivity, mechanical response to temperature, and potential impact on human health during mining operations. Repository-induced heating may accelerate the chemical reactions of cristobalite, opal-CT, and tridymite to quartz, which is the stable silica polymorph. In addition, all of the silica minerals are susceptible to dissolution and precipitation reactions. Therefore, the potential exists for substantial redistribution of silica with resulting changes in the permeability and porosity of the matrix and fractures in the repository environment. The results of the mineralogic model, showing ambient conditions, can be used to model in 3-D the effects of thermal and geochemical reactions of metastable silica polymorphs on repository performance. Tridymite and cristobalite also undergo phase transitions between 100 and 275°C (Thompson and Wennemer 1979 [DIRS 111126], pp. 1018 to 1025), which may have an impact on the mechanical integrity of the repository. The α to β reaction in cristobalite is of particular concern in thermal-load designs because of effects on porosity, permeability, and mechanical strength. Finally, the crystalline silica polymorphs (quartz, cristobalite, and tridymite) are all regulated health hazards.

Cristobalite and tridymite are abundant in the repository host horizon. Opal-CT is usually found in association with sorptive zeolites. Tridymite occurs above the water table and primarily above the Repository Host Horizon, particularly in those parts of the Topopah Spring and Tiva Canyon Tuffs where vapor-phase crystallization is common (Figures 6-21 and 6-22). Pseudomorphs of quartz replacing tridymite in deep fractures and cavities are 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 [DIRS 100053], pp. 483 to 484). Volumes of exceptionally high tridymite content are restricted to the upper strata within the Tiva Canyon and Topopah Spring Tuffs but rarely exceed 20 percent.

000130DC_MM_20.ai

Output: DTN: LA9908JC831321.001.

Figure 6-17. Smectite + Illite Distribution in North-South Cross Section Through the Repository

Output: DTN: LA9908JC831321.001.

Figure 6-18. Smectite + Illite Distribution and East-West Cross Section Through the Repository

000130DC_MM_22.ai

Output: DTN: LA9908JC831321.001.

Figure 6-19. Volcanic Glass Distribution in North-South Cross Section Through the Repository

Output: DTN: LA9908JC831321.001.

Figure 6-20. Volcanic Glass Distribution in East-West Cross Section Through the Repository

Cristobalite is typically a devitrification product that is found in virtually every sample above the water table. Opal-CT, which is a typical byproduct of zeolitization, is found below the water table before disappearing at depths at or below the Tram Tuff. Cristobalite and opal-CT are combined in the mineralogic model, partly because the extra analytical procedures necessary to distinguish them were not commonly applied to the borehole data, but also because the two minerals dissolve to similar aqueous silica concentrations. As is evident in Figures 6-23 and 6-24, cristobalite and opal-CT are very abundant in the devitrified tuffs of the Paintbrush Group. Occurrences below the Paintbrush Group units are primarily opal-CT in tuffs containing abundant sorptive zeolites. Cristobalite and opal-CT disappear at depth and are replaced by quartz-bearing assemblages.

Quartz is common in the lower Topopah Spring Tuff and is abundant at depth in the Crater Flat Group (Figures 6-25 and 6-26).

6.4 UNCERTAINTIES AND LIMITATIONS IN MINERALOGIC MODEL

6.4.1 Uncertainties

Several uncertainties are associated with the mineralogic model in regions distant from the boreholes. In particular, there are striking geographic differences in mineral abundances that relate to past geologic processes. These are most obvious in the stratigraphic depth of zeolitization increasing to the southwest (from the Calico Hills Formation to the Prow Pass Tuff) across the mineralogic model (Figures 6-11 to 6-16). Currently, the borehole data are not adequate for determining the precise location of the transition from vitric to zeolitic Calico Hills Formation. A consequence of this data inadequacy is the uncertainty associated with the trend of the transition to the north and west of borehole UZ-14 because of significant differences among UZ-14, G-2, and WT-24. There is also uncertainty related to the nature of the transition, that is, whether the depth to zeolitization decreases rapidly and smoothly along a well-defined front or whether zeolitized zones are interfingering with vitric zones along a highly irregular front.

6.4.2 Model Limitations

The most significant limitation of Version 3.0 of the mineralogic model is the scarce mineralogic data in the region beyond the western border of the repository. For example, an examination of Figure 4-1 demonstrates the importance of SD-6 in providing the only substantial quantity of mineralogic data along the western edge of Yucca Mountain. The uncertainty in the boundary regions of the mineralogic model is also elevated because of the limited number of sampling locations (see Figures 4-1 and 6-5). There is little impact if any to the users of the model because as documented in Section 1, they use the average mineral abundance layer values or the actual borehole mineral abundance data itself.

Output: DTN: LA9908JC831321.001.

Figure 6-21. Tridymite Distribution in North-South Cross Section Through the Repository

Output: DTN: LA9908JC831321.001.

Figure 6-22. Tridymite Distribution in East-West Cross Section Through the Repository

000130DC_MM_26.ai

Output: DTN: LA9908JC831321.001.

Figure 6-23. Cristobalite + Opal-CT Distribution in North-South Cross Section Through the Repository

000130DC_MM_27.ai

Output: DTN: LA9908JC831321.001.

Figure 6-24 Cristobalite + Opal-CT Distribution in East-West Cross Section Through the Repository

000130DC_MM_28.ai

Output: DTN: LA9908JC831321.001.

Figure 6-25. Quartz Distribution in North-South Cross Section Through the Repository

Output: DTN: LA9908JC831321.001.

Figure 6-26. Quartz Distribution in East-West Cross Section Through the Repository

Fault zones are represented as steeply dipping but continuous stratigraphic units. As a consequence, mineralogic predictions in the immediate vicinity of the major fault zones (Solitario Canyon and Ghost Dance) are less accurate. The accuracy of the model is still adequate in the immediate vicinity of the fault zones, and the impact to the overall model is minimal. Again, there is little impact if any to the users of the model because as documented in Section 1, they use the average mineral abundance layer values or the actual borehole mineral abundance data itself.

Quantitative mineralogic data from several boreholes were obtained primarily from cuttings rather than cores (all of WT-1 and WT-2, most of H-4, and significant portions of H-3, H-5, and p#1). Drill cuttings have a tendency to average mineral abundance over a finite depth range, and more consolidated rock fragments may be over-represented with respect to the softer, more friable rock fragments. The practice of washing cuttings before collection can actually remove specific mineral fractions (especially clays). These limitations can result in inaccurate mineral analyses and in variations in mineral abundance, becoming less distinct and spread over a greater vertical range. However, as documented in Appendices A through D this limitation does not significantly affect the mineralogic model as only 3 of the approximately 1,900 samples used in its construction could not be qualified due to concerns on the representativeness of its composition.

The use of numeric means for the sequence at each borehole (Section 6.2.3) is assumed to be an adequate representation of the mineral abundances by sequence/layer. This assumption is based on there being vertical continuity of each model sequence/layer as discussed in Section 5.

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7. VALIDATION

This section presents the validation of the mineralogic model by showing how the confidence-building criteria were satisfied during and after model development. Section 7.1 shows how the model development process satisfied the criteria in the technical work plan and AP-SIII.10Q. Section 7.2 provides a detailed discussion of the postdevelopment validation of the mineralogic model in accordance with the applicable criteria.

The level of confidence required for the model validation activity for the mineralogic model has been determined from the guidelines in AP-2.27Q, Attachment 3, *Levels of Models Importance, Validation, and Confidence* to be Level I as documented in *Technical Work Plan for: The Integrated Site Model* (BSC 2004 [DIRS 169635], Section 2.2.2). Because the mineralogic model does not provide any direct input to TSPA, its level of significance depends, in part, on its association with models that do provide input directly to TSPA. The mineralogic model (output DTN: LA9908JC831321.001) provides the abundance and distribution of 10 minerals and mineral groups within 22 stratigraphic sequences in the Yucca Mountain area. The mineral abundance data from the mineralogic model, averaged for each of the 10 mineral groups by the mineralogic model layers, are used as direct input to develop heat capacity values in *Heat Capacity Analysis Report* (BSC 2004 [DIRS 170003]; DTN: SN0307T0510902.003 [DIRS 164196]). The average rock grain heat capacity provided by DTN: SN0307T0510902.003 [DIRS 164196] for all mineralogic model layers is approximately 1 J/gK (Joules/gram-degree Kelvin) within the parameter uncertainty that is represented by the associated standard deviation. The standard deviations for the average rock grain heat capacity range from approximately 0.10 to 0.20 J/gK as shown in Table 6.5 of the *Heat Capacity Analysis Report* (BSC 2004 [DIRS 170003]). Comparing the layers average rock grain heat capacity with their uncertainty indicates that differences in mineral abundances have a minimal impact on heat capacity values.

The mineralogic model layer heat capacity values are then used by six model reports: *In-drift Natural Convection and Condensation Model Report* (BSC 2004 [DIRS 164327]), *Drift Degradation Analysis* (BSC 2004 [DIRS 166107]), *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862]), *Igneous Intrusion Impacts on Waste Packages and Waste Forms* (BSC 2004 [DIRS 168960]), *Dike/Drift Interactions* (BSC 2004 [DIRS 170028]), and *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 169565]). Although these models require Level II or III validation as shown in Table 1 of AP-2.27Q, calculation results of such coupled processes models are not sensitive to variations in the heat capacities as demonstrated by comparative studies in the previous and current revisions of *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2004 [DIRS 169866]) in which heat capacities are updated. Accordingly, Level I validation is appropriate for that intended use of the mineralogic model.

Furthermore, the measured mineral abundance data for borehole USW SD-9 are used as direct input in *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2004 [DIRS 169866]) and *Drift-Scale THC Seepage Model* (BSC 2004 [DIRS 169856]). The USW SD-9 data used in these coupled process models are discrete measurement values used to construct the mineralogic model, and are not the representation of the 3-D product output. The borehole mineral abundance data are then used to calculate mineral volume fractions and surface areas in the coupled process models. Uncertainties from use of these analytical results are associated with

the sampling and measurement uncertainties only and have no impact on the mineralogic model or its validation. Because of the relatively constant rock grain heat capacity values, variations in the mineralogic model are expected to have a minimal effect on the estimated mean annual dose (less than 0.1 mrem/year). In summary, Level I validation is appropriate for all intended uses of the mineralogic model.

7.1 CONFIDENCE BUILDING DURING MODEL DEVELOPMENT TO ESTABLISH SCIENTIFIC BASIS AND ACCURACY FOR INTENDED USE

For Level I validation, Section 2.2.2 of the technical work plan (BSC 2004 [DIRS 169635]) specifies the following steps for ‘Confidence Building During Model Development.’ The development of the model should be documented in accordance with the requirements of Section 5.3.2(b) of AP-SIII.10Q. Attachment 3 of AP-2.27Q also provides model validation guidance that is documented in Section 2.2.2 of the technical work plan. The development of the mineralogic model has been conducted according to all of the applicable criteria, as follows:

1. *Selection of input parameters and/or input data, and a discussion of how the selection process builds confidence in the model. [AP-SIII.10Q 5.3.2(b) (1) and AP-2.27Q Attachment 3, Level I (a)]*

The selection of input data builds confidence in the mineralogic model because all input data have been obtained from controlled sources, and provide the parameters or mineral species or groups of interest (see Table 4-1, Section 4.1.1). In addition, the input data are based on the most direct analytical method available, XRD determinations of mineralogical abundances. Furthermore, two independent activities were conducted to qualify all of the input data (see Steinborn 2002 [DIRS 160702] and Appendices A through D). Only 6 of the approximately 1900 data points could not be qualified.

2. *Description of calibration activities, and/or initial boundary condition runs, and/or run convergences, simulation conditions set up to span the range of intended use and avoid inconsistent outputs, and a discussion of how the activity or activities build confidence in the model. Inclusion of a discussion of impacts of any non-convergence runs [AP-SIII.10Q 5.3.2(b)(2) and AP-2.27Q Attachment 3, Level I (e)].*

Calibration activities are described in Section 6.2.4. These activities build confidence in the mathematical model. Documentation of calibration runs is provided in Section 6.2.4. This discussion refers to the establishment of the power factor (X) in the calculation of mineral distributions. Of the three choices examined (X=2, 4, or 6) in the development of the model, the value of 4 was selected as it provided the realistic representation of the mineralogical variation.

As described in the technical work plan, the mineralogic model does not provide simulation conditions (BSC 2004 [DIRS 169635] Section 2.2.2).

3. *Discussion of the impacts of uncertainties to the model results including how the model results represent the range of possible outcomes consistent with important uncertainties. [AP-SIII.10Q 5.3.2(b)(3) and AP-2.27Q Attachment 3, Level I (d) and (f)].*

Discussion of model uncertainties is provided in Section 6.4. The principal uncertainty is the projection of mineralogic abundances into the model layers away from the borehole data sources. This uncertainty, however, is contained in the uncertainty of the downstream models that use the mineralogic model. There is little impact, if any, to the uses of the mineralogic model because as described in Section 1 and above in Section 7, the downstream products either use the layer averages of mineral abundance values or the measured borehole mineral abundance data directly.

As described in the technical work plan (BSC 2004 [DIRS 169635], Section 2.2.2), the mineralogic model does not provide model predictions (performance parameters) that incorporate a range of possible outcomes, consistent with important uncertainties; it is a static representational model.

4. *Formulation of defensible assumptions and simplifications. [AP-2.27Q Attachment 3 Level I (b)].*

Assumptions are discussed in Section 5. The principal assumptions are the geologic Principles of Superposition and Original Horizontality, and Original Lateral Continuity and vertical continuity within a rock layer. Because these principles are generally applicable and there is no indication that there is anything unique about this site that would cause these principles not to be applicable, the application of these principles to this site is defensible.

5. *Consistency with physical principles, such as conservation of mass, energy, and momentum. [AP-2.27Q Attachment 3 Level I (c)]*

The mineralogic model is consistent with physical principles, and particularly geologic Principles of Superposition and Original Horizontality, and Original Lateral Continuity and vertical continuity within a rock layer. Because the mineralogic model is a static representational model that provides a 3-D representation of mineral abundances in the model volume, the consideration of dynamic principles such as conservation of mass, energy, and momentum does not apply in this case.

7.2 CONFIDENCE BUILDING AFTER MODEL DEVELOPMENT TO SUPPORT THE SCIENTIFIC BASIS OF THE MODEL

Postdevelopment model validation consists of corroborating model results (output DTN: LA9908JC831321.001) with acquired field data (XRD mineralogic abundance) not previously used to develop the model, following the guidelines provided in AP-SIII.10Q. Corroboration is performed on layers for which data are available. The basis for this validation is based on three geologic principles: Superposition, Original Horizontality, and Original Lateral Continuity (Jackson 1997 [DIRS 109119], p.362 and p. 361). Explanation of these principles and their application to this model are provided in Section 5. As discussed in Section 5 the postdevelopment model validation assumes that the mineral abundance results from boreholes can be compared because the rock layers are laterally continuous and that vertical continuity within each model sequence allows average mineral abundances to be determined for the sequences.

The validation plan was to obtain existing corroborating mineralogic data from a borehole located in the zeolitic (northeast) region of the mineralogic model, and a second in the vitric (southwest) region (BSC 2004 [DIRS 169635], Section 2.2.2). The specification of a zeolitic and vitric borehole was made to account for and recognize that some model layers have a bimodal composition. The bimodal composition could have had an affect on the results of the corroboration. Unfortunately, no independent data could be found from the vitric region for validation. The lack of a borehole for the vitric region of the model has little impact on the results of this validation activity. This is because the type of data and method of comparison between the independent data and model results are the same regardless of the borehole's location. Furthermore, use of heat capacity values (that are derived from the average mineral abundances) is based on the average layer value. The vitric and zeolitic heat capacity representations are not used. The reports citing these heat capacity values are: *In-drift Natural Convection and Condensation Model Report* (BSC 2004 [DIRS 164327], Section 6.3.5.2.2), *Drift Degradation Analysis* (BSC 2004 [DIRS 166107], Table 2, Attachment V, Table V-16), *Ventilation Model and Analysis Report* (BSC 2004 [DIRS 169862], Table 4-13), *Igneous Intrusion Impacts on Waste Packages and Waste Forms* (BSC 2004 [DIRS 168960], Table 4-2), *Dike/Drift Interactions* (BSC 2004 [DIRS 170028], Table 4-2), and *Multiscale Thermohydrologic Model* (BSC 2004 [DIRS 169565], Table 4-1, Appendix IV Table IV-3a). Therefore, the corroboration performed for the zeolitic region of the model provides confidence in the entire model.

Two data sets from the zeolitic zone of the model are available and suitable for corroboration DTN: LA9909PR831231.004 [DIRS 129623] and Maldonado and Koether 1983 [DIRS 101805], Table 4. The DTN: LA9909PR831321.004 [DIRS 129623] provides data from borehole UE-25 c#2 and Maldonado and Koether 1983 [DIRS 101805], Table 4 provides data from borehole USW G-2. Data from Maldonado and Koether 1983 [DIRS 101805] (USW G-2) provides more analyses; 28 versus 5 for DTN: LA9909PR831231.004 [DIRS 129623] (UE-25 c#2). Also, Maldonado and Koether 1983 [DIRS 101805] provides more mineral groups that are equivalent to those defined by the mineralogic model (7 versus 6). Because DTN: LA9909PR831231.004 [DIRS 129623] had fewer analyses and appropriate mineral groups it was determined that Maldonado and Koether 1983 [DIRS 101805] (USW G-2) was more appropriate independent data source for model validation.

Model validation is based on a comparison between the average mineral abundances for each model layer of the validating boreholes are compared to the mean value for the corresponding mineralogic model layer. If the borehole layer average is found to fall within the range defined by the average value and one standard deviation for the mineralogic model layers, then the validation is deemed successful (BSC 2004 [DIRS 169635], Section 2.2.2). This validation criterion is appropriate because it is based on the basic geologic principles stated in Section 5 used to construct the model (Superposition and Original Horizontality and Original Lateral Continuity, and vertical continuity within a rock layer). However, it must be noted that this validation criterion applies only if all of the data are indexed at the same percentage intervals and the number of mineral groups or species are comparable. Where these conditions are not met, the validation criterion must be adjusted suitably to take into account the deviations from these conditions. The mineralogic model layers average values and standard deviations are from the *Heat Capacity Analysis Report* (BSC 2004 [DIRS 170003], Tables 6.2 and 6.4).

Table 7-1 lists the data used for corroboration from borehole USW G-2 (Maldonado and Koether 1983 [DIRS 101805], Table 4). Mineral abundances are expressed in weight percent with the values “Tr” meaning trace (<5 percent), “<10” equal to 5–9 percent, and dashes (-) indicating no mineral detected. For the validation, the borehole mineral abundance values were averaged by layer. Where a value was reported as “Tr,” a numerical value of 2.5 was used; a value of 7 was used where “<10” was reported in the borehole data. Table 7-2 shows the borehole data averaged by layer compared to Version 3.0 of the mineralogic model mineral abundance averages by layer. The mineral groups from Section 6.2.3 that were analyzed by Maldonado and Koether are:

- Montmorillonite + Illite (Smectite + Illite)
- Sorptive zeolites (the sum of clinoptilolite, heulandite, and mordenite)
- Cristobalite + opal-CT
- Quartz
- Feldspar
- Analcime (nonsorptive zeolite)
- Illite-Mica (Mica)

The selection of these seven groups was appropriate and adequate, because they are equivalent to the groupings that were used to construct the mineralogic model as documented in Section 6.2.3.

The mineral comparison of “Volcanic Glass” vs. “Amorphous (ash)” are shown but not used for validation, because it appears that the two mineral analyses are not equivalent. This is based on the observation that when the model validation criteria for volcanic glass is compared to amorphous ash (Table 7-2) none of the values for the amorphous ash fall within the validation range. Furthermore, both the PTn layer and Tac layer are known to have high abundances of volcanic glass, 47.11 and 18.92 percent respectively. However, as shown in Table 7-2, the values for amorphous ash are 5.9 and 5.3 for the PTn and Tac layers. Based on these observations, the abundances for volcanic glass and amorphous ash are not equivalent.

Over 65 percent (32 of 49 values) of the borehole data can be validated when compared to Version 3.0 of the mineralogic model mineral abundances within 1 standard deviation (Table 7-2, values in large bold type). Those values shown in brackets indicate that these mineral abundance values were shown as “Tr” (trace = <5 percent). To permit a numerical comparison with the mineralogic model layer abundances, a numerical value of “2.5 percent” was assigned. A value of 2.5 percent was assumed, as it is half of 0 and 5 percent and, therefore, roughly equivalent to a “trace” value. If the range for the acceptance criteria for validation is changed to 2 standard deviations, 80 percent of the borehole values (40 of 49) fall within the mineralogic model layer averages (Table 7-2), indicating that the validation data corroborate the model.

The range for the acceptance criteria was changed from 1 to 2 standard deviations. This change is reasonable because: (1) As discussed previously, the independent corroborative data are not directly comparable to the input data of the mineralogic model; and (2) A normally distributed population 1 standard deviation encompasses 68 percent of the distribution, while 2 standard deviations encompasses 95 percent (Davis 1986 [DIRS 123714], Figure 2.12). The range for acceptance was changed to 2 standard deviations to see whether it would increase the number of acceptable samples, which it did. It is a reasonable assumption that the mineral abundances are

normally distributed, because it is a measured geologic parameter, the number of acceptable samples increased with the increase in standard deviation. This assumption is supported by the normal distribution observed for zeolite mineral abundances from Figure 6.5 of the *Heat Capacity Analysis Report* (BSC 2004 [DIRS 170003]).

Furthermore, calculation of the mineralogic model unit-specific rock grain heat capacity is not sensitive to the mineral abundances of the individual minerals because (1) the minerals are summed in calculating the average heat capacity for the model layers and (2) the heat capacity values for the mineral groups are similar (BSC 2004 [DIRS 170003], Appendix A), resulting in model layer-averages of approximately 1 J/gK (BSC 2004 [DIRS 170003], Table 6.5) despite observed variations in the mean mineralogic values for the model layers (BSC 2004 [DIRS 170003], Table 6.2). The varying mineralogic abundances and constant heat capacity values indicates that the calculations of the layer heat capacity values are relatively insensitive to mineral abundances. Subsequent coupled process modeling (by comparing heat capacity values used in the previous and current versions of *Mountain-Scale Coupled Processes (TH/THC/THM)* (BSC 2004 [DIRS 169866]) indicates that the thermal response is not sensitive to the variations in heat capacity values either.

Before determining the results of this validation, the nature of this corroboration must be evaluated. First, the relative precision Maldonado and Koether (1983 [DIRS 101805]) data shown in Table 7-1 and the input data that are used to construct the mineralogical model listed in Table 4-1 differ. The mineral abundance values provided by Maldonado and Koether are indexed at 10 percent intervals. The mineralogical model input data are indexed at 1 percent intervals. This can be verified by viewing the product output DTN: LA9908JC831321.001 and selecting the input file for a borehole, example file "G2.well." Second, the number of mineral groups or species is not directly comparable; the mineralogic model is constructed based on 10, while the corroborative data set used provides 7.

When these differences between the independent data set and the average value for the mineralogic model layers are taken into account, this validation was successful because it meets the validation criteria. The differences in precision between the input data used to construct the mineralogic model and the independent data set used for corroboration are expected to result in differences between the values because of the intrinsic differences between the two data sets. Therefore, it is appropriate to modify the validation criteria to two standard deviations because it still provides a relative indicator as to the relationship between the two data sets. Moreover, the result that 80 percent of the corroborating data fall within the two standard deviations validates the model under these circumstances. Despite the differences between the two data sets, the comparison indicates that the model results can be corroborated from the mineralogic model to the independent data set.

7.3 VALIDATION SUMMARY

The mineralogic model has been validated by applying acceptance criteria based on an evaluation of the model's relative importance to the potential performance of the repository system. Activities for confidence building during model development have been satisfied (Section 7.1). Also, all postdevelopment validation requirements defined in the technical work plan (BSC 2004 [DIRS 169635], Section 2.2.2) have been fulfilled (with justification for changes

in the validation criteria), including corroboration of model results with borehole mineral abundance data that were not used in the model development (Section 7.2). The model development activities and the postdevelopment validation activities described establish the scientific basis for the mineralogic model. No future activities need to be accomplished for model validation. The model validation activities have determined that the mineralogic model is adequate and sufficiently accurate with no limits or restrictions on its use for the stated and intended purpose.

Table 7-1. XRD Analyses for Mineral Abundance of Core Samples from USW G-2

MM3.0 Layer	Unit ^a	Sample Depth (m)	Montmorillonite	Illite-Mica	Illite	Quartz	Feldspar	Cristobalite-opal	Amorphous (ash)	Clinoptilolite	Heulandite/Clinoptilolite	Clinoptilolite/Heulandite	Clinoptilolite/Mordenite	Mordenite/Clinoptilolite	Mordenite	Analcime
PTn (seq. 20, layer 24)	Tpp	170.7	<10	Tr	-	Tr	30	40	<10	10	-	-	-	-	-	-
	Tpp	171.5	Tr	Tr	-	-	30	30	<10	-	20	-	-	-	-	-
	Tpp	187.2	<10	Tr	-	Tr	50	20	Tr	<10	-	-	-	-	-	-
	Tpp	205.7	20	Tr	-	-	20	10	<10	-	-	30	-	-	-	-
Tac (seq. 11, layers 11, 12, 13, 14)	Tac	539.6	Tr	-	-	Tr	10	<10	<10	-	-	-	70	-	-	Tr
	Tac	569.9	Tr	Tr	-	<10	10	<10	Tr	-	-	-	70	-	-	-
	Tac	600.5	Tr	Tr	-	Tr	10	<10	<10	-	-	-	70	-	-	-
	Tac	630.9	Tr	Tr	-	Tr	20	<10	<10	-	-	-	60	-	-	-
	Tac	664.0	Tr	Tr	-	Tr	10	<10	<10	-	-	-	-	70	-	-
	Tac	692.8	Tr	Tr	-	-	30	<10	Tr	-	-	-	-	-	50	-
	Tac	724.2	Tr	Tr	-	<10	20	Tr	<10	-	-	-	50	-	-	-
	Tac	753.2	Tr	Tr	-	10	30	Tr	Tr	-	-	-	40	-	-	-
Tacbt (seq. 10, layer 10)	Tacbt	783.4	Tr	Tr	-	20	30	-	Tr	-	-	-	-	30	-	-
	Tacbt	813.9	Tr	<10	-	20	30	-	Tr	-	-	-	-	30	-	-
Tcplc- Tcplc (seq. 8, layer 8)	Tcpm	878.2	Tr	Tr	-	40	50	-	Tr	-	-	-	-	-	-	-
	Tcpm	898.6	<10	Tr	-	20	60	-	Tr	-	-	-	-	-	-	-
Tcplv- Tcbuv (seq. 7, layer 7)	Tcplv	923.0	10	Tr	-	30	40	-	Tr	-	-	-	-	Tr	-	-
	Tcplv	934.5	Tr	Tr	-	Tr	20	10	20	-	-	-	40	-	-	-
	Tcplv	945.5	<10	-	Tr	-	20	20	20	-	-	-	-	30	-	-
	Tcplv	956.5	Tr	-	Tr	20	40	-	Tr	-	-	-	-	20	-	Tr
	Tcplv	983.7	<10	-	<10	20	20	-	Tr	-	-	-	30	-	-	10
Tcbuc- Tcbmd- Tcblc (seq. 6, layer 6)	Tcbuc	1011.6	Tr	Tr	Tr	30	50	-	Tr	-	-	-	-	-	-	-
	Tcbm	1018.0	Tr	Tr	-	30	60	-	Tr	-	-	-	-	-	-	-
	Tcbm	1033.3	Tr	Tr	-	40	50	-	Tr	-	-	-	-	-	-	-
	Tcblc	1050.9	Tr	Tr	Tr	20	50	Tr	Tr	-	-	-	-	-	-	10
	Tcblc	1060.7	<10	Tr	-	20	40	-	<10	-	-	-	-	-	20	-
Tctlv- Tctbt (seq. 3, layer 3)	Tctlv	1147.6	-	<10	40	30	10	-	<10	-	-	-	-	-	-	-
	Tctlv	1182.6	-	<10	30	30	10	-	<10	-	-	-	-	-	-	-

Sources: Sample Depth and Mineral Abundance source is Table 4 from Maldonado and Koether (1983 [DIRS 101805])
Mineral abundance is expressed in weight percent. Original estimated amounts were determined by Paul D. Blackmon, USGS. Tr, trace (<5 %), <10 = 5%-9%, dashes (-) indicate no mineral detected.

NOTE: Shading indicates different mineralogical model sequences.

^a Stratigraphy (Unit) source is DTN: MO9901MWDGFM31.000 (DIRS 103769).

