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Yucca Mountain Site Characterization Project

Geology of the USW SD-9 Drill Hole, Yucca Mountain, Nevada

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Abstract

Drill hole USW SD-9 is one of several holes drilled under Site Characterization Plan Study 8.3.1.4.3.1, also known as the "Systematic Drilling Program," as part of the U.S. Department of Energy characterization program at Yucca Mountain, Nevada, which has been proposed as the potential location of a repository for high-level nuclear waste. The SD-9 drill hole is located in the northern part of the potential repository area, immediately to the west of the Main Test Level drift of Exploratory Studies Facility and south of the North Ramp decline. Drill hole USW SD-9 is 2223.1 ft (677.57 m) deep, and the core recovered essentially complete sections of ash-flow tuffs belonging to the Yucca Mountain, Pah Canyon, and Topopah Spring Tuffs of the Miocene Paintbrush Group. The hole cored the entire Calico Hills Formation, which underlies the Paintbrush Group, and all but the lowermost part of the Prow Pass Tuff of the Crater Flat Group.

The drill hole was collared low in the welded portion of the Tiva Canyon Tuff; only 38.7 (11.8 m) of this formation was recovered. The Yucca Mountain Tuff is approximately 45-ft (13.7-m) thick, and the interior portion of this ash flow is partially welded. The Yucca Mountain Tuff thins to extinction southward. The Pah Canyon Tuff is 69.4 ft (21.15 m) thick and is completely nonwelded in this drill hole. The Topopah Spring Tuff consists of 1211.5 ft (369.25 m) of generally densely welded material; this is one of the thickest known sections of welded Topopah Spring Tuff at or near Yucca Mountain. Lithophysae are well developed locally within the parts of the Topopah Spring, and large lithophysal cavities up to several feet (many tenths of a meter) in diameter are present throughout roughly the lower two-thirds of the unit. This somewhat anomalous occurrence of very large lithophysal cavities, which is in addition to the better known presence of zones containing smaller, inch-scale (cm-scale) lithophysae within the Topopah Spring, may be related genetically to the greater thickness of the unit at this geographic location. The Calico Hills Formation in drill hole SD-9 consists of 341 ft (103.87 m) of nonwelded and mostly zeolitized tuffaceous materials. The hole cored 402.4 ft (122.65 m) of rocks belonging to the ash-flow sequences of the Prow Pass Tuff. The drill hole was stopped short of the base of the lowermost known ash-flow unit of the Prow Pass.

Quantitative and semiquantitative data are included in this report for core recovery, rock-quality designation (RQD), lithophysal cavity abundance, and fracturing. These data are spatially variable, both

within and among the major formational-level stratigraphic units. Nonwelded intervals in general exhibit higher recoveries and more intact (higher) RQD values than welded intervals. The most intact, highest-RQD materials encountered within the Topopah Spring belong to the lower 33.3 ft (10.15 m) of the middle nonlithophysal zone. Estimation of lithophysal cavity abundances is complicated by the existence of cavities much larger than the core diameter; drilling through intervals of these large cavities produced extensive zones of “lost” core and rubble.

This report includes quantitative data for the framework material properties of porosity, bulk and particle density, and saturated hydraulic conductivity. Graphical analysis of variations in these laboratory hydrologic properties indicates first-order control of material properties by the degree of welding and the presence of zeolite minerals. Many major lithostratigraphic contacts are not well expressed in the material-property profiles; contacts of material-property units are related more to changes in the intensity of welding. Approximate in-situ saturation data of samples preserved immediately upon recovery from the hole are included in the data tabulation.

Geophysical data have been obtained for the upper approximately 1500 ft (450 m) of the USW SD-9 drill hole; the lower part of the hole below the Topopah Spring Tuff has not been logged. Geophysical logs include density, gamma-ray, epithermal-neutron porosity, electrical-resistivity, and caliper profiles down to the base of the Topopah Spring Tuff. The bulk-density log provides the most lithologic information, and many of the lithologic subdivisions of the Paintbrush Group tuffs can be tied to distinctive changes in the density trace. Discrimination of welded from nonwelded rock types and of lithophysal zones and nonlithophysal zones is immediately apparent in the density log. Material-property units identified using geophysical logs do not correspond in detail to the broader, genetic lithostratigraphic unit boundaries.

Acknowledgments

This work was performed for the U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Site Characterization Project Office under contract EA9012M5X. Scientific investigations involving the Systematic Drilling Program are conducted under the descriptions of work contained in the Site Characterization Plan (DOE, 1988) and in Study Plan 8.3.1.4.3.1 (Rautman, 1993); the work-breakdown structure element is 1.2.3.2.2.2.1. The planning document that directed this work activity is WA-0301; prior to the effective date of WA-0301, work activities for this WBS element were conducted under WA-0014. The information and data documented in this report was conducted under a fully qualified quality assurance program. Full details associated with all reported data may be located in the Yucca Mountain Site Characterization Project records using the data-tracking numbers (DTNs) provided in the relevant sections of this report.

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Introduction

The U.S. Department of Energy is evaluating a site at Yucca Mountain, located in southern Nye County, Nevada, as the potential location for an underground high-level nuclear waste repository (fig. 1). This report contains results of geologic logging and lithologic description of core from drill hole USW SD-9, which is one of a number of holes being drilled at the Yucca Mountain site to characterize the subsurface geology of the proposed repository block. A suite of framework bulk and hydrologic properties are also reported in the context of the geologic description. These activities have been conducted under Site Characterization Plan (SCP; DOE, 1988) Study 8.3.1.4.3.1, “Systematic Acquisition of Site-Specific Subsurface Information,” which is commonly referred to as the Systematic Drilling Program.

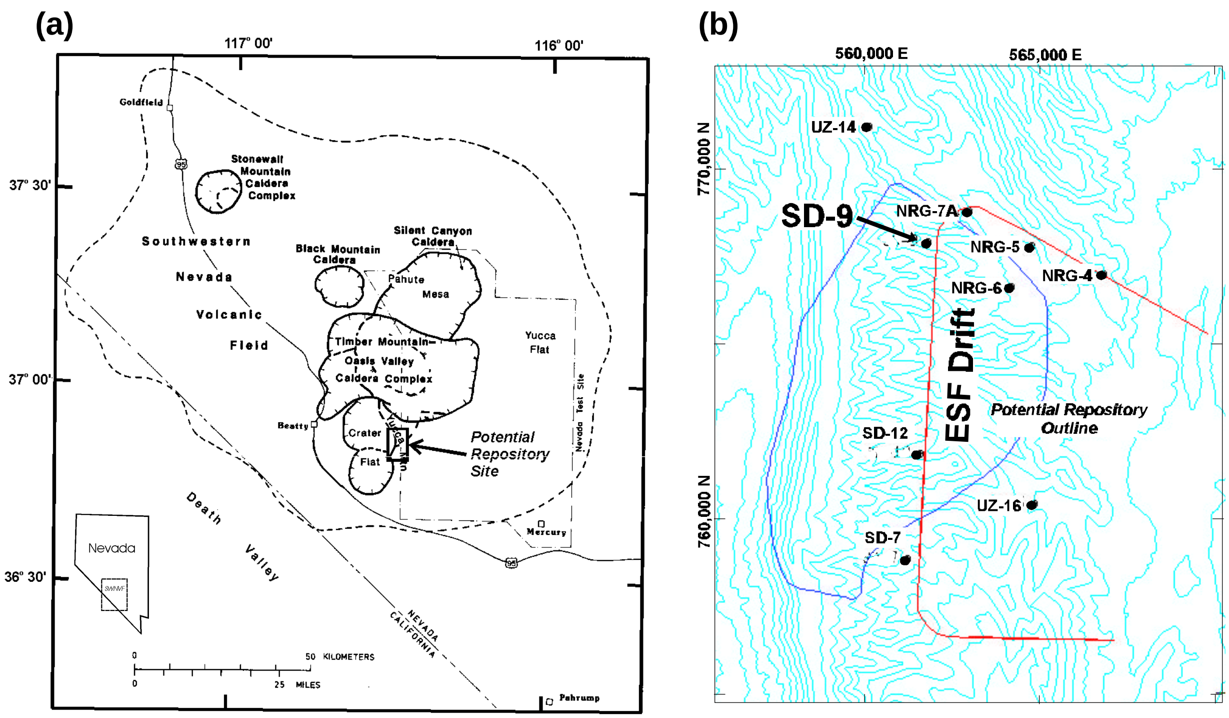

Figure 1. (a) Index map showing location of the potential Yucca Mountain repository site in southern Nevada in relationship to the southwestern Nevada volcanic field (after Byers and others, 1989). (b) Expanded map of the Yucca Mountain site showing location of drill hole USW SD-9 and selected other holes (Nevada State Plane coordinates in fe

Purpose of the Systematic Drilling Program

The Systematic Drilling Program (Rautman, 1993) was proposed to provide repository-design-critical information in a systematic sampling pattern (fig. 2) within the conceptual perimeter-drift boundary from the volume of rock to be occupied by the potential Yucca Mountain repository. The drilling program is to provide descriptions and samples of the repository host rock and of rocks both above and below the repository horizon along the postulated flow path(s) of deep, unsaturated-zone ground-water percolation. The Systematic

Drilling Program will also provide descriptive information and samples of rocks within the upper portion of the saturated zone, which include zeolitically altered materials that may act to retard radionuclides migrating away from a constructed repository.

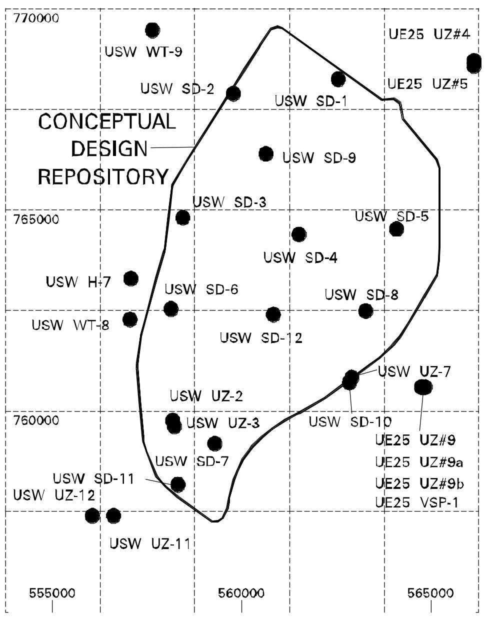

Figure 2. Gridded drilling pattern for the Systematic Drilling Pattern as proposed in Study Plan 8.3.1.4.3.1 (Rautman, 1993).

In addition to descriptive geologic information, core samples provide the raw material for quantitative measurements of thermal, mechanical, hydrologic, and geochemical material properties necessary for numerical modeling and regulatory evaluation of the waste-isolation performance of a potential nuclear-waste repository at Yucca Mountain. A basic set of framework material properties from USW SD-9 is included as part of this report. Other site-characterization studies (DOE, 1988) are also testing samples obtained from the USW SD-9 drill hole. Pore waters extracted from appropriately preserved core specimens and drill cuttings can provide isotopic evidence relevant to the age or residence time and source of the ground water, including data on the infiltration of water containing bomb-pulse isotopes from past atmospheric testing of nuclear weapons. The drill holes themselves provide access to the interior of Yucca Mountain for geophysical logging, down-hole video examination of the borehole walls, air-permeability testing, water-table monitoring and geochemical sampling, and in-situ instrumentation for monitoring temperatures, gas pressures, and changes in gas chemistry with time.

Regional Geologic Setting

Yucca Mountain is located within the southern portion of the southwestern Nevada volcanic field (Christiansen and others, 1965 and 1977; Byers and others, 1976, 1989). The southwestern Nevada volcanic field (fig. 1) comprises a thick sequence of widely distributed, 7- to 15-million-year-old silicic volcanic rocks, centered around the Timber Mountain, Oasis Valley, and Silent Canyon caldera complexes (Noble and others, 1968).

Yucca Mountain itself consists of a series of north-trending, eastward-dipping structural blocks that are bounded by mostly west-dipping normal faults (W.J. Carr and others, 1986). These fault blocks are composed principally of thick, welded ash-flow tuff deposits that are separated by thinner, nonwelded ash-flow tuffs, silicic lavas, and tuffaceous sedimentary units, all derived from a caldera complex to the north. Previous drilling at Yucca Mountain has shown that Tertiary volcanic rocks are in excess of 6000 ft (1829 m) thick in the vicinity of the potential repository (M.D. Carr and others, 1986). Pre-Tertiary rocks underlying Yucca Mountain include thick carbonate and clastic assemblages varying in age from Precambrian to Mississippian. A Mesozoic or Tertiary pluton may lie beneath the Calico Hills to the northeast of the site (Carr, 1984).

Volcanic Stratigraphy

Yucca Mountain consists of a thick sequence of variably welded and nonwelded ash-flow tuffs intercalated with thinner intervals of bedded (reworked) and air-fall tuffs. The general sequence of stratigraphic units is illustrated in table 1. Surface exposures within the main repository block are formed by the several formations of the Miocene Paintbrush Group. In descending sequence, these are the Tiva Canyon, the Yucca Mountain, Pah Canyon, and Topopah Spring Tuffs (Sawyer and others, 1994). The Tiva Canyon and

Topopah Spring Tuffs are regionally extensive and generally densely welded. The Yucca Mountain and Pah Canyon Tuffs are generally nonwelded to only moderately welded and they are much less extensive laterally, thinning to extinction toward the south. Each formation-level unit of the Paintbrush Group is separated from its neighbors by thin nonwelded ash-flow tuffs, air-fall tuffs or pumice-fall units, and reworked, bedded-tuffaceous deposits. These intervening tuffaceous materials are typically referred to collectively as "bedded tuff" without specific consideration of their actual lithologic character.

The Paintbrush Group in the general vicinity of the proposed repository typically is underlain by a heterogeneous sequence of rhyolitic rocks known as the Calico Hills Formation (Sawyer and others, 1994). Within the repository region itself, the Calico Hills consists of a downward sequence of five nonwelded ash-flow tuffs underlain by bedded-tuff unit and a basal tuffaceous sandstone unit (table 1) (Moyer and Geslin, 1995). Elsewhere in the Yucca Mountain region, the Calico Hills Formation consists of rhyolitic lava flows, ash-flow tuffs, air-fall tuffs, and tuffaceous sediments. Much of the Calico Hills Formation has been zeolitized; vitric tuffs are preserved principally in the southern portion of the Yucca Mountain site.

The Calico Hills Formation is underlain by the Crater Flat Group (Sawyer and others, 1994; Moyer and Geslin, 1995), which comprises, in descending sequence, the Prow Pass, Bullfrog, and Tram Tuffs. Each of these units represents a large-volume ash-flow eruption. Generally, the degree of welding in these units is much less than that exhibited by the tuffs of the Paintbrush Group, and the welded intervals may not be continuous in the subsurface. The greater part of each ash-flow sequence is nonwelded, with welded tuffs constrained to the interior of each unit. The three formation-level units are separated from one another by thin intervals of nonwelded tuff and tuffaceous sediments ("bedded tuff") in a manner similar to that of the Paintbrush Group.

Volcanic units underlying the Crater Flat Group are somewhat poorly known by comparison. They have been encountered at Yucca Mountain only in the deeper drill holes (for example: Spengler and others, 1981; Maldonado and Koether, 1983; Scott and Castellanos, 1984; Whitfield and others, 1984). None of these units was encountered in drill hole USW SD-9.

Petrogenesis and Zonation of Paintbrush Group Tuffs

Early field and petrologic descriptions of the stratigraphic units in the southwestern Nevada volcanic field include work by Lipman and Christiansen (1964) and Lipman and others (1966). In later work more directly focused on the potential Yucca Mountain repository site, the thick, welded intervals of the Tiva Canyon and Topopah Spring Tuffs were subdivided in geologic mapping by Scott and Bonk (1984) into a large number of informally named zones (table 1). This early zonation was based on a number of different characteristics, including weathering character and color, in addition to more exposure-independent lithologic characteristics such as phenocryst content, alteration phenomena, and rock type.

More recently, Buesch and others (1996) have redefined the zonation of the Paintbrush Group tuffs. These changes affect principally the thick, welded intervals of the Tiva Canyon and Topopah Spring Tuffs. According to Buesch and others, these two major ash-flow sheets are divided informally into crystal-rich upper members and crystal-poor lower members (table 2). This fundamental change in phenocryst content, which is paralleled by a downward change in chemical composition from quartz latite to rhyolite, originates in the eruption of these ash-flow sequences from a compositionally zoned magma chamber underlying the source calderas (Lipman and others, 1966). More differentiated, rhyolitic magma in the upper portions of the magma chamber erupted first, followed by less-differentiated magmatic material from lower levels as the eruption progressed. A gradational, compositional-transition zone is observed in both the Tiva Canyon and the Topopah Spring Tuffs, which exhibits attributes of both rock types.

Buesch and others further subdivide the crystal-rich and crystal poor members into a number of informal smaller zones and subzones (tables 1, 2). Some of these zones are based on widespread petrogenetic phenomena, principally cooling pro-

Table 1: Comparison of several stratigraphic subdivisions of volcanic rocks at Yucca Mountain and encountered on the Yucca Mountain Site Characterization Project. (no scale)

Geologic Unit (from Sawyer and others, 1994)		Older hydrologic zonation (modified after Scott and Bonk, 1984)			Zonation of Buesch and others (1996)	Thermal/mechanical unit (Ortiz and others, 1985)
Paintbrush Group	Tiva Canyon Tuff	Paintbrush Tuff	Tiva Canyon Member	ccr - caprock	Tpcrv	TCw
				cuc - upper cliff	Tpcrn	
				cul - upper lithophysal	Tpcrl	
					Tpcpul	
				cks - clinkstone	Tpcpmn	
				cll - lower lithophysal	Tpcpll	
				ch - hackly	Tpcplnh	
				cc - columnar	Tpcplnc	
					Tpcpv3	PTn
				ccs - shardy base	Tpcpv2	
					Tpcpv1	
	Yucca Mtn. Tuff		Yucca Mtn. Mbr.			
	Pah Cyn. Tuff		Pah Cyn. Mbr.			
	Topopah Spring Tuff		Topopah Spring Member	upper nonwelded	Tptrv3	
					Tptrv2	
				tc - caprock	Tptrv1	TSw1
				tr - rounded	Tptrn	
				tul - upper lithophysal	Tptrl	
					Tptpul	
				tn - nonlithophysal	Tptpmn	TSw2
				tll - lower lithophysal	Tptpll	
				tm - mottled	Tptpln	
				tv - basal vitrophyre	Tptpv3	TSw3
				nonwelded base	Tptpv2	CHn1
					Tptpv1	
Calico Hills Formation		Tuffaceous Beds of Calico Hills		(not subdivided)	Unit 5 Unit 4 Unit 3 Unit 2 Unit 1	
					bedded tuff unit basal sandstone unit	CHn2
Crater Flat Group	Prow Pass Tuff	Crater Flat Tuff	Prow Pass Member	Not subdivided	Unit 4	CHn3
					Unit 3	PPw
					Unit 2 Unit 1	CFUn
	"bedded tuff"		"bedded tuff"		bedded tuff unit	
	Bullfrog Tuff		Bullfrog Member		Not subdivided (?)	BFw
						CFMn1
	"bedded tuff"		"bedded tuff"			CFMn2
						CFMn3
	Tram Tuff		Tram Member			TRw
						Not Recognized

cesses, that affected the ash-flow tuffs during and shortly after deposition. Both the Tiva Canyon and Topopah Spring Tuffs exhibit quenched, non-welded, vitric zones at the upper and lower margins, where the hot mass of glassy pyroclastic shards cooled rapidly from exposure to ambient air or to the relatively cold, preexisting topography. Welded vitric zones, usually expressed as vitrophyres that compacted, fused, and cooled before devitrification could begin, are found inside the nonwelded vitric zones. The vitrophyre zones are thicker and more laterally extensive at the base of each ash-flow sequence because of the weight of the overlying, progressively accumulating tuff deposit. The major part of both the Tiva Canyon and Topopah Spring Tuffs compacted and cooled slowly because of the insulating effect provided by the quenched and largely nonwelded upper and lower margins of the deposits. The interior parts of each ash-flow sheet thus consist of moderately to densely welded, devitrified tuff.

Buesch and others also define other zones and subzones (table 2) that are related more to alteration phenomena. Residual magmatic gasses exsolved from the compacting and devitrifying mass of glassy shards and these gasses produced vapor-phase alteration consisting principally of microcrystalline, open-space growths of high-temperature silica and feldspar minerals. These phases are distinct from the more “primary” assemblages of minerals resulting from devitrification of the originally glassy mass of shards. Locally, the vapor pressure of the exsolving gas was sufficient to inflate secondary “bubbles,” known as lithophysal cavities, along crudely horizontal horizons where internal pressure exceeded the weight of the overlying column of compacting tuff. These lithophysal cavities are themselves rimmed by vapor-phase alteration minerals, and the alteration may extend some distance into the groundmass surrounding the cavity. The resulting, alternating lithophysae-bearing and non-lithophysae-bearing intervals figure prominently into the zonation of Buesch and others (table 2). Additional factors, such as presence and quantity of pumice, foreign lithic clasts, presence of spherulites, and fracturing habit, also have been used to define some of the subzones shown in table 2.

The thin, tabular nature of a cooling and compacting ash-flow sheet forces most of the thermal and pressure gradients that cause alteration to be oriented essentially normal to the long dimensions of the deposit. Thus, the alteration phenomena of vapor-phase altered zones, intervals of lithophysal cavity development, and zones of strong, near-vertical cooling joint development tend to be subhorizontal and stratiform. However, because these features are the result of secondary alteration phenomena, they can—and do—cross-cut “primary” stratification features such as the crystal-rich/crystal-poor transition.

Subdivisions of the Calico Hills Formation and Prow Pass Tuff (Crater Flat Group)

Recent review by Moyer and Geslin (1995) of older samples, data, and published lithologic descriptions has led to a refined subdivision of both the Calico Hills Formation and the Prow Pass Tuff, as these units were redefined by Sawyer and others (1994). The names and sequence of the informal units described by Moyer and Geslin from the Calico Hills Formation and the Prow Pass Tuff are illustrated in table 1.

Moyer and Geslin (1995) indicate that the Calico Hills Formation in the vicinity of Yucca Mountain comprises five pyroclastic units, a dominantly reworked “bedded-tuff” unit, and a basal volcaniclastic sandstone. Some of these units appear regionally discontinuous. The pyroclastic intervals are generally ash-flow tuff deposits separated by locally preserved air-fall tuff horizons; the content and composition of pumice clasts and lithic fragments are locally diagnostic of the different ash-flow groupings. The Calico Hills Formation, in notable contrast to the tuffs of the entire Paintbrush Group, contains volumetrically significant quantities of quartz phenocrysts, whereas the Paintbrush Group Tuffs are virtually quartz-free. There are indications that the basal sandstone may represent material reworked from the Wahmonie Formation, a distinctive, more mafic volcanic assemblage (Sawyer and others, 1994) not generally present in the Yucca Mountain region.

Moyer and Geslin have concluded that the Prow Pass consists of four regionally correlative pyroclastic tuff units plus an underlying interval of

Table 2: Zonation of the Tiva Canyon and Topopah Spring Tuffs According to Buesch and Others (1996) Showing Parallel Subdivisions

[Lithophysal intervals are shaded]

Tiva Canyon Tuff (Tpc)	Topopah Spring Tuff (Tpt)
crystal-rich member (Tpcr)	crystal-rich member (Tptr)
vitric zone (Tpcrv)	vitric zone(Tptrv)
non- to partially welded subzone (Tpcrv3)	non- to partially welded subzone (Tptrv3)
moderately welded subzone (Tpcrv2)	moderately welded subzone (Tptrv2)
vitrophyre subzone (Tpcrv1)	vitrophyre subzone (Tptrv1)
nonlithophysal zone (Tpcrn)	nonlithophysal zone (Tptrn)
subvitrophyre transition subzone (Tpcrn4)	
pumice-poor subzone (Tpcrn3)	
mixed pumice subzone (Tpcrn2)	
crystal transition subzone (Tpcrn1)	crystal transition subzone (Tptrn1)
lithophysal zone	lithophysal zone
crystal transition subzone (Tpcrl1)	crystal transition subzone (Tptrl1)
crystal-poor member	crystal-poor member
upper lithophysal zone	upper lithophysal zone
spherulite-rich subzone (Tpcpul1)	cavernous lithophysae subzone (Tptpul2)
	small lithophysae subzone (Tptpul1)
middle nonlithophysal zone (Tpcpmn)	middle nonlithophysal zone (Tptpmn)
upper subzone (Tpcpmn3)	upper subzone (Tptpmn3)
lithophysae-bearing subzone (Tpcpmn2)	lithophysae-bearing subzone (Tptpmn2)
lower subzone (Tpcpmn1)	lower subzone (Tptpmn1)
lower lithophysal zone (Tpcpll)	lower lithophysal zone (Tptpll)
lower nonlithophysal zone (Tpcpln)	lower nonlithophysal zone (Tptpln)
hackly subzone (Tpcplnh)	
columnar subzone (Tpcplnc)	
spherulitic pumice interval (Tpcplnc3)	
argillic pumice interval (Tpcplnc2)	
vitric pumice interval (Tpcplnc1)	
vitric zone (Tpcpv)	vitric zone (Tptpv)
vitrophyre subzone (Tpcpv3)	vitrophyre subzone (Tptpv3)
moderately welded subzone (Tpcpv2)	moderately welded subzone (Tptpv2)
non-to partially welded subzone (Tpcpv1)	non-to partially welded subzone (Tptpv1)
Pre-Tiva Canyon Tuff bedded tuff (Ppbt2)	**Pre-Topopah Spring Tuff bedded tuff (Tpbt1)**

"bedded tuff." Separation of the different ash flows is based in part on differences in welding and in the proportions and types of phenocrysts, pumices, and lithic fragments. The Prow Pass Tuff is crystal rich in comparison with the volumetrically dominant crystal-poor lower members of the Topopah Spring and Tiva Canyon Tuffs. Also in contrast with the Paintbrush units, the Crater Flat Group tuffs are quartz-bearing.

The USW SD-9 Drill Hole

Location

Drill hole USW SD-9 is located at Nevada state plane coordinates[†] 561,818.0 East, 767,988.5 North [fig 1(b)]. The collar of the hole is at an elevation of 4275 ft (1303.35 m). The hole is located approximately half-way up Wren Wash on the eastern side of Yucca Mountain. The hole is approximately 500 ft (150 m) west of the surface trace of the Ghost Dance Fault as mapped by Scott and Bonk (1984). The hole is also some 250 ft (75 m) to the west of the ESF main test level drift, as that drift was shown on design documents current when the hole was sited (fig. 3).

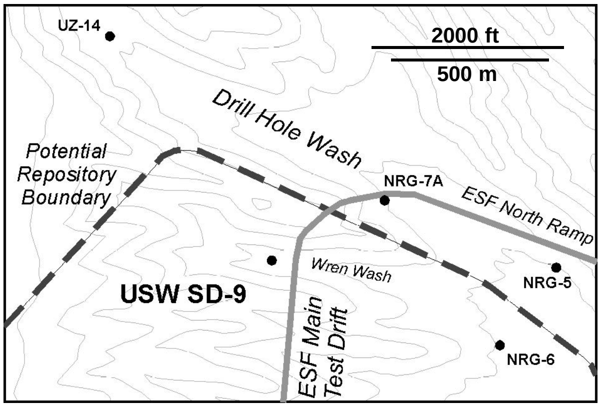

Figure 3. Location map of the potential repository region showing the USW SD-9 drill hole in Wren Wash and in relationship to nearby drill holes and the Exploratory Studies Facility.

Drilling History

Drill hole SD-9 was started on May 6, 1994, when the top of the borehole was augered to a depth of 8.65 ft (2.64 m) to set surface-conductor pipe. Bedrock was encountered at 52.6 ft (16.04 m) on May 25 beneath drill-pad fill and colluvial overburden. Continuous coring operations commenced using PQ-sized tools (yielding 3.35-inch core), and the hole reached a depth of 1000-ft (328 m) during the last core run on June 16. Moist core was noted below a depth of 1308 ft (398.78 m) on June 27, starting just above the basal vitrophyre of the Topopah Spring Tuff (unit Tptpv3, table 1). Perched water began flowing into the borehole at a slow rate at a depth of 1353 ft (412.50 m). The borehole was deepened to 1489.2 ft (454.02 m) and borehole conditions were observed using a downhole video camera. Water samples were collected by several bailer runs for geochemical analysis. Geophysical logs were run from a depth of 1487 ft (453.35 m) to the ground surface using gamma-ray, dual-induction, compensated-density, compensated epithermal-neutron, dielectric-propagation, and oriented-caliper tools.

The SD-9 drill hole was reamed to a diameter of 8-1/2 inches to a depth of 1487.6 ft (453.54 m) between July 26 to August 16, and 7-inch casing was placed in the borehole to prevent further inflows of perched water. Coring resumed on August 29, and the regional water table was encountered at 1877 ft (572.26 m) on September 10. A string of 4.5-inch casing was set to a depth of 1907 ft (581.40 m) to protect the unsaturated zone from contamination, and coring resumed using HX equipment (2.4-inch core). The hole was reached total depth at 2223.1 ft (677.77 m) on September 26, 1994. As of January 1996, no geophysical logs had been obtained from this lower portion of the SD-9 drill hole.

Method of Study

Geologic Logging and Core Description

Geologic logging and description of drill core is principally an interpretive activity. As such, the resulting geologic log is dependent upon the skill and experience of the individual performing the examination. The logging procedure used to describe core from drill hole USW SD-9 and other holes of the Systematic Drilling Program emphasizes physical description in an attempt to eliminate partially dependence on stratigraphic nomenclature that may change over time (compare Scott and Bonk, 1984; Buesch and others, 1996). A standardized geologic log form is used to record observations of lithology, composition, alteration, structure, and similar features, and of changes in those multiple characteristics with depth. The observations are thus effectively independent of the names applied to units of similar or contrasting character.

Interpretative geologic logging and core description consists of observing the rock in its intact, relatively undisturbed state. Core was laid

[†]Note: Nevada State Plane coordinates in feet are widely used on the Yucca Mountain Project. These coordinates are for the central zone of Nevada and are based on a Transverse Mercator projection. The origin of this projection for the central zone of Nevada is latitude 34°45'N., and the central meridian is at longitude 116°40'W. Metric conversions of Nevada State Plane Coordinates are distinctly separate from true metric coordinates obtained using the 10,000 metre Universal Transverse Mercator grid, Zone II.

out in continuous profile on examination tables at the Yucca Mountain Project Sample Management Facility. A graphical geologic log was prepared at a scale of 1:120 (one inch equals 10 feet) after macroscopic visual examination using a hand lens, binocular microscope, videotaped images and photographs of core intervals previously removed for laboratory measurement of selected material properties. The geologic log includes description of:

- contacts between geologic units
- degree of welding
- degree of devitrification
- size, type, and abundance of pumice
- size, type, and abundance of lithic clasts
- size, type, and abundance of phenocrysts
- size, type, and abundance of lithophysal cavities
- type, nature, and degree of alteration
- presence or absence of bedding or other depositional features
- fault zones or shear zones
- joints or fractures and fracture frequency
- percent core recovery
- RQD (rock quality designation)

Rock color descriptions follow the naming conventions prescribed in the rock-color chart published by the Geological Society of America (1991).

Laboratory Material Properties

A limited suite of framework material properties were measured in the laboratory for core samples taken from the USW SD-9 drill hole. Adjoining core samples were preserved at the drilling rig in sealed steel cans and plastic Lexan™ tubing. In-situ water contents were determined by gravimetry from the canned samples. Porosity, bulk density and particle density also were determined by gravimetry for the canned samples using Archimedes' principle. Initial water content and porosity were used to determine approximate in-situ saturations. Machined core plugs were cut from the larger samples preserved in Lexan™ and used to determine saturated hydraulic conductivity using Darcy's law relating water flow and pressure drop; the corresponding porosity values for these plugs were also determined. The laboratory property determinations were a collaborative effort of Sandia National Laboratories and the U.S. Geological Survey, Hydrologic Research Facility (USGS, 1991a).

Geology of Drill Hole USW SD-9

Overview

Drill hole USW SD-9 is located on a small divide between two washes draining the eastern slope of Yucca Mountain (fig. 3); this topographic position places the hole low within the Tiva Canyon stratigraphic section. Only the lowermost 38.7 ft of the Tiva Canyon Tuff, consisting of the lower nonlithophysal and the lower vitric zones, was encountered in the drill hole. A summary of geologic unit contacts is presented in table 3. Detailed lithologic descriptions for the rocks encountered in drill hole USW SD-9 are presented in Appendix A, and the corresponding, detailed geologic log sheets are in Appendix B.

The core begins in the Tiva Canyon Tuff with light-tan-gray, two-foot interval containing dark, vitric, pumice clasts and representing the lower part of the columnar subzone of the lower nonlithophysal zone. This unit is bounded below by a 1-1/2-inch-wide, low-angle fault filled with sandy clay gouge. Below this fault is 9.3 ft (2.84 m) of mostly nonwelded material belonging to the two lower vitric zones of the Tiva Canyon. Approximately ten ft (3 m) of section appears to have been cut out by the fault, but the actual amount of movement along the fault is unknown. The lower vitrophyre of the Tiva Canyon Tuff (Tpcpv3) is not present, and the gradationally less welded sequence beneath the fault represents what has also been termed the "shardy base" of the Tiva Canyon Tuff (Istok and others, 1994). A sequence of essentially nonwelded units underlies the Tiva Canyon Tuff section. Named units include the Yucca Mountain Tuff and Pah Canyon Tuff, each of which is separated from its neighbors by "bedded tuff" units of mixed lithology.

The Topopah Spring Tuff section, which underlies the nonwelded units, has a total thickness of 1211.5 ft (369.25 m). The top of the upper nonwelded zone (Tptrv3) has been located at 252.6 ft (77.01 m). Welding increases markedly at the upper contact of the "caprock" vitrophyre (Tptrv1).