Table 7-2. Comparison of Mineral Abundance Values from USW G-2 Core Samples and Mineralogic Model 3.0 Layer Averages with 1 Standard Deviation

MM3.0 Layer	Smectite + Illite Ave.	Montmorillonite + Illite Ave.	Sorptive Zeolites Ave.	Sorptive Zeolites Ave.	Cristobalite + Opal CT Ave.	Cristobalite + Opal CT Ave.	Quartz Ave.	Quartz Ave.	Feldspar Ave.	Feldspar Ave.	Analcime Ave.	Analcime Ave.	Mica Ave.	Illite-Mica Ave.		Volcanic Glass Ave.	Amorphous (ash) Ave.
PTn	12.13 ±4.93	9.1	1.68 ±2.51	16.8	8.07 ±5.51	25.0	1.30 ±0.69	[2.5]	24.81 ±13.0	32.5	0.00 ±0.00	0	0.94 ±0.50	[2.5]		47.11 ±18.3	5.9
Tac	1.23 ±0.75	[2.5]	39.66 ±22.9	60.0	13.50 ±5.77	<u>5.9</u>	6.03 ±3.19	4.9	22.42 ±8.37	17.5	0.00 ±0.01	[2.5]	0.84 ±0.95	[2.5]		18.92 ±24.1	5.3
Tacbt	5.11 ±3.18	2.5	22.39 ±11.8	30.0	5.01 ±3.76	<u>0</u>	16.69 ±7.16	20.0	33.36 ±5.20	30.0	0.00 ±0.00	0	2.01 ±1.33	4.8		14.49 ±16.2	2.5
Tcpuc-Tcplc	2.16 ±1.23	<u>4.8</u>	0.46 ±0.54	0	7.65 ±5.33	<u>0</u>	25.76 ±9.54	30.0	62.08 ±4.56	<u>55.0</u>	0.00 ±0.00	0	0.69 ±0.77	[2.5]		0.24 ±0.58	2.5
Tcplv-Tcbuv	4.87 ±4.28	5.1	47.64 ±12.3	<u>30.0</u>	9.54 ±2.94	<u>15.0</u>	8.83 ±6.18	<u>18.1</u>	25.37 ±3.46	28.0	2.29 ±4.08	6.2	0.42 ±0.37	[2.5]		2.67 ±3.69	9.5
Tcbuc-Tcbmd-Tcblc	2.01 ±1.30	3.1	0.22 ±0.37	20	4.72 ±4.47	2.5	28.16 ±6.49	28.0	60.45 ±5.13	50.0	0.00 ±0.00	10	3.04 ±2.22	2.5		0.17 ±0.28	3.1
Tctlv-Tctbt	2.76 ±2.30	35.0	0.60 ±0.92	0	3.99 ±5.24	0	28.66 ±7.44	30	60.46 ±4.83	10	0.03 ±0.04	0	3.05 ±1.81	7		0.00 ±0.00	7

NOTES: Values in shaded columns are validation values from Maldonado and Koether (1983 [DIRS 101805]) and averaged by layers shown in Table 7-1. Values in the unshaded columns are the model layer average mineral abundance with 1 standard deviation from BSC 2003 (DIRS 170003).

Mineral abundance is expressed in weight percent. Borehole values shown in large boldface validate the model. Underlined values are within 2 standard deviations of model values. Those values shown in brackets indicate that these mineral abundance values were originally reported as "Tr" (trace = <5 percent). To permit a numerical comparison with the mineralogic model layer abundances a numerical value of "2.5 percent" was assigned.

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8. CONCLUSIONS

The mineralogic model (output DTN: LA9908JC831321.001) provides the abundance and distribution of 10 minerals and mineral groups within 22 stratigraphic sequences in the Yucca Mountain area. This product output is cited as direct input by the *Heat Capacity Analysis Report* (BSC 2004 [DIRS 170003]) and Near-Field Environment and Transport model reports. The geologic framework model provides the stratigraphic framework for the XRD quantitative analyses of mineral abundances for the 24 boreholes data sets. The mineralogic model is an interpretation, or static representation, that is constructed based on basic geologic principles. The model possesses an inherent level of uncertainty that is a function of data distribution and geologic complexity, and predictions or alternative interpretations that fall within the range of uncertainty are considered acceptable. Uncertainty in the model is mitigated by the application of three fundamental geologic principles; the Principles of Superposition, Original Horizontality, and Original Lateral Continuity.

There are no confirmatory actions, such as compliance runs, additional sensitivity runs, and neutralization runs contained in this model report.

8.1 LIMITATIONS

Limitations that may be of importance to users of the mineralogic model are:

- The model is divided into 22 sequences that correlate with the layers defined by the geologic framework model. Users that require specific mineral abundances may be required to examine the input data sets that are also provided by the product output DTN: LA9908JC831321.001.
- Scarcity of mineralogic data in the western margin of the repository block, as well as in the boundary regions of the model. However, the manner in which the product output of the mineralogic model is used mitigates this limitation, as currently no users are concerned specifically about the mineralogic abundance near the model boundaries.
- A 3-D inverse-distance-weighting method is used to project mineral abundances from the controlling borehole data within a given sequence or layer. This projection into the model layer is based on the geologic Principle of Original Lateral Continuity.

8.2 CONCLUSIONS FOR THE YUCCA MOUNTAIN REVIEW PLAN CRITERIA

The following information describes how this analysis addresses the acceptance criteria in the Yucca Mountain Review Plan (NRC 2003 [DIRS 163274], Section 2.2.1.3.3.3). Only those acceptance criteria that are applicable to this report (see Section 4.2) are discussed. In most cases, the applicable acceptance criteria are not addressed solely by this report; rather, the acceptance criteria are fully addressed when this report is considered in conjunction with other analysis and model reports that describe phenomena affecting quantity and chemistry of water contacting engineered barriers and waste forms. Where a subcriterion includes several components, only some of those components may be addressed. How these components are addressed is summarized below.

2.2.1.3.3: Quantity and Chemistry of Water Contacting Engineered Barriers and Waste Forms

Acceptance Criterion 1: System Description and Model Integration Are Adequate.

Subcriterion (5): Sufficient technical bases and justification are provided in Sections 6.2 and 6.3 for mineralogical information developed in this model to support analysis of coupled thermal-hydrologic effects on seepage and flow for the total system performance assessment. The Mineralogical Model provides an interpretative structure of the geologic data developed from borehole samples and converts that data to a 3-D model of the mineral abundance at Yucca Mountain. Inputs to the model are discussed in Section 4.1. The model is developed in Section 6.2 and results are described in Section 6.3. Section 4.1 provides a list of inputs (Table 4-1). It also discusses mineralogic data, stratigraphic surfaces, and the stratigraphic framework developed from those surfaces. Appendices A through C discuss the qualification of some of the mineral abundance data from continuously cored boreholes and provide justification for their use. Section 6.2 discusses the basic components of the 3-D Mineralogical Model, which are a stratigraphic framework, mineralogic data from boreholes, and 3-D modeling software. It also discusses use of an inverse-distance-weighting method to estimate mineral distributions.

Subcriterion (8): Adequate technical bases are provided for determining the mineralogical information developed in this report. This information was developed from mineralogic data obtained from borehole samples (Sections 1 and 6.2) and is based on quantitative XRD analyses (Sections 4.1 and 6.2) of the borehole material. This model produces a mineral abundance distribution, which affects heat capacity and thermal expansion of the various rock layers. These parameters support thermal-hydrologic analyses of the Yucca Mountain stratigraphy.

Acceptance Criterion 2, Data are Sufficient for Model Justification.

Subcriterion (1): The geological values provided in the 3-D stratigraphic framework by the Mineralogic Model are adequately justified through incorporation of site-specific information (Sections 6.2 and 6.3) and validation of the model (Section 7). Adequate descriptions of how the data from XRD analyses were incorporated and interpolated to prepare the 3-D stratigraphic framework are provided in Section 6.2.

Acceptance Criterion 3, Data Uncertainty is Characterized and Propagated Through the Model Abstraction.

Subcriterion (1): The Mineralogical Model uses parameter values and assumed ranges that are technically defensible, reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate. This is demonstrated by use of qualified XRD data, stratigraphy from the Geological Framework Model, and baselined modeling software to produce mineral

abundance estimates in a 3-D stratigraphic framework discussed in Sections 6.2, 6.3, and 6.4. For example, in Section 4.1.1, minimum conservative values were assigned for “trace” XRD analyses.

Subcriterion (4): An adequate representation of uncertainties in the characteristics of the natural system and their effects on the output of the Mineralogical Model is provided in Section 6.4. For areas where borehole data is sparse, there is no impact to downstream models because as documented in Section 1, those models use the average mineral abundance layer values or the actual borehole mineral abundance data itself.

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ACC: DOC.20040610.0006.

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Energy, Office of Civilian Radioactive Waste Management.
ACC: DOC.20040805.0005.

LANL-YMP-QP-03.5, Rev 8. *Documenting Scientific Investigations*.
Notebook 99-01. Los Alamos, New Mexico: Los Alamos National Laboratory.
ACC: MOL.19971029.0005.

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ACC: MOL.19980826.0209.

9.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

LA000000000086.002. Mineralogic Variation in Drill Core UE-25 UZ#16 Yucca Mountain, Nevada. Submittal date: 03/28/1995.	107144
LA9910JC831321.001. Supplementary Mineralogical Data for Mineralogic Model 3.0. Submittal date: 10/29/1999.	113496
LADB831321AN98.002. Revised Mineralogic Summary of Yucca Mountain, Nevada. Submittal date: 05/26/1998.	109003
LADV831321AQ97.001. Mineralogic Variation in Drill Holes. Submittal date: 05/28/1997.	107142
LADV831321AQ97.007. Geotechnical Data Report: Hazardous Minerals. Submittal date: 01/27/1998.	113499
LADV831321AQ99.001. Quantitative XRD Results for the USW SD-6 and USW WT-24 Drill Core Samples. Submittal date: 04/16/1999.	109044
LAJC831321AQ98.005. Quantitative XRD Results for Drill Core USW SD-7, USW SD-9, USW SD-12 and UE-25 UZ#16. Submittal date: 10/27/1998.	109004
LASC831321AQ96.002. QXRD Analyses of Drill Core USW NRG-6 and USW UZ-14 Samples. Submittal date: 08/02/1996.	109042
LASC831321AQ98.001. Results of Real-Time Analysis for Erionite in Drill Hole USWWT-24, Yucca Mountain, Nevada. Submittal date: 02/10/1998.	109047
LASC831321AQ98.003. Results of Real Time Analysis for Erionite in Drill Hole USW SD-6, Yucca Mountain, Nevada. Submittal date: 06/11/1998.	109043
LASL831322AQ97.001. Updated Mineralogic and Hydrologic Analysis of the PTN Hydrogeologic Unit, Yucca Mountain, Nevada, as a Barrier to Flow. Submittal date: 10/09/1997.	109045

MO0004QGFMPICK.000. Lithostratigraphic Contacts from MO9811MWDGFM03.000 to be Qualified Under the Data Qualification Plan, TDP-NBS-GS-000001. Submittal date: 04/04/2000.	152554
MO0012MWDGFM02.002. Geologic Framework Model (GFM2000). Submittal date: 12/18/2000.	153777
MO0101XRDDRILC.001. XRD Analyses of Drill Core from Boreholes UE-25 J-12, USW WT-1, USW H-3, USW H-4, USW WT-2, UE-25 P#1, AND USW H-5. Submittal date: 01/26/2001.	169517
MO0101XRDDRILC.002. XRD Analyses of Drill Core from Boreholes UE-25 A#1 and USW G-2. Submittal date: 01/26/2001.	163795
MO0101XRDMINAB.001. XRD Analyses of Drill Core from Boreholes UE-25B#1, USW G-1, USW G-3, USW GU-3, and USW G-4. Submittal date: 01/26/2001.	163796
MO0106XRDDRILC.003. XRD Analyses of Drill Core from Borehole USW H-6. Submittal date: 06/08/2001.	163797
MO9510RIB00002.004. RIB Item: Stratigraphic Characteristics: Geologic/Lithologic Stratigraphy. Submittal date: 06/26/1996.	103801
MO9804MWDGFM03.001. An Update to GFM 3.0; Corrected Horizon Grids for Four Fault Blocks. Submittal date: 04/14/1998.	109050
MO9901MWDGFM31.000. Geologic Framework Model. Submittal date: 01/06/1999.	103769

9.4 OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

LA9908JC831321.001. Mineralogic Model "MM3.0" Version 3.0.
Submittal date: 08/16/99

9.5 SOFTWARE CODES

Landmark Graphics. 1998. *Software Code: STRATAMODEL*. V4.1.1. SGI. 153238
10121-4.1.1-00.

APPENDIX A

DATA QUALIFICATION REPORT: CUTTINGS MINERALOGY DATA

A1. INTRODUCTION

A1.1 PURPOSE

This data qualification report (DQR) uses the corroboration method according to Attachments 2 and 3 of AP-SIII.2Q, *Qualification of Unqualified Data*, to evaluate the data in DTN: MO0101XRDDRILC.001 [DIRS 169517]. The data addressed in this DQR originally were part of DTN: LADV831321AQ97.001 [DIRS 107142] or DTN: LADB831321AN98.002 [DIRS 109003]. These DTNs were evaluated by the technical assessment methods documented by Steinborn (2002 [DIRS 160702]). The data in these DTNs consisted of mineral abundances determined by quantitative X-ray diffraction analysis of drill core, sidewall core, and drill cuttings. As described by Steinborn, a decision was made to not attempt qualification of data for sidewall core or drill cuttings because of the uncertainty in identifying the stratigraphic location from which the samples were obtained. It was recommended that these samples be used only to corroborate assumptions or other data.

The unqualified data considered in this DQR were directly used in the *Mineralogic Model (MM3.0) Analysis Model Report* (BSC 2002 [DIRS 158730]), in which the mineral analyses are used to create three-dimensional representations of mineral distributions. The unqualified sidewall core and cuttings data provide mineralogic information for parts of the repository block and surrounding areas that otherwise would be unrepresented. In particular, many of these samples are from locations that are optimal to document lateral transitions in mineralogic assemblages. Three-dimensional representations of mineralogy and associated properties would be degraded by the omission of these data. Therefore, a qualification activity has been undertaken to assess the status of the specified data from sidewall core and cuttings.

The purpose of this DQR is to recommend data that can be cited as qualified for use in the mineralogic model report. The appropriateness and limitations (if any) of the data with respect to intended use are addressed in this DQR.

A1.2 SCOPE

This DQR evaluates the data identified in Qualification Plan for Unqualified Mineralogical Model (MDL-NBS-GS-000003) Data, which is Appendix A of *Technical Work Plan for: Integrated Site Model* (BSC 2004 [DIRS 169635], Appendix A). The data qualification plan identifies one unqualified DTN (MO0101XRDDRILC.001 [DIRS 169517]) containing or using acquired and developed mineral abundance data measured by investigators at Los Alamos National Laboratory (LANL). This DTN was created according to the recommendation of Steinborn (2002 [DIRS 160702]) that data from cuttings, sidewall samples, and intermittent core be segregated in a new, unqualified data package (Table A-1).

The predecessor DTN: LADB831321AN98.002 [DIRS 109003] contains data that were published originally in a LANL report (Bish and Chipera 1989 [DIRS 101195]), plus additional data. A subset of the mineral abundance data in this DTN is used directly in mapping the distribution of a selected number of minerals and in correlation with rock properties for specific lithostratigraphic intervals.

These data are generally unqualified because the data and/or the samples were acquired before issuance of the Office of Civilian Radioactive Waste Management *Quality Assurance Requirements and Description* (DOE 2004 [DIRS 171386]). Some of the data were acquired according to technical procedures that had not, at that time, been approved for Yucca Mountain Project work. Yucca Mountain Project approval was obtained for LANL in 1991 (Horton 1990 [DIRS 169954]). The current qualification effort relies in part on the review of methods used for the X-ray diffraction (XRD) analyses of core samples qualified by Steinborn (2002 [DIRS 160702]). The methods used to analyze sidewall core and cuttings samples typically were the same as for core samples analyzed during the same time period.

Table A-1. Source DTNs of MO0101XRDDRILC.001 (DIRS 169517) and Their Relevant Contents

LADV831321AQ97.001 [DIRS 107142]	Mineralogy of USW H-3 sidewall core and cuttings samples
LADB831321AN98.002 [DIRS 109003]	Mineralogy of UE-25 J-12 cuttings samples
	Mineralogy of USW H-3 sidewall core and cuttings samples
	Mineralogy of USW H-4 sidewall core and cuttings samples
	Mineralogy of USW WT-1 cuttings samples
	Mineralogy of UE-25 p#1 intermittent core, sidewall core, and cuttings samples
	Mineralogy of USW WT-2 intermittent core and cuttings samples
	Mineralogy of USW H-5 sidewall core and cuttings samples

The current qualification activity also addressed whether the correct data sets were placed into DTN: MO0101XRDDRILC.001 [DIRS 169517]. The criterion was that all XRD data from sidewall core, drill cuttings, and intermittent core used as input to the mineralogic model report (BSC 2002 [DIRS 158730]), and excluded from qualification by Steinborn (2002 [DIRS 160702]), should have been placed into the DTN. Identification of data used as input was based on the contents of DTN: LA9908JC831321.001, which contains the input files of mineralogic abundance data for the model. While it is true that the purpose of this qualification activity is to qualify data in DTN: MO0101XRDDRILC.001 [DIRS 169517] for any use on the Yucca Mountain Project, the specific data requirements of the mineralogical model must be addressed to provide maximum benefit. Appropriate recommendations will be made to achieve this goal.

In the process of this qualification activity, it was found that DTN: MO0101XRDDRILC.001 [DIRS 169517] and its predecessor DTN: LADB831321AN98.002 [DIRS 109003] do not contain all of the cuttings and sidewall core mineralogical data that were inputs to DTN: LA9908JC831321.001 and the mineralogic model report (BSC 2002 [DIRS 158730]). Sources of input to the mineralogical model also include DTN: LADV831321AQ97.001 [DIRS 107142] and DTN: LADV831321AQ97.007 [DIRS 113499], both of which are listed in the TDMS as qualified even though they contain data from unqualified cuttings samples. An additional data source was the unqualified DTN: LA9910JC831321.001 [DIRS 113496].

A1.3 BACKGROUND

The DTNs in Table A-1 contain XRD data that were collected by LANL investigators beginning in the early 1980s and completed by 1986. Descriptions of the analytical methodologies for

these data can be found in published LANL documents (Levy 1984 [DIRS 101392]; Bish and Vaniman 1985 [DIRS 101196]; Chipera and Bish 1988 [DIRS 105080], and Bish and Chipera 1989 [DIRS 101195]). Table A-2 is an excerpt from a data set in DTN: MO0101XRDDRILC.001 (DIRS 169517).

Table A-2. Sample Extraction from DTN: MO0101XRDDRILC.001 (DIRS 169517), SEP Table S01025_003, Illustrating the Data Type and Structure

S01025_003 Data Report							
Table Description:							
Mineral Abundance data from X-Ray Diffraction analyses of sidewall and drill cuttings from USW H-3, 01/02/1981 to 11/01/1988.							
TDIF: 311749							
DTN: MO0101XRDDRILC.001							
FOOTNOTES: Sample Number indicates depth in feet. Mineral Abundance values are reported in weight percent. All uncertainty values are valid within two standard deviations. Clinoptilolite Abundance represents clinoptilolite/heulandite group mineral abundance. Opal-CT present in zeolitic tuff is reported as cristobalite. (SW) = sidewall core sample from Levy (1984 [DIRS 101392]). Tr. = trace (less than 0.5%). - indicates not detected. Blanks are intended.							
PARAMETERS:							
SMECTITE ABUNDANCE							
MICA GROUP ABUNDANCE							
CLINOPTILOLITE ABUNDANCE							
MORDENITE ABUNDANCE							
TRIDYMITE ABUNDANCE							
QUARTZ ABUNDANCE							
CRISTOBALITE/OPAL ABUNDANCE							
FELDSPAR ABUNDANCE							
GLASS ABUNDANCE							
HEMATITE ABUNDANCE							
HORNBLLENDE ABUNDANCE							
SAMPLE NUMBER	DEPTH (m)	SMECTITE ABUNDANCE (%)	SMECTITE UNCERTAINTY (+/-)	MICA GROUP ABUNDANCE (%)	MICA GROUP UNCERTAINTY (+/-)	CLINOPTILO-LITE ABUNDANCE (%)	CLINOPTILO-LITE UNCERTAINTY (+/-)
470-480	143.3-146.3	-		2	1	-	
520-530	158.5-161.5	-		-		-	
1550(SW)	472.4	Tr.		1	1	2	3
1800(SW)	548.6	2	3	1	1	60	10

DTN=data tracking number; TDIF=technical data information form

A2. QUALIFICATION METHODS

The qualification method of corroboration is used in this DQR to determine the degree to which mineralogic data for the sidewall core and cuttings samples are consistent with qualified mineralogic information for the same stratigraphic units in nearby cored boreholes. The corroborating-data method involves comparing different data sets to evaluate the consistency of mineral content within lithostratigraphic units between the existing unqualified data and data that have been qualified under a qualification report or data with verified quality assurance status. In addition, inferences of similar primary texture, mineralogy, or mineralogical alteration between

cuttings data and the data from core samples were identified and documented wherever this information aided the corroboration process.

The initial evaluation of data quality and correctness reviewed the uncertainties associated with collection of cuttings and sidewall-core samples. The principal uncertainty is in assigning depths to the cutting samples and sidewall-core samples. The existing data sets of cuttings and sidewall-core samples lack the visible record of continuous core needed to provide the highest level of confidence in the accuracy of recorded sampling depths. Uncertainties may also be associated with the subsampling of cuttings samples. Subsampling can be problematic because the samples commonly have mixed lithologies including rock types from depths shallower than the nominal sample depth. Records supporting the unqualified data and the adequacy of the procedures or methods used were reviewed and addressed in the evaluation of these data. Types of records examined included evidence of procedures in use when the samples were collected, sample collection and description records, XRD analysis records, and additional types of sample analyses that document sample integrity.

A2.1 EVALUATION CRITERIA

The types of geologic sample materials subject to qualification are identified for each borehole in Table A-3. The criteria of consideration in evaluating the qualification of the unqualified cuttings mineralogical data include the following conditions:

- Do samples from a particular lithostratigraphic unit have mineralogic abundances similar to samples of the same unit from qualified borehole data sets?
- Do samples from a succession of lithostratigraphic units show mineralogic changes between units that are consistent with changes observed in the qualified data sets?
- Does at least some documentation exist for sample collection, sample description, or XRD analysis?
- Is the XRD methodology used comparable to the methodology used to collect data for qualified data sets?

These criteria were selected to incorporate the considerations in procedure AP-SIII.2Q, Attachments 2 and 3, plus data-specific considerations.

This evaluation was primarily qualitative in nature because the number of cuttings or sidewall samples from certain drill holes is small and many lithostratigraphic units are represented by only one sample in a data set. The basic statistic for data comparisons is the raw data range representing the upper and lower bounds of mineral abundance in a lithostratigraphic unit.

Table A-3. List of Boreholes in DTN: MO0101XRDDRILC.001 (DIRS 169517), Material Type Analyzed, and Qualification Status of the Material

Well	Material Type	Qualification Status
UE-25 J-12	Cuttings	Unqualified
UE-25 p#1	Cuttings, Intermittent Core, Sidewall Core	Unqualified
USW H-3	Cuttings, Sidewall Core	Unqualified
USW H-4	Cuttings, Sidewall Core	Unqualified
USW H-5	Cuttings, Sidewall Core	Unqualified
USW WT-1	Cuttings	Unqualified
USW WT-2	Cuttings, Intermittent Core	Unqualified

A3. EVALUATION RESULTS

The evaluation results are presented on a borehole-by-borehole basis in each of the following sections. Section A3.1 provides a comparison of samples analyzed between DTNs MO0101XRDDRILC.001 [DIRS 169517], LADB831321AN98.002 [DIRS 109003], LADV831321AQ97.001 [DIRS 107142], LADV831321AQ97.007 [DIRS 113499], LA9910JC831321.001 [DIRS 113496], and LA9908JC831321.001. Section A3.2 reviews the existing records pertinent to sample collection, description, and preparation for XRD analysis. Section A3.3 provides descriptions of the XRD methodologies used to analyze samples from the boreholes. Section A3.4 contains comparisons of mineralogical abundances between the unqualified data sets and qualified data sets from continuously cored boreholes.

A3.1 DTN ANALYSIS CONTENTS

This section provides comparisons of samples analyzed by quantitative XRD among DTNs MO0101XRDDRILC.001 [DIRS 169517], LADB831321AN98.002 [DIRS 109003], LADV831321AQ97.001 [DIRS 107142], LA9910JC831321.001 [DIRS 113496], and LA9908JC831321.001. A separate set of comparisons is made for each borehole data set to be evaluated. DTN: LA9908JC831321.001 contains the input files for the mineralogic model report (BSC 2002 [DIRS 158730]), with sample locations and mineralogical abundances rendered in a form suitable for the model. The purpose of the comparisons is to confirm the identities of DTNs that are sources for the model input and assure that all necessary unqualified source data are included in the qualification effort.

UE-25 J-12

Table A-4 shows that the J-12 sample analyses in DTN: MO0101XRDDRILC.001 [DIRS 169517] are derived completely and exclusively from DTN: LADB831321AN98.002 [DIRS 109003]. They are not used as input to the mineralogic model and therefore are not in the DTN that provides input files for the model.

Table A-4. Comparison for Equivalence of J-12 Analyzed Samples Included in Data Packages

MO0101XRDDRILC.001 [DIRS 169517] (depth interval in ft)	LADB831321AN98.002 [DIRS 109003] (depth interval in ft)	LA9908JC831321.001
620-630	620-630	No J-12 sample analyses as input
650-660	650-660	
710-720	710-720	
770-780	770-780	
860-870	860-870	
905-915	905-915	
983-992	983-992	
1067-1077	1067-1077	
1093-1097	1093-1097	
1107-1110	1107-1110	
1121-1126	1121-1126	
1136-1139	1136-1139	

UE-25 p#1

Table A-5 shows that the UE-25 p#1 sample analyses in DTN: MO0101XRDDRILC.001 [DIRS 169517] are derived completely from DTN: LADB831321AN98.002 [DIRS 109003]. Inputs to the Mineralogic Model (MM3.0) (BSC 2002 [DIRS 158730]) in DTN: LA9908JC831321.001 are also derived from DTN: LADB831321AN98.002 [DIRS 109003]. Two numbers (shown in bold type, corresponding to parts of the sampling depth intervals in meters) in DTN: LADB831321AN98.002 [DIRS 109003] are incorrect, and the errors also are present in DTN: MO0101XRDDRILC.001 [DIRS 169517]. The errors are traceable to Bish and Chipera (1989 [DIRS 101195], p. 24, 26). These errors were fixed in DTN: LA9908JC831321.001 for the one erroneous sample-depth conversion included in that DTN. However, DTN: LA9908JC831321.001 contains one erroneous entry for this borehole. The entry for elevation 131.0-m/depth 3,225 ft (shown in bold type) does not correspond to an analyzed sample. The mineralogic data associated with this entry correspond with data for 3,320-3,330-ft depth as listed in Bish and Chipera (1989 [DIRS 101195], p. 25) and in DTNs LADB831321AN98.002 [DIRS 109003] and MO0101XRDDRILC.001 [DIRS 169517]. The correct elevation would be $-(3325 \times 12 \div 39.37) + 1114 = 100.5$ m, where $12 \div 39.37$ is the feet-to-meters conversion factor and 1114 is the ground-level elevation in meters of the borehole (DTN: LA9908JC831321.001).