Table 3: Stratigraphic Unit Upper Contacts and Unit Thicknesses for the USW SD-9 Drill Hole

[All values in feet. Geologic names from nomenclature of Buesch and others (1996). Stratigraphic compendium, version of September 1995. Leaders (--): no difference in depth to contact; n/a: contact not included in stratigraphic compendium]

Unit	Abbreviation	Depth to Upper contact	Apparent thickness (ft)	Depth from Stratigraphic Compendium
Tiva Canyon Tuff (Tpc) — 38.7 ft thick[1]				
Crystal-poor lower nonlithophysal zone	Tpcplnc	53.6[1]	2.1[2]	30.0
Crystal-poor vitric zone	Tpcpv	55.7	36.6	57.2
moderately welded subzone	Tpcpv2	55.7	9.3[2]	57.2
nonwelded subzone	Tpcpv1	65.0	27.3	61.0[3]
Pre-Tiva Canyon bedded tuff	Tpcbt4	92.3	3.6	92.4
Yucca Mountain Tuff (Tpy) — 45.0 ft thick	Tpy	95.9	45.0	--
Slightly welded zone	--	121.7-133.7	12.0	n/a
Pre-Yucca Mountain bedded tuff	Tpbt3	140.9	16.8[2]	140.8
Pah Canyon Tuff (Tpp) — 69.4 ft thick	Tpp	157.7	69.4	156.5
Pre-Pah Canyon bedded tuff	Tpbt2	227.1	25.5	226.6
Topopah Spring Tuff (Tpt) — 1211.50 ft thick	Tpt			
Crystal-rich vitric zone	Tptrv	252.6	19.5	255.6
nonwelded subzone	Tptrv3	252.6	15.4	255.6
moderately welded subzone	Tptrv2	266.1	2.5	266.7
“caprock vitrophyre” subzone	Tptrv1	268.6	4.1	268.5[3]
Crystal-rich nonlithophysal zone	Tptrn	272.1	167.1	272.2
Crystal-rich lithophysal zone	Tptrl	439.2		--
Crystal transition interval	--	448.2-485.2	37.0	n/a
Compositional transition	--	454.7-468.6	13.9	n/a
Crystal-poor upper lithophysal zone	Tptpul	485.2	289.6	484.2[3]
Crystal-poor middle nonlithophysal zone	Tptpmn	728.8	117.0	736.8
lithophysae-bearing subzone	Tptpmn2	788.1-812.5	24.4	n/a
Crystal-poor lower lithophysal zone	Tptpll	845.8	341.2	--
Crystal-poor lower nonlithophysal zone	Tptpln	1187.0	178.0	1185.8[3]
Crystal-poor vitric zone	Tptpv	1365.0	99.1	--
lower vitrophyre subzone	Tptpv3	1365.0	53.7	--
moderately welded subzone	Tptpv2	1418.7	26.3	1418.4[3]
nonwelded subzone	Tptpv1	1445.0	19.0	1425.7
Pre-Topopah Spring bedded tuff	Tpbt1	1464.1	15.8	1464.1
Calico Hills Formation (Tac) — 340.8 ft thick				
unit 3	Tac3	1479.9	106.2	1479.9
unit 2	Tac2	1586.1	151.4	n/a
unit 1	Tac1	1737.5	26.9	n/a
bedded tuff	Tacbt	1764.4	39.0	1764.4
tuffaceous sandstone	Tacbs	1803.4	17.3	n/a
Prow Pass tuff (Tcp) — 402.4 ft thick[1]				
unit 4	Tcp4	1820.7	48.0	1820.7
unit 3	Tcp3	1868.7	147.1[2]	n/a
unit 2	Tcp2	2015.8	79.5	n/a
unit 1	Tcp1	2095.3[1]	127.8[1]	n/a

[1] entire unit not penetrated; partial thickness only
[2] may not be true thickness because of faulting
[3] markedly gradational contact subject to interpretation

Devitrification begins at 272.1 ft (82.96 m), defining the contact of the vitrophyre with the underlying upper nonlithophysal zone. The upper portion of the section is weakly, but progressively more lithophysal down to the upper contact of the upper lithophysal zone at 439.2 ft (133.90 m).[†] A compositional-transition interval has been described approximately 200 ft (60 m) below the top of the unit where the Topopah Spring changes gradationally from quartz latite to rhyolite. This compositional-transitional interval is 13.9 ft (4.24 m) thick and was observed between 454.7 and 468.6 ft (138.59–142.82 m). A somewhat overlapping transition interval, involving principally the abundance of phenocrysts, as been identified as a "crystal-transition" interval from about 448.2 to 485.2 ft (136.60–147.88 m). The base of this crystal-transition interval essentially corresponds to the contact between the lower crystal-poor member and the overlying crystal-rich members of the Topopah Spring Tuff described by Buesch and others (1996). There is, however, no apparent physical or depositional break associated with this "contact."

Very large lithophysae within the upper lithophysal zone are represented in the core as broken zones or unrecovered intervals, and these large lithophysal cavities are visible in the downhole video logs beginning at a depth of 441.5 ft (134.60 m). Although the number of smaller lithophysae diminishes beginning at 655.0 ft (199.70 m), isolated large lithophysal cavities are visible in video-camera logs down to about 760 ft (231.71 m), which is well into the middle nonlithophysal zone. The middle nonlithophysal zone is defined between depths of 728.8 and 845.8 ft (222.20–257.87 m). A "lithophysal-bearing subzone" is identified within the middle nonlithophysal zone from 788.1 to 812.5 ft (240.27 to 247.71 m). In contrast to the upper part of the middle nonlithophysal zone, the lower 33 ft (10.06 m) of this unit is relatively intact and exhibits a dense, compact, highly silicified (altered) texture.

The lower lithophysal zone was encountered at a depth of 845.8 ft (257.87 m), and large-diameter lithophysal cavities, intense fracturing, and numerous unrecovered zones were encountered beginning at about 860 ft (262.20 m). The large lithophysae continue well below the lower limit of the lower lithophysal zone at 1187.0 ft (361.78 m), extending almost to the depth of the lower vitrophyre. Intervals containing large, angular, rhyolite lithic fragments with clasts to 60.0 mm diameter are found at a number of depths from 1031.0 ft (314.33 m) to 1267.8 ft (386.52 m). A lithic zone containing 4–5 percent fragments of mixed quartz latite and rhyolite composition is present from 1267.8 ft to 1442.2 ft (439.70 m).

The top of the lower vitrophyre occurs at a depth of 1418.7 ft (432.53 m) and the unit is 53.7 ft (16.37 m) thick. Below the lower vitrophyre, the moderately-to-partially welded vitric zone contains a lithic-rich interval from 1431.5 to 1442.2 ft (436.43 to 439.70 m) Zeolitized pumice and very weakly altered shard boundaries indicate incipient zeolitization beginning at a depth of 1442.2 ft (439.70 m). A 3.8-ft (1.16 m) thick, pink, zeolitized interval from 1432.8 to 1436.6 ft (436.83 to 437.99 m), within the lithic-rich interval, may represent a large zeolitic block derived from deeper stratigraphic units. The basal nonwelded zone extends from 1445.0 to 1464.1 ft (440.55 to 446.37 m). The Topopah Spring Tuff is underlain by 15.8 ft (4.82 m) of bedded tuff.

The Calico Hills Formation was encountered at a depth of 1479.9 ft (451.05 m) and the unit is 340.8 ft (103.87 m) thick. The Calico Hills in this drill hole has been subdivided into three ash-flow tuff units, a reworked bedded tuff unit, and a basal tuffaceous sandstone, following the usage of Moyer and Geslin (1995). The unit is essentially entirely zeolitic. Numerous intervals of prominent red-brown rhyolitic lithic fragments are typical within the ash-flow deposits of Calico Hills.

The Calico Hills Formation is underlain by the Prow Pass Tuff, beginning at a depth of 1820.7 ft (554.92 m). This unit is subdivided into four ash-flow tuff units (Moyer and Geslin, 1995) that are a

[†]Note: The issue of distinguishing lithophysal and nonlithophysal zones is complex and represents a long-standing issue of some contention within the Yucca Mountain Project ever since Ortiz and others (1985) used the abundance of lithophysae as a criterion for distinguishing subunits of the Topopah Spring Tuff; see see "Thermal/Mechanical Units" beginning on page 11. A brief discussion of the criteria used to separate informally named lithophysal zones from other lithophysae-bearing units is presented beginning on page 12.

minimum of 402.4 ft (122.65 m) thick in SD-9. This observed thickness is not adjusted for the unknown effects of a minor fault observed in ash-flow unit 3. Drill hole USW SD-9 did not reach the base of ash-flow unit 1.

Thermal/Mechanical Units

A somewhat formalized thermal, mechanical, and hydrologic stratigraphy was defined originally by Ortiz and others (1985), based upon preliminary concepts put forward by Lappin and others (1982). The concept was to define coherent rock units for design and performance analyses based on rock properties, rather than on more classical geologic criteria. According to the original citation, "Two properties used to differentiate units are porosity and grain density" (p. 8). Further reading of the Ortiz reference indicates that this subdivision based on porosity and grain density translates to a first order subdivision between welded and non-welded materials, with additional subdivisions determined by whether the rocks are still vitric, or whether they have been altered either to a devitrification mineral assemblage or to zeolites. The so-called thermal/mechanical units were correlated in table 1 of Ortiz and others with the more conventional geologic stratigraphy then in use; this correlation is essentially reproduced intact in table 1 of this report. The thermal/mechanical units, as originally described, also subdivided the Topopah Spring welded interval into a lithophysae-rich upper portion in contrast with the lower part, which was presumed to be relatively poor in lithophysae (p. 11). In fact, the distribution of lithophysal alteration and lithophysal cavities is more complex than was recognized by Ortiz and her coworkers.

It is important to note that the major changes in material properties recognized as the basis for subdividing the volcanic section at Yucca Mountain by Ortiz and others do not correspond to the boundary of the geologic units, which are identified principally by major breaks and changes in the genetic process that produced the rocks of the southwestern Nevada volcanic field. The descriptive but unfortunate use by Ortiz and her coworkers of the conventional geologic names as the "base" for the thermal/mechanical unit names can cause confusion if the critical distinction between property-based and process-based nomenclature is not fully understood. Nevertheless, this physical-property subdivision that aggregates materials that behave in a similar manner has proven to be an enduring feature of the Yucca Mountain Project.

Table 4 presents the thermal/mechanical units identified from the SD-9 drill core. In keeping with Ortiz and others (1985), who presented a series of surfaces representing the bottom of each thermal/mechanical unit, table 4 gives the depths to each basal contact as well as the apparent thickness of each unit.

Table 4: Basal Contacts and Thicknesses of Thermal/Mechanical Units
[Definitions of thermal/mechanical units from Ortiz and others (1985), p. 11–12]

	Unit	Lower Contact (ft)	Apparent Thickness (ft)
TCw:	Tiva Canyon welded	55.7	--
PTn:	Paintbrush nonwelded	268.0	212.3
TSw1:	Topopah Spring welded, "lithophysae rich"	728.8	460.8
TSw2:	Topopah Spring welded, "lithophysae poor"	1365.0	636.2
TSw3:	Topopah Spring welded, vitrophyre	1418.7	53.7
CHn1:	Calico Hills nonwelded—lower nonwelded part of Topopah Spring Tuff plus ash-flow tuffs of Calico Hills Formation	1764.4	345.7
CHn2:	Calico Hills nonwelded—basal reworked zone and "bedded tuffs" of Calico Hills Formation	1820.7	56.3
CHn3:	"Calico Hills" nonwelded—upper nonwelded ash-flow tuffs of the Prow Pass Tuff	1910[1]	89.3

Table 4: Basal Contacts and Thicknesses of Thermal/Mechanical Units (Continued)
[Definitions of thermal/mechanical units from Ortiz and others (1985), p. 11–12]

	Unit	Lower Contact (ft)	Apparent Thickness (ft)
PPw:	Prow Pass welded—welded ash-flow tuffs of the Prow Pass Tuff	2012.4	102.4
CFUn	Upper Crater Flat nonwelded—lower nonwelded ash-flow tuffs of the Prow Pass Tuff	(2223.1)[2]	--

[1] Gradational contact; exaction location somewhat uncertain
[2] Total depth of drill hole; lower contact not penetrated

Structural Geology of SD-9

Three faults were observed in the SD-9 core. The uppermost of these faults is found at a depth of 55.7 ft (16.98 m), and it separates the columnar subzone of the Tiva Canyon Tuff, lower nonlithophysal zone, from the shardy-base subzone. This structure is a very low-angle fault (essentially normal to the core axis) containing approximately a 1- to 1.5-inch thick (3.9–5.9 mm) mixture of sandy and clayey gouge. The base of the columnar section is intensely fractured and these fractures are filled with cemented, milled fragments of the underlying shardy-base vitric interval. *Stratigraphic* offset is estimated to be no more than about 10 ft (3 m); however, to achieve this amount of stratigraphic offset on a displacement surface nearly parallel to depositional layering logically requires a significant amount of structural movement.

A second fault occurs within the slightly welded zone of the Yucca Mountain Tuff at a depth of 122.1 ft (37.23 m). About two inches (0.05 m) of soft clay gouge was found in this low-angle fault, although no indication of relative movement was apparent. No estimate of the offset along this fault is possible. Using analogy with the fault identified higher in the borehole at 55.7 ft, the similar-to-slightly thicker interval of recovered fault gouge suggests that stratigraphic offset may be roughly comparable (approximately 10 ft, 3 m), even though no offset marker horizons or thinned stratigraphic zones are present to provide direct evidence of offset. Achieving 10 ft of stratigraphic offset along a flat-lying fault suggests much larger structural displacement, however.

A third fault was identified within the Prow Pass Tuff at a depth of 1991.0 ft (607.01 m). This is also a low-angle fault (bounding surfaces at approximately 70–75° to the core axis), which is represented by about 2-1/2 inches (6–7 cm) of plastic, clay-rich gouge. This fault is estimated to exhibit approximately 62.7 ft (19.12 m) of stratigraphic displacement. The amount of structural movement on this relatively low-angle fault unquestionably is much greater.

Lithophysal Zones

The definition of lithophysal zones within the welded tuffs at Yucca Mountain is a complex problem that has a long history on the Yucca Mountain Project. The issue involves distinguishing (informally) named "lithophysal zones" from other intervals that may contain lithophysae. In logging and describing other recent core obtained from Yucca Mountain, T. C. Moyer (Science Applications International Corporation/U.S. Geological Survey, personal communication, 1994) originally indicated that lithophysal zones were to be defined simply based on "the presence of lithophysae." Ortiz and others (1985, p. 11) cited a threshold value of "approximately 10% by volume lithophysal cavities" as the criterion for separating their "lithophysae-rich" (TSw1) and "lithophysae-poor" (TSw2) subunits of the Topopah Spring welded tuff. Buesch and others (1996) present a more specific description of criteria for the identification of specifically named lithophysal zones (page 18; quoted almost in its entirety):

> *Lithophysal zones occur where vapor concentrates in the densely welded parts of ignimbrites* [ash-flow tuffs] *to form lithophysal cavities (Ross and Smith, 1961).... Lithophysae consist of a cavity, which is commonly coated with vapor-phase miner-*

als on the inner wall of the cavity, a fine-grained rim surrounding the cavity wall, and a thin very fine-grained border.... Many lithophysae in the Tiva Canyon and Topopah Spring Tuffs have light-gray (N8) to grayish-orange pink (10R8/2) rims of microscopic to barely macroscopic elongate crystals that radiate from the walls of the lithophysae into the surrounding groundmass. These rims are up to 3-cm wide. Locally, rims have 1- to 3-mm-wide, grayish red-purple (5YR4/2) borders. Associated with the lithophysae are light-gray (N8) to grayish-orange pink (10R8/2) spots 1- to 5-cm in diameter. Some spots may represent the cross sections of rims on lithophysae, whereas others have a crystal or lithic clast in the core that could have acted as a nucleation site. There is no genetic interpretation for the spots; however, they are characteristic for some lithophysal zones. ***Lithophysal zones in the Tiva Canyon and Topopah Spring Tuffs are identified by a combined occurrence of lithophysae and spots*** [emphasis added]. *The shape of the lithophysae and spots and width of the rims on the lithophysae can also be diagnostic of specific zones. Locally surface exposures contain lithophysae with diameters of up to 1 m; thus* ***regions of poor core recovery might indicate large lithophysae*** [emphasis added].

Vapor-phase altered rocks containing abundant (greater than 10 percent) lithophysae, with or without significant open-space cavities, are readily recognized and are easily assigned to discrete lithophysal zones. The real complication appears to be the recognition and treatment of lithophysal-style alteration associated with cavities that are too large to be recognized *directly* in the core (and by extension, recognition of the mere presence of lithophysae). Where very large lithophysae are penetrated by the drill string, the thin, brittle septae of rock dividing the cavities typically are shattered by the force of the rotating drill bit; this logically results in intervals of rubble and unrecovered core (cavity plus rubble blown away from the bit face into other parts of the cavity). Diagnostic, remnant vapor-phase alteration rims and distinctive cavity-coating minerals frequently can be identified in the recovered rubble fragments. The question essentially reduces to whether or not an interval exhibiting these very large lithophysal cavities, but *without* significant quantities of the small-scale lithophysae or vapor-phase-altered spots, can be classified as a “lithophysal zone.”

Descriptions of the SD-9 drill core for this report use multiple criteria derived from the description of lithophysal zones presented by Buesch and others (quotation above). In keeping with the logging philosophy presented in the section on core description beginning on page 7, the *principal emphasis* of the Systematic Drilling Program has been placed on objective description of the core and associated down-hole video imagery (particularly that presented in the foot-by-foot lithologic log contained in Appendix B). Association of unit names with these descriptions is distinctly secondary. Generally, named “lithophysal zones” identified in this report contain rocks exhibiting small (mesoscale) lithophysae and/or “spots,” and whose matrix is grayish red-purple in color. This type of material typically is associated with vapor-phase alteration of varying, but relatively strong, intensity immediately adjacent to observable lithophysae. The matrix of rocks from named *non*lithophysal zones is typically more brownish or orangish in color; note that description of rock colors is somewhat subjective, even when using standard rock-color charts. The finer-scale texture of the rock between lithophysal cavities in lithophysal zones is typically stretched and foliated, as if distorted by the inflating lithophysal cavities. Fracturing within named lithophysal zones is generally distinctive as well; fractures tend to be shorter and more irregular in form, and to exhibit rougher surfaces than those encountered outside the named lithophysal zones. Unquestionably, some of the names assigned in this report are somewhat in conflict with the description of the corresponding interval. The descriptions should take precedence, as these do reflect local heterogeneities in the tuff mass.

Drill hole USW SD-9 was collared below the lithophysal intervals of the Tiva Canyon Tuff. Within the Topopah Spring Tuff, prominent lithophysal alteration associated with the crystal-rich and crystal-poor upper lithophysal zones begins at 436 ft (132.93 m), approximately 164 ft (50 m) below the caprock vitrophyre (see log sheet 7, Appendix B**)**. Lithophysae increase rapidly in both abundance and size by a depth of 441.5 ft (134.60 m), as does the incidence of intervals of broken and unrecovered core. Many intervals of “lost” core are attributed to void space representing large lithophysae that are several core-diameters across. The highly broken nature of much “core” recovered from lithophysal zones is attributed to disintegration of the vuggy tuff during drilling.

Lithophysal cavity development decreases significantly beginning at a depth of approximately 630 ft (192.07 m; log sheets 9–10, Appendix B); the middle nonlithophysal zone is distinguished beginning at 728.8 ft (222.20 m; log sheet 11). Although lithophysae were not observed in the core, broken and unrecovered zones continue to occur through the middle nonlithophysal zone confirming the presence of large diameter lithophysae that are visible in the down-hole video. A 24-foot (8-m)-thick “lithophysae-bearing subzone” of the middle nonlithophysal zone (table 2), identified from 788.1 to 812.5 ft (240.27 to 247.71 m) depth (log sheet 13), also represents an interval of prominent large lithophysal cavity development. Only the lower 33.3-ft (10.15-m)-thick portion of the middle nonlithophysal zone appears to be devoid of large lithophysae (log sheet 12).

The lower lithophysal zone of the Topopah Spring Tuff was encountered at a depth of 845.8 ft (257.87 m; log sheet 13). In addition to lithophysae visible in the core, the material recovered from this unit also includes broken and unrecovered zones that appear to correspond to large (many centimeter) lithophysal cavities in visible in downhole video logs. No lithophysae are visible in the recovered core material from 899 to 962.6 ft (274.09 to 293.48 m; log sheets 13–14), although fragments of altered lithophysal rims, broken zones, unrecovered intervals and large lithophysae visible in the borehole video attest to their presence. Smaller lithophysae reappear in the core from 962.6 to 980 ft (293.48 to 298.78 m; log sheets 14–15), although the frequency of these features appears to decrease below about 980 ft. Small, well-formed lithophysae reappear in the core at a depth of 1060 ft (323.17 m); broken core and unrecovered intervals are more common below 1060 ft as well (log sheet 16). Both recovered lithophysae and these two indirect indicators of large lithophysal cavities increase in intensity to a depth of about 1110 ft (338.41 m). Below the depth of 1110 ft, the intensity of lithophysal-style alteration progressively decreases to a contact with the lower nonlithophysal (or “mottled” zone of Scott and Bonk, 1984), drawn somewhat arbitrarily at 1187 ft (361.89 m; log sheet 17). Indicators of large lithophysae are present, albeit less frequently, throughout of the lower Topopah Spring section (log sheets 18–20) to a depth of approximately 1354 ft (412.80 m); the top of the basal vitrophyre occurs at a depth of 1365 ft (416.16 m).

Rock Quality Considerations

Core Recovery

Percent core recovery was determined at the drill rig by Yucca Mountain Project drilling support staff during the coring of hole USW SD-9. Recording core recovery information is a relatively mechanical process and follows a set procedure. Core recovery data are presented in Appendix C, Table C-1; this information is also presented graphically in summary form in figure 4. Core recovery information is presented in more detail on the geologic log sheets of Appendix B, which allows inference of possible lithologic controls of lost core and as means of qualifying the reliability of the associated lithologic descriptions. Note the association of lower core-recovery values with the graphically portrayed abundance and size of lithophysal cavities on the log sheets; see also figure 4. Description of intervals with exceptionally poor core recovery requires a subjective “reading” of multiple lines of indirect evidence.

A generalized summary of the procedure used to determine core recovery is as follows.

1) The core is laid out in an appropriate manner. Broken segments are fitted back together as well as possible to represent in-situ dimensions. Rubble is reaggregated to continuous piles of approximately the core diameter.
2) The start and stop depths of the core run are identified from information provided by the driller and the length of the core run is determined.
3) The total length of core recovered from a given run is measured using a steel tape measure and the footage is recorded.
4) Recovery is computed as the percentage of material actually recovered from that interval.

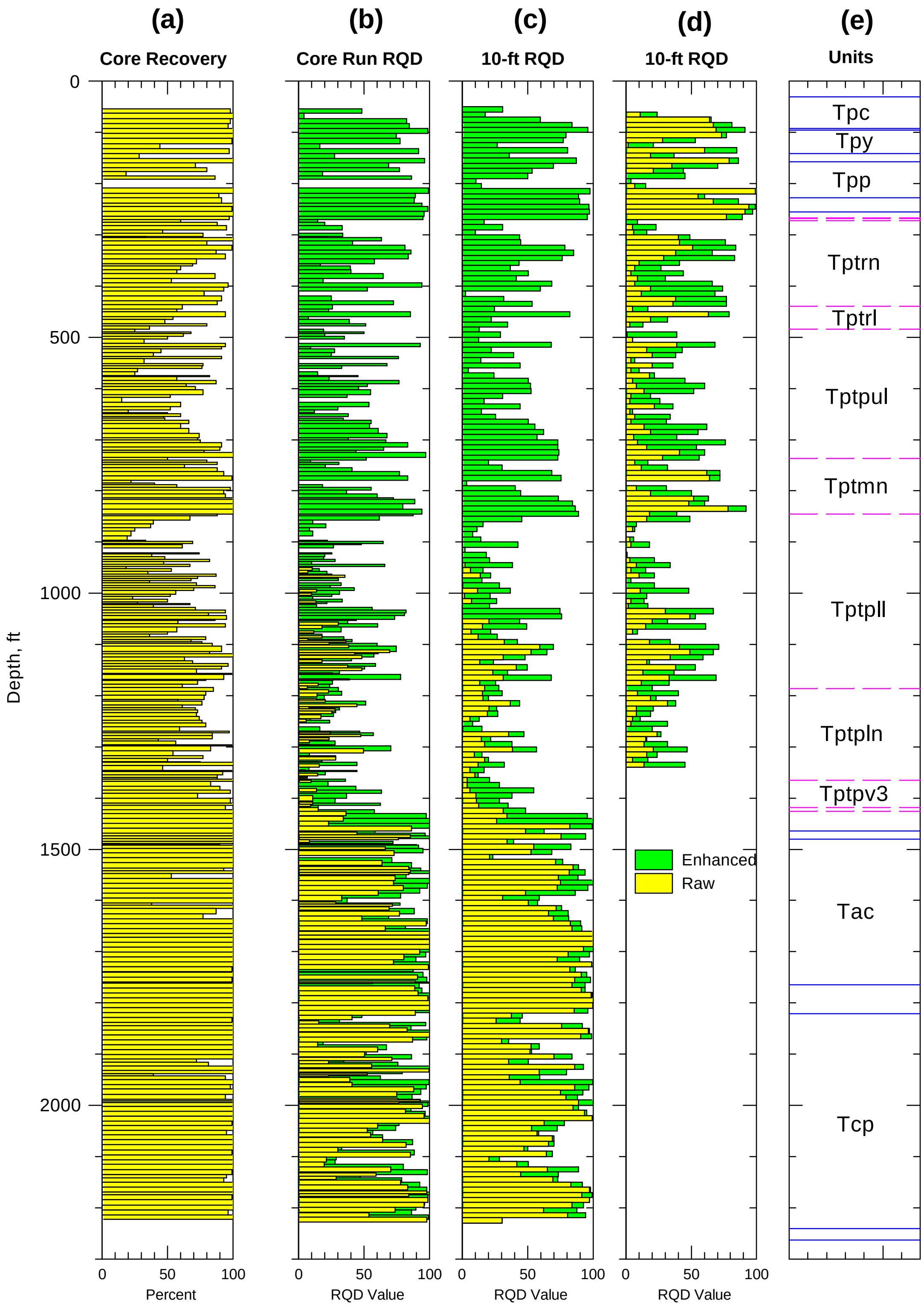

Figure 4. Plot showing (a) core recovery, (b) field-measured core-run RQD, (c) 10-ft averaged field-measured RQD, (d) 10-ft averaged video-analysis RQD, and (e) geologic unit assignments for the USW SD-9 drill hole as a function of depth. Dark grey bars are "enhanced" or original RQD values of Deere and Deere (1989); lighter grey bars are raw RQD values uncorrected for coring-induced fractures. Thinner geologic units are not labeled.

Core recovery data are only estimates. The accuracy of these estimates in reflecting the actual recovery for a core run can be quite precise for intervals of generally good recovery of essentially intact core. Accuracy diminishes markedly as the integrity of the core decreases, because loose rubble recovered in the core barrel must be approximated back to in-situ dimensions prior to measurement.

A summary of the core-recovery information is presented graphically in figure 4(a). Generally, core recovery correlates fairly well with rock type. Nonwelded intervals, such as those in the upper part of the hole above approximately 280 ft (85 m) and in the lower third of the hole below about 1450 ft (440 m), core well and yield near 100-percent recovery. Local exceptions, such as that at 200 ft (60 m), involve completely unlithified and reworked “bedded tuff” deposits that lack meaningful cohesion. Zeolitic rocks, present in the bottom one-third of the SD-9 drill hole, generally yield 100-percent recoveries as well. The densely welded tuffs of the main part of the Topopah Spring are brittle, highly fractured, and consequently yield relatively low recoveries. Nonlithophysal units appear to produce better recoveries than the lithophysal intervals. Comparison of the core runs from about 700 to 885 ft (213 to 270 m) with those immediately above and below demonstrates that some of the low core recoveries observed in the two main lithophysal zones of the Topopah Spring Tuff may be explained partially by the presence of the very large lithophysal cavities observed in down-hole video logs. In addition to producing rock rubble that may be lost during coring operations when the drill hole penetrates the weak, poorly supported margins of the cavities, the cumulative void space encountered by the drill hole may constitute a non-trivial fraction of certain intervals. Note also that the presence of these large lithophysal cavities is not limited to the more strictly defined “lithophysal zones” of Buesch and others (1996). This is particularly true for the lower nonlithophysal (Tptpln) interval. Note the marked differences in core recovery values between approximately 1200–1350 ft and 1350–1400 ft in figure 4(a). The deepest described large lithophysal cavity was encountered at a depth of 1354 ft (Appendix B, log sheet 20).

RQD (Rock Quality Designation)

Measurement of RQD is also a relative mechanical process, and it is usually performed as an adjunct to measurement of core recovery. Like core recovery, RQD has been defined on a per-run basis for each drilling interval (Deere and Deere,1989). RQD is generally also reported on the basis of a standardized interval, typically 10 feet (approximately 3 m). The use of a standard-length measurement interval reduces the occurrence of interspersed, wildly erratic RQD values that may be associated with numerous very short core runs (particularly in broken rock).

The procedure for determining RQD data is as follows.

1) The core is laid out in an appropriate manner as for core-recovery measurements.
2) The length of the core run is determined as for core-recovery measurements.
3) The cumulative footage of intact, whole core segments of sound rock longer than 4 inches (100 mm) as measured along the centerline of the core is measured using a steel tape measure. Ends that result from diagonal fracturing of the rock mass are excluded from the measurement (fig. 5). There are two alternatives for the treatment of fractures:
   (a) all extant fractures are considered as breaks in the core, regardless of whether or not the fractures appear to be natural or drilling induced; or
   (b) only natural fractures are considered to be breaks in the core.
4) The cumulative footage thus measured is converted to a percentage of the drilling interval and recorded to the nearest percent.

The originator of the RQD measurement system (Deere, 1963; see also Deere and Deere, 1989, p. 15, 43) recommended that only natural breaks in the core be considered. Deere and Deere explicitly state that breaks that are obviously an artificial result of the drilling and/or core-handling process are to be discounted in the determination of “broken” core. Criteria for identifying “natural” fractures may include: fracture in-filling or mineralization; obvious non-matching sides; the

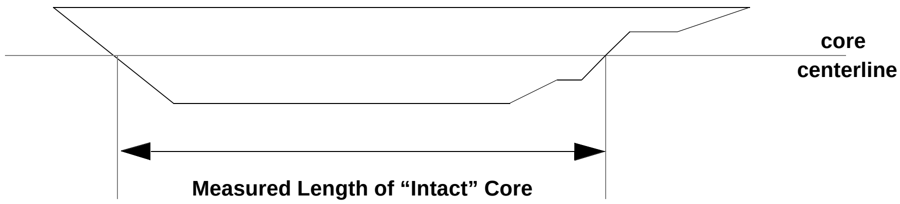

Figure 5. Conceptual sketch for measuring the length of “intact” core segments for RQD determinations. Segments must be longer than 4 inches (100 mm) to count toward RQD. Ends, “ears,” and other segments less than 4 inches in length are not included in the length measurement.

presence of gouge, slickensides, or other structures suggestive of relative movement; and potentially other site-specific features. Criteria for induced fractures include: actual observation of core breakage during handling; absence of any fracture-filling material other than drilling mud; clean, sharp edges that fit tightly together, and breaks at 90° to the core axis. If the origin of a particular break is in doubt, their procedure is to count it as a natural break, which would produce an RQD value that is conservative from a rock-stability standpoint. If all fractures are considered breaks in the core, the value that results is referred to in this report as “raw RQD.” If induced fractures are discounted, the value is referred to as “enhanced RQD” or “Deere RQD.”

The requirement for “sound rock” is also subjective, but it is intended (Deere and Deere, 1989, p. 16) to exclude intervals of altered, weathered, or otherwise unstable material that might conceivably be recovered “intact” (not fractured or broken). If the soundness of a particular core segment that would otherwise qualify is in doubt, it is excluded from the cumulative-length measurement for RQD determination. The intent is to be conservative from a design standpoint of estimating ground stability. In practice, such subjective decisions involving Yucca Mountain core are not an issue, as the type of alteration that typically produces “soft” yet intact core is virtually unknown from the upper portion of the volcanic section.

Measured RQD data for the individual core runs of drill hole USW SD-9 are given in Appendix D, table D-1. The 10-ft composite (averaged) RQD values are in table D-2. Both raw and enhanced RQD values are presented in the tables. RQD values for the SD-9 drill hole are shown in graphical form in figure 4, parts (b), (c), and (d). RQD values are also included graphically on the detailed geologic log sheets in Appendix B for comparison with the geologic description.

Note that there two sources of RQD data and RQD composites. The data in table D-1 and the columns in table D-2 that are headed “Drilling Support” are based on actual physical measurement of the core by drilling support staff at the time of recovery of the core from the hole. The values in the columns of table D-2 that are headed “Study 8.3.1.14.2” are based on office interpretation of video images of the core that were filmed immediately upon opening of the core barrel in the field. The field-measured values benefit from direct physical observation of the core, including examination of actual fracture surfaces for the presence of mineralization and other phenomena that may bear on the issue of natural versus induced. However, the logistics of sampling the core at the rig site and preserving those samples in near-in-situ hydrologic conditions limits the time that can be spent examining a core run to a few minutes. The video-based RQD measurements, which were actually obtained as part of SCP Study 8.3.1.14.2 (Soil and Rock Properties of Potential Locations of Surface Facilities; USGS, 1991b), are not subject to this time limitation; however, these data are limited by the inability to examine the core itself physically. The values portrayed on the detailed geologic log of drill hole SD-9 (Appendix B) are the 10-foot composite, field-measured, enhanced (Deere) RQD values from table D-2 (column 3).

A confounding factor for the SD-9 drill hole is that drilling support staff did not record the raw piece-length measurements for the upper part of the hole. The procedure controlling this work at that time provided only for recording of adjusted piece length, corresponding to enhanced or original RQD as defined by Deere and Deere (1989). A revised procedure for recording both measurements became effective with core run number 163 (table D-1) beginning at a depth of 1124.4 ft (342.70 m). Video-based RQD values were not obtained below 1340 ft (408 m) because these values were developed specifically for use in design of the Exploratory Studies Facility. The deeper part of the drill hole is below this zone of short-term engineering interest.

Examination of figure 4 indicates that the differences among the various RQD values are relatively insignificant in light of the fact that RQD is a rough, preliminary estimate of rock mass integrity. Design decisions for ground support of underground openings, such as the Exploratory Studies Facility or a potential repository, are generally based on large categorical groupings of RQD values (table 5).

Table 5: RQD and Rock-Quality Descriptors
[after Deere and Deere (1989)]

RQD	Description
90–100	Excellent
75–90	Good
50–75	Fair
25–50	Poor
0–25	Very poor

As anticipated, the core-run RQD values are noticeably more variable than the ten-foot composites. For these composite values, the enhanced or Deere RQD values are logically lower than the raw values, for which the impact of drilling and sample handling have not been discounted. Note that in some intervals, such as from 300 to 700 ft [90–210 m; figure 4(d)], the effect of ostensibly coring-induced fractures may be rather significant. Generally, the integrity of the thick welded Topopah Spring interval (250 to 1460 ft; 77 to 446 m) is rather poor by any measure. The presence of lithophysal cavities and of brittle, fractured, welded materials produces low values of RQD. Typically the nonlithophysal zones (270–440, 730–845, and 11907–1420 ft) exhibit higher values than do the lithophysal zones (440–729, 846–1187 ft). Rock quality is markedly higher in the largely nonwelded intervals above about 280 ft (85 m) and below 1420 ft (433 m).

Measured Lithophysal Cavity Information

Quantitative information regarding the abundance of the smaller lithophysal *cavities* (as distinct from the abundance of lithophys*ae* and of large cavities) is reported in Appendix E, table E-1. This data is also summarized graphically in figure 6(a). Core-recovery information from figure 4(a) is repeated in figure 6 for comparison purposes.

The data contained in table E-1 were obtained by comparing the surface area of the core and core-video images occupied by actual cavities with standard charts for estimating mineral percentages in thin sections. *Lithophysal cavities larger than the core diameter, or which were sufficiently large that the core was rubblized during the drilling process are not included in these estimates*. As suggested by one of the emphasized statements in the Buesch and others quotation (see page 12), the presence of broken and unrecovered intervals has been found to be associated with what appear to be large-diameter lithophysal cavities in down-hole video images. Recovered rubble containing fragments of vapor-phase altered rock and open-space crystalline material (cavity linings of Buesch and others) confirms this remote-sensing interpretation. Note that the down-hole video images suggest that such large lithophysal cavities may be quite abundant locally: compare for example the core recovery data or RQD data (from fig. 4) with the down-hole distribution of lithophysal cavities in figure 6.