Table A-5. Comparison for Equivalence of UE-25 p#1 Analyzed Samples Included in Data Packages

MO0101XRDDRILC.001 [DIRS 169517] (depth interval in ft/m)	LADB831321AN98.002 [DIRS 109003] (depth interval in ft/m)	LA9908JC831321.001 (midpoint elevation in m/depth in ft)
200-210/61.8-64.0	200-210/61.8-64.0	1051.5/205
260-270/79.2-82.3	260-270/79.2-82.3	1033.2/265
280-290/85.3-88.4	280-290/85.3-88.4	1027.1/285
410-420/125.0-128.0	410-420/125.0-128.0	987.5/415
570-580/173.7-176.8	570-580/173.7-176.8	938.7/575
810-820/246.9-249.9	810-820/246.9-249.9	865.6/815
900-910/274.3-277.4	900-910/274.3-277.4	838.2/905
1040-1050/317.0-320.0	1040-1050/317.0-320.0	795.5/1045
1240-1250/378.0-381.0	1240-1250/378.0-381.0	reassigned to 730.0/1260
1260-1270/384.0-387.1	1260-1270/384.0-387.1	728.4/1265
1290/393.2 (sidewall core)	1290/393.2 (sidewall core)	720.8/1290
1340-1350/408.4-411.5	1340-1350/408.4-411.5	704.0/1345
1400/426.7 (sidewall core)	1400/426.7 (sidewall core)	687.3/1400
1420/432.8 (sidewall core)	1420/432.8 (sidewall core)	681.2/1420
1470/448.1 (sidewall core)	1470/448.1 (sidewall core)	reassigned to 668.0/1463
1590-1598/484.6-487.1	1590-1598/484.6-487.1	627.8/1595
1640-1650/499.9-502.9	1640-1650/499.9-502.9	612.6/1645
1690-1700/515.1-518.2	1690-1700/515.1-518.2	597.4/1695
1730-1740/527.3-530.4	1730-1740/527.3-530.4	585.2/1735
1790-1800/545.6-548.6	1790-1800/545.6-548.6	566.9/1795
1830-1840/557.8-560.8	1830-1840/557.8-560.8	554.7/1835
1870-1880/570.0-573.0	1870-1880/570.0-573.0	542.5/1875
1920-1930/585.2-588.3	1920-1930/585.2-588.3	527.3/1925
1970-1980/600.5-603.5	1970-1980/600.5-603.5	512.0/1975
1990-2000/606.6-609.6	1990-2000/606.6-609.6	505.9/1995
2030-2040/618.7-621.8	2030-2040/618.7-621.8	493.7/2035
2070-2080/630.9/634.0	2070-2080/630.9/634.0	481.5/2075
2120-2130/646.2-649.2	2120-2130/646.2-649.2	466.3/2125
2150-2160/655.3-658.4	2150-2160/655.3-658.4	457.2/2155
2210-2220/673.6-676.7	2210-2220/673.6-676.7	438.9/2215
2240-2250/682.8-685.8	2240-2250/682.8-685.8	429.7/2245
2280-2290/694.9-698.0	2280-2290/694.9-698.0	417.5/2285
2330-2340/710.2-713.2	2330-2340/710.2-713.2	402.3/2335
2370-2380/722.4-725.4	2370-2380/722.4-725.4	390.1/2375
2410-2420/734.6-737.6	2410-2420/734.6-737.6	377.9/2415
2460-2470/749.8-752.9	2460-2470/749.8-752.9	362.7/2465
2510-2520/765.0-768.1	2510-2520/765.0-768.1	347.4/2515
2570-2580/783.3-786.4	2570-2580/783.3-786.4	329.1/2575
2630-2640/801.6-804.7	2630-2640/801.6-804.7	310.9/2635
2650-2660/807.7-810.8	2650-2660/807.7-810.8	304.8/2655
2690-2700/819.9-823.0	2690-2700/819.9-823.0	292.6/2695

Table A-5. Comparison for Equivalence of UE-25 p#1 Analyzed Samples Included in Data Packages (Continued)

MO0101XRDDRILC.001 [DIRS 169517] (depth interval in ft/m)	LADB831321AN98.002 [DIRS 109003] (depth interval in ft/m)	LA9908JC831321.001 (midpoint elevation in m/depth in ft)
2750-2760/838.2-841.2	2750-2760/838.2-841.2	274.3/2755
2790-2800/850.4-853.4	2790-2800/850.4-853.4	262.1/2795
2840-2850/865.6-868.7	2840-2850/865.6-868.7	246.8/2845
2890-2900/880.9-883.9	2890-2900/880.9-883.9	231.6/2895
2940-2950/896.1-899.2	2940-2950/896.1-899.2	216.4/2945
2980-2990/908.3-911.4	2980-2990/908.3-911.4	204.2/2985
3030-3040/923.5-926.6	3030-3040/923.5-926.6	188.9/3035
3080-3090/938.8-941.8	3080-3090/938.8-941.8	173.7/3085
3130-3140/954.0-957.1	3130-3140/954.0-957.1	158.5/3135
3160-3170/963.2-966.2	3160-3170/963.2-966.2	149.3/3165
3230-3240/984.5-987.6	3230-3240/984.5-987.6	128.0/3235
3270-3280/996.7-999.7	3270-3280/996.7-999.7	115.8/3275
3320-3330/1011.9-1015.0	3320-3330/1011.9-1015.0	131.0/3225 location is in error
3370-3380/1027.2-1030.2	3370-3380/1027.2-1030.2	85.3/3375
3410-3420/1039.4-1042.4	3410-3420/1039.4-1042.4	73.1/3415
3453/1052.5 (core)	3453/1052.5 (core)	61.5/3453
3480-3490/1060.7-1063.8	3480-3490/1060.7-1063.8	51.8/3485
3510-3520/1069.8-1072.9	3510-3520/1069.8-1072.9	42.6/3515
3550-3560/1082.0-1085.1	3550-3560/1082.0-1085.1	30.4/3555
3560-3570/1085.1-1088.1	3560-3570/1085.1-1088.1	27.4/3565
3590-3600/1094.2-1097.3	3590-3600/1094.2-1097.3	18.2/3595
3630-3640/1106.4-1109.5	3630-3640/1106.4-1109.5	6.1/3635
3650-3660/1112.5-1115.6	3650-3660/1112.5-1115.6	0.0/3655
3660-3670/1115.6-1118.6	3660-3670/1115.6-1118.6	-3.1/3665
3690-3700/1124.7-1127.8	3690-3700/1124.7-1127.8	-12.2/3695
3720-3730/1133.9-1136.9	3720-3730/1133.9-1136.9	-21.4/3725
3750-3760/1143.0-1146.0	3750-3760/1143.0-1146.0	-30.5/3755
3790-3800/1155.2-1158.2	3790-3800/1155.2-1158.2	-42.7/3795
3820-3830/1164.3-1167.4	3820-3830/1164.3-1167.4	-51.9/3825
3860-3870/1176.5-1179.6	3860-3870/1176.5-1179.6	-64.1/3865
3913/1192.7 (core)	3913/1192.7 (core)	-78.7/3913
3916/1193.6 (core)	3916/1193.6 (core)	-79.6/3916
3928/1197.3 (core)	3928/1197.3 (core)	-83.3/3928
3940-3950/1200.9-1204.0	3940-3950/1200.9-1204.0	-88.4/3945
3980-3990/1213.1-1216.2	3980-3990/1213.1-1216.2	-100.6/3985
4040-4050/1231.4-1234.4	4040-4050/1231.4-1234.4	-118.9/4045
4070-4080/1240.5-1243.6	4070-4080/1240.5-1243.6	-128.1/4075
4080-4090/1243.6- 1249.1	4080-4090/1243.6- 1249.1	Paleozoic unit not in model
4170-4180/1271.0-1274.1	4170-4180/1271.0-1274.1	Paleozoic unit not in model
4313-4318/1314.6-1316.1	4313-4318/1314.6-1316.1	Paleozoic unit not in model

NOTE: Erroneous information is in bold type.

USW H-3

Table A-6 shows that the USW H-3 sample analyses in DTN: MO0101XRDDRILC.001 [DIRS 169517] are derived from DTN: LADB831321AN98.002 DIRS 109003], duplicated by data in LADV831321AQ97.001 [DIRS 107142]. It also shows that some of the data used as input by Version 3.0 of the mineralogic model (BSC 2002 [DIRS 158730]) were derived only from DTN: LADV831321AQ97.001 [DIRS 107142] and are missing from DTN: MO0101XRDDRILC.001 [DIRS 169517].

Table A-6. Comparison for Equivalence of USW H-3 Analyzed Samples Included in Data Packages

MO0101XRDDRILC.001 [DIRS 169517] (depth interval in ft/m)	LADB831321AN98.002 [DIRS 109003] (depth interval in ft/m)	LADV831321AQ97.001 [DIRS 107142] (depth interval in ft/m)	LA9908JC831321.001 (midpoint elevation in m/depth in ft)
470-480/143.3-146.6	470-480/143.3-146.6	470-480/143.3-146.6	1338.4/475
520-530/158.5-161.5	520-530/158.5-161.5	520-530/158.5-161.5	1323.2/525
540-550/164.6-167.6	540-550/164.6-167.6	540-550/164.6-167.6	1317.1/545
610-620/185.9-189.0	610-620/185.9-189.0	610-620/185.9-189.0	1295.7/615
740-750/225.6-228.6	740-750/225.6-228.6	740-750/225.6-228.6	1256.1/745
800-810/243.8-246.9	800-810/243.8-246.9	800-810/243.8-246.9	1237.8/805
870-880/265.2-268.2	870-880/265.2-268.2	870-880/265.2-268.2	1216.5/875
930-940/283.5-286.5	930-940/283.5-286.5	930-940/283.5-286.5	1198.2/935
990-1000/301.8-304.8	990-1000/301.8-304.8	990-1000/301.8-304.8	1179.9/995
1030-1040/313.9-317.0	1030-1040/313.9-317.0	1030-1040/313.9-317.0	1167.7/1035
1100-1110/335.3-338.3	1100-1110/335.3-338.3	1100-1110/335.3-338.3	1146.4/1105
1160-1170/353.6-356.6	1160-1170/353.6-356.6	1160-1170/353.6-356.6	1128.1/1165
1270-1280/387.1-390.1	1270-1280/387.1-390.1	1270-1280/387.1-390.1	1094.6/1275
1320-1330/402.3-405.4	1320-1330/402.3-405.4	1320-1330/402.3-405.4	1079.3/1325
		1360-1370/414.5-417.6	1067.1/1365
		1440-1450/438.9-442.0	1042.8/1445
		1480-1490/451.1-454.2	1030.6/1485
		1500-1510/457.2-460.2	1024.5/1505
1550/472.4 (sidewall core)	1550/472.4 (sidewall core)	1550/472.4 (sidewall core)	1010.8/1550
1655/504.5 (sidewall core)	1655/504.5 (sidewall core)	1655/504.5 (sidewall core)	978.7/1655
1700/518.2 (sidewall core)	1700/518.2 (sidewall core)	1700/518.2 (sidewall core)	965.0/1700
1800/548.6 (sidewall core)	1800/548.6 (sidewall core)	1800/548.6 (sidewall core)	934.6/1800
1900/579.1 (sidewall core)	1900/579.1 (sidewall core)	1900/579.1 (sidewall core)	904.1/1900
2400/731.5 (sidewall core)	2400/731.5 (sidewall core)	2400/731.5 (sidewall core)	751.7/2400
2440/743.7 (sidewall core)	2440/743.7 (sidewall core)	2440/743.7 (sidewall core)	739.5/2440
2490/759 (sidewall core)	2490/759 (sidewall core)	2490/759.0 (sidewall core)	724.2/2490

NOTE: Blank boxes are intentional.

USW H-4

Table A-7 shows that the USW H-4 sample analyses in DTN: MO0101XRDDRILC.001 [DIRS 169517] are derived completely and exclusively from DTN: LADB831321AN98.002 [DIRS 109003]. There is a one-to-one correspondence between the

DTN: MO0101XRDDRILC.001 [DIRS 169517] data set and the data set in DTN: LA9908JC831321.001 that is output of the mineralogic model.

Table A-7. Comparison for Equivalence of USW H-4 Analyzed Samples Included in Data Packages

MO0101XRDDRILC.001 [DIRS 169517] (depth interval in ft/m)	LADB831321AN98.002 [DIRS 109003] (depth interval in ft/m)	LA9908JC831321.001 (midpoint elevation in m/depth in ft)
310-320/94.5-97.5	310-320/94.5-97.5	1152.5/315
390-400/118.9-121.9	390-400/118.9-121.9	1128.1/395
440-450/134.1-137.2	440-450/134.1-137.2	1112.9/445
490-500/149.4-152.4	490-500/149.4-152.4	1097.6/495
640-650/195.1-198.1	640-650/195.1-198.1	1051.9/645
830-840/253.0-256.0	830-840/253.0-256.0	994.0/835
910-920/277.4-280.4	910-920/277.4-280.4	969.6/915
940-950/286.5-289.6	940-950/286.5-289.6	960.5/945
1040-1050/317.0-320.0	1040-1050/317.0-320.0	930.0/1045
1150-1160/350.5-353.6	1150-1160/350.5-353.6	896.5/1155
1190-1200/362.7-365.8	1190-1200/362.7-365.8	884.3/1195
1230-1240/374.9-378.0	1230-1240/374.9-378.0	872.1/1235
1312/399.9 (sidewall core)	1312/399.9 (sidewall core)	848.6/1312
1320-1330/402.3-405.4	1320-1330/402.3-405.4	844.6/1325
1350-1360/411.5-414.5	1350-1360/411.5-414.5	835.5/1355
1410-1420/429.8-432.8	1410-1420/429.8-432.8	817.2/1415
1420/432.8 (sidewall core)	1420/432.8 (sidewall core)	815.7/1420
1455/443.5 (sidewall core)	1455/443.5 (sidewall core)	805.0/1455
1540-1550/469.4-472.4	1540-1550/469.4-472.4	777.6/1545
1550/472.4 (sidewall core)	1550/472.4 (sidewall core)	776.1/1550
1600-1610/487.7-490.7	1600-1610/487.7-490.7	770.0/1570*
1640-1650/499.9-502.9	1640-1650/499.9-502.9	747.1/1645
1656/504.8 (sidewall core)	1656/504.8 (sidewall core)	741.0/1665*
1710-1720/521.2-524.3	1710-1720/521.2-524.3	725.8/1715
1790-1800/545.6-548.6	1790-1800/545.6-548.6	701.4/1795
1900-1910/579.1-582.2	1900-1910/579.1-582.2	667.9/1905
1980-1990/603.5-606.6	1980-1990/603.5-606.6	643.5/1985

* These samples were reassigned to different depths, as shown here and explained in the BSC report (2002 [DIRS 158730], p. II-9).

USW H-5

Comparison of the data contents of DTNs MO0101XRDDRILC.001 [DIRS 169517] and LA9908JC831321.001 indicated that there must be additional sources of input to the mineralogic model (BSC 2002 [DIRS 158730]) beside DTN: LADB831321AN98.002 [DIRS 109003] (the precursor of DTN: MO0101XRDDRILC.001 [DIRS 169517]). Two other DTNs were found to be input sources. DTN: LADV831321AQ97.007 [DIRS 113499] is listed in the Technical Data Management System as a qualified DTN even though it contains unqualified data from the USW H-5 cutting samples. This DTN is identified in the mineralogic model (BSC 2002 [DIRS 158730]) as an input source. DTN: LA9910JC831321.001 [DIRS 113496] is listed as

unqualified in the Technical Data Management System and is not identified as an input source in the mineralogic model (BSC 2002 [DIRS 158730]). Table A-8 shows how the three DTNs, with some duplication, comprise the input to the mineralogical model.

Table A-8. Comparison for Equivalence of USW H-5 Analyzed Samples Included in Data Packages

MO0101XRDDRILC.001 [DIRS 169517] and LADB831321AN98.002 [DIRS 109003] (depth interval in ft/m)	LA9910JC831321.001 [DIRS 113496] (depth interval in ft/depth interval midpoint in m)	LADV831321AQ97.007 [DIRS 113499] (depth interval in ft/m)	LA9908JC831321.001 (midpoint elevation in m/depth in ft)
	40-50/13.7		1464.9/45
50/15.2			1463.3/50
	110-120/35.1		1443.5/115
	160-170/50.3		1428.3/165
190/57.9			1420.7/190
	230-240/71.6		1407.0/235
	320-330/99.1		1379.5/325
	380-390/117.3		1361.2/385
420/128			reassigned to 1353.0/412
450/137.2			1341.4/450
	460-470/141.7		1336.8/465
		620-630/189.0-192.0	1288.1/625
700/213.4		700/213.4	1265.2/700
		720-730/219.5-222.5	1257.6/725
		750-760/228.6-231.6	1248.5/755
800-810/243.8-246.9		800-810/243.8-246.9	1233.2/805
830-840/253.0-256.0		830-840/253.0-256.0	1224.1/835
		860-870/262.1-265.2	1214.9/865
920-930/280.4-283.5		920-930/280.4-283.5	1196.6/925
970-980/295.7-298.7		970-980/295.7-298.7	1181.4/975
		990-1000/301.8-304.8	1175.3/995
1050/320		1050/320.0	1158.5/1050
		1090-1100/332.2-335.3	1144.8/1095
1150-1160/350.3-353.6		1150-1160/350.5-353.6	1126.5/1155
		1200-1210/365.8-368.8	1111.3/1205
1230-1240/374.9-378.0		1230-1240/374.9-378.9	1102.2/1235
1290-1300/393.2-396.2		1290-1300/393.2-396.2	1083.9/1295
		1350-1360/411.5-414.5	1065.6/1355
1380-1390/420.6-423.7		1380-1390/420.6-423.7	1056.4/1385
1450-1460/442.0-445.0		1450-1460/442.0-445.0	1035.1/1455
1490-1500/454.2-457.2		1490-1500/454.2-457.2	1022.9/1495
		1530-1540/466.3-469.4	1010.7/1535
1590-1600/484.6-487.7		1590-1600/484.6-487.7	992.4/1595
1610/490.7		1610/490.7	987.9/1610

Table A-8. Comparison for Equivalence of USW H-5 Analyzed Samples Included in Data Packages (Continued)

MO0101XRDDRILC.001 [DIRS 169517] and LADB831321AN98.002 [DIRS 109003] (depth interval in ft/m)	LA9910JC831321.001 [DIRS 113496] (depth interval in ft/depth interval midpoint in m)	LADV831321AQ97.007 [DIRS 113499] (depth interval in ft/m)	LA9908JC831321.001 (midpoint elevation in m/depth in ft)
		1630-1640/496.8-499.9	980.2/1635
		1650-1660/502.9-506.0	974.1/1655
1666/507.8 (sidewall core)			970.8/1666
1710-1720/521.2-524.3			955.8/1715
1750/533.4			945.2/1750
1762/537.1 (sidewall core)			941.5/1762
	1760-1770/538.0		940.6/1765
1800/548.6 (sidewall core)			929.9/1800
	1820-1830/556.3		922.3/1825
1852/564.5 (sidewall core)			914.1/1852
1875/571.5 (sidewall core)			907.1/1875
	1890-1900/577.6		901.0/1895
	1900-1910/580.6		897.9/1905
	1910-1920/583.7		894.9/1915
1917/584.3 (sidewall core)			894.3/1917
	1920-1930/586.7		891.8/1925
1930/588.3			890.3/1930
	1950-1960/595.9		882.7/1955
1966/599.2 (sidewall core)			879.3/1966
	1990-2000/608.1		Reassigned to 879.2/1966.5
	2070-2080/632.5		846.1/2075
	2140-2150/653.8		Reassigned to 830.0/2128
2200/670.6			808.0/2200
	2230-2240/681.2		797.4/2235
	2260-2270/690.4		788.2/2265

Note: Blank boxes are intentional.

USW WT-1

Table A-9 shows that the USW WT-1 sample analyses in DTN: MO0101XRDDRILC.001 [DIRS 169517] are derived completely and exclusively from DTN: LADB831321AN98.002 [DIRS 109003]. Inputs to the mineralogic model report (BSC 2002 [DIRS 158730]) in DTN: LA9908JC831321.001 also are derived from DTN: LADB831321AN98.002 [DIRS 109003].

Table A-9. Comparison for Equivalence of USW WT-1 Analyzed Samples Included in Data Packages

MO0101XRDDRILC.001 [DIRS 169517] (depth interval in ft/m)	LADB831321AN98.002 [DIRS 109003] (depth interval in ft)	LA9908JC831321.001 (midpoint elevation in m/depth in ft)
440-450/134.1-137.2	440-450	1065.4/445
500-510/152.4-155.4	500-510	1047.1/505
550-560/167.6-170.7	550-560	1031.8/555
640-650/195.1-198.1	640-650	1004.4/645
690-700/210.3-213.4	690-700	989.2/695
780-790/237.7-240.8	780-790	961.7/785
840-850/256.0-259.1	840-850	943.4/845
930-940/283.5-286.5	930-940	916.0/935
1000-1010/304.8-307.8	1000-1010	894.7/1005
1090-1100/332.2-335.3	1090-1100	867.2/1095
1160-1170/353.6-356.6	1160-1170	845.9/1165
1220-1230/371.9-374.9	1220-1230	827.6/1225
1300-1310/396.2-399.3	1300-1310	*
1320-1330/402.3-405.4	1320-1330	*
1340-1350/408.4-411.5	1340-1350	*
1380-1390/420.6-423.7	1380-1390	778.9/1385
1410-1420/429.8-432.8	1410-1420	769.7/1415
1470-1480/448.1-451.1	1470-1480	*
1510-1520/460.2-463.3	1510-1520	*
1550-1560/472.4-475.5	1550-1560	*
1570-1580/478.5-481.6	1570-1580	*

*Exclusion of these analyses is documented in the BSC report (2002 [DIRS 158730], p. II-12, II-13).

USW WT-2

Table A-10 shows that the USW WT-2 sample analyses in DTN: MO0101XRDDRILC.001 [DIRS 169517] are derived completely and exclusively from DTN: LADB831321AN98.002 [DIRS 109003]. Inputs to the mineralogic model report (BSC 2002 [DIRS 158730]) in DTN: LA9908JC831321.001 are also derived from DTN: LADB831321AN98.002 [DIRS 109003]. One sample number (shown in bold type, corresponding to the sampling depth interval in feet) in DTN: LADB831321AN98.002 [DIRS 109003] is incorrect, and the error is also present in DTN: MO0101XRDDRILC.001 [DIRS 169517]. The sample number, “420-450,” does not conform to the typical ten-foot sampling interval for drill cuttings. Notebook entries documenting the collection, description, and receipt of the USW WT-2 samples from the U.S. Geological Survey (USGS) Core Library confirm that the correct footage for the sample is 420-430 ft (Broxton 1990 [DIRS 169640], p. 58; Caporuscio 1986 [DIRS 169644], p. 128). The substitution of “450” for “430” appears to have been derived from a typographical error in Bish and Vaniman (1985 [DIRS 101196], p. 29) that was repeated in Bish and Chipera (1989 [DIRS 101195], p. 49). The conversion from depth in feet to depth in meters in the source documents and in the DTNs reflects the correct footage. The midpoint elevation for the sample used in DTN: LA9908JC831321.001 also is correct.

Table A-10. Comparison for Equivalence of USW WT-2 Analyzed Samples Included in Data Packages

MO0101XRDDRILC.001 [DIRS 169517] (depth interval in ft/m)	LADB831321AN98.002 [DIRS 109003] (depth interval in ft)	LA9908JC831321.001 (midpoint elevation in m/depth in ft)
250-260/76.2-79.2	250-260/76.2-79.2	1223.2/255
260-270/79.2-82.3	260-270/79.2-82.3	1220.1/265
290-300/88.4-91.4	290-300/88.4-91.4	1211.0/295
370-380/112.8-115.8	370-380/112.8-115.8	1186.6/375
420-450¹/128.0-131.0	420-450¹/128.0-131.0	1171.4/425
510-520/155.4-158.5	510-520/155.4-158.5	1143.9/515
570-580/173.7-176.8	570-580/173.7-176.8	1125.6/575
650-660/198.1-201.1	650-660/198.1-201.1	1101.3/655
720-730/219.5-222.5	720-730/219.5-222.5	1079.9/725
780-790/237.7-240.8	780-790/237.7-240.8	1061.6/785
850-860/259.1-262.1	850-860/259.1-262.1	1040.3/855
930-940/283.5-286.5	930-940/283.5-286.5	1015.9/935
990-1000/301.8-304.8	990-1000/301.8-304.8	997.6/995
1060-1070/323.1-326.1	1060-1070/323.1-326.1	976.3/1065
1130-1140/344.4-347.5	1130-1140/344.4-347.5	955.0/1135
1190-1200/362.7-365.8	1190-1200/362.7-365.8	936.7/1196
1200-1210/365.8-368.8	1200-1210/365.8-368.8	933.6/1205
1250-1260/381.0-384.0	1250-1260/381.0-384.0	918.4/1255
1300-1310/396.2-399.3	1300-1310/396.2-399.3	903.1/1305
1360-1370/414.5-417.6	1360-1370/414.5-417.6	884.8/1365
1420-1430/432.8-435.9	1420-1430/432.8-435.9	866.6/1425
1450-1460/442.0-445.0	1450-1460/442.0-445.0	857.4/1455
1470-1480/448.1-451.1	1470-1480/448.1-451.1	851.3/1475
1520-1530/463.3-466.3	1520-1530/463.3-466.3	836.1/1525
1570-1580/478.5-481.6	1570-1580/478.5-481.6	820.8/1575
1640-1650/499.9-502.9	1640-1650/499.9-502.9	799.5/1645
1710-1720/521.2-524.3	1710-1720/521.2-524.3	778.2/1715
1750-1760/533.4-536.4	1750-1760/533.4-536.4	766.0/1755
1820-1830/554.7-557.8	1820-1830/554.7-557.8	744.6/1825
1910-1920/582.2-585.2	1910-1920/582.2-585.2	717.2/1915
2000-2010/609.6-612.6	2000-2010/609.6-612.6	689.8/2005
2050.25/624.9 (core)	2050.25/624.9 (core)	²
2053.7/626 (core)	2053.7/626 (core)	²
2059.3/627.7 (core)	2059.3/627.7 (core)	²

¹The original collection and sample receipt notebook entries identify the footage of this sample as 420-430 ft. See text for further explanation.

²These analyses from MO0101XRDDRILC.001 (DIRS 169517) were also included in LA9908JC831321.001 but were assigned to slightly different depths, as explained in the BSC report (2002 [DIRS 158730], p. II-13).

A3.2 SAMPLE COLLECTION AND PREPARATION FOR XRD ANALYSIS

A3.2.1 Samples from J-12

The J-12 water well was spudded on August 4, 1957, and completed to a depth of 887 ft on October 9, 1957 (Fenix and Scisson, Inc., 1988 [DIRS 169661]). Records from Burns & McDonnell Engineering Company (1959 [DIRS 169662]) indicate that the hole was cased for the full 887-ft depth. The hole was recompleted in August 1968, to a depth of 1,139 ft. Fenix and Scisson, Inc. (1988 [DIRS 169661]) found that drilling records were not available for the deepening of the hole. Of the 12 sample analyses for J-12 samples contained in DTN: MO0101XRDDRILC.001 [DIRS 169517], 5 samples are from depths corresponding to the initial well completion, and the remaining 7 samples are from depths associated with the deepening of the well.

In the course of this qualification activity, no records were found to document LANL sampling of the J-12 cuttings, sample descriptions, or sample preparation for XRD analysis. Based on the lack of documentation and the fact that the J-12 data were not used in the mineralogic model report (BSC 2002 [DIRS 158730]), a decision was made to not attempt qualification of this data set.

A3.2.2 Samples from Other Drill Holes

Records of sample collection, sample description, and sample preparation and analysis by XRD are partial to complete for samples from drill holes USW H-3, USW H-4, USW H-5, USW WT-1, USW WT-2, and UE-25 p#1. Table A-11 summarizes the records that have been identified. As noted by Steinborn (2002 [DIRS 160702]), it is likely that more records exist.

Table A-11. Summary of Records for Sample Collection and XRD Analysis

Drill Hole	Sample Collection and Description Records	Sample Preparation and XRD Analysis Records
USW H-3	Byers 1982 [DIRS 169663]; Vaniman 1983 [DIRS 169665], p. 84-85; Levy 1996 [DIRS 106676], p. 1,4,21-23; LANL 1997 [DIRS 169667]	Levy 1996 [DIRS 106676], p. 4,10,23; Bish 2001 [DIRS 169750], p. 46
USW H-4	Vaniman 1983 [DIRS 169665], p. 85-87; Levy 1996 [DIRS 106676], p. 23; Caporuscio, 1986 [DIRS 169644], p. 135	Levy 1996 [DIRS 106676], p. 4,10
USW H-5	Vaniman 1983 [DIRS 169665], p. 67-70,72-75,87-88; Levy 1996 [DIRS 106676], p. 25; Caporuscio 1986 [DIRS 169644], p. 135; LANL 1992 [DIRS 169718]	Levy 1996 [DIRS 106676], p. 10; Bish 2001 [DIRS 169750], p. 45-46
USW WT-1	Broxton 1990 [DIRS 169640], p.61-63; Caporuscio 1986 [DIRS 169644], p. 127	no records found
USW WT-2	Broxton 1990 1986 [DIRS 169640], p. 58-60; Caporuscio 1986 [DIRS 169644], p. 128	no records found

Table A-11. Summary of Records for Sample Collection and XRD Analysis (Continued)

Drill Hole	Sample Collection and Description Records	Sample Preparation and XRD Analysis Records
UE-25 p#1	Caporuscio 1986 [DIRS 169644], p. 131-133; Chipera 1986 [DIRS 169680], p.100	Chipera 1986 [DIRS 169680], p.34,36,37,38,39,40,48,49,50, 52,53,55,56,57,58,59,60,62,63,64,65,66,68,69, 101,102; Bish 2001 [DIRS 169750], p. 2-5; Chipera et al. 1989 [DIRs 169683], p. 2,3

A3.3 X-RAY DIFFRACTION METHODOLOGY

X-ray diffraction analysis of the cutting samples, sidewall core samples, and intermittent core samples was conducted in the same time period as XRD analysis of samples from the continuously cored boreholes. The same analytical equipment and software were used. Documentation and evaluation of technical procedures found to be acceptable by Steinborn (2002 [DIRS 160702]) for qualification of XRD mineralogic data from core samples apply to the data under consideration here as well. Table A-12 identifies specific published sources of information about XRD analytical techniques for the borehole data sets considered for qualification.

Table A-12. Published Sources on XRD Mineralogy for Unqualified Data Sets

Borehole	Published Information Source on XRD Methodology
UE-25 p#1	Chipera and Bish (1988 [DIRS 105080]) for all samples
USW H-3	Levy (1984 [DIRS 101392]) for samples 1550, 1655, 1700, 1800, 1900, 2400, 2440, 2490;
USW H-4	Levy (1984 [DIRS 101392]) for sidewall core samples
USW H-5	Levy (1984 [DIRS 101392]) for samples 50, 190, 420, 450, 700, 1050, 1610, 1666, 1750, 1762, 1800, 1852, 1875, 1917, 1930;
USW WT-1	Bish and Chipera (1989 [DIRS 101195]) for all samples
USW WT-2	Bish and Chipera (1989 [DIRS 101195]) for all samples

A3.4 DATA CORROBORATION ANALYSIS

The comparison of mineral abundance data between boreholes with unqualified cuttings and boreholes with qualified core was conducted with restrictions imposed by the nature of mineralogic variation within the study area and by certain characteristics of the data sets. Variations in mineralogy across the Yucca Mountain area reflect primary compositional differences between consecutive ash flows. Lateral and vertical variability in pyroclastic constituents of ash flows and in post-depositional cooling and crystallization history also affects the mineralogy. Superimposed upon the variations in primary pyroclastic and syngenetic (high-temperature post-depositional crystallization) mineralogy are mineralogic changes due to alteration. The most important alteration was zeolitic alteration of originally glassy tuff. Distribution of zeolitic alteration was affected by multiple episodes of tectonic tilting and past

variations in the position of the water table. A conceptual model that explains the interrelationship between these factors and the distribution of zeolitization is given by Levy (1991 [DIRS 100053]).