Because of the difficulty of obtaining rigorously quantitative information on the fraction of large (greater-than-core-diameter) lithophysal cavities from the down-hole video imagery, a surrogate quantitative measure potentially indicative of these

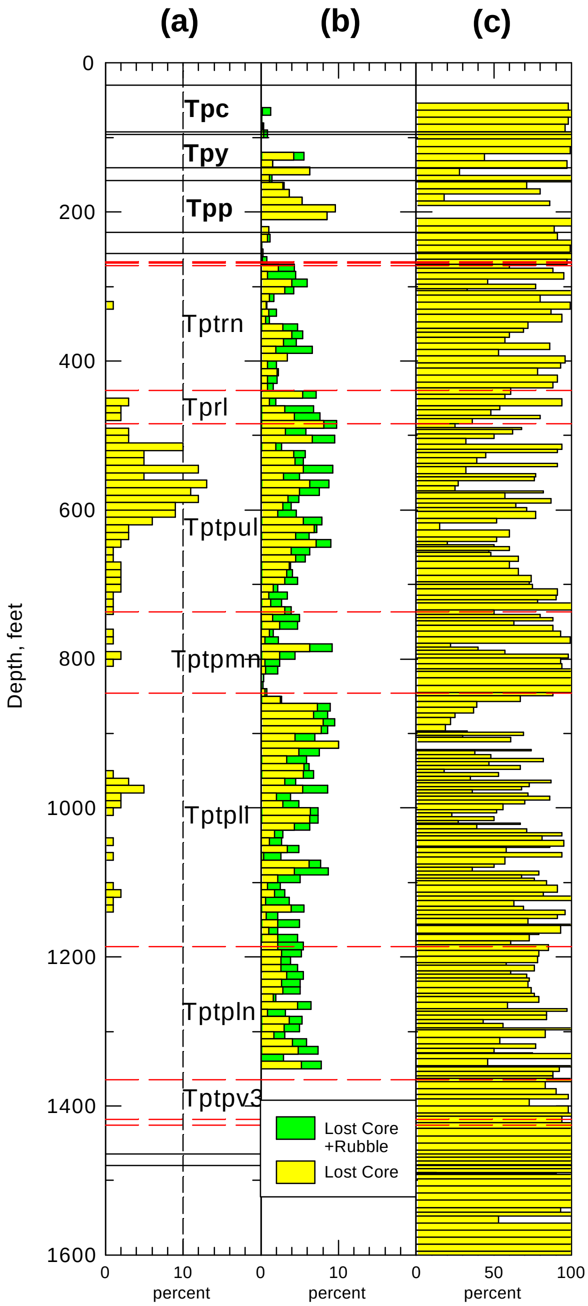

Figure 6. Graph showing (a) abundance of small lithophysal cavities, (b) core loss and core loss plus rubble zones, and (c) core recovery as a function of depth for the USW SD-9 drill hole. Selected major stratigraphic units and subdivisions of the Topopah Spring Tuff are indicated by horizontal lines (solid and dashed, respectively).

large void spaces is presented for comparison in figure 6. Column (b) of the figure illustrates the percentage of lost core and the percentage of lost core plus the cumulative percentage of rubblized material for each 10-ft (3-m) interval. Core recovery for individual core runs is also presented on the figure in column (c).

Although equating core loss (or core loss-plus-rubble) with the fraction of large lithophysal cavity void space involves a presumption that core is not lost during drilling for any other reason, the graph of figure 6(b) does place a reasonable upper limit on the extent of development of the large lithophysal cavities. Figure 6(a) is completely consistent with the independent information shown on the detailed core logs of Appendix B. There are very few open, small lithophysal cavities in the lower lithophysal zone above a depth of about 962.6 ft (292.38 m; log sheets 13–14 vs. sheet 15; Appendix B), and open cavities below this depth die out below about 1000 ft (305 m; sheet 15). The geologic log again describes small lithophysae with minor cavity development from about 1050–1070 (320–326 m; log sheet 16), and again from 1120–1170 ft (340–357 m; sheet 17). In similar fashion, figure 6(b) is quite consistent with the record of observations of large lithophysal cavities from the down-hole video log. Large cavities are described in the log of Appendix B starting at a depth of 860 ft (362 m; log sheet 13), at essentially the same depth where core recovery drops markedly and RQD values go virtually to zero (detail in the right-hand columns of log sheet 13). Large cavities were observed nearly to the top of the lower vitrophyre (lithostratigraphic unit Tptpv3); the bottom of the last such cavity observed in the down-hole video imagery was at a depth of 1354.0 ft (382.20 m; log sheet 20). Although material below a depth of 1187.0 ft (361.89 m; log sheets 17–20) is assigned to the lower “nonlithophysal” zone, it must be explicitly recognized that such named-unit assignments are secondary to the actual descriptive information contained in the geologic log (Appendix B), and that the assigned names represent an overall *interpretation* of the descriptive material.

Fracture Information

Fracture information has been measured during logging of the core from drill hole USW SD-9.

Fractures are represented schematically on the geologic log sheets in Appendix B. This representation is only semiquantitative; however, it does capture much of the general style of fracturing. Fracture density is approximately shown, and fracture orientations are shown with respect to the core axis (effectively vertical at SD-9). The simultaneous presentation of fracture style with the other geologic indicators allows some understanding of controls on fracture density, orientation, and mineralization; this qualitative fracture description is available for the entire drill core. More quantitative fracture information has been acquired from detailed counting and measurement for the upper portion of the SD-9 drill core. These data have been summarized into 10-foot depth increments, and the numeric values are presented in Appendix F, table F-1.

The quantitative fracture data are presented in figure 7. The fracture density log shown in part (a) of figure 7 distinguishes coring- and handling-induced fractures from natural fractures. The "natural" category actually includes both natural fractures and fractures of "indeterminate" origin. Part (b) of figure 7 portrays fracture orientations by 30-degree increments; a somewhat expanded frequency scale has been used to allow better visualization of the different orientation classes. The appendix contains a more detailed 10-degree categorization of fractures. Neither the tabular fracture data nor the illustrations in this report has been corrected for the well-known effect of fracture dip on the numbers of fractures observed in a vertical borehole (Scott and others, 1983):

$$F_c = \frac{F_m}{\cos\alpha} \quad , \tag{1}$$

where F_c is the ***c***orrected fracture frequency adjusted for fracture dip, α, and F_m is the ***m***easured fracture density. The impact of this cosine-correction factor can be relatively large in selected intervals.

Part (c) of figure 7 provides a breakdown of clean fractures in contrast to fractures that contain some degree of mineralization or veining. Mineralization is most common in the uppermost part of the drill hole, principally associated with the columnar subzone of the Tiva Canyon Tuff and with the crystal-rich vitric and nonlithophysal zones of the Topopah Spring Tuff. Note that both of these intervals are immediately below relatively porous materials: surface colluvium and the Paintbrush nonwelded interval, respectively. Mineralized fractures are least abundant in the lithophysal zones of the Topopah Spring, and they appear to be most extensively developed in the lower Topopah near the location of the perched water body. Perched water was encountered in SD-9 at a depth of 1353 ft (412.5 m) (see also page 7).

RQD values and core recovery information are also shown in figure 7 for comparison. Although rock quality and RQD values should be inversely related to fracture density, there is no clear *overall* correspondence between the more highly fractured intervals and intervals of low RQD (presumably containing highly broken rock). In fact, in some intervals there appears to be a *positive* relationship, with lower RQD values [profile (d)] in those zones with the fewest natural fractures [profile (a)]. Examination of figure 7 [columns (a), (d) and (e)] also suggests that there is a positive correlation between core recovery and both fracture density and RQD. The cause of this correlation is that fractures cannot actually be measured and counted in core that is not recovered. Measurement of RQD is affected in a similar manner in that missing core adds zero footage to the cumulative footage of core segments greater than four inches.

Figure 8 presents the results of several different attempts to adjust the measured fracture density data for the impacts of "unobservable" core. Table F-1 contains a summary of "lost core" for each 10-foot composite interval; these values were determined through office analysis of the video images of the recovered core, and are not directly comparable to the core recovery data measured by drilling support staff (table C-1). Additionally, table F-1 contains the cumulative footage for each depth increment that was logged as "rubble zone." The question of the number of actual, in-situ fractures represented by an interval of "rubble" is problematic. Certainly some disaggregation of rock is associated with the drilling process. However, it is possible to place some limits on the number of real fractures that may be represented by logged rubble zones.

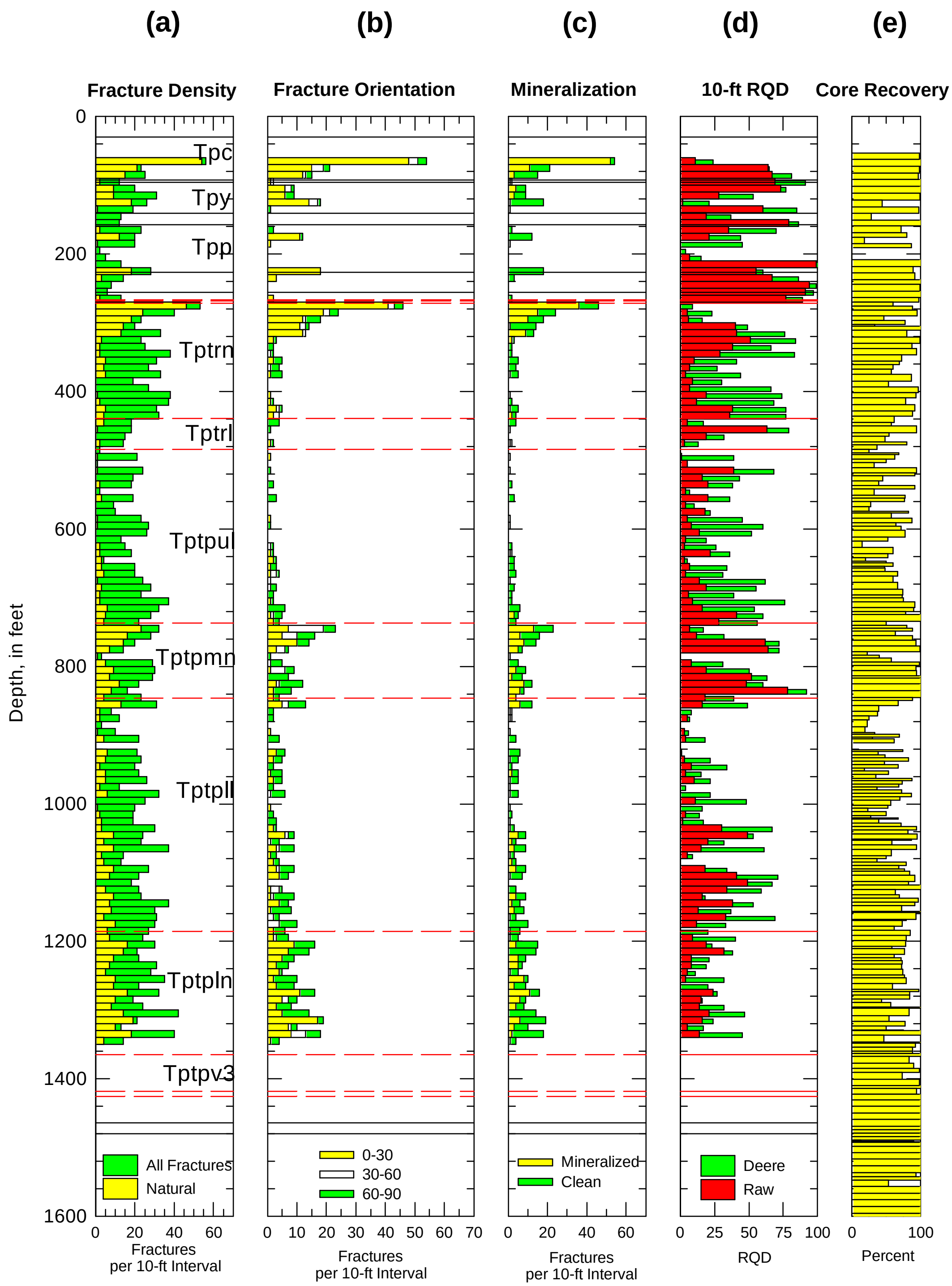

Figure 7. Graphs showing (a) measured fracture density, (b) fracture orientation (dip), (c) mineralized fractures, (d) 10-ft video-analysis RQD, and (e) core recovery for the upper portion of the USW SD-9 drill hole. Solid horizontal lines in (1) indicate top and bottom contacts of the Tiva Canyon and Topopah Spring Tuffs and the top of the Calico Hills Formation. Dashed horizontal lines are contacts of Topopah Spring zonal units.

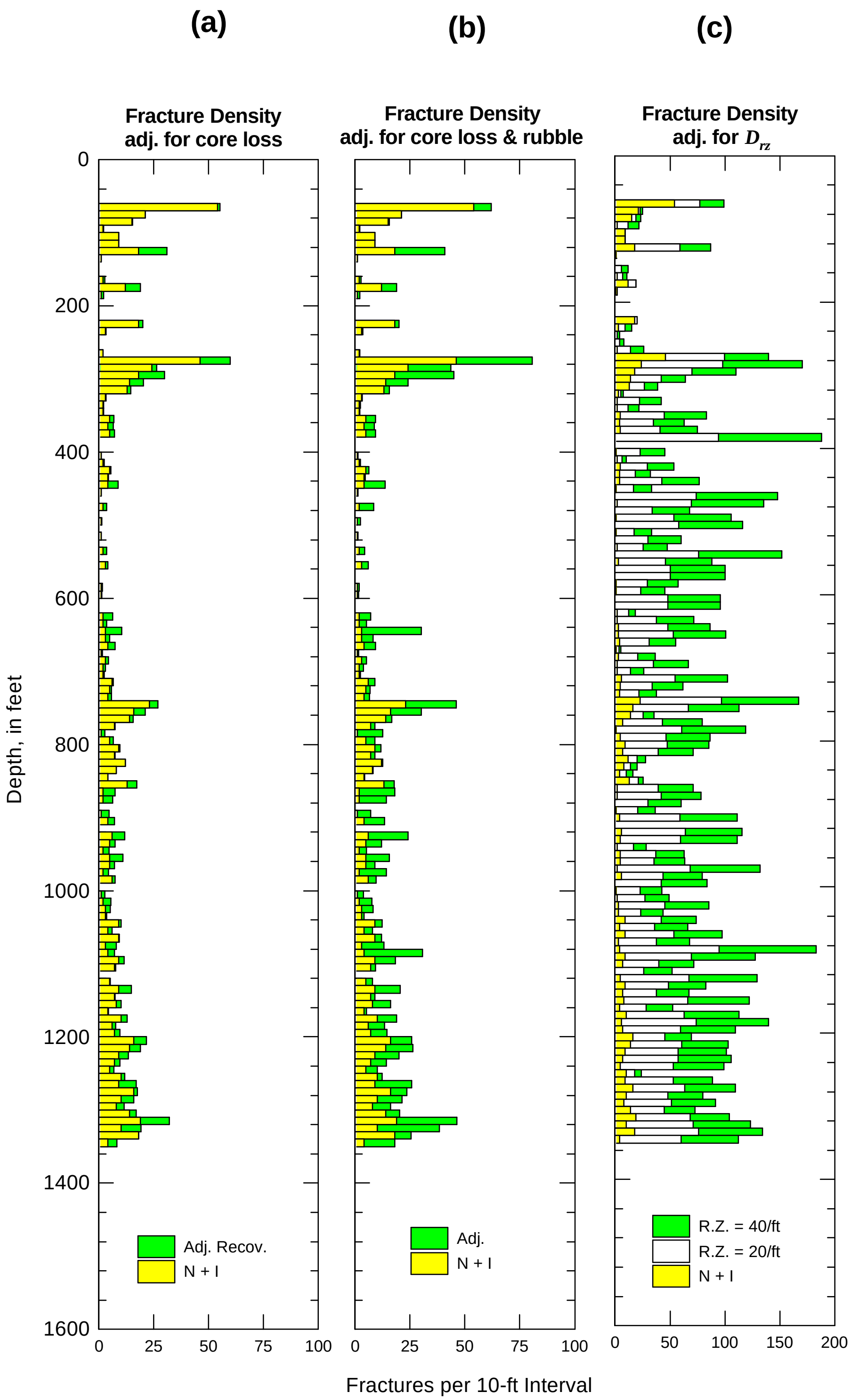

Figure 8. Graphs showing fracture density adjusted for measurement effects of lost core and rubble zones. (a) Adjusted for core recovery only. (b) Adjusted for core recovery and length of rubble zones. (c) Adjusted for core recovery and for intensity of fracturing in rubble zones. See text for method of calculation. Note expanded frequency scale in (c).

Part (a) of figure 8 presents both the number of "natural" (natural plus indeterminate) fractures logged from the core video tapes and the likely number of fractures that would have been logged had there been 100 percent core recovery. The formula for this adjustment is as follows:

$$N_{cl} = \frac{N + I}{(10 - CL)/10} \quad , \qquad (2)$$

where N_{cl} is the number of fractures per 10-ft interval adjusted for ***c***ore ***l***oss, $N + I$ is the counted number of natural and indeterminate fractures, and CL is the cumulative footage of lost core in the 10-ft interval.

Equation (2) adjusts only for unrecovered intervals. Part (b) of figure 8 attempts an additional first-order correction for the effect of fractures that could not be logged individually because the core was rubblized. This correction is:

$$N_{cr} = \frac{N + I}{(10 - (CL + RZ))/10} \quad , \qquad (3)$$

where N_{cr} is now the number of fractures adjusted for both ***c***ore loss and ***r***ubble zones and RZ is the cumulative footage of those rubble zones in the relevant 10-ft depth interval.

Both equations (2) and (3) amount to an assumption that the density of fracturing present in the in-place rock for those parts of the core that were either lost or rubblized is essentially the same as the density of fracturing present in the core that was recovered. This assumption of equal fracture densities in both lost and recovered core probably is not conservative from a rock-mass stability standpoint. One might anticipate lost (or rubblized) intervals to have been more densely fractured than material that maintained its integrity to some extent during the mechanical agitation of drilling and core retrieval.

A more hypothetical and less-conservative adjustment of the measured fracture densities has been attempted in part (c) of figure 8. For this adjustment, a rubble zone is considered to consist of an arbitrary number of fractures per foot of rubble. The total number of fractures per 10-ft depth increment is then simply the core-recovery-adjusted fracture density, N_{cl}, plus the footage of rubble times this assumed fracture density:

$$N_{rz} = N_{cl} + D_{rz} \times L_{rz} \quad . \qquad (4)$$

Here, N_{rz} is the desired total number of fractures, adjusted for ***r***ubble-***z***one fracture density, L_{rz} is the cumulative length of rubblized material, and D_{rz} is either 20 or 40 fractures per foot of rubble. The values of 20 and 40 fractures per foot originate from the criteria that drilling support staff used to distinguish the intervals that would be classified as rubble zones. An initial value of 40 fractures per foot as the criterion was later reduced to 20 per foot after it became evident that much of the rock at Yucca Mountain was highly fractured. Note that these values were selected merely to eliminate the time-consuming recording of each individual fracture separately during the logging of highly broken intervals, and that neither value for D_{rz} may necessarily be correct for any particular interval of core. Mechanical disaggregation of some otherwise-intact core is anticipated during the course of drilling. Additionally, the presence of large lithophysal cavities in parts of the welded-tuff sequences means that some intervals of lost core may, in fact, represent actual void space in the rock; such void space is not "fractured," per se. Unsupported (but unfractured) rock, particularly near the upper margins of large lithophysal cavities, may be mechanically broken by pressure of the advancing drill string and dropped into the cavity to be recovered as "rubble" when the coring assembly advances to the bottom of the cavity.

Framework Hydrologic Properties

Laboratory Techniques

Core samples were obtained at regular intervals for laboratory measurements of framework material properties. "Framework material properties" are defined in Study Plan 8.3.1.4.3.1 (Rautman, 1993) as porosity, bulk and particle density, and saturated hydraulic conductivity. Water contents were also determined and used to compute saturation. Measurement of framework material properties was carried out in collaboration with SCP Study 8.3.1.2.2.3 (USGS, 1991a).

Approximately 580 eight-inch long core samples were collected for hydrologic analyses on a nominal 3-ft, regular sampling interval. Each core sample was subdivided into two subsamples. A 2-

inch long core fragment was placed in a metal container and sealed within minutes of core retrieval from the hole, An immediately adjacent 6-inch subsample was preserved in a Lexan™ tube that was capped and sealed with duct tape. The intent was to preserve in-situ moisture contents as closely as possible and especially to prevent dry-out of the core and subsequent irreversible changes in pore geometry caused by desiccation of clays and zeolites. Such changes have been demonstrated to affect permeability measurements irreversibly.

Porosity, bulk density, particle density, and water content were determined in the laboratory for the hermetically sealed 2-inch core fragments. Separately, a subset of the 6-inch core samples were subcored to produce specimens suitable for measurement of saturated hydraulic conductivity. Core plugs were trimmed using a small diamond saw to approximate right-circular cylinders approximately 2.5 cm in diameter and 3–10 cm long prior to testing. Porosity, bulk density, and particle density were also measured for these prepared specimens.

Water content was determined by gravimetry and is reported as cubic centimeters per cubic centimeter. Porosity (ϕ, in cubic centimeters per cubic centimeter and expressed as a decimal fraction for simplicity), bulk density (ρ_b, in grams per cubic centimeter), and particle density (ρ_p, in grams per cubic centimeter) were determined using gravimetry and Archimedes' principle to determine sample volume. There were two departures from the classical application of this technique. First, the samples were initially saturated with carbon dioxide gas by introducing the gas into an evacuated bell jar containing the samples; this process, which was repeated three times, prevents air entrapment in small internal pores within the densely welded tuff samples because the CO_2 is water-soluble. The samples were then saturated with degassed distilled water under a vacuum. Scoping studies have indicated that saturated weights did not change meaningfully following a single iteration of this vacuum-saturation process, even with the addition of a pressure-saturation step. Second, the samples were dried in a relative-humidity (RH)-controlled oven at 60°C and 65-percent RH (after concepts proposed by Bush and Jenkins, 1970), rather than at 105°C and associated ambient RH. Soeder and others (1991) advocated the use of a lower temperature, humidified technique, not only to preserve water present in the crystal structure of any clays or hydrated minerals (such as zeolites), but also to retain water loosely bound to grain surfaces which is otherwise unavailable for unsaturated flow. The selected RH of 65 percent translates to an estimated residual-saturation pressure for Yucca Mountain samples of approximately –700 bars (L.E. Flint, U.S. Geological Survey, written communication, 1996).

Particle density, as used in this report, is similar to the more commonly reported grain density. However, because particle density is a property computationally derived from intact core samples, totally encapsulated void space (which is inaccessible to water flow) is not considered. Particle density is almost invariably lower than a grain density determination obtained by crushing the rock and measuring the change in total volume. Particle density will approach grain density for rocks that have little totally encapsulated pore space. Bulk-property measurements were repeated after more conventional sample drying at 105°C to allow for comparison with other reported data (ASTM, 1990). Sample weights were reduced to the desired bulk properties as follows.

$$\rho_b = \frac{\text{dry weight}}{\text{bulk volume}}\ , \qquad (5)$$

$$\phi = \frac{\text{pore volume}}{\text{bulk volume}}\ , \text{ and} \qquad (6)$$

$$\rho_p = \frac{\text{dry weight}}{\text{bulk volume - pore volume}}\ , \text{ where} \quad (7)$$

$$\text{pore volume} = \frac{(\text{saturated weight} - \text{dry weight})}{\rho_w}\ , \quad (8)$$

and ρ_w is the temperature-adjusted density of water (in grams per cubic centimeter). Bulk volume is simply the weight of the fully-saturated sample submerged in water (by Archimedes' principle). Volumetric water content (VWC) was determined as:

$$\text{WVC} = \left(\frac{\text{saturated weight} - \text{dry weight}}{t}\right) \cdot \rho_b\ . \quad (9)$$

Saturated hydraulic conductivity, K_s, in meters per second and usually presented as $\log_{10} K_s$ in this report, was measured using a constant-head method. The core plugs were saturated with tap water using the vacuum evacuation/CO_2 flooding technique. Each sample was encased in heavy vinyl tubing and placed in a chamber (Hassler permeameter) that produced a hydraulic confining pressure (0.41–0.55 MPa), slightly exceeding the gradient across the sample, to prevent escape flow around the sides of the sample. Confining pressures of this magnitude do not affect the permeability of the rock, especially since welded samples have compressive strengths on the order of 100 MPa (Nimick and Schwartz, 1987). A separate system provided J-13 tap water under pressure for flow through the sample. Effluent was weighed on a top-loading balance and the mass was recorded as a function of time as the water left the sample. Saturated hydraulic conductivity was computed from Darcy's law:

$$K_s = \frac{Q}{A} \cdot \frac{L}{\Delta H} \quad , \qquad (10)$$

where Q is the quantity of water flowing through the sample per unit time (cm^3/sec), A is the cross-sectional area of the sample core plug (cm^2), ΔH is the change in total head (cm) across the sample, and L is the length (cm) of the core plug. Note that K_s has been converted to units of meters per second in all tables and figures in this report.

Material-Properties Data

Results of the laboratory material-properties determinations are presented in Appendix G. Table G-1 contains bulk properties (porosity, bulk density, particle density) and initial water contents for both relative-humidity oven-dried and 105°C-dried samples. Saturated hydraulic conductivity measurements are presented in table G-2. Separate porosity measurements were also obtained from the permeability-plug samples. These supplemental porosity data are listed in the table of conductivity values.

Data from table G-1 are presented graphically in log format in figure 9. The figure includes both the relative-humidity and 105°C data, which are represented by different symbols. Note that the two values for each sample are essentially identical throughout most of the upper portion of the drill hole. Major differences in the properties measured by these two techniques occur only in the presence of hydrated minerals, such as clays and particularly zeolites. Generally, the picture that emerges from the material-properties data is reflective of the thermal/mechanical units identified in table 4. The saturated hydraulic conductivity data from table G-2 are presented in graphical format in figure 10, together with the corresponding porosity measurements from these subcored sample plugs. Note that samples identified as exhibiting no measurable flow through the Hassler permeameter have been assigned an arbitrary K_s value for plotting purposes of 10^{-14} m/sec ($\log_{10} K_s = -14$). Porosity and bulk density values from table G-1 are also illustrated on the log sheets of Appendix B, as are values for approximate in-situ saturation.

The major lithologic subdivisions of the rock column penetrated by drill hole USW SD-9 can be identified in the material-property profiles shown in figure 9. The unsampled material to a depth of approximately 50 ft (15 m) corresponds to the drilled interval consisting of drill-pad fill and colluvial deposits [to a depth of 53.6 ft (16.34 m) as indicated in the geologic log of Appendix B]. The welded portion of the Tiva Canyon Tuff is represented by a few measured porosity values of approximately 0.10, down to a depth of 55.7 ft (16.98 m). Below this depth, porosity values increase progressively through the lower vitric zone of the Tiva Canyon (the shardy-base interval; Istok and others, 1994), and they remain high (0.30–0.50) through the interval comprising the base of the Tiva Canyon Tuff, the Yucca Mountain and Pah Canyon Tuffs (and associated bedded tuffs), and the nonwelded subzone of the upper vitric zone of the Topopah Spring Tuff. The bottom of this latter subzone is at 266.1 ft (81.13 m), where the porosity decreases abruptly to only a few percent. Welded materials with porosities generally less than 0.10–0.12 form the bulk of the remainder of the Topopah Spring Tuff, extending through the base of the basal vitrophyre subzone of the lower vitric zone (Tptpv3) at 1418.7 ft (432.53 m), in which the values again drop abruptly to nearly zero.

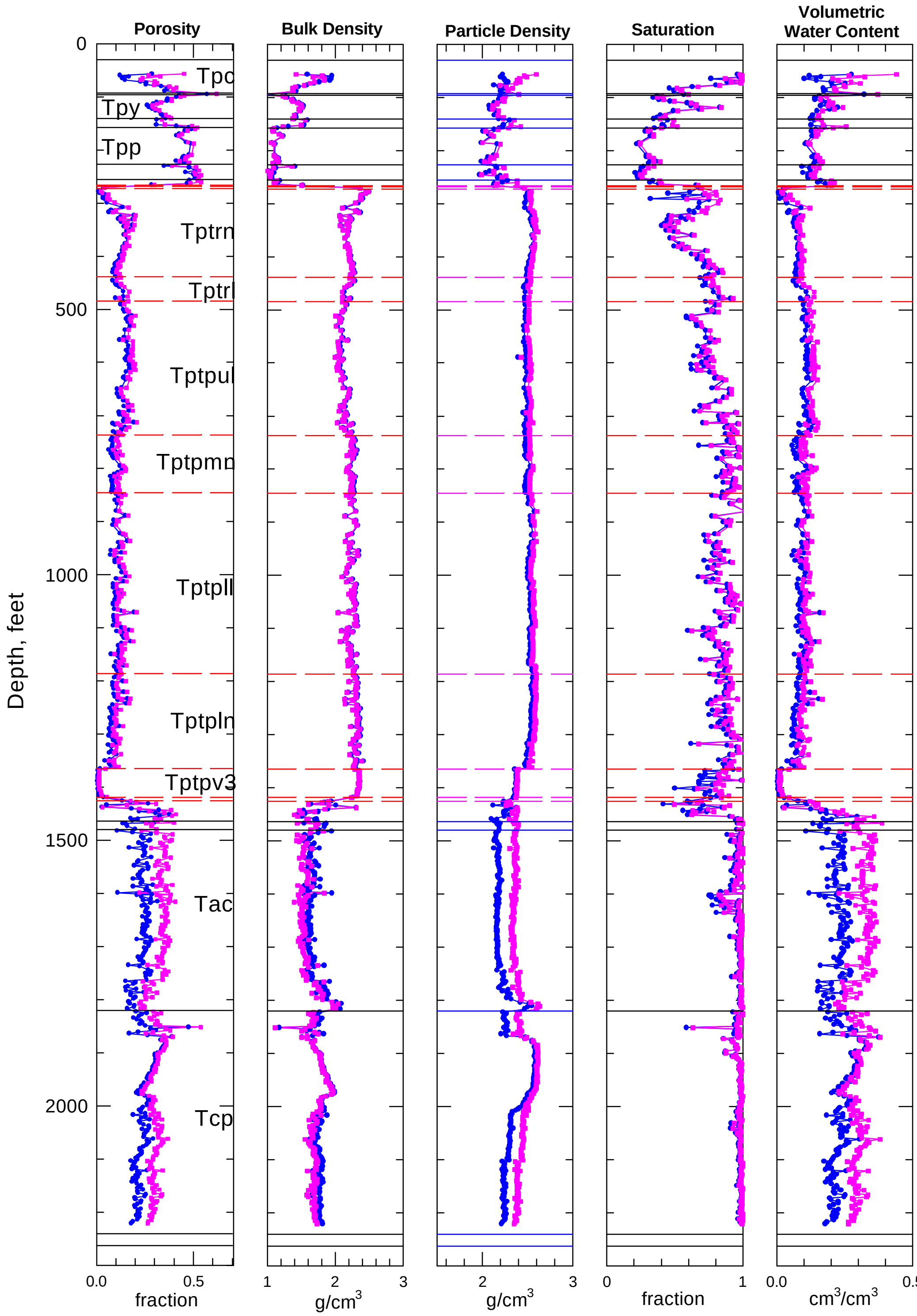

Figure 9. Porosity, bulk density, particle density, saturation, and water content profiles of core samples collected from the USW SD-9 drill core. Solid circles–relative-humidity oven-dried samples; open squares–105°C-dried samples. Solid horizontal lines indicate top and bottom contacts of the Tiva Canyon and Topopah Spring Tuffs, the Calico Hills Formation, and the Prow Pass Tuff. Dashed horizontal lines are contacts of Topopah Spring zonal units.

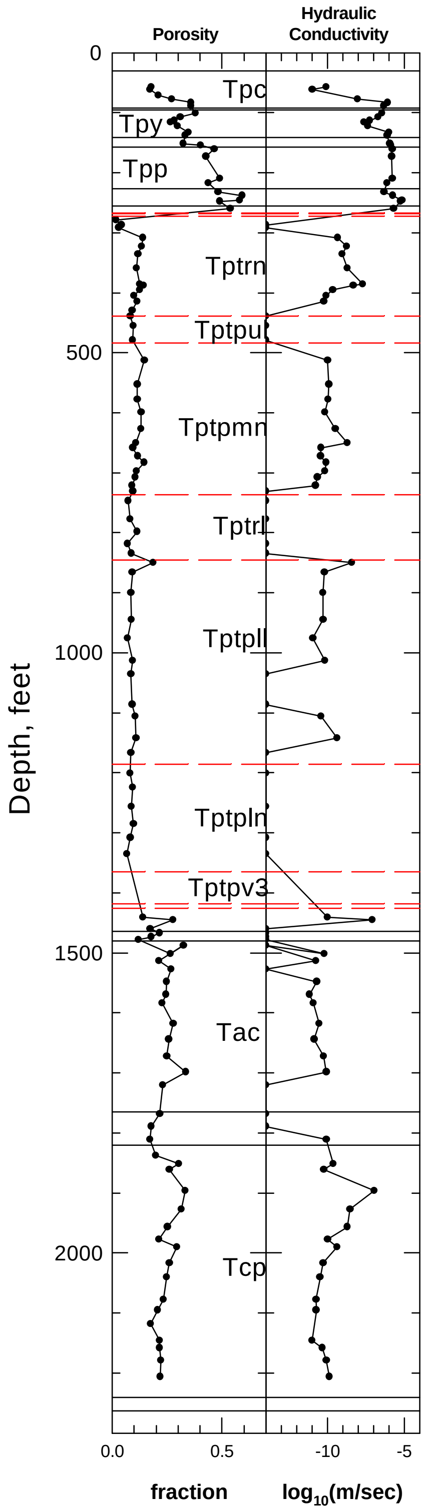

Figure 10. Porosity and saturated hydraulic conductivity profiles of core samples collected from the USW SD-9 drill core. Solid horizontal lines indicate top and bottom contacts of the Tiva Canyon and Topopah Spring Tuffs, the Calico Hills Formation, and the Prow Pass Tuff. Dashed horizontal lines are contacts of Topopah Spring zonal units.

The lowermost zones of the Topopah Spring Tuff exhibit a general increase in porosity and constitute a largely nonwelded interval (including the pre-Topopah Spring bedded tuff) that extends to approximately 1479.9 ft (451.19 m). The two porosity values begin to diverge markedly at approximately 1450 ft (440 m), representing the presence of zeolitized materials in the underlying Calico Hills Formation. The dichotomy between the relative-humidity dried samples and their 105°C-dried counterparts is particularly well displayed by the particle density data (center profile in figure 9). The base of the Calico Hills Formation occurs at 1820.7 ft (555.09 m), although the most prominent change in porosity is associated with the bedded tuff and basal tuffaceous sandstone units of the Calico Hills [1764.4–1820.7 ft (537.93–555.09 m)]. The remainder of the hole consists of ash-flow units of the Prow Pass Tuff. These units are generally zeolitized, as indicated by separation of the relative-humidity and 105°C data, with the exception of an interval from approximately 1870–2000 ft. This interval corresponds approximately to ash-flow unit 3 (Tcp3), from 1868.7 to 2015.8 ft (5690.73–614.57 m; log sheets 27–29, Appendix B). The geologic description of this interval notes the presence of vapor-phase mineralization and slight welding. A somewhat poorly defined and strongly asymmetric ⊂-shaped welding profile can be identified through this interval. The ⊂ is reversed and more prominent in the particle-density profile (fig. 9).