Paired borehole mineralogy data sets of qualified core data and unqualified cuttings (plus sidewall core and intermittent core) data were selected on the basis of physical proximity plus comparable ground-level elevations of boreholes. These criteria were applied to minimize the effects of lateral and vertical mineralogical variability on the comparisons of mineralogy data sets. The comparisons of mineralogical data were made for individual lithostratigraphic units or successions of units, based on unit contacts from DTN: MO0004QGFMPICK.000 [DIRS 152554]. This qualified DTN contains unit contacts for both the boreholes with qualified core and those with unqualified cuttings. Unit descriptions and abbreviations are listed in A-13. The locations of unit contacts in boreholes without continuous core were determined more from downhole logs than from cuttings data. Most of the contacts are located within ten-foot intervals represented by cuttings samples. These samples would therefore contain material from two adjacent lithostratigraphic units. In addition, some cuttings, sidewall, or intermittent core samples located near unit boundaries have mineralogic affinities to an adjacent unit rather than the unit to which they would belong simply on the basis of sample footage location. This phenomenon was recognized by the authors of the BSC report (2002 [DIRS 158730]), who omitted some sample data from their model or adjusted the footage of some samples to avoid placing mineralogic data in an inappropriate lithostratigraphic unit. Unit contacts in cored holes are not free of these potential discrepancies because contacts in cored holes may have been selected more on the basis of rock texture than of mineralogy. In this report, such discrepancies are addressed on an individual basis.

Mineral-abundance data for lithostratigraphic units are presented as ranges bounded by the highest and lowest values. In general, neither the qualified nor the unqualified data sets contain enough analyses from any single lithostratigraphic unit to justify statistical comparisons of mean or standard deviation between borehole data sets. Borehole cuttings data sets typically contain four or fewer analyses for each unit.

The listings of individual samples used for comparison between unqualified and qualified data sets are contained in Appendices A (unqualified data) and B (qualified data). Analyses of cavity fillings, fracture fillings, and inclusions were omitted from the comparisons because these samples do not represent the bulk mineralogy of the lithostratigraphic units in which they were collected. Calcite-rich samples in the qualified data sets were omitted from the comparisons, because these samples have an altered mineralogy and are not typical. In tables of this section where data are presented as ranges of mineral content, zeroes are substituted for “not detected” symbols present in the original DTN tables and in the appendices of this report. Symbols for approximate mineral content (e.g., ~1), also present in some of the original DTN tables in this section. In some comparison tables, mineral abundances for feldspar and silica minerals (tridymite, quartz, cristobalite, and opal) from the appendix have been combined to simplify the comparisons.

Lithostratigraphic units and their abbreviations, as used in this report, are listed in Table A-13. The unit names and boundaries are taken from DTN: MO0004QGFMPICK.000 [DIRS 152554]. The units are listed in order from lesser to greater depths and from younger to older ages. The

term, “crystallized,” as used in the lithostratigraphic unit descriptions, has a meaning equivalent to the term “devitrified,” which is in more common usage in the petrographic descriptions of core and cutting samples cited in this report. Devitrification refers here to the high-temperature crystallization of glassy tuffs to mineral assemblages dominated by anhydrous silica minerals and feldspar.

Table A-13. Lithostratigraphic Unit Descriptions and Abbreviations

Unit Abbreviation	Lithostratigraphic Unit Description
Tpc_un	Tiva Canyon Tuff nondivided
Tpcpv3	Tiva Canyon Tuff, crystal-poor vitric densely welded subzone
Tpcpv2	Tiva Canyon Tuff, crystal-poor vitric moderately welded subzone
Tpcpv1	Tiva Canyon Tuff, crystal-poor vitric nonwelded to partially welded subzones
Tpbt4	Pre-Tiva Canyon Tuff bedded tuff
Tpy	Yucca Mountain Tuff nondivided
Tpbt3	Pre-Yucca Mountain Tuff bedded tuff
Tpp	Pah Canyon Tuff nondivided
Tpbt2	Pre-Pah Canyon Tuff bedded tuff
Tptrv3	Topopah Spring Tuff crystal-rich vitric nonwelded to partially welded zones
Tptrv2	Topopah Spring Tuff crystal-rich vitric moderately welded zone
Tptrv1	Topopah Spring Tuff crystal-rich vitric densely welded zone
Tptrn	Topopah Spring Tuff crystal-rich non-lithophysal zone
Tptrl	Topopah Spring Tuff crystal-rich lithophysal zone
Tptpul	Topopah Spring Tuff crystal-poor upper lithophysal zone
Tptpmn	Topopah Spring Tuff crystal-poor middle nonlithophysal zone
Tptpll	Topopah Spring Tuff crystal-poor lower lithophysal zone
Tptpln	Topopah Spring Tuff, crystal-poor lower nonlithophysal zone
Tptpv3	Topopah Spring Tuff, crystal-poor vitric densely welded subzone
Tptpv2	Topopah Spring Tuff, crystal-poor vitric moderately welded subzone
Tptpv1	Topopah Spring Tuff, crystal-poor vitric nonwelded to partially welded subzones
Tpbt1	Pre-Topopah Spring Tuff bedded tuff
Tac	Calico Hills Formation undifferentiated
Tacbt	Pre-Calico Hills Formation bedded tuff
Tcpuv	Prow Pass Tuff upper vitric (zeolitic) nonwelded to partially welded zones
Tcpuc	Prow Pass Tuff, upper crystallized nonwelded to partially welded zones
Tcpm	Prow Pass Tuff, crystallized moderately to densely welded zones
Tcplc	Prow Pass Tuff, lower crystallized nonwelded to partially welded zones
Tcplv	Prow Pass Tuff, lower vitric (zeolitic) nonwelded to partially welded zones
Tcpbt	Pre-Prow Pass Tuff bedded tuff
Tcbuv	Bullfrog Tuff upper vitric (zeolitic) nonwelded to partially welded zones
Tcbuc	Bullfrog Tuff, upper crystallized nonwelded to partially welded zones
Tcbm	Bullfrog Tuff, crystallized moderately to densely welded zones

Table A-13. Lithostratigraphic Unit Descriptions and Abbreviations (Continued)

Unit Abbreviation	Lithostratigraphic Unit Description
Tcblc	Bullfrog Tuff, lower crystallized nonwelded to partially welded zones
Tcblv	Bullfrog Tuff, lower vitric (zeolitic) nonwelded to partially welded zones
Tcbbt	Pre-Bullfrog Tuff bedded tuff
Tctuv	Tram Tuff, upper vitric (zeolitic) nonwelded to partially welded zones
Tctuc	Tram Tuff, upper crystallized nonwelded to partially welded zones
Tctm	Tram Tuff, crystallized moderately to densely welded zones
Tctlc	Tram Tuff, lower crystallized nonwelded to partially welded zones
Tctlv	Tram Tuff, lower vitric (zeolitic) nonwelded to partially welded zones
Tctbt	Pre-Tram Tuff bedded tuff
Tund	lower Tertiary units undifferentiated
Pz	Paleozoic and older units

Source: DTN: MO0004QGFMPICK.000 (DIRS 152554).

UE-25 p#1 Compared with UE-25 UZ#16, USW SD-12, USW G-4, and USW G-1

For purposes of corroboration, the mineralogical data from the upper part of p#1 were compared with qualified data from UE-25 UZ#16. This is the borehole closest to p#1 that has qualified data. The data are compared in Table A-14. Mineralogic data from the lower part of p#1 are compared with qualified data from USW G-1 (Table A-16).

For the devitrified units of the Topopah Spring Tuff, ranges of mineralogic abundance in both boreholes generally overlap. The absence of either glass or major hydrous alteration products (smectite or zeolites) in the devitrified units is a common characteristic of both data sets.

One cutting sample from the 1240-1250-ft depth in p#1 straddles the boundary between Tptpv2 and Tptpv1 at 1243 ft. Data for this sample are listed in Table A-14 as Tptpv2/1. A downward transition from vitric to zeolitic tuff is located within the Tptpv2 + Tptpv1 interval in both boreholes. In UZ#16, the transition lies within Tptpv2. The transition cannot be specified as lying within Tptpv2 or Tptpv1 in p#1, but the absence of glass in the sample suggests the transition is within Tptpv2, in agreement with the UZ#16 data.

A p#1 sidewall sample from 1,470-ft falls within the devitrified Tcpc lithostratigraphic unit two feet below the boundary with the overlying vitric Tcuv unit. This sample contains 39 percent mordenite plus minor smectite and therefore must have been partly vitric prior to the hydrous-mineral alteration. The mineralogy of the sample therefore represents a transition between Tcuv and Tcpc. The uppermost Tcpc sample from UZ#16 contains 8 percent mordenite, which is the upper end of the smectite + mordenite range for UZ#16 samples in the Tcpc and the only sample in that lithostratigraphic unit that contains mordenite. This similarity is corroborative of the location and mineralogy of the p#1 sample.

The single p#1 sample analysis from the Tptpmn unit falls outside the range of UZ#16 values for the major constituents quartz, cristobalite, and feldspar. In Table A-15, this analysis is compared

to mineral-abundance ranges for tridymite, quartz, cristobalite, and feldspar in the Tptpmn unit of three qualified borehole data sets in addition to UZ#16. The feldspar content of the p#1 sample is similar to values in USW G-4 but the cristobalite content falls far below the ranges of the other boreholes and the quartz content is slightly to substantially higher. Byers (1983 [DIRS 169692]) described a thin section of this sample (570-580-ft-depth, identified in his unpaginated notebook as P1-580) as a partially welded, devitrified ash-flow tuff. The Tptpmn unit is described by Buesch et al. (1996 [DIRS 100106]) as densely welded, devitrified tuffs. Based on the welding difference, it appears that the 570-580-ft sample does not represent the lithology of the Tptpmn unit. No documentation or sample remainder was found that could explain the origin of this atypical material. Therefore, it will be recommended that the data for this material be excluded from qualification.

Table A-14. Mineral-Abundance Ranges, UE-25 p#1 and UE-25 UZ#16 (weight percent)

Unit	Smectite ± Mordenite		Clinoptilolite		Tridymite		Quartz		Cristobalite ± Opal		Feldspar		Glass	
	p#1	UZ16	p#1	UZ16	p#1	UZ16	p#1	UZ16	p#1	UZ16	p#1	UZ16	p#1	UZ16
Tptrn	0	Tr.-5	0	0-0	14	3-22	0	0-0	6	5-13	76	64-81	0	0-0
Ttpul	2-3	4-6	0-0	0-0	Tr.-4	1-16	3-9	2-11	24-25	17-29	54-71	54-58	0-0	0-0
Ttpmn	2	3-4	0	0-0	Tr.	Tr.-4	30	6-23	3	13-27	67	54-57	0	0-0
Ttpll	1-2	1-6	0-0	0-0	0-0	1-7	27-36	0-36	1-5	5-26	59-61	50-58	0-0	0-0
Ttpln	0	2-6	0	0-0	0	0-5	27	14-31	5	8-23	67	45-57	0	0-0
Ttpv2		2		10		0		2		20		17		49
Ttpv2/1	1		54		0		Tr.		20		24		0	
Ttpv1	1	1	62	80	0	0	Tr.	3	23	13	14	8	0	0
Tac	Tr.-10	1-19	34-56	38-72	0-0	0-0	2-17	3-9	0-22	10-26	21-39	6-19	0-9	0-0
Tacbt	12	5-9	0	40-42	0	0-0	24	8-11	0	20-27	40	18-27	22	0-0
Tcpuc	39	3-8	0	0-0	0	0-0	25	17-41	0	0-20	40	48-58	0	0-0

Table A-14. Mineral-Abundance Ranges, UE-25 p#1 and UE-25 UZ#16 (weight percent)
(Continued)

Unit	Smectite ± Mordenite		Clinoptilolite		Tridymite		Quartz		Cristobalite ± Opal		Feldspar		Glass	
Tcpm	0	3-4	3	0-0	0	0-0	39	24-39	0	0-14	60	58-62	0	0-0
Tcplc	5	6-7	0	0-0	0	0-0	37	11-20	0	15-27	58	55-56	0	0-0
Tcplv	3-7	3	40-60	42	0-0	0	4-11	5	14-17	28	17-25	28	0-0	0

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517), LA0000000000086.002 (DIRS 107144), LAJC831321AQ98.005 (DIRS 109004).

Table A-15. Ranges of Mineral Content in the Tptpmn of UE-25 p#1, UE-25 UZ#16, USW SD-12, and USW G-4 (weight percent)

Borehole	Tridymite	Quartz	Cristobalite/Opal	Feldspar
UE-25 p#1	Tr.	30	3	67
UE-25 UZ#16	Tr.-4	6-23	13-27	54-57
USW SD-12	2-4	3-11	26-34	52-54
USW G-4	0-17	3-4	13-28	62-68

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517), LA0000000000086.002 (DIRS 107144), LAJC831321AQ98.005 (DIRS 109004), LADV831321AQ97.001 (DIRS 107142), MO0101XRDMINAB.001 (DIRS 163796)

There is a substantial difference in the values for quartz and cristobalite/opal between the single p#1 sample and the UZ#16 samples in the Tcplc unit. The p#1 1,640-1,650-ft sample values (Table A-15) fall within the ranges for quartz and cristobalite/opal in the overlying Tcpm unit of both p#1 and UZ#16. It is noteworthy that the lowest analyzed sample in the UZ#16 Tcpm unit has quartz and cristobalite/opal values that are more typical of the underlying Tcplc unit. The larger UZ#16 data set shows a downward change from quartz >> cristobalite/opal to quartz ≤ cristobalite/opal that is offset by about 20 ft above the unit boundary between Tcpm and Tcplc. In p#1, the same mineralogic change is present but is offset by about 10 ft below the unit boundary. Therefore, this particular discrepancy between the two mineralogy data sets exists because the lithostratigraphic unit boundaries were not picked on the basis of the mineralogic change. The p#1 data for the Tcpm and Tcplc units are corroborated by the UZ#16 data.

Mineralogic data for the lower part of p#1, with the exception of Paleozoic-section samples, are compared with data from USW G-1 in Table A-16. Common aspects of both data sets are the presence of only small amounts of clay and zeolite in the devitrified units Tcbuc, Tcbm, Tcblc (not recognized in USW G-1), Tctuc, and Tctm. The originally vitric units Tcbpt, Tcblv, Tcbbt, Tctuv, and Tctlv have clay and zeolites as major constituents.

Sample p#1 2030-2040, in the Tcbm unit, is listed as containing seven percent glass. The presence of glass in the middle of a ~300-ft-thick devitrified interval (Tcbuc-Tcbm-Tcblc) is unlikely. No thin section of this sample is available for examination. In the absence of

information to support the presence of glass in this sample, it will be recommended that the sample not be qualified.

Table A-16. Mineral-Abundance Ranges, UE-25 p#1 and USW G-1 (weight percent)

Unit	Smectite ± Mordenite		Clinoptilolite ± Analcime		Tridymite		Quartz		Cristobalite ± Opal		Feldspar		Glass	
	p#1	G-1	p#1	G-1	p#1	G-1	p#1	G-1	p#1	G-1	p#1	G-1	p#1	G-1
Tcpbt	24	9	45	33	0	0	12	2	0	8	18	41	0	0
Tcbuc	Tr.-5	1-3	0-9	0-0	0-0	0-0	27-45	32-35	0-0	Tr.-1	39-64	62-67	0-0	0-0
Tcbm	Tr.-2	Tr.-1	0-0	0-0	0-0	0-0	31-39	32-36	0-0	0-Tr.	59-65	63-67	0-7	0-0
Tcblc	3	*	Tr.	*	0	*	29	*	0	*	61	*	0	*
Tcblv	31	27-39	14	40-48	0	0-0	28	Tr.-3	0	2-10	33	12-20	0	0-0
Tcbbt	10	14-26	8	26-42	0	0-0	29	12-21	0	1-1	52	17-30	0	0-0
Tctuv	6-11	4-15	6-35	15-40	0-0	0-0	22-32	4-18	0-0	4-8	32-45	33-52	0-0	0-0
Tctuc	7	1-3	0	0-0	0	0-0	40	31-36	0	0-1	49	62-64	0	0-0
Tctm	0-2	1-2	0-0	0-2	0-0	0-0	24-43	30-36	0-0	0-Tr.	51-77	61-67	0-0	0-0
Tctlv	4-25	4-18	0-13	4-41	0-0	0-0	29-42	18-38	0-0	0-0	34-57	20-43	0-0	0-0

*Tcblc is not recognized in USW G-1.

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517), MO0101XRDMINAB.001 (DIRS 163796).

The lowermost Tertiary unit, Tund, combines multiple pyroclastic deposits. In p#1, the Tund unit is 1217 ft thick, whereas in G-1 it is 2442 ft from the top of the unit to the depth of the lowest analyzed sample. This large difference of thickness precludes the use of a side-by-side mineralogic-abundance comparison between data sets for this unit. Instead, the comparison is based on general mineralogic similarities and on the vertical variations in illite/smectite interstratification in p#1 and G-1.

Tund samples in p#1 and G-1 are similar in the lack of tridymite and cristobalite/opal. The only exception is one sample from near the top of Tund in G-1 that contains 6 percent cristobalite/opal. Chlorite is generally absent from rocks above the Tund and the upper Tund,

but is a common constituent in trace to minor quantities in the lower Tund of both borehole data sets.

Investigations of illite/smectite interstratification in p#1 and G-1 are documented in Chipera and Bish (1988 [DIRS 105080]) and Bish (1989 [DIRS 101194]). These references describe the increasing proportions of illite with depth and its inferred correlation with increasing temperature. Ordering of the interstratifications changes with depth from random to more highly ordered. Chipera and Bish (1988 [DIRS 105080], p. 17) compared the suites of illite/smectite samples for p#1 and G-1 (also G-2), most of which represent the Tund, and found similar trends with increasing depth. They attributed the similarities to similar alteration histories. In particular, an inferred early higher-temperature alteration event with temperatures increasing with depth was recognized in both data sets. This suggests that the p#1 sample set reflects good depth control.

No qualified data sets exist for comparison with the three lowermost samples from p#1 representing the Paleozoic section. Therefore, these samples cannot be qualified by corroboration with qualified data. The Paleozoic section is not part of the mineralogic model report (BSC 2002 [DIRS 158730]) and the data for these three samples are not used as input to the model.

USW H-3 Compared with USW GU-3

Two samples within two feet or less of a lithostratigraphic unit boundary, one from each borehole, were reassigned to an adjacent unit based on strong mineralogic affinity to that unit. Sample GU-3 1598.5 falls within the devitrified Tcpcu unit (upper boundary at 1,597-ft depth) but contains 45 percent glass. This sample was moved to the overlying vitric Tcpcv for the purpose of unit-to-unit mineralogic comparison. Sample H-3 1700 falls within the devitrified Tcplc unit two feet above the boundary with the underlying vitric Tcplv unit. The sample contains 15 percent glass and therefore was moved to the underlying unit.

The succession of lithostratigraphic units shown in Table A-17 includes distinctive lithologic-unit transitions that correspond to mineralogic transitions. Mineralogic features common to both USW H-3 and USW GU-3 data sets include:

- Restriction of detectable hornblende to the phenocryst-rich Tacbt.
- Transition from Tcpcv to Tcpcu corresponds to a transition from glass bearing to non-glass-bearing mineral assemblages.
- Transition from Tcplc to Tcplv corresponds to a transition from non-glass-bearing mineral assemblages to assemblages containing either glass or clinoptilolite derived from the alteration of glass.

The raw-value ranges of mineral abundances within lithostratigraphic units are generally similar in USW H-3 and USW-GU-3. One difference is observed in the Tptpln unit. The H-3 samples have cristobalite heavily predominant over quartz, whereas the GU-3 samples show the opposite pattern. Both Tptpln sample sets are small, with two H-3 samples and three GU-3 samples. The

cristobalite > quartz pattern in the Tptpln unit is uncommon within the qualified data sets, but similar patterns are present in two samples from the lower Tptpln in USW SD-12 where this unit was very well sampled. Non-overlapping mineral-abundance ranges exist in the Tptpv3 data, but this unit typically shows high variability in mineral abundances. The mineralogic differences between the single H-3 sample and the GU-3 samples are attributable to a higher glass content in the H-3 sample.

Table A-17. Mineral-Abundance Ranges, USW H-3 and USW GU-3 (weight percent)

Unit	Hornblende		Clinoptilolite		Tridymite		Quartz		Cristobalite ±Opal		Feldspar		Glass	
	H-3	GU-3	H-3	GU-3	H-3	GU-3	H-3	GU-3	H-3	GU-3	H-3	GU-3	H-3	GU-3
Tptrn	0-0	0-0	0-0	0-0	Tr.-13	4-20	0-0	0-4	8-24	5-20	76-77	70-80	0-0	0-0
Tptpul	0-0	0-0	0-0	0-0	Tr.-21	5-12	0-0	0-2	5-29	22-22	71-73	65-70	0-0	0-0
Tptpmn	0-0	0-0	0-0	0-0	0-Tr.	0-6	2-4	1-6	26-27	17-22	68-69	65-70	0-0	0-0
Tptpll	0-0	0-0	0-0	0-0	0-4	0-10	Tr.-29	4-17	3-24	12-27	66-72	65-75	0-0	0-0
Tptpln	0-0	0-0	0-0	0-0	0-Tr.	0-0	2-2	17-35	23-29	3-10	67-74	60-70	0-0	0-0
Tptpv3	0	0-0	0	0-0	0	0-0	2	3-8	7	17-27	19	35-35	70	30-40
Tptpv2	0	0	0	0	0	0	2	4	5	12	23	40	70	45
Tptpv1	0	0-0	0	0-0	0	0-0	Tr.	4-7	Tr.	6-7	3	25-30	97	55-65
Tacbt	0-1	0-2	0-1	0-2	0-0	0-0	Tr-3	5-17	1-5	4-6	11-47	25-50	34-81	20-65
Tcpuv	0	0-0	1	0-0	4	0-0	12	4-5	20	2-5	50	45-45	10	45-45
Tcpuc	0	0-0	2	0-0	7	0-15	10	2-20	7	2-30	70	65-70	0	0-0
Tcpm	0	1	2	0	7	0	7	12	7	12	75	70	0	0
Tcplv	0-0	0-0	2-60	30-70	0-0	0-0	7-10	4-7	0-15	4-7	30-60	19-40	0-15	0-38

Table A-17. Mineral-Abundance Ranges, USW H-3 and USW GU-3 (weight percent) (Continued)

Unit	Hornblende		Clinoptilolite		Tridymite		Quartz		Cristobalite ±Opal		Feldspar		Glass	
Tcpbt	0	0	75	60	2	0	2	4	2	10	15	25	0	0
Tcblv	0-1	0-0	65-75*	40-50	0-0	0-0	2-2	2-5	2-2	5-7	15-30	35-45	0-0	0-0
Tctuv	0	0-0	70*	30-40*	0	0-0	2	5-7	0	8-10	20	40-50	0	0-0

*includes mordenite.

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517), LADV831321AQ97.001 (DIRS 107142), MO0101XRDMINAB.001 (DIRS 163796).

USW H-4 Compared with USW SD-12, UE-25 UZ#16, and USW G-4

Examination of the mineralogical data for H-4 and the three closest drill holes with qualified data revealed considerable variability. Because of this variability, it was determined that comparisons of data for the purpose of corroboration would have to include some input from all three qualified data sets.

Preliminary examination of H-4 mineralogical data organized by lithostratigraphic unit identified one potential outlier sample analysis. The XRD analysis of Calico Hills Formation (Tac) sample H-4 1320-1330 indicates that it is composed exclusively of crystalline silica (dominantly quartz) and feldspar. This mineralogic composition closely matches the compositions of devitrified tuffs in the Prow Pass Tuff (e.g., H-4 1710-1720) and other devitrified tuffs. The Calico Hills Formation is not known to contain any fully devitrified intervals at Yucca Mountain, but it typically contains lithic clasts of densely welded, devitrified tuff in a matrix of glassy clasts or zeolitized glassy clasts. Moyer and Geslin (1995 [DIRS 101269]) specify the lithic-clast content of the upper part of the Calico Hills Formation as less than or equal to 5 percent, with presumably higher contents in localized lithic-clast swarms.

At the time the H-4 1320-1330 sample was collected, the variations in lithology and mineralogy of the Calico Hills Formation were poorly known. The USGS drill hole report for USW H-4 describes the Tuffaceous beds of Calico Hills (informal usage) as nonwelded to partly welded, devitrified and zeolitized, with possible silicification of the upper 11 m. The tuff is described as containing abundant rhyolitic lithic fragments (Whitfield et al. 1984 [DIRS 101366], p. 7). The notebook entry for the 1,320-1,330-ft sampling interval made at the time the LANL sample was collected from materials at the USGS Core Library describes it as “silicified tuff of unknown origin” (Vaniman 1983 [DIRS 169665]). The remnant of this sample was examined under the binocular microscope at LANL for the current investigation. It contained subequal portions of lithic clasts (dark densely welded, devitrified tuff) and zeolitic nonwelded tuff plus vitric nonwelded tuff. The aliquot of this sample submitted for XRD apparently contained little or none of the nonwelded tuff because the analysis shows no zeolite or glass content. Existing documentation of the dominant lithology of this rock unit suggests it is very unlikely that the source rock could have been composed only of devitrified tuff. Even a lithic-clast swarm, sampled over a 10-ft interval, would not yield a sample that is exclusively devitrified tuff. Based on the information cited here, H-4 1320-1330 data are omitted from the comparison of H-4 data

and qualified mineralogical data and a recommendation will be made that the data for this sample not be qualified.

One sidewall sample, H-4 1656, nominally falls within TcpuV but was reassigned to a lower unit whose boundary is six feet below the sample collection depth. The boundary separates vitric Prow Pass Tuff (TcpuV) from underlying devitrified tuff (TcpuC). Sample H-4 1656 is devitrified, but its cryptocrystalline texture differs from the coarser texture of a sample lower in the TcpuC (Levy 1984 [DIRS 101392], p. 21) in ways that suggest it must be close to the vitric-devitrified boundary.

Table A-18 compares the contents of the most abundant rock-forming minerals in the Tptpln of H-4 and three qualified borehole data sets. This lithostratigraphic unit consists of densely welded, devitrified tuff. The Tptpln intervals in all four boreholes are similar in containing little or no tridymite. The intervals are most notably different in their feldspar contents. H-4 and G-4 have very similar ranges of feldspar content. SD-12 and UZ#16 also have very similar ranges of feldspar content, but these ranges do not overlap with the ranges for H-4 and G-4. The differences in feldspar content are matched by greater or lesser amounts of quartz or cristobalite/opal, although the abundance ranges for the two silica minerals show substantial overlap among all four data sets. This comparison shows that the abundance ranges of tridymite, quartz, and cristobalite/opal in the three qualified borehole data sets are corroborative of the data from H-4. The feldspar data show that genuine variability exists among the qualified data sets but that at least one of the data sets is a good corroborative match to the H-4 data.

Table A-18. Ranges of Mineral Content in the Tptpln of USW H-4, USW SD-12, UE-25 UZ#16, and USW G-4 (weight percent)

Borehole	Tridymite	Quartz	Cristobalite/Opal	Feldspar
USW H-4	0-0	6-15	18-23	64-70
USW SD-12	1-3	7-24	15-30	53-57
UE-25 UZ#16	0-5	14-31	8-23	45-57
USW G-4	0-0	2-25	13-24	60-69

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517), LADV831321AQ97.001 (DIRS 107142), LAJC831321AQ98.005 (DIRS 109004), LA0000000000086.002 (DIRS 107144), MO0101XRDMINAB.001 (DIRS 163796).

Mineralogic changes across unit boundaries are documented and compared in Table A-19. Characteristic mineralogic changes across boundaries, observed in H-4 plus at least one of SD-12 and UZ#16, include the change from assemblages dominated by feldspar plus silica in the Tptprn-Tptpln to an assemblage with glass plus minor smectite and clinoptilolite in the Tptpv3. The Tpbtl-Tac-Tacbt sequence in the three drill holes consists of originally vitric tuffs in which the glass has been slightly to completely altered to clinoptilolite and smectite, with or without mordenite. The data for SD-12 and UZ#16 show that there is considerable lateral variability in the degree of alteration within specific units. The H-4 data for Tpbtl more closely resemble SD-2 (persistence of glass), whereas the H-4 data are more similar to UZ#16 data in the Tac (complete alteration of glass). The single Tacbt sample from H-4 has alteration (presence of clinoptilolite, absence of glass) that generally falls within or close to the highly variable ranges of alteration in SD-12 and UZ#16. The values for feldspar+silica that are generally higher in the

Tacbt than in the Tac for all three drill holes reflect the higher phenocryst and lithic-clast content of the Tacbt (Vaniman et al. 1984 [DIRS 101363], p. 24-25).

The mineralogic changes from Tcpu_v downward to the devitrified sequence Tcpu_c-Tcpu_m-Tcpu_l are the disappearance of clinoptilolite and the appearance of a mineral assemblage dominated by feldspar plus silica. For these changes, the H-4 data are consistent with the data from SD-12 and UZ#16. The downward change from the devitrified units to the Tcpu_l is marked in all three drill holes by the reappearance of clinoptilolite.

Table A-19. Mineral-Abundance Ranges, USW H-4, USW SD-12, and UE-25 UZ#16 (weight percent)

Unit	Smectite ± Mordenite			Clinoptilolite			Feldspar+Silica			Glass		
	H-4	SD-12	UZ#16	H-4	SD-12	UZ#16	H-4	SD-12	UZ#16	H-4	SD-12	UZ#16
Ttptr _n	0	0-2	Tr.-5	0	0-0	0-0	96	95-100	94-103	0	0-0	0-0
Ttpu _l	2-2	3-5	4-6	0-0	0-0	0-0	97-98	92-98	90-96	0-0	0-0	0-0
Ttpm _n	2	3-5	3-4	0	0-0	0-0	98	93-96	91-99	0	0-0	0-0
Ttp _l	1-3	2-5	1-6	0-0	0-0	0-11 ²	95-99	93-98	88-100	0-0	0-0	0-0
Ttp _n	1-2	0-4	2-6	0-0	0-1	0-14 ²	97-99	92-98	84-97	0-0	0-0	0-0
Ttpv ₃	0-20	0-2	0-73	0-5	0-0	0-4	30-49	11-18	8-23	30-70	72-85	0-82
Ttpv ₂	No samples in H-4 data set											
Ttpv ₁	No samples in H-4 data set											
Tpbt ₁	2	2	8 ¹	5	1	83	42	12	11	50	85	0
Tac	0-25 ¹	0-3	1-19 ¹	29-78	1-10	38-72	18-52	9-35	22-54	0-0	58-89	0-0
Tacbt	0	3-11 ¹	5-9 ¹	31	12-68	40-42	61	22-78	53-58	0	0-62	0-0

Table A-19. Mineral-Abundance Ranges, USW H-4, USW SD-12, and UE-25 UZ#16 (weight percent)
(Continued)

Unit	Smectite ± Mordenite			Clinoptilolite			Feldspar+Silica			Glass		
Tcpuv	0	7	-----	10	58	-----	90	39	-----	0	0	-----
Tcpuc Tcpm Tcplc	0-3	Tr.-5	3-8 ¹	0-0	0-0	0-0	96- 102	89- 99	85- 100	0-0	0-0	0-0
Tcplv	0-23 ¹	2-15 ¹	3	11- 22	10- 65	42	63- 77	38- 84	61	0-0	0-0	0

= no samples analyzed from this unit.

Tr. = trace amount present.

Blanks are intentional.

¹ includes mordenite in at least one sample.

² the zeolite present is stellerite.

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517), LADV831321AQ97.001 (DIRS 107142),
LAJC831321AQ98.005 (DIRS 109004), LA000000000086.002 (DIRS 107144).

USW H-5 Compared with UE-25 UZ#16 and USW GU-3

The dominant mineralogy of the Tpc_un unit of the Tiva Canyon Tuff in USW H-5 is compared with the mineralogy of two qualified data sets in Table A-20. For this devitrified-rock interval, there is a very close similarity in the raw-data ranges of mineral abundance between H-5 and GU-3. Comparison of H-5 data with data from UZ#16 shows a general similarity of mineralogic content, although UZ#16 has higher cristobalite/opal content and lower feldspar content.

Table A-20. Ranges of Mineral Content in the Tpc_un of USW H-5, UE-25 UZ#16, and USW GU-3
(weight percent)

Borehole	Tridymite	Quartz	Cristobalite/Opal	Feldspar
USW H-5	2-31	0-6	0-29	66-80
UE-25 UZ#16	Tr.-7	Tr.-4	25-33	57-62
USW GU-3	0-25	0-2	6-30	70-75

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517), LADV831321AQ97.007 (DIRS 113499),
LA9910JC831321.001.001 (DIRS 113496), LA000000000086.002 (DIRS 107144),
LAJC831321AQ98.005 (DIRS 109004), MO0101XRDMINAB.001 (DIRS 163796)

The H-5 data set contains no samples from Tpcpv3 or Tpcpv2. Mineralogic comparisons of units from the Tpcpv1 downward are complicated by large variations in secondary-mineral alteration, both within and between boreholes. For units affected by variable alteration, the corroboration of H-5 data is based on similarities of primary mineralogic or textural characteristics.

Three samples from H-5 were recognized as having mineralogic compositions similar to the units directly above their nominal unit assignments based on depth. These reassignments are equivalent to changes made in the mineralogic model report (BSC 2002 [DIRS 158730]). Sample H-5 1666 falls within the Tptpv2 unit beginning at 1659 ft. The published petrographic description of the highly altered sample indicates that it has a relict densely welded texture

characteristic of the Tptpv3 (Levy 1984 [DIRS 101392], p. 27). It was reassigned to Tptpv3 for the purpose of this qualification activity. The same reassignment was made by BSC (2002 [DIRS 158730]).

The XRD analysis for sample H-5 1990-2000 contains 59 percent glass even though the recorded sample depth falls within the devitrified Tcpcv unit extending from 1,967-2,085-ft depth. This discrepancy was addressed in the BSC report (2002 [DIRS 158730]) by reassigning the sample to the overlying vitric Tcpcv. Examination of the sample remainder shows it to be composed of vitric tuff and devitrified tuff, with the vitric tuff predominant. Given that the nominal sample depth is more than 20 ft below the top of the devitrified Tcpcv unit, it is likely that this sample contains a very large impurity of vitric tuff from the overlying unit. It will be recommended that this sample and its associated XRD analysis be excluded from qualification.

Sample H-5 2140-2150 was moved from the vitric Tcplv unit to the devitrified Tcplc unit whose lower boundary is located at 2,130-ft depth. The sample remainder contains a very small amount of residual glassy clasts, but the XRD analysis of the sample shows no glass content. Therefore, the sample was moved to Tcplc.

The comparison of Tpcpv1 mineralogy for H-5 and UZ#16 shows similar smectitic alteration of still partly glassy tuff (Table A-21). The Tpy samples differ between the two borehole data sets in degree of smectitic alteration, but the samples share high glass content and very low content of feldspar and silica phenocrysts. Data for the Tpbv3 in H-5, UZ#16, and GU-3 all show smectitic alteration of vitric tuff with highly variable contents of feldspar and silica phenocrysts. The Tptrn, Tptrl, Tptpul, and Tptpmn are all devitrified tuff units with minor smectitic alteration. Samples from the Tptpll and Tptpln units of UZ#16 are unusual in containing modest amounts of the zeolite stellerite but otherwise are similar to the H-5 and GU-3 samples with slight smectitic alteration of devitrified tuff. Alteration in the Tptpv3 of both H-5 and UZ#16 is highly variable. In both holes, some samples contain substantial smectite and minor clinoptilolite and other samples contain mostly unaltered glass. The GU-3 samples are less altered but fall within the ranges of alteration for H-5 and UZ#16.

Samples of Tac from H-5 and GU-3 are predominantly vitric with phenocrysts or lithic inclusions of silica+feldspar composition and minor alteration to smectite and clinoptilolite. Alteration of the Tacbt unit in H-5 is intermediate between UZ#16 and GU-3, but a somewhat higher content of silica+feldspar phenocrysts and lithic inclusions is a common attribute of all three borehole data sets. Mineralogic proportions in the Tcpcv are somewhat different between H-5 and GU-3 samples, although both sets are partly vitric. The higher silica+feldspar content of the GU-3 samples reflects their locations lower in the Tcpcv unit, probably transitional to the underlying devitrified tuff.

Table A-21. Mineral-Abundance Ranges, USW H-5, UE-25 UZ#16, and USW GU-3 (weight percent)

Unit	Smectite ± Mordenite			Clinoptilolite			Feldspar+Silica			Glass		
	H-5	UZ#1 6	GU-3	H-5	UZ#1 6	GU-3	H-5	UZ#1 6	GU-3	H-5	UZ#1 6	GU-3
Tpcpv 1	15	8-14	-----	0	0-0	-----	45	4-29	-----	40	63- 82	-----
Tpy	0	9-12	-----	0	0-0	-----	3	0-3	-----	96	85- 91	-----
Tpbt3	14	6-18	4	0	0-0	0	14	11- 29	58	69	59- 78	40
Tptrn	Tr.-1	Tr.-5	0-1	0-0	0-0	0-0	90- 100	94- 103	95- 99	0-0	0-0	0-0
Tptrl	3	7	-----	0	0	-----	97	104	-----	0	0	-----
Tptpu l	0-5	4-6		0-0	0-0		94- 100	90- 96		0-0	0-0	
Tptp mn	Tr.-3	3-4		0-0	0-0		91- 97	91- 99		0-0	0-0	
Tptpll	2-4	1-6	0-1	0-0	0-11*	0-0	95- 100	88- 100	96- 100	0-0	0-0	0-0
Tptpl n	Tr.-2	2-6	0-1	0-0	0-14*	0-0	95- 99	84- 97	97- 98	0-0	0-0	0-0
Tptpv 3	0-50	0-73	2-2	0-10	0-4	0-0	10- 57	17- 23	60- 65	0-90	0-82	30-40
Tptpv 2	No samples in H-5 data set											
Tptpv 1												
Tpbt1												
Tac	0-3	1-19	0-1	0-6	38- 72	0-3	7-30	22- 54	36- 46	70- 95	0-0	55-65
Tacbt	0-3	5-9	3-3	10- 52	40- 42	0-2	12- 75	53- 58	36- 71	0-78	0-0	20-65
Tcpuv	3-5	-----	2-4	0-51	-----	0-0	15- 17	-----	52- 54	31- 75	-----	45-45

Table A-21. Mineral-Abundance Ranges, USW H-5, UE-25 UZ#16, and USW GU-3 (weight percent) (Continued)

Unit	Smectite ± Mordenite			Clinoptilolite			Feldspar+Silica			Glass		
Tcpuc	1	3-8	0-1	0	0-0	0-0	90	85-97	88-97	0	0-0	0-0
Tcpm	No samples in H-5 data set											
Tcplc	1	6-7	0	0	0-0	0	103	90-94	101	0	0-0	0
Tcplv	Tr.-10	3	0-3	60-64	42	30-70	28-39	61	30-52	0-0	0	0-38
Tcpbt	13	-----	0	56	-----	60	34	-----	39	0	-----	0

NOTES:

= no samples analyzed from this unit.

Tr. = trace amount present.

Blanks are intentional.

*The zeolite present is stellerite.

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517), LADV831321AQ97.007 (DIRS 113499), LA9910JC831321.001.001 (DIRS 113496), LA000000000086.002 (DIRS 107144), LAJC831321AQ98.005 (DIRS 109004), MO0101XRDMINAB.001 (DIRS 163796).

USW WT-1 Compared with UE-25 UZ#16 and USW GU-3

Mineral abundances in WT-1 are compared with UE-25 UZ#16 and USW GU-3 in Table A-22. For the devitrified units Tptrn, Tptrl, Tptpul, Tptpmn, Tptpll, and Tptpln, the three data sets have very similar ranges of mineral abundances except for the presence of stellerite in the Tptpll and Tptpln of UZ#16. The vitric tuff of Tpb3 has minor smectitic alteration and residual glass in all three data sets. The Tptpv3 samples from all three data sets are partly devitrified with variable contents of smectite and clinoptilolite.

Sample WT-1 1570-1580 spans the interval from six to sixteen feet below the base of the Tac, which is the lowest recognized unit in WT-1 (see Table B-5). This makes it unclear which unit from a qualified data set should be used for comparison. The largest cuttings in the sample remainder have the appearance of a densely welded tuff, and the XRD analysis is consistent with this lithology. A USGS report (1995 [DIRS 169694], p. 6) shows that bit cutting samples from 1560 ft to 1610 ft are contaminated with densely welded tuff fragments of Tiva Canyon Tuff that are larger than the other cuttings. Page 6 of this report also proposed that a fault exists from 1540 to 1564 ft and that the unit below the Tac is the Bullfrog Tuff (Tcb). Because of the uncertainties in unit identification and sample integrity, it will be recommended that this sample be excluded from qualification.

Table A-22. Mineral-Abundance Ranges, USW WT-1, UE-25 UZ#16, and USW GU-3 (weight percent)

Unit	Smectite ± Mordenite			Clinoptilolite			Feldspar+Silica			Glass		
	WT-1	UZ#1 6	GU-3	WT-1	UZ#1 6	GU-3	WT-1	UZ#1 6	GU-3	WT-1	UZ#1 6	GU-3
Tpbt3	5	6-18	4	0	0-0	0	24	11- 29	58	70	59- 78	40
Tptrn	0-0	Tr.-5	0-1	0-0	0-0	0-0	95- 100	94- 103	95- 99	0-0	0-0	0-0
Tptrl	No samples in WT-1 data set											
Tptpu l	1-1	4-6		0-0	0-0		98- 99	90- 96		0-0	0-0	
Tptp mn	1-1	3-4		0-0	0-0		98- 99	91- 99		0-0	0-0	
Tptpll	1-3	1-6	0-1	0-1	0-11*	0-0	95- 98	88- 100	96- 100	0-0	0-0	0-0
Tptpl n	0	2-6	0-1	0	0-14*	0-0	99	84- 97	97- 98	0	0-0	0-0
Tptpv 3	1-2	0-73	2-2	2-14	0-4	0-0	83- 98	17- 23	60- 65	0-0	0-82	30-40
Tptpv 2	1	2	2	29	10	0	70	39	56	0	49	45
Tptpv 1	No samples in WT-1 data set											
Tpbt1												
Tac	8-18	1-19	0-1	25- 40	38- 72	0-3	46- 56	22- 54	36- 46	0-0	0-0	55-65
below Tac	3			5			92			0		

NOTES:

----- = no samples analyzed from this unit.

Tr. = trace amount present.

Blanks are intentional.

*The zeolite present is stellerite.

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517), LA0000000000086.002 (DIRS 107144), LAJC831321AQ98.005 (DIRS 109004), MO0101XRDMINAB.001 (DIRS 163796).

USW WT-2 compared with USW SD-12 and UE-25 UZ#16

The upper boundary of unit Tcplv at 1,794 ft is the lowest recognized unit boundary in WT-2. In SD-12, about half a kilometer away (BSC 2002 [DIRS 158730], p. 27), the Tcplv is 268 ft thick. Therefore, it is likely that the WT-2 samples from 1,820-1,830, 1,910-1,920, and 2,000-2,010 ft belong to the Tcplv unit. The WT-2 Tcplv unit in Table A-23 is represented by the summarized mineralogic data from these three samples. Mineralogic data for three WT-2 core samples from the lowermost ten feet of the borehole are compared to data for Tcb samples in SD-12.

Mineral abundances in the Tptrn, Tptpul, Tptpmn, Tptpll, Tptpln, Tacbt, Tcplv, Tcb, and Tcb are similar in all three borehole data sets. Samples from the Tpbt2, Tptpv3, Tptpv2, and Tptpv1 units in WT-2 tend to have higher feldspar+silica and lower glass contents than the SD-12 and UZ#16 samples from the corresponding units. Some similar higher feldspar+silica values have been measured in qualified borehole data sets. For example, feldspar+silica values in the Tptpv3 of GU-3 are in the 60-65 weight percent range and are comparable to the 48-69 weight percent values for WT-2. The feldspar+silica content of a Tptpv2 sample from GU-3 is 56 weight percent, comparable to 57 weight percent in WT-2. The sample remainders of the questioned analyses were examined for impurities and were estimated to contain less than 5 volume percent of devitrified tuff impurities. Therefore, the differences among data sets are considered acceptable.

Table A-23. Mineral-Abundance Ranges, USW WT-2, USW SD-12, and UE-25 UZ#16 (weight percent)

Unit	Smectite ± Mordenite			Clinoptilolite			Feldspar+Silica			Glass		
	WT-2	SD-12	UZ#16	WT-2	SD-12	UZ#16	WT-2	SD-12	UZ#16	WT-2	SD-12	UZ#16
Tpbt2	4-7	-----	8-16	0-0	-----	0-0	47-59	-----	19-22	30-50	-----	58-71
Tptrn	1-1	0-2	Tr.-5	0-0	0-0	0-0	97-97	95-100	95-99	0-0	0-0	0-0
Tptpul	1-3	3-5	4-6	0-0	0-0	0-0	98-99	92-98	90-96	0-0	0-0	0-0
Tptpmn	1-2	3-5	3-4	0-0	0-0	0-0	96-98	93-96	91-99	0-0	0-0	0-0
Tptpll	1-2	2-5	1-6	0-0	0-0	0-11*	96-99	93-98	88-100	0-0	0-0	0-0
Tptpln	1-3	0-4	2-6	0-0	0-1	0-14*	96-98	92-98	84-97	0-0	0-0	0-0
Tptpv3	1-2	0-2	0-73	1-1	0-0	0-4	48-69	11-18	8-23	30-50	72-85	0-82

Table A-23. Mineral-Abundance Ranges, USW WT-2, USW SD-12, and UE-25 UZ#16 (weight percent)
(Continued)

Unit	Smectite ± Mordenite			Clinoptilolite			Feldspar+Silica			Glass		
Tptpv 2	2	Tr.-2	2	0	0-0	10	57	18- 35	39	40	65- 80	49
Tptpv 1	1	0-8	1	1	0-3	80	58	7-22	24	40	74- 93	0
Tpbt1	No samples analyzed in WT-2											
Tac	1-1	0-3	1-19	1-5	1-10	38- 72	59- 66	9-35	22- 54	30- 40	58- 89	0-0
Tacbt	0-3	3-11	5-9	19- 24	12- 68	40- 42	71- 78	22- 78	53- 58	0-0	0-62	0-0
Tcpuv	No samples analyzed in WT-2											
Tcpuc	1	2-3	3-8	2	0-0	0-0	96	89- 96	85- 97	0	0-0	0-0
Tcpm	1-1	Tr.-5	3-4	1-1	0-0	0-0	97- 98	91- 99	97- 100	0-0-	0-0	0-0
Tcplc	No samples analyzed in WT-2											
Tcplv	0-4	2-15	3	19- 42	10- 65	42	58- 78	38- 84	61	0-0	0-0	0
Tcb	1-1	0-2		0-0	0-0		96- 96	95- 98		0-0	0-0	

NOTES:

----- = no samples analyzed from this unit.

Tr. = trace amount present.

Blanks are intentional.

*The zeolite present is stellerite.

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517), LA0000000000086.002 (DIRS 107144),
LAJC831321AQ98.005 (DIRS 109004), MO0101XRDMINAB.001 (DIRS 163796)**A4. CONCLUSIONS**

The data sets for boreholes UE-25 p#1, USW H-3, USW H-4, H-5, WT-1, and WT-2 are recommended for qualification with the exceptions noted below. Mineral abundances in these data sets generally show very good correspondence with abundances in the same lithostratigraphic units of qualified data sets. These data are qualified for use in the mineralogic model 3.0.

Data for UE-25 J-12 should remain unqualified because no records were found to document collection, description, or analysis of the samples. These data are not input to the mineralogic model report (BSC 2002 [DIRS 158730]).

The following errors were noted in these data:

- Data from sample p#1 570-580 are excluded from qualification due to the questionable representativeness of the sample material.
- Data for sample p#1 2030-2040, in the Tcbm unit, are excluded from qualification because the XRD analysis shows the sample containing seven percent glass. The presence of glass in the middle of a ~300-ft-thick devitrified interval (Tcbuc-Tcbm-Tcblc) is unlikely.
- Data from samples p#1 4080-4090, 4170-4180, and 4313-4318 are excluded from qualification because they represent the Paleozoic section and no qualified data from Paleozoic samples exist for corroboration.
- USW H-4 1320-1330 XRD data are not qualified due to unrepresentative subsampling for XRD analysis.
- USW H-5 1990-2000 XRD data are not qualified due to the likely abundant presence of impurities from an overlying unit
- The XRD data for sample USW WT-1 1570-1580 are not qualified due to the uncertainties in unit identification and sample integrity.

There were roughly several thousand mineral abundance values used to construct Version 3.0 of the mineralogic model. The eight errors noted above constitute a very small and insignificant portion of the data. There is no significant impact to the model because of these errors.

The Qualified status of LADV831321AQ97.001 [DIRS 107142] recommended by Steinborn (2002 [DIRS 160702]) is incorrect because the DTN contains cuttings data from borehole USW H-3 that remained unqualified. The qualification recommendation made by Steinborn (2002 [DIRS 160702]) was based on the qualification of the software POWD10. Steinborn (2002 [DIRS 160702]) did not examine the cuttings samples contained in the DTN. The qualification activity in this report includes cuttings data from borehole USW H-3, and the results qualify the DTN for use in this report.

Similarly, the qualified status of LADV831321AQ97.007 [DIRS 113499] is incorrect because the DTN contains cuttings data from borehole USW H-5 that are still unqualified. The qualification activity in this report includes cuttings data from the borehole USW H-5, and the results qualify the DTN for use in this report.

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APPENDIX B

**SELECTED MINERALOGIC-ABUNDANCE DATA FROM DATA SETS TO BE
QUALIFIED**

Table B-1. Selected Mineralogic-Abundance Data for Drill Hole UE-25 p#1 (weight percent)

	Smectite/ Mordenite	Clinoptilolite/ Analcime	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
p#1 Tptrn 150-228							
p#1 200-210	-/-	-/-	14	-	6	76	-
p#1 Tptrl 228-248							
not analyzed							
p#1 Tptpul 248-493							
p#1 260-270	2/-	-/-	Tr.	3	24	71	-
p#1 280-290	2/-	-/-	Tr.	5	25	68	-
p#1 410-420	3/-	-/-	4	9	24	59	-
p#1 Tptpmn 493-640							
p#1 570-580	2/-	-/-	Tr.	30	3	67	-
p#1 Tptpll 640-958							
p#1 810-820	2/-	-/-	-	27	5	59	-
p#1 900-910	1/-	-/-	-	36	1	61	-
p#1 Tptpln 958-1090							
p#1 1040-1050	-/-	-/-	-	27	5	67	-
p#1 Tptpv3 1090-1200							
not analyzed							
p#1 Tptpv2 1200-1243							
partly sampled, see below							
p#1 Tptpv1 1243-1270							
p#1 1240-1250	1/-	54/-	-	Tr.	20	24	-
p#1 1260-1270	1/-	62/-	-	Tr.	23	14	-

Table B-1. Selected Mineralogic-Abundance Data for Drill Hole UE-25 p#1 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite/ Analcime	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
p#1 Tac 1270-1390							
p#1 1290 (sidewall core)	2/-	37/-	-	3	22	39	-
p#1 1340-1350	Tr./-	56/-	-	2	20	21	-
p#1 1400 (sidewall core)	10/-	34/-	-	17	-	29	9
p#1 Tacbt 1390-1441							
p#1 1420 (sidewall core)	12/-	-/-	-	24	-	40	22
p#1 Tcpuv 1441-1468							
not analyzed							
p#1 Tcduc 1468-1535							
p#1 1470 (sidewall core)	5/34	-/-	-	25	-	40	-
p#1 Tcpc 1535-1630							
p#1 1590-1598	-	3/-	-	39	-	60	-
p#1 Tcplc 1630-1680							
p#1 1640-1650	5/-	-/-	-	37	-	58	-
p#1 Tcplv 1680-1790							
p#1 1690-1700	7/-	40/-	-	11	17	25	-
p#1 1730-1740	3/-	60/-	-	4	14	17	-
p#1 Tcpcbt 1790-1826							
p#1 1790-1800	1/23	45/-	-	12	-	18	-
p#1 Tcbuv not present							
p#1 Tcbuc 1826-1953							
p#1 1830-1840	Tr./-	-/-	-	45	-	39	-
p#1 1870-1880	3/-	9/-	-	27	-	55	-
p#1 1920-1930	5/-	-/-	-	28	-	64	-
p#1 Tcbm 1953-2130							
p#1 1970-1980	Tr./-	-/-	-	35	-	61	-

Table B-1. Selected Mineralogic-Abundance Data for Drill Hole UE-25 p#1 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite/ Analcime	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
p#1 1990-2000	1/-	-/-	-	39	-	60	-
p#1 2030-2040	2/-	-/-	-	31	-	59	7
p#1 2070-2080	Tr./-	-/-	-	39	-	59	-
p#1 2120-2130	Tr./-	-/-	-	36	-	65	-
p#1 Tcblc 2130-2162							
p#1 2150-2160	3/-	Tr./-	-	29	-	61	-
p#1 Tcblv 2160-2240							
p#1 2210-2220	3/28	-/14	-	28	-	33	-
p#1 Tcbbt 2240-2262							
p#1 2240-2250	7/3	-/8	-	29	-	52	-
p#1 Tctuv 2262-2340							
p#1 2280-2290	6/-	31/4	-	22	-	32	-
p#1 2330-2340	11/-	2/4	-	32	-	45	-
p#1 Tctuc 2340-2395							
p#1 2370-2380	7/-	-/-	-	40	-	49	-
p#1 Tctm 2395-2595							
p#1 2414-2420	Tr./-	-/-	-	43	-	51	-
p#1 2460-2470	2/-	-/-	-	32	-	61	-
p#1 2510-2520	-	-/-	-	24	-	77	-
p#1 2570-2580	2/-	-/-	-	30	-	71	-
p#1 Tctlc 2595-2616							
not analyzed							
p#1 Tctlv 2616-2863							
p#1 2630-2640	7/-	-/-	-	34	-	57	-
p#1 2650-2660	15/-	-/-	-	31	-	51	-

Table B-1. Selected Mineralogic-Abundance Data for Drill Hole UE-25 p#1 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite/ Analcime	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
p#1 2690-2700	4/-	-/-	-	34	-	56	-
p#1 2750-2760	13/-	13/-	-	32	-	35	-
p#1 2790-2800	21/-	4/-	-	29	-	39	-
p#1 2840-2850	25/-	-/Tr.	-	42	-	34	-
p#1 Tctbt not recognized							
p#1 Tund 2863-4080							
p#1 2890-2900	15/-	-/-	-	34	-	47	-
p#1 2940-2950	4/-	-/2	-	36	-	55	-
p#1 2980-2990	6/-	-/6	-	29	-	55	-
p#1 3030-3040	11/-	-/1	-	30	-	53	-
p#1 3080-3090	15/-	-/-	-	44	-	34	-
p#1 3130-3140	6/-	2/5	-	34	-	50	-
p#1 3160-3170	13/-	3/11	-	37	-	39	-
p#1 3230-3240	5/-	Tr./19	-	38	-	37	-
p#1 3270-3280	5/-	2/13	-	36	-	43	-
p#1 3320-3330	25/-	4/-	-	38	-	25	-
p#1 3370-3380	22/-	2/-	-	35	-	35	-
p#1 3410-3420	7/-	3/6	-	35	-	44	-
p#1 3453 (core)	6/-	2/13	-	38	-	39	-
p#1 3480-3490	7/-	7/4	-	40	-	42	-
p#1 3510-3520	11/-	-/-	-	37	-	49	-
p#1 3550-4560	4/-	-/-	-	43	-	45	-
p#1 3560-3570	7/-	-/-	-	42	-	49	-
p#1 3590-3600	9/-	-/-	-	42	-	48	-
p#1 3630-3640	19/-	-/-	-	32	-	41	1

Table B-1. Selected Mineralogic-Abundance Data for Drill Hole UE-25 p#1 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite/ Analcime	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
p#1 3650-3660	19/-	-/-	-	29	-	42	1
p#1 3660-3670	16/-	-/-	-	30	-	51	1
p#1 3690-3700	15/-	-/3	-	36	-	38	1
p#1 3720-3730	20/-	-/2	-	27	-	41	1
p#1 3750-3760	15/-	Tr./-	-	33	-	36	-
p#1 3790-3800	14/-	-/-	-	35	-	23	1
p#1 3820-3830	9/-	Tr./-	-	44	-	19	-
p#1 3860-3870	10/-	-/-	-	52	-	33	-
p#1 3913 (core)	37/-	-/-	-	53	-	-	-
p#1 3916 (core)	45/-	-/-	-	49	-	-	Tr.
p#1 3928 (core)	40/-	-/-	-	18	-	-	-
p#1 3940-3950	9/-	-/Tr.	-	39	-	44	-
p#1 3980-3990	13/-	2/2	-	32	-	48	-
p#1 4040-4050	16/-	2/Tr.	-	29	-	29	-
p#1 4070-4080	29/-	1/Tr.	-	30	-	38	-
p#1 Pz 4080 to bottom							
p#1 4080-4090	These samples contain 80-93 % dolomite, 1-9 % smectite, 4-8 % quartz, and 3-4 % calcite.						
p#1 4170-4180							
p#1 4313-4318							

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517); DTN: MO0004QGFMPICK.000 (DIRS 152554).

- = not detected; Tr. = trace amount much less than 1%.