A few of the internal zones of the Topopah Spring Tuff can be identified within the thick welded portion of this unit. Notably, the thin vitrophyre subzone (the “caprock” vitrophyre; Tptrv1) of the upper vitric zone is easily identifiable by its particularly low porosity values (0.05 or less) at approximately 270 ft (82 m). The much thicker basal vitrophyre subzone of the lower vitric zone (Tptpv3) is also easily identified by the 50-ft (15-m) interval near 1400 ft (425 m) of uniformly low (less than 0.05) porosity values. Note also that the basal vitrophyre subzone also exhibits uniform and distinctly lower values of particle density because of the glassy rock type. A suggestion of lower particle densities is associated with the caprock vitrophyre as well.

With the exception of a part of the upper Topopah Spring interval, the majority of the many zones and subzones identified within the Topopah Spring Tuff (table 1) are essentially indistinguishable in the porosity profile. The same holds true for the other bulk-property profiles as well. The exceptions include part of the crystal-rich nonlithophysal zone (Tptrnl) at approximately 325 to 400 ft (100–120 m) and an interval within the upper lithophysal zone (Tptrl and Tptpul) from approximately 450 to 650 ft (140–200 m). Both of these intervals appear to exhibit somewhat higher porosity values (0.10 to as much as 0.20).

Saturation and initial water content data are also presented in figure 9. Water contents (right-hand-most column) invariably are higher in the nonwelded intervals above about 200 ft (60 m) and below 1450 ft (440 m). There is simply more void space in these materials to contain moisture. Note that a non-negligible fraction of the total water content of the zeolitic samples, those obtained from below about 1450 ft (440 m), consists of weakly bound water that is driven off with heating above 105°C. Saturation values are also portrayed graphically on the log sheets of Appendix B.

Saturations are high in the very near-surface samples immediately below surficial colluvium, most likely because of the influence of near-surface infiltration. Saturations generally decrease down hole through the nonwelded PTn interval and then increase progressively through the thick Topopah Spring Tuff welded section. Exceptions to this general trend can be related directly to lower porosities in the partially welded zone within the Yucca Mountain Tuff from about 100 to 120 ft (30–36 m), and to the relatively sharp increase in porosity just below the caprock vitrophyre of the Topopah Spring Tuff at approximately 300 ft (90 m). Saturations approach 1.0 at about 700–900 ft (210–275 m) in the less vapor-phase altered, lower-porosity middle nonlithophysal zone, and again at approximately 1300 ft (396 m). Perched water was first encountered at 1353 ft (412.5 m), although the core had been described in drilling reports as “moist” beginning at approximately 1308 ft (398.78 m). Core saturations decrease in samples obtained from immediately above and within the basal vitrophyre subzone. Samples from below the basal vitrophyre in the lower part of the pre-Topopah Spring bedded tuff are essentially fully saturated, although an interval of noticeably lower saturations is present from roughly 1600 to 1625 ft (487–495 m). An explanation for this decrease in water content is not immediately apparent. The regional water table was encountered at a depth of 1877 ft (572.26 m).

Geophysical Log Data

Geophysical logging activities were conducted in drill hole USW SD-9 on July 13, 1995 to a depth of approximately 1500 ft (450 m). The five geophysical surveys included: (1) compensated density-gamma ray log, (2) epithermal neutron porosity-gamma ray log, (3) dual induction-gamma ray log, (4) dielectric propagation-gamma ray log, and (5) oriented 4-arm caliper. Drill-hole deviation data, including borehole azimuth and inclination, were also recorded. Note that the lower portion of SD-9 (below approximately 1500 ft or 450 m) had not been logged as of December 1994. The majority of the geophysical log traces are shown in figure 11. Because the geophysical logs consist of digital data on 0.5-ft (0.15-m) spacings, this information is not presented in an appendix to this report. The actual trace values can be obtained from the Yucca Mountain Project records facilities using data-tracking number (DTN) TWUSWSD9000095.001.

Density Log Response

The density log [fig. 11(a)] displays the expected responses both to welding and to the development of lithophysal cavities. Bulk density values drop between depths of 67 and 80 feet (20.43–24.39 m) as the logging tool passed from the densely welded lower nonlithophysal zone of the Tiva Canyon Tuff through the progressively less-welded material of the vitric zone; Istok and others have documented continuously changing bulk density values in this shardy base interval. The bedded tuff (Tpbt4) separating the Tiva Canyon tuff from the underlying Yucca Mountain tuff at about 92–95 ft (28–29 m) exhibits a low bulk density. A small increase in density is recorded on the log through the slightly welded middle portion of the Yucca Mountain Tuff between 105 and 130 feet (32.01–39.63 m). Density values decrease through the bedded tuff underlying the Yucca Mountain Tuff (Tpbt3) to very low values of bulk density

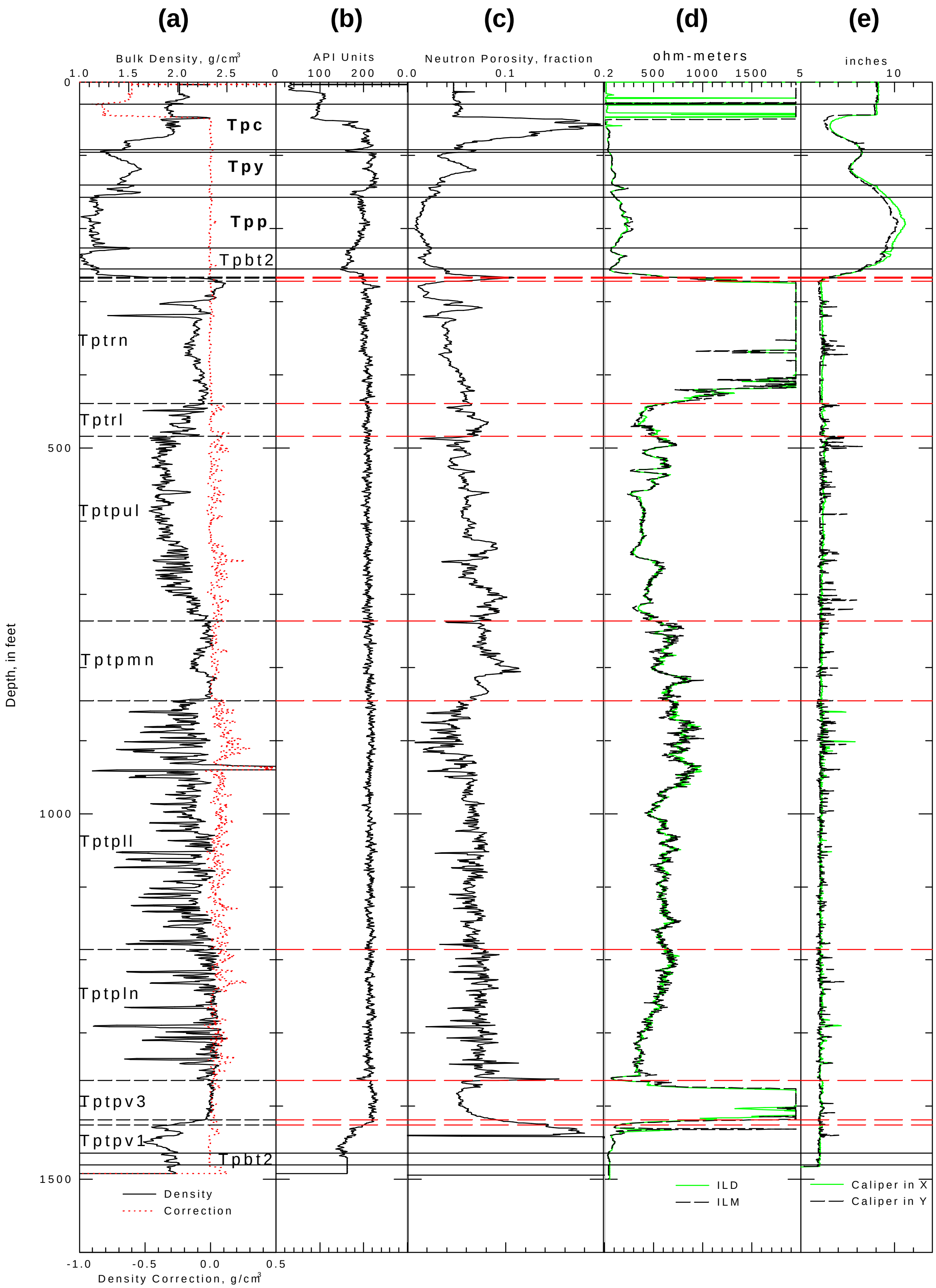

Figure 11. Geophysical log traces from the USW SD-9 drill hole: (a) density log; (b) gamma-ray log; (c) epithermal neutron porosity log; (d) induction log; and (e) caliper log. Log trace data from DTN TMUSWSD9000095.001

(1.15 g/cm^3 and less) in both the Pah Canyon tuff and its underlying bedded tuff (Tpbt2).

The density-log values increase at a depth of about 250 ft (76 m), corresponding to the bottom of the pre-Pah Canyon bedded tuff, and at approximately 265 ft (81 m), density increases abruptly to nearly 2.5 g/cm^3 as the tool passed nonwelded-to-welded transition located slightly below the stratigraphic top of the Topopah Spring Tuff. The density trace continues to indicate high bulk density values through the densely welded upper nonlithophysal zone of the Topopah Spring tuff from 272.1–439.2 feet (82.9–133.9 m). The upper lithophysal zone is well expressed in the density log response as the presence of large lithophysal cavities reduces the overall bulk density of the densely welded rock. Note that bulk density values indicated by the geophysical tool response (less than 2.0 g/cm)^3 are slightly but consistently lower than the laboratory-measured values of bulk density for equivalent depths reported in Appendix G (generally slightly greater than 2.0 g/cm^3).

Bulk density values increase within the middle nonlithophysal zone from 730 to 845 ft (220–260 m), although short intervals (largely obscured by the compressed vertical scale of figure 11) of noticeably lower density within the upper part of this zone are attributed to widely spaced, large lithophysal cavities such as were observed in the down-hole video images. Lower density values also characterize the lithophysae-bearing subzone between depths of 788.1 and 812.5 feet (240.27 to 247.71 m). The trace of the density log through the lower 33.3 feet (10.06 m) of the middle nonlithophysal zone is relatively flat, which is consistent with the general absence of large lithophysal cavities in video images from this section and the higher core recoveries noted in figure 4(a).

At the top of the lower lithophysal zone, density values drop sharply and vary markedly in a somewhat erratic manner; this log response appears to reflect the prominent development of large lithophysae in this part of the densely welded section. This extreme variation in log density continues downward through the lower lithophysal zone, as described from core, into and through the lower nonlithophysal zone. The density log values stabilize at approximately the upper boundary of the lower vitrophyre unit at about 1365.0 feet (416.16 m; log sheet 20, Appendix B). This response pattern appears to be the result of the continued presence of widely-spaced, large lithophysae noted in the borehole video survey. Bulk density values decrease slightly through the lower vitrophyre unit, but then decrease rapidly (and progressively) from about 2.3 to 1.7 g/cm^3 through the gradationally “partially” welded zone above the nonwelded basal unit of the Topopah Spring Tuff.

Gamma-Ray Log Response

The gamma-ray logging tool responds principally to the presence of radioactive potassium (^{40}K) in the whole rock. The log response [fig. 11(b)] indicates lower count rates (API units) above a depth of roughly 50 ft (15 m), which corresponds approximately to the contact of surficial alluvial deposits with bedrock welded tuff of the Tiva Canyon. Below this depth, the gamma-ray log trace is generally unremarkable, reflecting a generally uniform potassium content. Noticeable low count-rate spikes occur at depths of about 95 and 150 ft (29 m and 46 m, respectively). A broader interval of low gamma-ray values is present between about 240 and 260 ft (73–79 m). These gamma-ray lows correspond approximately to the “bedded-tuff” intervals underlying the Tiva Canyon, Yucca Mountain, and Pah Canyon Tuffs, respectively. Presumably, these reworked intervals were weathered sufficiently that some of the radioactive (and non-radioactive) potassium was leached from the rock.

Epithermal Neutron Porosity Log Response

The neutron-porosity log responds principally to the presence of water (hydrogen atoms) in the rock. Higher “porosity” values indicate greater absorption of neutrons by moisture. The log trace [fig. 11(c)] is low in the near-surface welded part of the Tiva Canyon. Neutron porosity values increase markedly with the end of dense welding at the base of the columnar subzone of the lower nonlithophysal zone of the Tiva Canyon Tuff. Neutron porosity values then decrease progressively through the lower vitric portion of the Tiva Canyon to the contact of the underlying bedded tuff (Tpbt4) at 92.3 feet (28.1m). A small increase in neutron porosity is indicated within the bedded tuff unit.

With the notable exception of a small increase within the slightly welded portion of the Yucca Mountain Tuff (centered at a depth of approximately 110 ft (33 m), neutron porosity values are relatively low down to the onset of welding located somewhat below the stratigraphic top of the Topopah Spring Tuff at 252.6 feet (77.0m). The other bedded tuff units (Tpbt3 and Tpbt2) within the upper Paintbrush nonwelded interval (PTn) exhibit little or no effect on neutron porosity values.

Within the upper vitric zone of the Topopah Spring Tuff, the neutron porosity values increase toward the upper contact of the caprock vitrophyre at 268.0 feet (81.7m). Below the vitrophyre, neutron porosity values return to relatively low values. Neutron porosity values typically increase through the upper lithophysal zones and the character of the log response within lithophysal intervals is markedly more erratic, and the tool may be responding to low apparent moisture contents within the large lithophysal cavities. A marked interval of high neutron porosity values occurs at approximately the base of the lithophysal-bearing subzone of the middle nonlithophysal zone of the Topopah Spring Tuff. Neutron porosity values are somewhat low but relatively slowly varying in the lower vitrophyre subzone, and the log trace indicates rapidly increasing values through the partially welded and nonwelded vitric subzones between 1418.7 and 1464.1 feet (432.4–446.3 m).

Dual-Induction Log Response

The dual-induction log tool responds to the apparent resistivity of the rocks surrounding the bore hole. Both the induction log deep and medium traces are portrayed in figure 11(d). A third electrical tool, the spherical-focused log, was also run in drill hole SD-9; however data from this tool are available only below approximately 1450 ft (440 m), and the trace is not included on the figure.

Electrical-type logging tools are somewhat problematic to interpret in the unsaturated zone, and the traces for this tool are included only for completeness. The high-resistivity spikes above 50 ft (15 m) appear to be artifacts associated with steel surface casing. Resistivity values are generally low throughout the Paintbrush nonwelded (PTn) interval, and increase abruptly to off-scale readings (greater than 2000 Ω-m) at the top of the Topopah Spring Tuff. Resistivity values are off scale essentially throughout the upper nonlithophysal portion of the Topopah Spring. The prominent lithophysal zones of the Topopah Spring are not easily identified in the induction-log traces. The upper lithophysal zone exhibits resistitvities of slightly less than 500 Ω-m, whereas readings in the lower lithophysal zone are somewhat higher than 500 Ω-m. Resistivity values decrease in the lower part of the lower nonlithophysal zone, reaching a prominent minimum value just above the lower vitrophyre. Off-scale resistivity readings are associated with the Topopah lower vitrophyre subzone. Resistivity values decrease progressively through the moderately welded portion of the basal Topopah vitric zone, and remain low to the bottom of the logged interval.

Caliper Log Response

The upper part of drill hole USW SD-9 (below surface casing to 53.6 ft (16.34 m) was drilled using tools that produced an approximately 6-inch (15-cm) diameter drill hole. The caliper log trace [fig. 11(e)], which consists of two measurements at each depth in mutually perpendicular directions, indicates that the drill hole is severely washed out in the Paintbrush nonwelded interval above 268.6 ft (81.86 m). Changes in the caliper log through this zone approximate changes in the degree of welding. Hole diameter increases progressively through the shardy-base portion of the partially welded and nonwelded basal Tiva Canyon Tuff, decreases through the partially welded portion of the Yucca Mountain Tuff, and then increases to a maximum of about 10.5 inches (27 cm) immediately above 200 ft (61 m) within the nonwelded ash flows of the Pah Canyon Tuff. Core recovery was essentially zero at this depth [fig. 4(a)]. Hole diameter then decreases progressively to the nominal hole size at the top of the caprock vitrophyre subzone of the Topopah Spring welded tuff.

Hole diameter within the welded portion of the Topopah Spring Tuff are generally in-gauge when averaged over thicker intervals. However, short, rather large washed-out intervals that may increase hole diameter by a third to more than 8 inches (20 cm) are common throughout the welded interval.

These enlarged intervals are thought to correspond to large lithophysal cavities intersected by the bore hole and to intervals of highly fractured rock that “ravel” into the hole with the mechanical agitation of the rotating drill string.

Summary and Conclusions

Drill hole USW SD-9 is one of several holes drilled under Site Characterization Plan Study 8.3.1.4.3.1, also known as the “Systematic Drilling Program,” as part of the U.S. Department of Energy characterization program at the Yucca Mountain site. The SD-9 drill hole was located in the northern part of the potential repository area. The hole is immediately to the west of the Main Test Level drift of Exploratory Studies Facility. The location is just south of the curve connecting the North Ramp decline with the north-south main test level drift. The drill hole collar is located in the bottom of Wren Wash, which has eroded nearly to the base of the Tiva Canyon Tuff. Core from drill hole USW SD-9 recovered essentially complete sections of ash-flow tuffs belonging to the Yucca Mountain, Pah Canyon, and Topopah Spring Tuffs of the Miocene Paintbrush Group, as well as a complete section of the Calico Hills Formation and all but the lowermost part of the Prow Pass Tuff section of the Crater Flat Group.