Table B-2. Selected Mineralogic-Abundance Data for Drill Hole USW H-3 (weight percent)

	Hornblende/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opa I	Feldspar	Glass
Unit or Sample Depth Range in feet							
H-3 Tptrn 449-526.9							
H-3 470-480	-/-	-	13	-	8	77	-
H-3 520-530	-/-	-	Tr.	-	24	76	-
H-3 Tptpul 540-680.1							
H-3 540-550	-/-	-	21	-	5	73	-
H-3 610-620	-/-	-	Tr.	-	29	71	-
H-3 Tptpmn 680.1-848.1							
H-3 740-750	-/-	-	-	4	26	68	-
H-3 800-810	-/-	-	Tr.	2	27	69	-
H-3 Tptpll 848.1-1049.9							
H-3 870-880	-/-	-	-	29	3	66	-
H-3 930-940	-/-	-	-	14	16	69	-
H-3 990-1000	-/-	-	4	Tr.	23	72	-
H-3 1030-1040	-/-	-	Tr.	3	24	72	-
H-3 Tptpln 1049.9-1194							
H-3 1100-1110	-/-	-	Tr.	2	23	74	-
H-3 1160-1170	-/-	-	-	2	29	67	-
H-3 Tptpv3 1194-1308							
H-3 1270-1280	-/-	-	-	2	7	19	70
H-3 Tptpv2 1308-1341							
H-3 1320-1330	-/-	-	-	2	5	23	70
H-3 Tptpv1 1341-1392							
H-3 1360-1370	-/-	-	-	Tr.	Tr.	3	97
H-3 Tacbt 1437-1495							

Table B-2. Selected Mineralogic-Abundance Data for Drill Hole USW H-3 (weight percent) (Continued)

	Hornblende/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opa I	Feldspar	Glass
H-3 1440-1450	-/-	-	-	Tr.	5	11	81
H-3 1480-1490	1/-	1	-	3	1	47	34
H-3 Tcpuv 1495-1518							
H-3 1500-1510	-/-	1	4	12	20	50	10
H-3 Tcpcu 1518-1640							
H-3 1550 (sidewall core)	-/-	2	7	10	7	70	-
H-3 Tcpcm 1640-1690							
H-3 1655 (sidewall core)	-/-	2	7	7	7	75	-
H-3 Tcplc 1690-1702							
sample moved to Tcplv							
H-3 Tcplv 1702-1899.9							
H-3 1700 (sidewall core) moved to Tcplv	-/-	2	-	10	15	60	15
H-3 1800 (sidewall)	-/-	60	-	7	-	30	-
H-3 Tcpcb 1899.9-1907.1							
H-3 1900 (sidewall core)	-/-	75	2	2	2	15	-
H-3 Tcblv 2397-2449.1							
H-3 2400 (sidewall core)	1/-	75	-	2	2	15	-
H-3 2440 (sidewall core)	-/30	35	-	2	2	30	-
H-3 Tctuv 2477-2567							
H-3 2490 (sidewall core)	-/25	45	-	2	-	20	-

Sources: DTN: LADV831321AQ97.001 (DIRS 107142); DTN: MO0101XRDDRILC.001 (DIRS 169517); DTN: MO0004QGFMPIK.000 (DIRS 152554).

- = not detected; Tr. = trace amount much less than 1%.

Table B-3. Selected Mineralogic-Abundance Data for Drill Hole USW H-4 (weight percent)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
H-4 Tptrn 254-376							
H-4 310-320	-/-	-	11	-	10	75	-
H-4 Tptpul 376-576							
H-4 390-400	2/-	-	14	2	13	68	-
H-4 440-450	2/-	-	19	2	13	64	-
H-4 490-500	2/-	-	11	~1	18	67	-
H-4 Tptpmn 576-703							
H-4 640-650	2/-	-	-	4	26	68	-
H-4 Tptpll 703-987							
H-4 830-840	3/-	-	12	~1	14	68	-
H-4 910-920	~1/-	-	-	11	20	67	-
H-4 940-950	~1/-	-	-	7	21	71	-
H-4 Tptpln 987-1185							
H-4 1040-1050	~1/-	-	-	6	23	70	-
H-4 1150-1160	2/-	-	-	15	18	64	-
H-4 Tptpv3 1185-1209							
H-4 1190-1200	-/-	5	-	-	15	15	70
H-4 1230-1240	20/-	-	-	4	20	25	30
H-4 Tptpv2-1 1209-1312							
not sampled							
H-4 Tpbt1 1312-1317							
H-4 1312 (sidewall core)	2/-	5	-	10	7	25	50
H-4 Tac 1317-1572							
H-4 1350-1360	-	78	-	3	9	10	-
H-4 1410-1420	-/5	52	-	7	9	31	-

Table B-3. Selected Mineralogic-Abundance Data for Drill Hole USW H-4 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
H-4 1420 (sidewall core)	2/-	70	-	2	2	25	-
H-4 1455 (sidewall core)	-/25	45	-	2	2	20	-
H-4 1540-1550	3/16	29	-	11	10	31	-
H-4 1550 (sidewall core)	2/-	75	-	1	2	15	-
H-4 Tacbt 1572-1626.9							
H-4 1600-1610	-/-	31	-	17	9	35	-
H-4 Tcpuv 1626.9-1662							
H-4 1640-1650	-/-	10	-	6	24	60	-
H-4 Tcplc 1662-1746							
H-4 1656 (sidewall core, moved from Tcpuv)	-/-	-	-	2	35	65	-
H-4 1710-1720	~1/-	-	-	33	3	61	-
H-4 Tcplm 1746-1820							
H-4 1790-1800	3/-	-	-	15	17	64	-
H-4 Tcplc 1820-1840							
not sampled							
H-4 Tcplv 1840-2263.1							
H-4 1900-1910	-/-	22	-	5	16	56	-
H-4 1980-1990	-/23	11	-	2	6	55	-

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517); DTN: MO0004QGFMPIK.000 (DIRS 152554).

- = not detected; Tr. = trace amount much less than 1%.

Table B-4. Selected Mineralogic-Abundance Data for Drill Hole USW H-5 (weight percent)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
H-5 Tpc_un 0-404							
H-5 40-50	-/-	-	31	Tr.	-	66	-
H-5 50	-/-	-	17	-	2	80	-
H-5 110-120	Tr./-	-	17	-	13	68	-
H-5 160-170	Tr./-	-	13	-	20	70	-
H-5 190	-/-	-	2	-	23	75	
H-5 230-240	Tr./-	-	10	1	22	69	-
H-5 320-330	1/-	-	3	6	22	69	-
H-5 380-390	-/-	-	2	-	29	68	-
H-5 Tpcpv3 404-404							
H-5 Tpcpv2 404-420							
H-5 Tpcpv1 420-437.5							
H-5 420	15/-	-	-	1	12	32	40
H-5 Tpbt4 437.5-438							
not sampled							
H-5 Tpy 438-457							
H-5 450	-	-	-	1	-	2	96
H-5 Tpbt3 457-471							
H-5 460-470	14/-	-	-	-	2	12	69
H-5 Tpp-Tptrv1 471-564							
not sampled							
H-5 Tptrn 564-700							
H-5 620-630	1/-	-	4	1	9	76	-
H-5 700	Tr./-	-	20	-	15	65	-

Table B-4. Selected Mineralogic-Abundance Data for Drill Hole USW H-5 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
H-5 Tptrl 700-741							
H-5 720-730	3/-	-	23	-	9	65	-
H-5 Tptpul 741-988							
H-5 750-760	5/-	-	17	1	17	62	-
H-5 800-810	3/-	-	Tr.	2	24	72	-
H-5 830-840	-/-	-	Tr.	-	24	76	-
H-5 860-870	4/-	-	8	4	23	59	-
H-5 920-930	2/-	-	Tr.	3	24	71	-
H-5 970-980	2/-	-	Tr.	2	26	71	-
H-5 Tptpmn 988-1088							
H-5 990-1000	3/-	-	3	1	28	59	-
H-5 1050	Tr./-	-	-	2	40	55	-
H-5 Tptpll 1088-1450							
H-5 1090-1100	4/-	-	4	4	26	61	-
H-5 1150-1160	2/-	-	-	26	10	62	-
H-5 1200-1210	3/-	-	3	22	11	61	-
H-5 1230-1240	2/-	-	-	7	23	69	-
H-5 1290-1300	2/-	-	-	10	18	71	-
H-5 1350-1360	2/-	-	3	15	16	61	-
H-5 1380-1390	2/-	-	-	15	20	65	-
H-5 Tptpln 1450-1582							
H-5 1450-1460	Tr./-	-	-	20	8	71	-
H-5 1490-1500	2/-	-	-	9	21	68	-
H-5 1530-1540	1/-	-	-	21	14	60	-
H-5 Tptpv3 1582-1659							
H-5 1590-1600	35/-	10	-	-	17	40	-
H-5 1610	-/-	-	-	1	2	7	90
H-5 1630-1640	Tr./-	-	-	1	2	9	88

Table B-4. Selected Mineralogic-Abundance Data for Drill Hole USW H-5 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
H-5 1650-1660	-/-	-	-	2	5	4	89
H-5 1666 (sidewall core) (moved from Tptpv2)	50/-	10	-	1	12	25	-
H-5 Tptpv2-Tpbt1 1659-1705							
not sampled							
H-5 Tac 1705-1879.9							
H-5 1710-1720	3/-	-	-	5	5	20	70
H-5 1750	-/-	Tr.?	-	2	5	5	85
H-5 1762 (sidewall core)	-/-	-	-	1	1	5	95
H-5 1760-1770	-/-	6	-	3	4	6	81
H-5 1800	-/-	-	-	2	2	10	85
H-5 1820-1830	Tr./-	4	-	4	2	10	80
H-5 1852 (sidewall core)	-/-	-	-	2	-	7	90
H-5 1875 (sidewall core)	-/-	Tr.?	-	2	Tr.?	5	92
H-5 Tacbt 1879.9-1944.9							
H-5 1890-1900	1/-	11	-	4	3	6	75
H-5 1900-1910	Tr./-	10	-	3	1	8	78
H-5 1910-1920	Tr./-	18	-	5	5	7	65
H-5 1917 (sidewall core)	-/-	25	-	30	10	35	-
H-5 1920-1930	3/-	52	-	14	7	16	6
H-5 1930	2/-	50	-	15	-	30	-
H-5 Tcpuv 1944.9-1967							
H-5 1950-1960	3/-	51	-	2	5	8	31
H-5 1966 (sidewall core)	5/-	-	-	2	-	15	75
H-5 Tcduc 1967-2085							
H-5 1990-2000 excluded from corroboration	1/-	10	-	Tr.	9	21	59
H-5 2070-2080	1/-	-	-	29	3	68	-

Table B-4. Selected Mineralogic-Abundance Data for Drill Hole USW H-5 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
H-5 Tcpm 2085-2113							
not sampled							
H-5 Tcplc 2113-2130							
H-5 2140-2150 moved from Tcplv	1/-	-	-	27	7	69	-
H-5 Tcplv 2130-2240.1							
H-5 2200	Tr./-	60	-	2	2	35	-
H-5 2230-2240	2/8	64	-	4	16	8	-
H-5 Tcplt 2240.1-2263.1							
H-5 2260-2270	6/7	56	-	3	20	11	-
H-5 Tcbuv 2263.1-2310							
not sampled							

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517); DTN: LADV831321AQ97.007 (DIRS 113499); DTN: LA9910JC831321.001 (DIRS 113496); DTN: MO0004QGFMPIK.000 (DIRS 152554).

- = not detected; Tr. = trace amount much less than 1%.

Table B-5. Selected Mineralogic-Abundance Data for Drill Hole USW WT-1 (weight percent)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
WT-1 Tpbt3 435-446							
WT-1 440-450	5/-	-	8	-	4	12	70
WT-1 Tpbt2 446-477							
not sampled							
WT-1 Tptrv3-Tptrv1 477-492							
not sampled							
WT-1 Tptrn 492-575							
WT-1 500-510	-/-	-	11	-	12	72	-
WT-1 550-560	-/-	-	19	-	10	71	-
WT-1 Tptrl 575-593							
not sampled							
WT-1 Tptpul 593-733							
WT-1 640-650	1/-	-	11	9	16	62	-
WT-1 690-700	1/-	-	-	19	19	61	-
WT-1 Tptpmn 733-888							
WT-1 780-790	1/-	-	3	25	9	61	-
WT-1 840-850	1/-	-	6	20	16	56	-
WT-1 Tptpll 888-1187							
WT-1 930-940	3/-	-	5	26	7	57	-
WT-1 1000-1010	1/-	-	-	22	16	60	-
WT-1 1090-1100	1/-	-	-	24	15	58	-
WT-1 1160-1170	1/-	1	11	10	18	58	-
WT-1 Tptpln 1187-1299							
WT-1 1220-1230	-/-	-	5	27	8	59	-
WT-1 Tptpv3 1299-1337							

Table B-5. Selected Mineralogic-Abundance Data for Drill Hole USW WT-1 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
WT-1 1300-1310	1/-	2	-	35	4	59	-
WT-1 1320-1330	2/-	14	-	20	13	50	-
WT-1 Tptpv2 1337-1368							
WT-1 1340-1350	1/-	29	-	10	9	51	-
WT-1 Tptpv1 1368-1380							
not sampled							
WT-1 Tpbt1 1380-1384							
partly sampled, 1380-1390							
WT-1 Tac 1384-1564							
WT-1 1380-1390	-/12	40	-	8	7	31	-
WT-1 1410-1420	-/8	40	-	3	8	40	-
WT-1 1470-1480	-/18	25	-	10	7	39	-
WT-1 1510-1520	-/10	43	-	8	5	33	-
WT-1 1550-1560	-/12	40	-	14	7	26	-
WT-1 no units defined below 1564							
WT-1 1570-1580	-/3	5	-	26	9	57	-

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517); DTN: MO0004QGFMPIK.000 (DIRS 152554).

- = not detected; Tr. = trace amount much less than 1%.

Table B-6. Selected Mineralogic-Abundance Data for Drill Hole USW WT-2 (weight percent)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
WT-2 Tpbt2 247-271							
WT-2 250-260	4/-	-	-	2	11	34	50
WT-2 260-270	7/-	-	-	1	7	51	30
WT-2 Tptrv3-1 271-285							
not analyzed							
WT-2 Tptrn 285-380							
WT-2 290-300	1/-	-	10	-	9	78	-
WT-2 370-380	<1/-	-	19	1	5	72	-
WT-2 Tptpul 421-590							
WT-2 420-450	1/-	-	12	2	11	73	-
WT-2 510-520	1/-	-	13	3	21	62	-
WT-2 570-580	3/-	-	13	5	21	59	-
WT-2 Tptpmn 590-727							
WT-2 650-660	2/-	-	10	6	22	58	-
WT-2 720-730	1/-	-	10	8	19	61	-
WT-2 Tptpll 727-1014							
WT-2 780-790	1/-	-	6	21	10	59	-
WT-2 850-860	1/-	-	13	14	16	56	-
WT-2 930-940	1/-	-	13	11	17	57	-
WT-2 990-1000	2/-	-	-	14	21	62	-
WT-2 Tptpln 1014-1179							
WT-2 1060-1070	3/-	-	-	16	19	61	-
WT-2 1130-1140	<1/-	-	-	13	15	70	-

Table B-6. Selected Mineralogic-Abundance Data for Drill Hole USW WT-2 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
WT-2 Tptpv3 1179-1223							
WT-2 1190-1200	2/-	1	-	4	9	56	30
WT-2 1200-1210	1/-	1	-	7	15	26	50
WT-2 Tptpv2 1223-1264							
WT-2 1250-1260	2/-	-	-	9	12	36	40
WT-2 Tptpv1 1264-1315							
WT-2 1300-1310	<1/-	1	-	10	12	36	40
WT-2 Tptbt1 1315-1319							
not analyzed							
WT-2 Tac 1319-1521							
WT-2 1360-1370	<1/-	<1	-	11	8	40	40
WT-2 1420-1430	<1/-	4	-	11	4	50	30
WT-2 1450-1460	1/-	<1	-	14	8	44	30
WT-2 1470-1480	<1/-	5	-	8	8	49	30
WT-2 Tacbt 1521-1594							
WT-2 1520-1530	3/-	24	-	11	12	48	-
WT-2 1570-1580	-/-	19	-	18	7	53	-
WT-2 TcpuV not recognized							
WT-2 TcpuC 1594-1706							
WT-2 1640-1650	1/-	2	-	22	7	67	-
WT-2 Tcpcm 1706-1776							
WT-2 1710-1720	1/-	<1	-	22	7	69	-
WT-2 1750-1760	1/-	1	-	14	17	66	-
WT-2 TcplC 1776-1794							
not analyzed							
WT-2 TcplV 1794-not defined							
WT-2 1820-1830	4/-	19	-	5	14	59	-
WT-2 1910-1920	-/-	42	-	5	6	47	-
WT-2 2000-2010	-/4	30	-	3	3	55	-
WT-2 Tcb?							

Table B-6. Selected Mineralogic-Abundance Data for Drill Hole USW WT-2 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
WT-2 2050.25 (core)	1/-	-	-	18	9	69	-
WT-2 2053.7 (core)	1/-	-	-	19	10	67	-
WT-2 2059.5 (core)	<1/-	-	-	21	9	66	-

Sources: DTN: MO0101XRDDRILC.001 (DIRS 169517); DTN: MO0004QGFMPICK.000 (DIRS 152554).

- = not detected; Tr. = trace amount much less than 1%.

APPENDIX C
SELECTED QUALIFIED MINERALOGIC-ABUNDANCE DATA

Table C-1. Selected Mineralogic-Abundance Data for Drill Hole UE-25 UZ#16 (weight percent)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
UZ#16 Tpc_un 39.5-140.8							
UZ#16 54.8-55.0	2/-	-	4	2	28	61	-
UZ#16 64.7-64.9	3/-	-	7	4	25	62	-
UZ#16 78.6-78.9	3/-	-	3	1	30	59	-
UZ#16 88.7-88.8	2/-	-	3	1	31	59	-
UZ#16 102.1-102.2	3/-	-	3	Tr.	32	57	-
UZ#16 112.5-112.7	3/-	-	2	Tr.	32	58	-
UZ#16 126.0-126.2	1/-	1	Tr.	Tr.	33	59	-
UZ#16 140.2-140.3	1/-	-	Tr.	2	32	58	-
UZ#16 Tpcpv2 140.8-153 not sampled							
UZ#16 Tpcpv1 153-160.7							
UZ#16 154.2-154.5	8/-	-	-	-	12	17	63
UZ#16 156.1-156.2	14/-	-	-	Tr.	Tr.	4	82
UZ#16 Tpbt4 160.7-165.9							
UZ#16 165.1-165.3	6/-	-	-	5	2	16	71
UZ#16 Tpy 165.9-173.4							
UZ#16 167.4-167.5	12/-	-	-	-	-	3	85
UZ#16 171.3-171.5	9/-	-	-	-	-	-	91
UZ#16 Tpbt3 173.4-188.8							
UZ#16 174.9-175.1	11/-	-	-	1	2	8	78
UZ#16 179.3-179.4	6/-	-	-	7	2	20	65
UZ#16 183.9-184.1	18/-	-	-	2	1	19	59
UZ#16 188.5-188.7	7/-	-	-	Tr.	1	20	70
UZ#16 Tpbt2 188.8-217							
UZ#16 190.4-190.5	16/-	-	-	2	1	19	58
UZ#16 201.8-202.2	9/-	-	-	3	Tr.	19	64

Table C-1. Selected Mineralogic-Abundance Data for Drill Hole UE-25 UZ#16 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
UZ#16 211.4-211.6	8/-	-	-	Tr.	Tr.	19	71
UZ#16 Tptrv3 217-228.1							
UZ#16 223.7-224.2	9/-	18	-	-	15	55	-
UZ#16 224.1-224.7	6/-	18	-	2	24	48	-
UZ#16 227.0-227.2	5/-	17	-	1	34	41	-
UZ#16 Tptrv2 228.1-229.4							
not sampled							
UZ#16 Tptrv1 229.4-238.9							
UZ#16 230.1-230.3	1/-	-	-	Tr.	1	21	73
UZ#16 234.1-234.2	Tr./-	-	-	Tr.	2	38	58
UZ#16 Tptrn 238.9-357.8							
UZ#16 249.8-250.0	1/-	-	3	-	13	78	-
UZ#16 269.2-269.8	1/-	-	7	-	11	81	-
UZ#16 290.8-291.2	1/-	-	12	-	8	77	-
UZ#16 309.1-309.5	Tr./-	-	13	-	8	77	-
UZ#16 331.7-332.2	1/-	-	22	-	5	76	-
UZ#16 348.7-349.7	5/-	-	22	-	8	64	-
UZ#16 Tptrl 357.8-371							
UZ#16 370.2-370.7	7/-	-	22	3	8	61	-
UZ#16 Tptpul 371-545							
UZ#16 391.6-392.0	6/-	-	11	4	21	54	-
UZ#16 412.7-413.0	4/-	-	16	2	19	56	-
UZ#16 435.1-435.5	4/-	-	7	3	28	58	-
UZ#16 458.6-458.9	4/-	-	10	11	17	56	-
UZ#16 484.4-485.7	4/-	-	4	5	29	55	-
UZ#16 509.6-510.0	4/-	-	3	9	28	54	-
UZ#16 533.3-533.6	4/-	-	1	11	25	55	-
UZ#16 Tptpmn 545-669							
UZ#16 552.9-553.3	3/-	-	Tr.	21	16	57	-
UZ#16 577.3-577.6	3/-	-	1	23	13	57	-

Table C-1. Selected Mineralogic-Abundance Data for Drill Hole UE-25 UZ#16 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
UZ#16 602.8-603.4	3/-	-	3	12	27	57	-
UZ#16 627.9-628.2	3/-	-	1	10	26	56	-
UZ#16 648.8-649.3	4/-	-	4	6	27	54	-
UZ#16 Tptpl 669-935							
UZ#16 674.2-674.7	5/-	-	1	27	13	58	-
UZ#16 701.5-701.9	3/-	-	1	36	5	58	-
UZ#16 726.1-726.4	1/-	2*	7	23	10	57	-
UZ#16 751.4-751.7	3/-	-	1	29	10	56	-
UZ#16 773.0-773.4	1/-	3*	3	17	19	56	-
UZ#16 797.0-797.2	1/-	1*	1	14	23	57	-
UZ#16 820.6-820.9	3/-	1*	1	26	11	56	-
UZ#16 843.0-843.5	3/-	Tr.*	6	18	16	55	-
UZ#16 862.4-862.7	2/-	5*	5	9	22	55	-
UZ#16 876.8-877.1	3/-	11*	4	10	21	53	-
UZ#16 896.2-896.6	4/-	-	6	9	24	54	-
UZ#16 910.2-910.4	6/-	2*	3	18	18	56	-
UZ#16 925.4-925.7	4/-	5*	4	12	26	50	-
UZ#16 Tptpln 935-1107.5							
UZ#16 940.0-940.4	4/-	1*	Tr.	27	13	57	-
UZ#16 954.3-954.7	3/-	2*	3	18	20	52	-
UZ#16 970.9-971.4	5/-	2*	2	17	21	51	-
UZ#16 984.2-984.8	4/-	4*	2	18	21	52	-
UZ#16 1001.0-1001.6	5/-	4*	1	22	16	50	-
UZ#16 1014.9-1015.0	6/-	-	5	14	21	53	-
UZ#16 1029.2-1029.5	5/-	14*	3	15	21	45	-
UZ#16 1030.4-1030.6	4/-	8*	2	20	18	50	-
UZ#16 1047.0-1047.3	4/-	2*	2	24	13	55	-
UZ#16 1059.6-1059.8	5/-	-	3	15	23	54	-
UZ#16 1074.8-1075.1	4/-	1*	2	21	17	54	-
UZ#16 1090.4-1090.6	4/-	2*	1	24	15	53	-

Table C-1. Selected Mineralogic-Abundance Data for Drill Hole UE-25 UZ#16 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
UZ#16 1104.1-1104.4	2/-	-	-	31	8	57	-
UZ#16 Tptpv3 1107.5-1165.2							
UZ#16 1113.1-1113.2a	73/-	4	-	Tr.	10	10	-
UZ#16 1113.1-1113.2b	5/-	-	-	1	7	14	73
UZ#16 1135.3-1135.6	3/-	-	-	1	9	7	80
UZ#16 1149.2-1149.5	-/-	-	-	1	10	7	82
UZ#16 1157.4-1157.6	1/-	-	-	1	12	10	75
UZ#16 Tptpv2 1165.2-1178							
UZ#16 1166.5-1167.0	2/-	10	-	2	20	17	49
UZ#16 Tptpv1 1178-1190							
UZ#16 1179.8-1180.5	1/-	80	-	3	13	8	-
UZ#16 Tpbtt1 1190-1197							
UZ#16 1190.2-1191.2	6/2	83	-	1	6	4	-
UZ#16 Tac 1197-1455.4							
UZ#16 1202.8-1203.1	1/12	66	-	3	14	6	-
UZ#16 1215.7-1216.0	1/11	72	-	3	12	7	-
UZ#16 1235.5-1235.7	1/7	69	-	3	18	7	-
UZ#16 1256.6-1256.9	8/-	72	-	3	10	12	-
UZ#16 1261.0-1261.2a	1/-	66	-	3	22	11	-
UZ#16 1275.7-1276.0	3/8	54	-	6	18	13	-
UZ#16 1300.2-1300.3	9/5	58	-	5	20	10	-
UZ#16 1305.0-1305.3	2/9	60	-	5	19	11	-
UZ#16 1312.0-1312.4	3/12	54	-	4	18	11	-
UZ#16 1335.4-1336.2	1/11	38	-	9	26	19	-
UZ#16 1342.7-1343.0	3/16	55	-	3	19	10	-
UZ#16 1362.3-1362.7	3/13	52	-	4	17	11	-
UZ#16 1379.3-1379.5	3/9	60	-	4	21	9	-
UZ#16 1417.5-1418.0	2/8	58	-	4	19	11	-
UZ#16 1441.3-1441.8	2/12	65	-	3	17	6	-
UZ#16 Tacbt 1455.4-1485							

Table C-1. Selected Mineralogic-Abundance Data for Drill Hole UE-25 UZ#16 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
UZ#16 1460.2-1460.7	5/4	42	-	8	27	18	-
UZ#16 1476.7-1477.0	5/-	40	-	11	20	27	-
UZ#16 Tcpuv 1485-1497.7							
not sampled							
UZ#16 Tcduc 1497.7-1571							
UZ#16 1498.4-1498.9	-/8	-	-	17	20	48	-
UZ#16 1521.7-1522.2	3/-	-	-	41	-	54	-
UZ#16 1539.3-1539.7	4/-	-	-	41	-	56	-
UZ#16 1561.2-1561.7	4/-	-	-	39	-	58	-
UZ#16 Tcpc 1571-1638							
UZ#16 1579.1-1579.9	3/-	-	-	38	-	59	-
UZ#16 1600.2-1600.4	4/-	-	-	39	-	58	-
UZ#16 1618.7-1619.2	3/-	-	-	24	14	62	-
UZ#16 Tcplc 1638-1669.2							
UZ#16 1638.7-1639.2	7/-	-	-	20	15	55	-
UZ#16 1655.5-1656.0	6/-	-	-	11	27	56	-
UZ#16 Tcplv 1669.2-bottom							
UZ#16 1683.5-1684.0	3/-	42	-	5	28	28	-

Sources: LA000000000086.002 (DIRS 107144), MO0004QGFMPICK.000 (DIRS 152554).

- = not detected; Tr. = trace amount much less than 1%.

*Stellerite fracture fillings.

Table C-2. Selected Mineralogic-Abundance Data for Drill Hole USW G-1 (weight percent)

	Smectite/ Mordenite	Clinoptilolite/ Analcime	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
G-1 Tcpcb 2154.9-2173.3							
G-1 2173	-/9	33 (c)	-	2	8	41	-
G-1 Tcbuv 2173.2-2337							
G-1 2190	4/-	51 (c)	-	4	23	19	-
G-1 2198	1/2	48 (c)	-	4	20	20	-
G-1 2256	-/44	Tr. (c)	-	3	22	26	-
G-1 2279	Tr./38	29 (c)	-	3	8	21	-
G-1 2290	2/43	31 (c)	-	3	2	18	-
G-1 2316	-/23	30 (c)	-	19	-	27	-
G-1 Tcbuc 2337-2461							
G-1 2401	3/-	-	-	35	Tr.	62	-
G-1 2456	1/-	-	-	32	1	67	-
G-1 Tcbm 2461-2547							
G-1 2486	1/-	-	-	33	-	67	-
G-1 2499	Tr./-	-	-	32	Tr.	66	-
G-1 2506	Tr./-	-	-	32	Tr.	63	-
G-1 2544	Tr./-	-	-	36	Tr.	64	-
G-1 Tcblc not recognized							
G-1 Tcblv 2547-2601.6							
G-1 2564	Tr./27	40 (c)	-	3	10	20	-
G-1 2600	-/39	48 (c)	-	Tr.	2	12	-
G-1 Tcbbt 2601.6-2639.4							
G-1 2606	Tr./26	42 (c)	-	12	1	17	-
G-1 2607	-/21	26 (c)	-	20	1	29	-
G-1 2622	Tr./14	30 (c)	-	21	1	30	-
G-1 Tctuv 2639.4-2800							
G-1 2641	2/6	30/-	-	4	7	44	-

Table C-2. Selected Mineralogic-Abundance Data for Drill Hole USW G-1 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite/ Analcime	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
G-1 2663	Tr./15	40/-	-	5	4	33	-
G-1 2734	Tr./4	31/-	-	16	8	40	-
G-1 2765	4/Tr.	15/-	-	18	8	52	-
G-1 Tctuc 2800-2840							
G-1 2804	1/-	-/-	-	31	1	62	-
G-1 2805	3/-	-/-	-	33	1	62	-
G-1 2820	1/-	-/-	-	36	Tr.	65	-
G-1 2838	2/-	-/-	-	31	-	64	-
G-1 Tctm 2840-2956							
G-1 2868	1/-	-/-	-	36	Tr.	63	-
G-1 2884	2/-	-/-	-	34	-	64	-
G-1 2915	2/-	-/-	-	36	-	61	-
G-1 2932	1/-	-/-	-	36	-	64	-
G-1 2937	2/-	-/-	-	35	-	63	-
G-1 2948	2/-	2/-	-	30	-	67	-
G-1 Tctlc 2956-3005							
G-1 2966	1/-	-/-	-	36	-	67	-
G-1 2981	3/-	-/-	-	37	-	58	-
G-1 Tctlv 3005-3522							
G-1 3018	18/-	-/4	-	33	-	34	-
G-1 3079	11/-	13/5	-	36	-	34	-
G-1 3167	10/-	19/5	-	31	-	31	-
G-1 3288	17/-	40/1	-	18	-	20	-
G-1 3401	4/-	10/2	-	38	-	43	-
G-1 Tctbt 3522-3558.2							
G-1 3523	7/-	13/1	-	32	-	46	-
Tund 3558.2-bottom of hole							

Table C-2. Selected Mineralogic-Abundance Data for Drill Hole USW G-1 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite/ Analcime	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
G-1 3621	24/-	-/-	-	3	6	59	-
G-1 3810	65/-	-/-	-	-	-	37	-
G-1 3940	48/-	2/2	-	19	-	23	2
G-1 4246	17/-	-/6	-	38	-	38	-
G-1 4400	7/-	-/13	-	39	-	42	-
G-1 4503	4/-	-/19	-	39	-	37	-
G-1 4555	21/-	-/2	-	22	-	47	-
G-1 4612	13/-	-/7	-	34	-	41	-
G-1 4626	4/-	-/-	-	42	-	52	-
G-1 4652	7/-	-/11	-	40	-	38	-
G-1 4700	6/-	-/7	-	46	-	40	-
G-1 4750	8/-	-/10	-	37	-	44	-
G-1 4805	8/-	-/9	-	38	-	43	-
G-1 4848	6/-	-/11	-	41	-	38	-
G-1 4876	4/-	-/4	-	45	-	45	-
G-1 4912	7/-	-/8	-	43	-	37	-
G-1 4941	27/-	-/7	-	27	-	25	-
G-1 4958	8/-	-/17	-	46	-	30	-
G-1 4998	30/-	-/3	-	39	-	27	-
G-1 5026	5/-	-/2	-	45	-	51	-
G-1 5049	52/-	-/-	-	5	-	28	-
G-1 5093	5/-	-/2	-	39	-	47	Tr.
G-1 5126	2/-	-/15	-	50	-	33	Tr.
G-1 5167	2/-	-/14	-	46	-	40	Tr.
G-1 5212	1/-	-/16	-	48	-	38	Tr.
G-1 5253	1/-	-/27	-	36	-	35	-
G-1 5296	2/-	-/19	-	37	-	39	Tr.
G-1 5310	29/-	-/-	-	23	-	52	-
G-1 5311	6/-	1/-	-	46	-	45	-

Table C-2. Selected Mineralogic-Abundance Data for Drill Hole USW G-1 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite/ Analcime	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
G-1 5329	11/-	12/-	-	40	-	40	Tr.
G-1 5338	41/-	1/-	-	28	-	26	-
G-1 5348	9/-	Tr./-	-	35	-	44	-
G-1 5378	46/-	15/-	-	17	-	24	-
G-1 5412	5/-	12/-	-	40	-	40	Tr.
G-1 5433	35/-	20/-	-	9	-	27	Tr.
G-1 5458	26/-	25/-	-	18	-	28	-
G-1 5477	5/-	-/12	-	44	-	36	-
G-1 5498	5/-	-/17	-	38	-	41	-
G-1 5534	38/-	20/4	-	8	-	24	-
G-1 5560	5/23	23/-	-	21	-	33	Tr.
G-1 5596	2/-	1/7	-	34	-	50	Tr.
G-1 5637	3/-	-/16	-	38	-	42	1
G-1 5679	20/-	-/13	-	24	-	36	Tr.
G-1 5699	5/-	-/9	-	33	-	50	Tr.
G-1 5746	12/-	-/10	-	32	-	46	1
G-1 5803	10/-	-/-	-	29	-	54	1
G-1 5847	13/-	-/-	-	29	-	54	1
G-1 5898	7/-	-/12	-	42	-	34	-
G-1 5947	12/-	2/15	-	28	-	34	1
G-1 5980	14/-	4/-	-	29	-	40	2

Sources: MO0101XRDMINAB.001 (DIRS 163796), MO0004QGFMPICK.000 (DIRS 152554).

- = not detected; Tr. = trace amount much less than 1%.

Table C-3. Selected Mineralogic-Abundance Data for Drill Hole USW GU-3 (weight percent)

Unit or Sample Depth Range in feet	Smectite/ Hornblende	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
GU-3 Tpc_un 0-348.1							
GU-3 45.0	-/-	-	6	-	17	75	-
GU-3 79.0	-/-	-	25	2	6	70	-
GU-3 103.1	-/-	-	7	2	20	70	-
GU-3 196.3	-/-	-	-	-	25	75	-
GU-3 245.7	2/-	-	3	2	25	70	-
GU-3 303.6	<1/-	-	-	-	25	75	-
GU-3 316.8	-/-	-	-	-	22	75	-
GU-3 341.5	3/-	-	-	-	30	70	-
GU-3 Tpb3 375.5-391.7							
GU-3 376.1	4/-	-	-	3	5	50	40
GU-3 Tptrn 427.8-542							
GU-3 429.0	-/-	-	4	4	20	70	-
GU-3 430.5	-/-	-	4	-	12	80	-
GU-3 465.5	-/-	-	10	-	9	80	-
GU-3 482.0	-/-	-	20	-	7	70	-
GU-3 520.3	-/-	-	20	-	5	70	-
GU-3 525.3	~1/-	-	20	1	6	70	-
GU-3 Tptpul 548-688							
GU-3 579.0	~1/-	-	12	-	22	65	-
GU-3 633.4	~1/-	-	7	2	22	70	-
GU-3 674.7	~1/-	-	5	2	22	70	-
GU-3 Tptpmn 688-830							
GU-3 702.5	~1/-	-	-	6	17	70	-
GU-3 769.1	~1/-	-	6	~1	22	65	-
GU-3 Tptpll 830-1044							
GU-3 849.4	~1/-	-	-	4	17	75	-

Table C-3. Selected Mineralogic-Abundance Data for Drill Hole USW GU-3 (weight percent) (Continued)

Unit or Sample Depth Range in feet	Smectite/ Hornblende	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
GU-3 910.5	~1/-	-	-	4	27	65	-
GU-3 924.3	~1/-	-	10	12	12	65	-
GU-3 951.1	~1/-	-	5	8	17	70	-
GU-3 954.8	~1/-	-	-	17	12	70	-
GU-3 1027	-/-	-	-	6	17	75	-
GU-3 Tptpln 1044-1186.7							
GU-3 1061.0	-/-	-	-	20	7	70	-
GU-3 1130.3	-/-	-	-	17	10	70	-
GU-3 1175.0	~1/-	-	-	35	3	60	-
GU-3 Tptpv3 1186.7-1280							
GU-3 1195.7	2/-	-	-	3	27	35	30
GU-3 1227	2/-	-	-	8	17	35	40
GU-3 Tptpv2 1280-1317							
GU-3 1302.4	2/-	-	-	4	12	40	45
GU-3 Tptpv1 1317-1406.3							
GU-3 1322.0	-/-	-	-	4	7	30	65
GU-3 1344.8	-/-	-	-	7	7	30	55
GU-3 1369.6	-/-	-	-	4	6	25	65
GU-3 1394.5	-/-	-	-	4	6	30	65
GU-3 1394.6	-/-	-	-	4	6	30	65
GU-3 Tac 1412.5-1506.3							
GU-3 1415.5	-/-	-	-	5	6	35	55
GU-3 1439.2	Tr./-	-	-	20	6	20	55
GU-3 1439.5	~1/-	-	-	5	6	35	55
GU-3 1468.5	-/-	-	-	5	6	35	55
GU-3 1493.7	~1/-	2	-	5	6	25	65

Table C-3. Selected Mineralogic-Abundance Data for Drill Hole USW GU-3 (weight percent) (Continued)

Unit or Sample Depth Range in feet	Smectite/ Hornblende	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
GU-3 1498.3	-/-	3	-	7	6	25	65
GU-3 Tacbt 1506.3-1553.9							
GU-3 1510.7	3/-	-	-	5	6	25	65
GU-3 1537.5	3/2	2	-	17	4	50	20
GU-3 Tcpuv 1553.9-1597							
GU-3 1571.6	2/-	-	-	4	5	45	45
GU-3 1598.5 moved to Tcpuv	4/-	-	-	5	2	45	45
GU-3 Tcduc 1597-1663							
GU-3 1603.0	-/-	-	-	2	30	65	-
GU-3 1624.2	-/-	-	7	20	2	70	-
GU-3 1653.3	~1/-	-	15	15	3	70	-
GU-3 Tcpc 1663-1744							
GU-3 1709.0	~1/-	-	-	12	12	70	-
GU-3 Tcplc 1744-1755							
GU-3 1744.0	-/-	-	-	6	25	70	-
GU-3 Tcplv 1755-1992.3							
GU-3 1827.2	2/-	30	-	4	7	19	38
GU-3 1874	-/-	50	-	7	5	40	-
GU-3 1935.8	3/-	60	-	4	4	30	-
GU-3 1986	-/-	70	-	4	6	20	-
GU-3 Tcpc 1992.3-1998.7							
GU-3 1993.1	-/-	60	-	4	10	25	-
GU-3 Tcblv 2550.8-2617							
GU-3 2577.4	3/-	50	-	2	5	35	-
GU-3 2615.3	2/-	40	-	5	7	45	-

Table C-3. Selected Mineralogic-Abundance Data for Drill Hole USW GU-3 (weight percent) (Continued)

	Smectite/ Hornblende	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
GU-3 Tctuv 2637-2719							
GU-3 2656.6	4/-	30	-	5	8	50	-
GU-3 2695.7	~1/-	30	-	7	10	40	-

Sources: MO0101XRDMINAB.001 (DIRS 163796), MO0004QGFMPIK.000 (DIRS 152554).

- = not detected; Tr. = trace amount much less than 1%.

Table C-4. Selected Mineralogic-Abundance Data for Drill Hole USW G-4 (weight percent)

	Smectite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
G-4 Tptpmn 674-774							
G-4 676	3	-	4	4	23	66	-
G-4 694	3	-	17	4	13	62	-
G-4 746	~1	-	-	3	28	68	-
G-4 Tptpln 1127.9-1316.5							
G-4 1163	-	-	-	16	15	69	-
G-4 1190	1	-	-	25	13	60	-
G-4 1244	1	-	-	17	15	67	-
G-4 1282	1	-	-	16	18	65	-
G-4 1283-1293E	1	-	-	6	23	69	-
G-4 1299	2	5	-	8	23	62	-
G-4 1301	1	5	-	9	20	65	-
G-4 1310	1	3	-	5	24	65	-
G-4 1314*	45	28	-	2	14	11	

Source: MO0101XRDMINAB.001 (DIRS 163796), MO0004QGFMPIK.000 (DIRS 152554).

*This sample is excluded from the comparison with Tptpln in other drill hole samples because the presence of abundant smectite and clinoptilolite means it is from a localized alteration zone.

- = not detected; Tr. = trace amount much less than 1%.

Table C-5. Selected Mineralogic-Abundance Data for Drill Hole USW SD-12 (weight percent)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
SD-12 Tptrn 330.7-436.4							
SD-12 331.1	Tr./-	-	4	5	25	63	-
SD-12 337.8	1/-	-	6	-	15	79	-
SD-12 376.3	Tr./-	-	13	-	9	77	-
SD-12 395.9	-/-	-	14	Tr.	7	74	-
SD-12 419.8	2/-	-	16	Tr.	10	74	-
SD-12 Tptpul 470.2-663.7							
SD-12 489.6	4/-	-	14	3	21	55	-
SD-12 517.4	3/-	-	9	1	27	56	-
SD-12 534.7	4/-	-	7	3	30	55	-
SD-12 561.9	5/-	-	7	3	28	54	-
SD-12 580.7	5/-	-	6	9	25	55	-
SD-12 602.6	4/-	-	8	12	23	55	-
SD-12 629.7	4/-	-	5	6	29	54	-
SD-12 654.4	3/-	-	7	15	19	56	-
SD-12 Tptpmn 663.7-786.9					30		
SD-12 679.5-679.9	4/-	-	2	8		53	-
SD-12 706.0-706.1	5/-	-	4	11	26	52	-
SD-12 733.0-733.3	5/-	-	3	5	34	54	-
SD-12 759.8-760.1	4/-	-	4	9	28	54	-
SD-12 785.5-785.8	3/-	-	4	3	34	54	-
SD-12 Tptpll 786.9-1065.5							
SD-12 807.0	4/-	-	3	10	27	53	-
SD-12 831.4	4/-	-	3	33	6	56	-
SD-12 852.9	4/-	-	14	13	16	55	-
SD-12 881.1	3/-	-	3	23	17	54	-
SD-12 903.1	5/-	-	4	12	25	54	-

Table C-5. Selected Mineral-Abundance Data for Drill Hole USW SD-12 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
SD-12 929.9	4/-	-	7	24	10	55	-
SD-12 954.7	3/-	-	4	16	22	54	-
SD-12 979.7	2/-	-	3	11	26	54	-
SD-12 Tptpln 1065.5-1278.1							
SD-12 1160.8-1161.1	4/-	-	1	21	20	55	-
SD-12 1180.9-1181.1	4/-	-	1	24	15	54	-
SD-12 1200.2-1200.6	3/-	-	2	17	24	54	-
SD-12 1219.2-1220.2	4/-	-	2	9	27	54	-
SD-12 1240.4-1240.6	2/-	-	2	16	23	57	-
SD-12 1261.9-1262.1	3/-	-	2	19	22	53	-
SD-12 1271.1-1271.3	3/-	-	3	7	30	53	-
SD-12 1273.4-1273.45	-/-	1	2	7	29	56	-
SD-12 Tptpv3 1278.1-1308							
SD-12 1278.5-1278.8	2/-	-	-	1	-	10	72
SD-12 1291.4-1291.8	-/-	-	-	1	8	6	85
SD-12 1301.0-1301.4	Tr./-	-	-	Tr.	10	8	82
SD-12 Tptpv2 1308-1337.5							
SD-12 1309.3	Tr./-	-	-	1	20	14	65
SD-12 1319.0	Tr./-	-	-	1	18	15	66
SD-12 1320.6	Tr./-	-	-	1	18	13	68
SD-12 1333.2	2/-	-	-	1	8	9	80
SD-12 Tptpv1 1337.5-1408.1							
SD-12 1342.1	Tr./-	-	-	1	4	4	91
SD-12 1351.9	Tr./-	-	-	1	6	5	88
SD-12 1361.9	-/-	-	-	1	3	4	92
SD-12 1371.4	Tr./-	-	-	1	2	4	93
SD-12 1381.1	1/-	2	-	1	4	5	87

Table C-5. Selected Mineral-Abundance Data for Drill Hole USW SD-12 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
SD-12 1388.0	Tr./-	2	-	3	5	8	82
SD-12 1399.2	1/-	3	-	5	5	12	74
SD-12 1408.0	8/-	1	-	2	3	9	77
SD-12 Tpbt1 1408.1-1411.5							
SD-12 1410.5-1410.6	2/-	1	-	2	3	7	85
SD-12 Tac 1411.5-1599.5							
SD-12 1439.9-1440.1	-/-	1	-	2	2	6	89
SD-12 1458.7-1458.9	Tr./-	4	-	2	2	5	87
SD-12 1480.2-1480.5	Tr./-	4	-	4	4	9	79
SD-12 1500.8-1501.0	1/-	5	-	4	4	7	79
SD-12 1519.8-1520.1	2/-	5	-	6	12	17	58
SD-12 1540.9-1541.3	2/-	10	-	5	9	10	64
SD-12 1561.1-1561.3	3/-	3	-	3	5	8	78
SD-12 1581.3-1581.6	2/-	9	-	4	5	7	73
SD-12 Tacbt 1599.5-1648.4							
SD-12 1600.0-1600.3	4/-	12	-	7	5	10	62
SD-12 1600.0-1600.3	7/4	51	-	2	30	8	-
SD-12 1601.5-1601.8	5/-	68	-	4	15	6	-
SD-12 1609.9-1610.4	3/-	30	-	11	7	11	34
SD-12 1620.4-1620.6	4/-	59	-	8	18	14	-
SD-12 1641.4-1641.7	9/-	14	-	8	25	45	-
SD-12 Tcpuv 1648.4-1677							
SD-12 1656.3-1656.8	7/-	58	-	3	23	13	-
SD-12 Tcpuc 1677-1787							
SD-12 1680.7-1680.9	2/-	-	-	35	-	54	-
SD-12 1700.3-1700.6	3/-	-	2	34	4	55	-
SD-12 1720.1-1720.4	2/-	-	3	32	2	56	-

Table C-5. Selected Mineral-Abundance Data for Drill Hole USW SD-12 (weight percent) (Continued)

	Smectite/ Mordenite	Clinoptilolite	Tridymite	Quartz	Cristobalite±Opal	Feldspar	Glass
Unit or Sample Depth Range in feet							
SD-12 1739.8-1740.2	2/-	-	3	32	2	58	-
SD-12 1760.0-1760.4	3/-	-	3	30	2	60	-
SD-12 1780.2-1780.4	2/-	-	-	26	10	60	-
SD-12 Tcpcm 1787-1842							
SD-12 1799.4-1800.0	2/-	-	3	31	4	57	-
SD-12 1821.2-1821.6	Tr./-	-	-	21	18	60	-
SD-12 1840.6-1840.8	5/-	-	-	9	27	55	-
SD-12 Tcplc 1842-1865							
SD-12 1860.0-1860.3	2/-	-	-	5	31	57	-
SD-12 Tcplv 1865-2133							
SD-12 1874.4-1874.5	6/5	10	-	4	45	34	-
SD-12 1891.6-1891.9	5/10	50	-	6	11	22	-
SD-12 1911.8-1911.9	5/4	48	-	5	21	19	-
SD-12 1929.7-1929.9	3/6	51	-	4	21	19	-
SD-12 1950.0-1950.7	3/5	56	-	4	16	21	-
SD-12 1972.1-1972.4	2/-	65	-	4	15	19	-
SD-12 Tcb 2137.8-bottom							
SD-12 2148.6	2/-	-	-	26	13	56	-
SD-12 2163.0	-/-	-	-	33	6	59	-

Sources: LADV831321AQ97.001 (DIRS 107142), LAJC831321AQ98.005 (DIRS 109004), MO0004QGFMPIK.000 (DIRS 152554).

- = not detected; Tr. = trace amount much less than 1%.

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APPENDIX D

SOURCE DATA TRACKING NUMBERS FOR OUTPUT DTN: LA9908JC831321.001

The following text illustrates the source relationship for the source of mineralogic model, Version 3.0, DTN: LA9908JC831321.001. This also demonstrates that all data provided by the source DTNs are qualified by Steinborn, T.L. (2002 [DIRS 160702]), and the qualification activities contained in Appendices A, B, and C of this report.

LA9908JC831321.001—Product output DTN from the mineralogic model (MM3.0)

Listing of some DTNs from Table 4-1 that relate to the qualification activity in Appendices A-C of this report:

1. **LA000000000086.002** (DIRS 107144) **Qualified**, Verified using AP-3.15Q Procedure, Developed.
2. **LA9910JC831321.001** (DIRS 113496) Unqualified
Qualified by activity contained in Appendices A-C, this report.
3. **LADB831321AN98.002** (DIRS 109003) Unqualified
Separated into these five DTNs by Steinborn 2002 (DIRS 160702), Table 10:
 - (a) **MO0101XRDMINAB.001** (DIRS 163796), Boreholes: UE-25b#1, USW G-1, USW G-3, USW GU-3, and USW G-4, **Qualified by Steinborn 2002**.
 - (b) **MO0101XRDDRILC.000** (DIRS 169516), Borehole: UE-25 J-13 (not an input to MM3.0), Not qualified.
 - (c) **MO0106XRDDRILC.003** (DIRS 163797), Borehole: USW H-6, **Qualified by Steinborn 2002**.
 - (d) **MO0101XRDDRILC.002** (DIRS 163795), Boreholes: UE-25 a#1 and USW G-2, **Qualified by Steinborn 2002**.
 - (e) **MO0101XRDDRILC.001** (DIRS 169517), Cuttings, sidewall samples, and intermittent core samples. **Qualified** by activity contained in Appendices A-C, this report.
4. **LADV831321AQ97.001** (DIRS 107142), **Qualified** by activity contained in Appendices A-C, this report.
5. **LADV831321AQ97.007** (DIRS 113499), **Qualified** by activity contained in Appendices A-C, this report.
6. **LADV831321AQ99.001** (DIRS 109044), **Qualified**, Verified using AP-3.15Q Procedure, Acquired.
7. **LAJC831321AQ98.005** (DIRS 109004), **Qualified**, Verified using AP-3.15Q Procedure, Acquired.

8. **LASC831321AQ96.002 (DIRS 109042), Qualified,** Verified using AP-3.15Q Procedure, Acquired.
9. **LASC831321AQ98.001 (DIRS 109047), Qualified,** Verified using AP-3.15Q Procedure, Acquired.
10. **LASC831321AQ98.003 (DIRS 109043), Qualified,** Verified using AP-3.15Q Procedure, Acquired.
11. **LASL831322AQ97.001 (DIRS 109045), Qualified,** Verified using AP-3.15Q Procedure, Acquired.

APPENDIX E

GENERAL OBSERVATIONS AND SUMMARY OF MINERALOGY

E1. INTRODUCTION

The stratigraphy of volcanic units at Yucca Mountain is complex, including both tuffs and lavas. However, within the areal extent of the mineralogic model, the only lavas of any significance occur within sequence 2 (Tund—undifferentiated older Tertiary rocks). In the mineralogic model, lavas, flow breccias, and tuffs within this sequence are grouped together because there are insufficient data for subdivision. The consequences of this grouping are minimal because (1) these units, below the Crater Flat Group, are far enough below the water table to be of little consequence in transport and (2) mineral alteration at these depths is so pervasive that the original lithology has only a limited effect on the alteration products. Above sequence 2, however, there are clear and definitive relationships between the nature of the tuffs and the occurrence of alteration minerals (principally clays and zeolites).

The tuffs above sequence 2 generally occur as ash-flow units with interspersed bedded tuffs. Within the area of the mineralogic model, the thicker ash flows generally have nonwelded to poorly welded exteriors at the margins of more welded interiors. Typically, where thicker than a few tens of meters, the welded ash-flow interiors have devitrified to a mineral assemblage consisting principally of feldspar plus anhydrous silica minerals. Above sequence 2 these devitrified zones rarely contain zeolites; where zeolites do occur in devitrified units, their abundance is low (generally less than 10 percent). In contrast, the nonwelded to poorly welded ash-flow margins and the bedded tuffs between ash flows are readily zeolitized, with typical zeolite abundances in the range of 25 to 80 percent below the water table and up to approximately 330 ft (100 m) above the water table. The relationships between marginal zones of initially vitric tuff and zeolitization strongly indicate that zeolites cannot become abundant unless vitric tuff was originally present. The same relationships also lead to distinct transitions between zeolitized and devitrified sequences, particularly within the tuffs of the Crater Flat Group (mineralogic model sequences 3 through 9). In these sequences, the transition from abundant zeolitization of the flow margins to the devitrified flow interiors is typically definitive and abrupt (within about 3.3 ft [1 m]). In places where this transition is definitive in the mineralogic data but inconsistent with the STRATAMODEL and the Geologic Framework Model version 3.1 sequence, the elevations of the mineralogic data were adjusted. This prevented dispersion of zeolites into devitrified units and mixing of devitrification mineralogy into zeolitized sequences. Adjustments are listed in Table E-1.

From sequence 9 to sequence 13 in the mineralogic model (upper nonwelded Prow Pass Tuff to the moderately to densely welded lower vitric zone of the Topopah Spring Tuff), there is a highly variable transition between vitric and zeolitic lithologies. Because the initial tuff deposits in these sequences were all largely vitric, there are few stratigraphic controls over the extent of hydrous mineral alteration. However, the mineralogic data show that the bedded tuff below the Calico Hills Formation (sequence 10) is more readily altered to zeolite or smectite than the overlying ash flows (sequence 11). Conversely, sequence 11 is never significantly altered if the underlying bedded tuff is not significantly altered. At the top of this series of originally vitric sequences (sequence 13) is a common zone of smectite and zeolite alteration, with total hydrous mineral abundances ranging from a few percent to complete alteration of the upper few feet (decimeters) of the vitrophyre. In some places, this zone of alteration extends into the base of the overlying devitrified horizon (Tptpln, sequence 14). The elevations of mineralogic data corresponding to highly altered, basal Tptpln samples were adjusted to fall within the vitric

horizon (sequence 13) (Table E-1). This prevented dispersion of high zeolite and smectite abundances into the lower nonlithophysal zone (devitrification mineralogy) of the Topopah Spring Tuff (Table E-1).

Sequences 14 through 18 of the mineralogic model make up the thick devitrified interior of the Topopah Spring Tuff. The upper boundary of unit 18 is defined by a transition from devitrified to vitric composition. Therefore, mineralogic data near the contact of sequences 18 (upper devitrified Topopah Spring Tuff) and 19 (upper vitrophyre of the Topopah Spring Tuff) were adjusted in some boreholes to prevent unrealistic distribution of abundant glass into the devitrified tuff or extensive devitrification into the vitrophyre (Table E-1).

Sequence 20 in the mineralogic model incorporates all of the heterogeneous deposits from the zone of decreased welding at the top of the Topopah Spring Tuff (Tpdrv2) through the nonwelded base of the Tiva Canyon Tuff (Tpcpv1). This interval is principally composed of initially vitric ash-flow and bedded deposits; however, it includes locally devitrified sequences in the Yucca Mountain Tuff and Pah Canyon Tuff in the north (e.g., in borehole G-2). In sequence 20, glasses are predominantly altered to smectite, with only local occurrences of significant zeolitization (e.g., in borehole UZ#16). The transition to sequence 21, the moderately to densely welded vitric base of the Tiva Canyon Tuff, is gradational; sequence 21 is distinguished by an intermingling of vitric remnants, devitrification, and smectite alteration. The transition from sequence 21 to sequence 22, the devitrified interior of the Tiva Canyon Tuff, is distinguished by a sharp decrease in smectite and/or glass. Sequence 22 consists of devitrification minerals throughout the areal extent of the mineralogic model. The elevations of mineralogic data were adjusted where unrealistic glass abundances would have been introduced from sequence 21 and where alluvial or surface-alteration features would have been introduced from above (Table E-1). Alluvial and surface- weathering features are not currently included in the mineralogic model.

E2. SUMMARY OF MINERALOGIC RELATIONS

This section describes the mineralogy typical of each mineralogic model sequence and the rationale for modifying the elevations of sample data where such adjustments were deemed necessary. Modifications to the mineralogic data (as available in the TDMS) for the purpose of mineralogic model Version 3.0 are documented in Table E-1.

E2.1 SEQUENCE 22: DEVITRIFIED TIVA CANYON TUFF (ALLUVIUM–Tpcplnc)

The devitrified Tiva Canyon Tuff consists principally of feldspar and the anhydrous silica polymorphs (cristobalite, tridymite, and quartz). The primary distinction between this sequence and the underlying sequence in the mineralogic model is the absence of glass in sequence 22. A minor exception to this distinction is seen in borehole SD-6 at an elevation of 4,494.4 ft (1,369.9 m) above mean sea level (msl), where a sample from the base of sequence 22 contained 7 percent glass, apparently representing a transitional lithology between the typical mineral properties of sequence 22 and the properties of underlying sequence 21. The sample collected at 2.6 ft (0.8 m) below, in sequence 21, contained 54 percent glass; the elevation of this sample was adjusted downward in the mineralogic model (Table E-1).

As a devitrified unit, sequence 22 generally contains no zeolites. In one instance, the uppermost core sample from sequence 22 (in borehole SD-9 at an elevation of 4,217.8 ft (1,285.6 m) above msl) contained 29 percent zeolite (clinoptilolite). This sample was collected from a surface breccia that is not representative of sequence 22; this zeolite-bearing sample was therefore excluded from the mineralogic model.

E2.2 SEQUENCE 21: DENSELY TO MODERATELY WELDED VITRIC BASE OF TIVA CANYON TUFF (Tpcpv3–Tpcpv2)

The densely to moderately welded vitric base of the Tiva Canyon Tuff is glass rich, with variable amounts of alteration to smectite. The greater welding of sequence 21 is the principal distinction between this sequence and the top of the underlying sequence (sequence 20).

E2.3 SEQUENCE 20: PTn UNIT (Tpcpv1–Tptrv2)

The PTn unit is the least homogeneous sequence of the mineralogic model. The PTn includes the nonwelded base of the Tiva Canyon Tuff, the Yucca Mountain and Pah Canyon Tuffs with intercalated bedded tuffs, and the upper nonwelded portion of the Topopah Spring Tuff. Most of these units contain glass and variable amounts of smectite alteration. Alteration to zeolite is less common, although significant zeolitization occurs in G-2 and UZ#16 and there are minor occurrences of zeolite in boreholes SD-12, UZ-14, UZN-31, and UZN-32. Remnants of glass are almost pervasive, with the exception of those areas where the Yucca Mountain and/or Pah Canyon Tuffs are devitrified (boreholes G-2 and UZ-14), where smectite alteration and devitrification occur at the base of the PTn (boreholes SD-7 and UZ#16), and where glass was completely altered to smectite (some bedded tuffs in boreholes UZN-31 and UZN-32).

E2.4 SEQUENCE 19: UPPER VITROPHYRE OF TOPOPAH SPRING TUFF (Tptrv1)

High glass content (greater than 20 percent; generally greater than 75 percent) distinguishes sequence 19 (the upper vitrophyre of the Topopah Spring Tuff) from the underlying devitrified unit (Tptrn). This densely welded quartz-latic glass is generally only slightly altered to smectite and rare clinoptilolite. In some instances, the depth assignments from the Geologic Framework Model version 3.1 placed samples that were largely devitrified and contained only small amounts of glass (in borehole SD-9 at an elevation of 4,001.3 ft [1,219.6 m] above msl, 7 percent glass) or samples that were fully devitrified and contained no glass (UZ#16 at 3,763.7 ft [1,147.2 m] above msl) into sequence 19. Because sequence 19 is defined as a vitrophyre, these samples were reassigned to sequence 18 in the mineralogic model. In another instance, a sample with 23 percent glass (in borehole SD-12 at 4,011.8 ft [1,222.8 m] above msl) was assigned by GFM3.1 to sequence 18, which is a devitrified unit. In this instance, the sample was reassigned to sequence 19 in the mineralogic model.

E2.5 SEQUENCE 18: QUARTZ-LATITIC TO RHYOLITIC TRANSITION ZONE AND LITHIC-RICH ZONE OF TOPOPAH SPRING TUFF (Tptrn–Tp tf)

This sequence within the Topopah Spring Tuff includes the transition from quartz-latic composition (above) to rhyolitic composition (below). Mineralogically, this interval has a generally higher tridymite:quartz ratio than the underlying devitrified zones of the Topopah Spring Tuff. The upper part of the sequence contains small amounts of glass (less than

10 percent) in boreholes NRG-7a and SD-9. In one instance, the depth assignments from GFM3.1 placed a sample that was devitrified, had a high tridymite:quartz ratio, and was free of glass or hydrous alteration minerals (in borehole SD-6 at an elevation of 4,388.1 ft [1,337.5 m] above msl) in sequence 20. In this case, the sample was reassigned to sequence 18 in the mineralogic model. In another instance, a sample that was devitrified and contained no glass (in borehole G-2 at 4,327 ft [1,318.9 m] above msl) was assigned to sequence 19; this sample was reassigned to devitrified sequence 18 in the mineralogic model ([Table E-1](#)).

E2.6 SEQUENCE 17: UPPER LITHOPHYSAL ZONE OF TOPOPAH SPRING TUFF (Tptpul)

This sequence of devitrified rhyolitic tuff has a relatively constant feldspar content but highly variable ratios of tridymite:crystalite:quartz.

E2.7 SEQUENCE 16: MIDDLE NONLITHOPHYSAL ZONE OF TOPOPAH SPRING TUFF (Tptpmn)

This sequence of devitrified rhyolitic tuff has a relatively constant feldspar content but highly variable ratios of tridymite:crystalite:quartz. Small amounts of zeolite (stellerite) occur in the rock matrix in borehole UZ#16.

E2.8 SEQUENCE 15: LOWER LITHOPHYSAL ZONE OF TOPOPAH SPRING TUFF (Tptpll)

This sequence of devitrified rhyolitic tuff has a relatively constant feldspar content but highly variable ratios of tridymite:crystalite:quartz. In borehole UZ#16, amounts of zeolite (stellerite) up to 11 percent occur in dispersed fractures and in the rock matrix.

E2.9 SEQUENCE 14: LOWER NONLITHOPHYSAL ZONE OF TOPOPAH SPRING TUFF (Tptpln)

This sequence of devitrified rhyolitic tuff has a relatively constant feldspar content but highly variable ratios of tridymite:crystalite:quartz. In UZ#16, amounts of zeolite (stellerite) up to 14 percent occur in dispersed fractures and in the rock matrix. The base of the sequence may contain low percentages of glass, smectite, and/or zeolite, transitional with the altered upper surface of sequence 13. In one instance, the Geologic Framework Model version 3.1 placed a sample that was devitrified and contained less than 2 percent hydrous alteration minerals (in borehole SD-9 at 2,915.8 ft [886.8 m] above msl) into the underlying vitrophyre sequence 13. In this case, the sample was reassigned to sequence 14 in the mineralogic model. In another instance, a devitrified sample with only 6 percent zeolite alteration (in borehole G-3 at an elevation of 3,666.3 ft [1,117.5 m] above msl) was assigned by the Geologic Framework Model version 3.1 to sequence 13; this sample was reassigned to sequence 14 in the mineralogic model. At borehole NRG-7a, the basal sample from Tptpln was altered to smectite and transitional to sequence 13 and was assigned to sequence 13. The remaining 11 samples from Tptpln were averaged into a single sample value (located at 2,834.6 ft [864.0 m] above msl) to preserve the stratigraphic relationships.

E2.10 SEQUENCE 13: DENSELY TO MODERATELY WELDED VITRIC BASE OF TOPOPAH SPRING TUFF (Tptpv3–Tptpv2)

This sequence consists of the lower densely welded quenched-glass horizon (vitrophyre) and the underlying moderately welded glass of the Topopah Spring Tuff. In many boreholes, the upper few inches to feet (centimeters to decimeters) of this sequence are extensively altered to smectite and zeolites. The division of sequence 13 into two equal-thickness layers captures this alteration, in part, with the upper layer (17) having greater alteration than the lower layer (16). Generally, the glass contents in this sequence are high (70 to 100 percent), with the exception of smectite and zeolite alteration that can completely replace the glass at the sequence top or at depths throughout the sequence (in boreholes UZ-14 and WT-24). Zeolite alteration in sequence 13 includes most of the occurrences of the mineral erionite (a carcinogen that poses an inhalation hazard) at Yucca Mountain.

In some instances, the depth assignments from the Geologic Framework Model version 3.1 placed samples with abundant smectite and zeolite into sequence 14 (Tptpln), which, as a devitrified sequence, should not be associated with large amounts of hydrous minerals. These instances are common and occur in G-1 at an elevation of 3,063.6 ft (933.8 m) above msl, in borehole G-2 at 3,463.2 ft (1,055.6 m) above msl, in borehole G-4 at 2,852 ft (869.3 m) above msl, in borehole NRG-7a at 2,795.2 ft (852.0 m) above msl, and in borehole UZ-14 at 3,147.3 ft (959.3 m) above msl. These samples were reassigned to sequence 13 in the mineralogic model.

E2.11 SEQUENCE 12: NONWELDED TO BEDDED ZONE AT BASE OF TOPOPAH SPRING TUFF (Tptpv1–Tpbt1)

This sequence varies from highly zeolitized with no remnant glass in the northern and eastern parts of Yucca Mountain, to vitric and relatively unaltered in the west and south. Where the underlying Calico Hills Formation (sequence 11) is fully zeolitized, the transition from vitric to zeolitic properties usually occurs near the top of sequence 12 or in the lower part of sequence 13 (in borehole WT-24).

E2.12 SEQUENCE 11: CALICO HILLS FORMATION (Tac)

As with sequence 12, the Calico Hills Formation (sequence 11) varies from highly zeolitized with no remnant glass in the northern and eastern parts of Yucca Mountain, to vitric and relatively unaltered in the west and south. Transitions from vitric to zeolitized properties within sequence 11 are highly variable, ranging from dispersion of low zeolite abundances (less than 10 percent) across tens of meters (in borehole SD-12), to stacked sills of high zeolite abundance (up to 69 percent) between largely vitric layers (in borehole SD-7). Because the vitric:zeolitic ratios vary with depth in some parts of sequence 11, these variations are approximated by the subdivision of sequence 11 into four layers. One sample from borehole SD-12, collected at an elevation of 2,742.4 ft (835.9 m) above msl, contained a very sharp (centimeter-scale) transition between Tac and Tacbt. In this instance, the two parts of the sample (upper poorly zeolitic and glassy, lower zeolitic and without glass) are on opposite sides of the contact between sequence 11 and sequence 10.

There are no data for sequence 11 at a particularly crucial borehole (H-3). There are data for sequence 10 and sequence 12 at H-3, both of which are nonzeolitic and vitric in nature. The observed mineralogic relations at other boreholes demonstrate that if the upper part of sequence 10 (the bedded tuff below the Calico Hills Formation) is vitric, sequence 11 is also vitric (in boreholes G-3, H-5, SD-6, and SD-12) (see Section 6.3.1). In the absence of mineralogic data for sequence 11 at H-3, the mineralogic model would predict abundant zeolite at borehole H-3 (due in part to the influence of borehole SD-7). This prediction is viewed as unrealistic. Consequently, a synthetic datum was placed at borehole H-3 in sequence 11. Because the mineralogic values for borehole H-3 are most similar to those of borehole G-3, the mineralogic values of sequence 11 at borehole H-3 were assigned to be equal to the average values for sequence 11 at borehole G-3.

E2.13 SEQUENCE 10: BEDDED TUFF BELOW CALICO HILLS FORMATION (Tacht)

Sequence 10, consisting of the bedded tuffs below the Calico Hills Formation, is invariably zeolitized where the overlying ash flows (sequence 11) are zeolitized; however, sequence 10 may also be extensively zeolitized (10–68 percent zeolite) where the overlying ash flows are poorly zeolitized (0–12 percent zeolite at boreholes H-5 and SD-12). In borehole SD-6, however, the greater alteration of the bedded tuff in sequence 10 is expressed by a higher smectite abundance rather than a difference in zeolitization. Because it more readily alters to sorptive minerals, sequence 10 is treated separately from the overlying Calico Hills ash flows in the mineralogic model.

E2.14 SEQUENCE 9: UPPER NONWELDED ZONE OF PROW PASS TUFF (Tcpu)

Sequence 9 is vitric in boreholes to the south and west (G-3, H-3, and SD-6), both vitric and zeolitic in some transitional areas (H-5 and H-6), and zeolitized in the other boreholes for which data are available. In general, the zeolitization of the overlying bedded tuffs (sequence 10) is an indication of zeolitization in sequence 9, although the data from SD-6 indicate that the extensive formation of smectite (14–17 percent) in sequence 10 is not associated with any alteration in sequence 9. In some instances, the depth assignments from the Geologic Framework Model version 3.1 placed samples that were zeolitized or glassy and representative of sequence 9 (p#1 at an elevation of 2,184.7 ft [665.9 m] above msl and H-5 at 2,855.9 ft [870.5 m] above msl) into underlying devitrified sequence 8. In these cases, the samples were reassigned to sequence 9 in the mineralogic model.

E2.15 SEQUENCE 8: CENTRAL CRYSTALLINE (NONZEOLITIC) ZONES OF PROW PASS TUFF (Tcpu– Tcplc)

The devitrified central crystalline portions of the Prow Pass Tuff contain feldspar, cristobalite, and quartz across most of Yucca Mountain. Tridymite also occurs in boreholes to the south (G-3, H-3, and SD-7), where the Prow Pass Tuff is well above the water table. Sequence 8 is generally distinguished from the overlying and underlying sequences by the absence of any glass or zeolites, although minimal zeolitization (8 percent) may occur in the uppermost part of sequence 8 (UZ#16) or dispersed throughout (1 to 2 percent at H-3, p#1, and WT-2). The latter effect may be a product of sample impurity where cuttings were analyzed. In some instances, the depth

assignments from the Geologic Framework Model version 3.1 placed samples (a#1 at an elevation of 1,883.8 ft [574.2 m] above msl and H-5 at 2,706 ft [824.8 m] above msl) that were devitrified (zeolite-free) and representative of sequence 8 into sequence 7 (zeolitic). In these cases, the samples were reassigned to sequence 8 in the mineralogic model.

E2.16 SEQUENCE 7: LOWER NONWELDED PROW PASS TUFF TO UPPER NONWELDED BULLFROG TUFF (Tcplv–Tcbuv)

Sequence 7 is fully zeolitized in all boreholes except at the very top of the sequence in a#1 and G-3. In G-3 the remnant glass at the top of sequence 7 occurs well above the water table; in a#1 the remnant glass at the top of this sequence occurs below the water table. This is a rare instance of glass preservation in the saturated zone. The sorptive zeolites in sequence 7 are partially supplanted by analcime only in G-2. In some instances, the depth assignments from the Geologic Framework Model version 3.1 placed samples that were zeolitized and representative of sequence 7 into devitrified sequence 8 (SD-7 at an elevation of 2,604 ft [793.7 m] above msl and SD-9 at 2,258 ft [688.4 m] above msl). In these cases, the samples were reassigned to sequence 7 in the mineralogic model. In SD-7, two devitrified samples representative of sequence 6 (see below) were assigned by the Geologic Framework Model version 3.1 to sequence 7 (two samples from SD-7 at 2,292 ft [698.6 m] above msl); these samples were reassigned to sequence 6 in the mineralogic model. In one instance, the depth assignments from the Geologic Framework Model version 3.1 placed a devitrified sample (H-6 at 2,441.6 ft [744.2 m] above msl) into sequence 7. Because this sequence should contain only zeolitic or glassy samples, this sample was excluded from the mineralogic model.

E2.17 SEQUENCE 6: CENTRAL CRYSTALLINE (NONZEOLITIC) ZONES OF BULLFROG TUFF (Tcbuc–Tcblc)

The devitrified central crystalline portions of the Prow Pass Tuff contain abundant feldspar and quartz. Cristobalite occurs with quartz in G-1, G-2, G-3, G-4, H-6, SD-7, and WT-2. Tridymite occurs only at the top of sequence 6 in G-3 and at more than one depth in SD-6, in both instances well above the water table. Zeolites are absent. In some instances, the depth assignments from the Geologic Framework Model version 3.1 placed in sequence 7 samples that were devitrified, contained no zeolites, and were representative of sequence 6 (SD-12 at an elevation of 2,193.9 ft [668.7 m] and 2,179.4 ft [664.3 m] above msl; and WT-2 at 2,217.8, 2,214.2, and 2,208.6 ft [676.0, 674.9, and 673.2 m] above msl). These samples were reassigned to sequence 6 in the mineralogic model.

E2.18 SEQUENCE 5: LOWER NONWELDED BULLFROG TUFF TO UPPER NONWELDED TRAM TUFF (Tcblv–Tctuv)

Sequence 5 is completely zeolitized in all boreholes. The sorptive zeolites, however, are partially supplanted by analcime in G-2 and p#1. In some instances, the depth assignments from the Geologic Framework Model version 3.1 placed zeolitic or smectite-rich samples that are typical of sequence 5 (G-2 at an elevation of 1,643 ft [500.8 m] above msl; and G-3 at 2,307.4 ft [703.3 m] above msl) into the adjacent devitrified sequence (sequence 6). In such cases, the samples were reassigned to sequence 5 in the mineralogic model. In another instance, the depth assignments from the Geologic Framework Model version 3.1 placed samples that were

zeolitized and representative of sequence 5 into the underlying devitrified sequence 4 (SD-7 at 1,850.4, 1,822.2, and 1,797.2 ft [564.0, 555.4, and 547.8 m] above msl). In these cases, the samples were also reassigned to sequence 5.

E2.19 SEQUENCE 4: CENTRAL CRYSTALLINE (NONZEOLITIC) ZONES OF TRAM TUFF (Tctuc–Tctlc)

The devitrified central crystalline portions of the Tram Tuff contain abundant feldspar and quartz. Minor amounts of cristobalite occur in G-1; major amounts of cristobalite occur in G-3 and H-6; and zeolites occur along with the devitrification products in G-3.

E2.20 SEQUENCE 3: LOWER NONWELDED TRAM TUFF AND UNDERLYING BEDDED TUFF (Tctlv–Tctbt)

Sequence 3 was sampled in G-3, H-6, and p#1 (smectite + sorptive zeolite alteration), in G-1 (smectite + sorptive zeolite + analcime alteration), and in b#1 and G-2 (smectite + analcime alteration). The clays represented by smectite + illite included a significant illite component in many of these occurrences.

E2.21 SEQUENCE 2: UNDIFFERENTIATED LAVAS, FLOW BRECCIAS, BEDDED TUFFS, LITHIC RIDGE TUFF, SEDIMENTS, AND TUFF OF YUCCA FLAT (Tund)

Sequence 2 incorporates a highly varied sequence of lithologies. Sorptive zeolites occur in some portions of this sequence; however, they are largely supplanted by analcime and authigenic albite (authigenic albite is included among the other feldspars in the mineralogic model).

E2.22 SEQUENCE 1: PALEOZOIC ROCKS

Paleozoic rocks were sampled only in p#1. These rocks contain no zeolites but do contain significant amounts of clay. Although the calcite abundances are low (3–4 percent), these rocks are rich in carbonates and contain up to 93 percent dolomite. The mineralogy of the Paleozoic sequence was not modeled in the mineralogic model.

Table E-1. Adjustments to Borehole Sample Elevations

Borehole	Original Elevation (meters above msl)	Modified Elevation (meters above msl)	Explanation	
a#1	1142.3	1147.0	Too close to boundary	
	1114.9	1116.0	Too close to boundary	
	860.4	854.0	Too close to boundary	
	809.5	806.0	Too close to boundary	
	785.4	783.0	Too close to boundary	
	778.1	773.0	Too close to boundary	
	643.3	637.0	Too close to boundary	
	634.8	621.0	Too close to boundary	
	574.2	Unchanged	Assigned to sequence 7 by GFM3.1	MM assigned to sequence 8
	479.7	474.0	Too close to boundary	
b#1	439.7	Unchanged	Basal duplicate	
	170.0	172.4	Too close to boundary	
	-7.2	-13.0	Too close to boundary	
G-1	-14.8	Unchanged	Basal duplicate	
	933.8	932.0	Assigned to sequence 14 by GFM3.1	MM assigned to sequence 13, Magic Zone
G-2	-496.7	Unchanged	Basal duplicate	
	1318.9	1317.0	Assigned to unit 19 by GFM3.1	MM assigned to sequence 18
	1055.6	1048.0	Assigned to sequence 14 by GFM3.1	MM assigned to sequence 13, Magic Zone
	500.8	490.0	Assigned to sequence 6 by GFM3.1	MM assigned to sequence 5
	-14.3	Removed	Spherulite sample not included	
G-3	-272.8	Unchanged	Basal duplicate	
	1420.3	Removed	Vein sample	
	1349.3	1347.0	Too close to boundary	
	1348.9	1346.0	Too close to boundary	
	1117.5	Unchanged	Assigned to sequence 13 by GFM3.1	MM assigned to sequence 14
	1048.7	1047.0	Too close to boundary	
	1019.6	1018.0	Too close to boundary	
	992.9	Unchanged	Assigned to sequence 10 by GFM3.1	MM assigned to sequence 9
	703.3	700.0	Assigned to sequence 6 by GFM3.1	MM assigned to sequence 5
G-4	-48.2	Unchanged	Basal duplicate	
	869.3	866.5	Assigned to sequence 14 by GFM3.1	MM assigned to sequence 13, Magic Zone
	452.6	448.0	Too close to boundary	
	404.2	400.0	Too close to boundary	
H-3	355.4	Unchanged	Basal duplicate	
	Addition	1054.0	Synthetic sample added to provide mineralogy for sequence 11	Sample mineralogy the same as average values for sequence 11 in G-3
	724.2	Unchanged	Basal duplicate	

Table E-1. Adjustments to Borehole Sample Elevations (Continued)

Borehole	Original Elevation (meters above msl)	Modified Elevation (meters above msl)	Explanation	
H-4	759.3	770.0	Too close to boundary	
	743.8	741.0	Assigned to sequence 9 by GFM3.1	MM assigned to sequence 8
	643.5	Unchanged	Basal duplicate	
H-5	1350.6	1353.0	Too close to boundary	
	870.5	879.2	Assigned to sequence 8 by GFM3.1	MM assigned to sequence 9
	824.8	830.0	Assigned to sequence 7 by GFM3.1	MM assigned to sequence 8
	788.2	Unchanged	Basal duplicate	
H-6	744.2	Removed	Sample mineralogy indicates problems with sample location	
	141.7	Unchanged	Basal duplicate	
NRG-6	1105.4	1110.0	Too close to boundary	
	912.1	Unchanged	Basal duplicate	
NRG-7a	1260.5	Removed	Sequence 21 does not exist in MM at this location	
	1191.6	1192.0	Too close to boundary	
	901.3	Combined	Sample at 864.0	
	894.0	Combined	Sample at 864.0	
	887.6	Combined	Sample at 864.0	
	880.3	Combined	Sample at 864.0	
	873.8	Combined	Sample at 864.0	
	867.8	Combined	Sample at 864.0	
	864.6	Combined	Sample at 864.0	
	861.6	Combined	Sample at 864.0	
	857.9	Combined	Sample at 864.0	
	854.9	Combined	Sample at 864.0	
	852.7	Combined	Sample at 864.0	
	Addition	864.0	Average of 11 samples from 901.3 to 852.7	
	852.7	851.0	Assigned to sequence 14 by GFM3.1	MM assigned to sequence 13, Magic Zone
	821.0	Unchanged	Basal duplicate	
p#1	734.5	730.0	Too close to boundary	
	665.9	668.0	Assigned to sequence 8 by GFM3.1	MM assigned to sequence 9
	-128.1	Unchanged	Basal duplicate	
	-131.1	Removed	Sample of Paleozoic	Not modeled in MM
	-158.5	Removed	Sample of Paleozoic	Not modeled in MM
	-201.5	Removed	Sample of Paleozoic	Not modeled in MM
SD-6	1369.1	1368.2	Too close to boundary	
	1369.0	1368.1	Too close to boundary	
	1365.2	1363.7	Too close to boundary	
	1364.4	1363.6	Too close to boundary	
	1364.1	1363.5	Too close to boundary	
	1337.5	1335.0	Assigned to sequence 20 by GFM3.1	MM assigned to sequence 18
	1054.2	1055.5	Too close to boundary	
	1054.0	1055.4	Too close to boundary	

Table E-1. Adjustments to Borehole Sample Elevations (Continued)

Borehole	Original Elevation (meters above msl)	Modified Elevation (meters above msl)	Explanation	
	1033.9	1035.0	Too close to boundary	
	1020.5	1022.0	Too close to boundary	
	974.6	985.0	Too close to boundary	
	973.6	984.0	Too close to boundary	
	966.3	969.0	Too close to boundary	
	844.0	Unchanged	Basal duplicate	
SD-7	1245.8	1248.0	Too close to boundary	
	1002.8	1003.4	Too close to boundary	
	885.4, #1	886.5	Too close to boundary	Sample #1 at this elevation adjusted
	885.4, #2	Removed	Second sample at this depth removed	Fracture sample
	793.7	788.0	Assigned to sequence 8 by GFM3.1	MM assigned to sequence 7
	698.6, both samples	693.0	Assigned to sequence 7 by GFM3.1	MM assigned to sequence 6
	564.0	570.0	Assigned to sequence 4 by GFM3.1	MM assigned to sequence 5
	555.4	569.5	Assigned to sequence 4 by GFM3.1	MM assigned to sequence 5
SD-9	547.8	569.0	Assigned to sequence 4 by GFM3.1; also basal duplicate	MM assigned to sequence 5
	1286.1	Removed	Breccia sample removed from MM	
	1283.4	Removed	Sequence 21 not present in MM	
	1281.0	Removed	Sequence 21 not present in MM	
	1219.6	1218.2	Assigned to sequence 19 by GFM3.1	MM assigned to sequence 18
	886.8	890.0	Assigned to sequence 13 by GFM3.1	MM assigned to sequence 14
	688.4	685.0	Assigned to sequence 8 by GFM3.1	MM assigned to sequence 7
SD-12	625.3	Unchanged	Basal duplicate	
	1222.8	1224.0	Assigned to sequence 18 by GFM3.1	MM assigned to sequence 19
	893.7, two samples	894.4	Too close to boundary	
	835.9, #1	837.0	Assigned to sequence 10 by GFM3.1	Two samples at 835.9 span sequence 11 and sequence 10 contact; MM assigned top sample to sequence 11
	668.7	652.0	Assigned to sequence 7 by GFM3.1	MM assigned to sequence 6
	664.3	651.0	Assigned to sequence 7 by GFM3.1 and basal duplicate	MM assigned to sequence 6
UZ-14	1344.4	Removed	Sequence 22 not present in MM	
	1338.9	Removed	Sequence 22 not present in MM	

Table E-1. Adjustments to Borehole Sample Elevations (Continued)

Borehole	Original Elevation (meters above msl)	Modified Elevation (meters above msl)	Explanation	
	1263.8	1268.0	Too close to boundary	
	1263.1	1267.0	Too close to boundary	
	1262.5	1264.0	Too close to boundary	
	1206.8	1212.0	Too close to boundary	
	996.6	978.6	Too close to boundary	
	990.3	978.4	Too close to boundary	
	984.4	978.2	Too close to boundary	
	959.3	955.0	Assigned to sequence 14 by GFM3.1	MM assigned to sequence 13, Magic Zone
	929.5	930.1	Too close to boundary	
	917.4	922.2	Too close to boundary	
	916.6	922.0	Too close to boundary and Basal duplicate	
UZ#16	1147.2	1145.0	Assigned to sequence 19 by GFM3.1	MM assigned to sequence 18
	1106.1	1102.0	Too close to boundary	
	834.7, #2	Removed	Lithic fragment not included in MM	
	762.2	760.0	Too close to boundary	
	705.8	Unchanged	Basal duplicate	
UZN-31	1239.3	1266.0	Too close to boundary	
	1238.6	1247.4	Too close to boundary	
	1237.9	1247.4	Too close to boundary	
	1237.1	1247.3	Too close to boundary	
	1236.2	1247.1	Too close to boundary	
	1235.5	1246.8	Too close to boundary	
	1234.7	1241.6	Too close to boundary	
	1217.2	1217.9	Too close to boundary	
	1216.4	1217.9	Too close to boundary	
	1215.7	1217.9	Too close to boundary	
	1214.8	1217.9	Too close to boundary	
	1214.2	1217.9	Too close to boundary	
	1213.4	1217.9	Too close to boundary	
	1212.7	1217.9	Too close to boundary	
	1211.9	1217.9	Too close to boundary	
	1211.2	1217.9	Too close to boundary	
	1210.7	1217.9	Too close to boundary	
	1209.8	1217.3	Too close to boundary	
	1209.2	1217.2	Too close to boundary	
	1208.6	Unchanged	Basal duplicate	
UZN-32	1236.9	1247.2	Too close to boundary	
	1236.1	1247.0	Too close to boundary	
	1235.6	1246.9	Too close to boundary	
	1234.9	1246.8	Too close to boundary	
	1234.2	1246.5	Too close to boundary	
	1217.2	1217.9	Too close to boundary	
	1216.4	1217.9	Too close to boundary	
	1215.7	1217.9	Too close to boundary	
	1214.9	1217.9	Too close to boundary	
	1214.2	1217.9	Too close to boundary	
	1213.4	1217.9	Too close to boundary	

Table E-1. Adjustments to Borehole Sample Elevations (Continued)

Borehole	Original Elevation (meters above msl)	Modified Elevation (meters above msl)	Explanation	
	1212.8	1217.9	Too close to boundary	
	1211.9	1217.9	Too close to boundary	
	1211.1	1217.9	Too close to boundary	
	1210.4	1217.9	Too close to boundary	
	1209.5	1217.9	Too close to boundary	
	1208.8	1217.9	Too close to boundary	
	1208.0	1217.9	Too close to boundary	
	1207.3	1217.9	Too close to boundary	
	1206.5	1217.9	Too close to boundary	
	1205.7	1217.1	Too close to boundary	
WT-1	803.2	Removed	Sequence 13 not present in MM	
	797.1	Removed	Sequence 13 not present in MM	
	791.0	Removed	Sequence 13 not present in MM	
	751.4	767.0	Too close to boundary	
	739.2	766.0	Too close to boundary	Sequence 10 not present in MM
	727.0	765.0	Too close to boundary and basal duplicate	
	720.9	Removed		
WT-2	676.0	645.0	Assigned to sequence 7 by GFM3.1	MM assigned to sequence 6
	674.9	644.0	Assigned to sequence 7 by GFM3.1	MM assigned to sequence 6
	673.2	643.0	Assigned to sequence 7 by GFM3.1 and basal duplicate	MM assigned to sequence 6
WT-24	735.0	Unchanged	Assigned to sequence 11 in GFM3.1	MM assigned to sequence 10

Table E-1. Adjustments to Borehole Sample Elevations (Continued)

Borehole	Original Elevation (meters above msl)	Modified Elevation (meters above msl)	Explanation	
	730.2	Unchanged	Assigned to sequence 11 in GFM3.1	MM assigned to sequence 10
	726.5	Unchanged	Assigned to sequence 11 in GFM3.1	MM assigned to sequence 10
	725.5	Unchanged	Assigned to sequence 11 in GFM3.1	MM assigned to sequence 10
	724.7	Unchanged	Assigned to sequence 11 in GFM3.1 and basal duplicate	MM assigned to sequence 10

NOTES: UZN-31 and UZN-32 were combined into a single borehole in the MM. The assignment of identical elevations to multiple samples (e.g., UZN-31 and UZN-32) causes no problems for the STRATAMODEL calculation of mineral abundances. There are several occurrences of two analyzed samples with the same elevation; they are referred to as #1 and #2, according to the order in which they are presented in the table.

Addition = A sample at H-3 in the Tac was added, with mineralogy derived from the results of Tac in G-3. A sample at NRG-7a in Tptpln was added; it was derived from the average of 11 samples within Tptpln in NRG-7a.

Assigned to sequence = Sample elevation adjusted (or in some cases not adjusted) to assign sample to a different mineralogic-stratigraphic sequence on the basis of sample mineralogy.

Basal duplicate = The basal sample in all boreholes is duplicated per STRATAMODEL requirements.

Combined = Eleven samples in NRG-7a, all from Tptpln, were averaged as a single sample located at 864.0 meters within Tptpln.

GFM = geologic framework model

Magic Zone = Refers to highly altered, smectite-rich samples occurring near the contact of Tptpln and Tptpv3. Such samples were assigned to the Tptpv3 sequence in the MM.

MM = mineralogic model

msl = mean sea level

Removed = Some samples of fracture minerals, lithic fragments, etc. that are included in the technical database were not included in the MM.

Too close to boundary = Sample elevation adjusted to keep samples in the correct mineralogic-stratigraphic sequence.

Sequence x not present in MM = In some places, a stratigraphic sequence pinches out in the vicinity of a borehole and is not present in the MM.