Wren Wash and the SD-9 drill hole are located relatively close to the inferred source calderas of the Paintbrush Group ash-flow and related tuffs, compared with drill holes located farther to the south within the potential repository block. The Yucca Mountain Tuff is approximately 45-ft (13.7-m) thick, and the interior portion of this ash flow is partially welded. The Yucca Mountain Tuff thins to extinction southward. The Pah Canyon Tuff is 69.4 ft (21.15 m) thick in this drill hole and is completely nonwelded. The Topopah Spring Tuff consists of 1211.5 ft (369.25 m) of generally densely welded material; this is one of the thickest known sections of welded Topopah Spring Tuff at or near Yucca Mountain. Lithophysae are well developed locally within the part of the Topopah Spring, and large lithophysal cavities up to several feet (many tenths of a meter) in diameter are present throughout roughly the lower two-thirds of the unit. This somewhat anomalous occurrence of very large lithophysal cavities, which is in addition to the better known presence of zones containing smaller, inch-scale (cm-scale) lithophysae within the Topopah Spring, may be related to the greater thickness of the unit at this geographic location. The Calico Hills Formation underlies the Paintbrush Group tuffs, and this unit consists of 341 ft (103.87 m) of nonwelded and mostly zeolitized tuffaceous materials. Rocks totaling 402.4 ft (122.65 m) in thickness and belonging to the ash-flow sequences of the Prow Pass Tuff underlie the Calico Hills Formation. The drill hole was stopped short of the base of the lowermost known ash-flow unit of the Prow Pass Tuff, and the true thickness of this unit is not known.

Quantitative and semiquantitative data are included in this report for core recovery, rock-quality designation (RQD), lithophysal cavity abundance, and fracturing. These data are variable spatially, both within and among the major formational-level stratigraphic units. Core recovery and RQD values are typically somewhat inversely correlated with the degree of welding; nonwelded intervals exhibit higher recoveries and more intact (higher) RQD values. An exception is a completely unconsolidated nonwelded interval near the base of the Pah Canyon Tuff. RQD is distinctly lower in the main lithophysal zones. Rocks of the nonwelded and generally zeolitized intervals belonging to the Calico Hills Formation and Prow Pass Tuff yielded virtually complete core recovery and the consistently highest RQD indices of the entire drill hole. Quantitative information regarding lithophysal cavity abundances is complicated by the existence of cavities much larger than the core diameter; drilling through intervals of these large cavities produced large zones of “lost” core and rubble.

Quantitative data for the framework material properties of porosity, bulk density, and saturated hydraulic conductivity are tabulated in this report. Graphical representations of variations in these laboratory hydrologic properties reflect the degree of welding and the presence of zeolitization. Many of the contacts between primary, genetic geologic contacts are not expressed in the material-property profiles. Approximate in-situ saturation data of samples preserved immediately upon recovery from the hole are included in the data tabulation. These numeric values of the framework material properties can be used to develop a “material-property stratigraphy” that appears to correspond in a first-order manner to the older thermal/mechanical stratigraphy used for some Yucca Mountain Project activities.

Geophysical logs have been obtained for the upper approximately 1500 ft (450 m) of the USW SD-9 drill hole (to near the base of the Paintbrush Group). The lower part of the hole has not been logged. The suite of geophysical log traces included in the report include density, gamma-ray, epithermal-neutron porosity, electrical resistivity, and caliper profiles down to the base of the Topopah Spring Tuff. The bulk-density log provides the most lithologic information, and several of the lithologic subdivisions identified in the SD-9 drill hole can be tied to distinctive changes in the density trace. Discrimination of welded from nonwelded rock types and lithophysal from nonlithophysal zones is immediately apparent in the density log. This independent line of evidence also confirms the fact that the broader, genetic lithostratigraphic unit boundaries do not correspond in detail to material property units as identified either through the use of geophysical logs or laboratory measurements on core samples.

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Appendix A: Detailed Lithologic Descriptions

Lithologic Unit Descriptions

The following are unit-by-unit descriptions of the USW SD-9 core. The SD-9 Borehole was hammer-drilled to 53.6 ft (16.34 m); drill-pad-fill material and alluvial overburden were neither cored nor described. The descriptions that follow are based on the detailed geologic log sheets presented in Appendix B, and reference to the log forms may be helpful when reading these lithologic unit descriptions. Although these descriptions emphasize the new stratigraphic nomenclature proposed by Buesch and others (1996), the unit descriptions are cross-referenced where feasible to the older zonation of the Paintbrush Group tuffs published by Scott and Bonk in 1984. These older names and some of their historical modifications are well entrenched on the Yucca Mountain Project.

Tiva Canyon Tuff (Tpc)

Crystal-poor lower nonlithophysal zone (Tpcpln) 53.6–55.7 ft (16.34–16.98 m)

Columnar subzone (Tpcplnc) 53.6–55.7 ft (16.34–16.98 m)

The lowermost portion of the columnar subzone (columnar zone of Scott and Bonk) is characterized by a light tan-gray, densely welded, devitrified matrix punctuated by dark, vitric, flattened, rectangular pumice clasts with feathery ends. More sparse, larger pumice clasts have been argillically altered to pink clay. The rock is composed of 4–6 percent dark pumice fragments, 1–2 percent dark vitric lithics, and 3–4 percent phenocrysts of feldspar with minor biotite. Joints are dominantly smooth and high-angle (nearly parallel to the core axis), and are typically coated by vapor-phase minerals. The contact at 55.7 ft (16.98 m) between the columnar subzone and the underlying lower vitric zone is faulted, with 0.1 ft (30.5 mm) of sandy-clay gouge that appears related genetically to the vitric zone. The columnar subzone is severely fractured because of its proximity to this low-angle fault (nearly perpendicular to the core axis in a vertical drill hole), and then healed (refilled) with milled fragments of the vitric zone in the fracture voids.

Crystal-poor vitric zone (Tpcpv) 55.7–92.3 ft (16.98–28.14 m)

Moderately welded subzone (Tpcpv2) 55.7–65.0 ft (16.98–19.92 m)

This partially welded section of the lower vitric zone (described as the “shardy base” of the columnar zone of Scott and Bonk; Istok and others, 1994) is composed of a matrix of moderately deformed orange-brown bubble-wall shards that enclose light pink-gray, weakly altered pumice clasts, 1 percent small brown angular lithic fragments, and 2–3 percent phenocrysts. Some pumice fragments are as large as 1.6 inches (40 mm) in diameter; some are altered to orange clay and about one-fourth of the clasts are black and vitric. Phenocrysts are dominantly feldspar, with traces of biotite. Approximately 3–5 percent of the shards that make up the matrix are obsidian.

Nonwelded subzone (Tpcpv1) 65.0–92.3 ft (19.82–28.14 m)

The nonwelded subzone (also aggregated as part of the shardy base interval by Istok and others, 1994) occurs from a depth of 65.0 to 79.0 ft (19.82 to 24.09 m). The lower nonwelded subzone contains 7–10 percent pale orange-brown, weakly altered pumice fragments up to 1 inch (28 mm) in diameter, 1–2 percent small brown angular lithics, 3–4 percent phenocrysts of feldspar, and traces of biotite in a vitric, nonwelded matrix composed mostly of partially argillized, orange-brown bubble-wall shards. Approximately 20–25 percent of the shards constituting the matrix are black and vitric. Fractures in this interval are generally smooth and are commonly coated with a black mineral. At a depth of 88.7 ft (27.04 m), the pumice content increases with proximity to the base of the Tiva Canyon section. The lowermost subunit is a 1.2 inch (30.5 mm)-thick pumice fall underlain by a sharp basal contact.

Pre-Tiva Canyon Tuff bedded tuff (Tpbt4) 92.3–95.9 ft (28.14–29.24 m)

The upper contact of the pre-Tiva Canyon Tuff bedded tuff is a weakly developed paleosurface. The unit has a sandy, clast-supported texture with 5–7 percent small, white, angular pumice fragments, 4–5 percent feldspar, and traces of biotite phenocrysts. This unit grades downward into a medium-grained pumice-fall deposit that becomes coarser downward. The fallout deposit is composed of mixed pumice types; 10–15 percent of the clasts are a black obsidian variety.

Yucca Mountain Tuff (Tpy) ***95.9–140.9 ft (29.24–42.95 m)***

The Yucca Mountain Tuff is a vitric, weakly vapor-phase-altered, nonwelded ash-flow tuff containing 5–10 percent small, dense-textured, vitric pumice fragments, 1–2 percent phenocrysts of feldspar and lesser biotite, and 1 percent small angular lithics of quartz latite. The matrix is composed of a pale red-brown weakly altered mass of indistinguishable material that contains 5 percent black vitric shards, which increase in abundance downward to 10–12 percent. The tuff becomes slightly welded from 121.7 to 133.7 ft (37.10 to 40.76 m), and contains 10–15 percent black shards in a gray vitric matrix with hazy, recrystallized (altered?) spots. Pale-colored, vitric pumice clasts grade downward into black vitric, “soft lithics” in this zone. The lower contact is depositional.

A second faulted interval is present at a depth of 122.1 ft (37.21 m). This 0.15-ft (0.046-m) thick gouge zone of soft clayey material is essentially flat-lying, as was the fault encountered at 55.7 ft (16.98 m) marking the division between the Tiva Canyon columnar subzone and the underlying shardy-base interval.

Pre-Yucca Mountain Tuff bedded tuff (Tpbt3) 140.9–157.7 ft (42.96–48.08 m)

The pre-Yucca Mountain Tuff bedded tuff is a clast-supported, highly pumiceous unit with a vitric matrix. The bedded tuff consists of 25–35 percent small, subangular pumice fragments, 1–2 percent phenocrysts of feldspar and minor biotite, and 1 percent small dark lithics in an altered and reworked vitric matrix containing 2–3 percent black shards. Three sets of well-sorted, oscillatory 2- to 5-cm-thick, lithic-rich pumice-fall beds occur between depths of 143.2 and 143.5 ft (43.66 to 43.75 m). From 143.5 to 154.2 ft (47.01 m), the rock exhibits a reworked bedded texture with a pumice content of 15–20 percent; pumice clasts are slightly larger than near the top of the unit. A well-sorted pumiceous ash fall grades downward into a coarse-grained pumice fall from 154.2 ft to 156.7 ft (47.77 m). The final interval from 156.7 ft to the bottom of the unit at 157.7 ft (48.08 m) is a sandy, clast-supported bedded tuff composed of material similar in composition to, and presumably derived from, the underlying Pah Canyon Tuff.

Pah Canyon Tuff (Tpp) ***157.7–227.1 ft (48.08–69.24 m)***

The Pah Canyon Tuff is an ash-flow deposit containing 25–30 percent pale-colored, subangular pumice clasts (0.12–1.77 inch; 3–45 mm) set in a nonwelded, vitric, slightly altered light-brick-red matrix. The pumice clasts are bimodal, with approximately equal portions of a light gray, dense-textured, vitric variety and a finely-laminated vesicular type, all of which vary in size from 0.47 to 1.77 inch (12–45 mm). Pumice clasts become green and zeolitized below 164.0 ft (50 m) depth. The Pah Canyon Tuff also contains 1 percent dark-colored, 0.31–0.39-inch (8–10-mm) lithic fragments and 3–5 percent phenocrysts of feldspar with traces of biotite. A characteristic, pumiceous, basal “white zone” is present from 223.9 to 227.1 ft (68.26 to 69.24 m).

Pre-Pah Canyon Tuff bedded tuff (Tpbt2) 227.1–252.6 ft (69.24–77.01 m)

The pre-Pah Canyon Tuff bedded tuff is nonwelded, vitric, sandy textured and probably reworked. The unit grades downward to a coarse-grained, pumice fall at 230.8 ft (70.37 m). The bedded tuff is composed of 20–25 percent small, light-gray, laminated and red-gray, altered pumice clasts, 2–4 percent dark vitric lithic clasts, 3–5 percent feldspar phenocrysts and 2 percent biotite flakes in an altered matrix with 4–5 percent black shard content. The coarse-grained fallout deposit from 230.8 to 252.6 ft (77.01 m) contains 85–90 percent coarse, white, vitric pumice clasts up to 0.79 inch (20 mm) in diameter and a mixture of lithics that constitute 5–10 percent of the rock. A weakly developed paleosol surface with hematite staining is visible at 245.9 ft (74.97 m) in the pre-sampling core videos.

Topopah Spring Tuff (Tpt)

Crystal-rich vitric zone 252.6–272.1 ft (77.01–82.96 m)

Nonwelded subzone (Tptrv3) 252.6–266.1 ft (77.01–81.13 m)

A 1.18 inch (30 mm), pink-clay and small pumice-clast zone found at 255.5 ft (77.90 m) has been identified by the Buesch and others (1996) as the upper part of a presumed paleosol unit. However, the ash-flow material both above and below this pink-clay marker are virtually identical in composition and texture. Thus, the upper contact of the Topopah Spring Tuff—and of the nonwelded vitric subzone—is placed at 252.6 ft (77.01 m), where the rock type changes from the coarse-grained pumice fall, assigned to the pre-Pah Canyon budded tuff, to nonwelded ash-flow tuff similar to some dozen or so feet (several meters) of underlying, nonwelded material.

The upper, vitric, nonwelded subzone (part of the caprock zone of Scott and Bonk) is pumiceous, normally containing 15–20 percent pumice clasts. The pumice content within this upper part of the Topopah Spring tuff appears to increase progressively from 15 or 20 percent to about 80–90 percent between 261.1 ft (79.60 m), and the most prominent change in rock type at the top of the vitrophyre subzone at 268.6 ft (81.89 m). The entire upper portion of Topopah Spring Tuff is crystal rich, containing up to 20 percent phenocrysts of feldspar and biotite. However, the uppermost portion of the nonwelded subzone has a noticeably reduced phenocryst content (only 3–5 percent). Small, angular, quartz latite lithics (2–3 percent) are easily identified by their contrasting hardness relative to the nonwelded tuff.

Moderately welded subzone (Tptrv2) 266.1–268.6 ft (81.13–81.89 m)

Increased welding creates what is also sometimes referred to as a “sintered” interval within the pumiceous zone just above the vitrophyre subzone. The upper contact is placed at the uppermost limit of flattening affecting large gray pumice clasts that compose 80–90 percent of the pumiceous interval at the bottom of the upper vitric nonwelded subzone. Note that this “contact” is gradational. The rock is clast-supported, and consists of approximately 10 percent devitrified and vitric lithic clasts and 3–5 percent feldspar and oxybiotite phenocrysts in a vitric matrix. Elsewhere at Yucca Mountain, the moderately welded interval is indistinguishable, and the rock type changes from virtually nonwelded to vitrophyre over an interval of inches.

Densely welded (vitrophyre) subzone (Tptrv1) 268.6–272.1 ft (81.89–82.96 m)

The densely welded or vitrophyre subzone (also known as the “caprock vitrophyre” after the description of Scott and Bonk, 1984) is composed of dark-colored, densely fused, crystal-rich glass. A distinctive red vitrophyre containing black glass fiamme from 268.6 to 271.6 ft (81.89 to 82.80 m) overlies an equally distinctive black vitrophyre from 271.6 ft to 272.1 ft (82.96 m). Phenocrysts of feldspar make up 15–20 percent of the rock with trace quantities of oxybiotite and rare pyroxene. A large, porphyritic pumice clast is present at 268.7 ft (81.92 m). Thin, pale blue, weakly opaline, vapor phase silica coatings are present preferentially on open, dominantly subhorizontal, joints.

Laboratory material property data, discussed earlier in this report (See “Framework Hydrologic Properties” on page 23.), indicates that the greatest change in rock properties occurs at the very sharp upper contact of the underlying vitrophyre subzone.

Crystal-rich nonlithophysal zone (Tptrnl) 281.0–439.2 ft (85.67–133.90 m)

The upper contact of the upper, crystal-rich nonlithophysal zone (rounded zone of Scott and Bonk) is gradational, and this unit is distinguished from the caprock vitrophyre only by the presence of incipient devitrification. The unit is composed of 15–17 percent phenocrysts, 10–30 percent cognate pumice clasts, 10–15 percent exotic (hard) quartz-latitic clasts, and 2–3 percent rhyolitic soft-lithic fragments set in densely welded, devitrified matrix. Phenocrysts include sanidine, minor plagioclase and biotite, with lesser pyroxene and hornblende, and accessory magnetite. Predominantly light gray to light pink-gray, vapor-phase altered pumice fragments increase abruptly from 5–10 percent to around 30 percent approximately 50 ft (15.24 m) below the top of the unit at about 230 ft (70 m).

Fine-grained, aphyric and porphyritic volcanic lithic fragments are present throughout the unit. Lithophysae are only weakly developed and these are widely spaced within the nonlithophysal zone, changing in form from weakly opened vugs near the upper contact of the unit to small, flattened lithophysae in a lower zone from 318.0 to 322.7 ft (96.95 to 98.38 m) depth. The uppermost vapor-phase mineral coating of a lithophysal cavity occurs at a depth of 329.0 ft (100.30 m). Vapor-phase alteration of the matrix is pronounced, although relict shard textures are preserved locally.

Crystal-rich lithophysal zone (Tptrl) and Crystal-poor upper lithophysal zone (Tptpul) 439.2–728.8 ft (133.90–222.20 m)

The abundance of lithophysae increases abruptly to more than 10 percent of the rock at 439.2 ft (133.90 m) defining the upper lithophysal interval of the Topopah Spring Tuff. Scott and Bonk (1984) subdivided this interval into a host of laterally equivalent and vertically variable units based principally upon color. The intensity of vapor-phase alteration associated with the lithophysae also increases with depth, and the densely welded and devitrified matrix of the core becomes pale red-purple. Lithophysae continues to increase in abundance downward. At 439.2 ft, the core averages about 25 percent lithophysae that are approximately 0.39–1.18 inch (10–30 mm) in diameter and exhibit pink-gray alteration halos. Rock constituents in the crystal--rich portion of this interval include 10–12 percent feldspar phenocrysts, 0.5 percent oxybiotite crystals, and less than 1 percent small, hard lithic fragments (red-brown quartz latite). Nonlithophysal pumice clasts constitute approximately 25 percent of the rock at the top and bottom of the upper lithophysal zone, but diminish inward and are absent in the center of this interval. Pumice clasts up to 0.98–1.97 inches (25–50 mm) change from light gray or white at the top of the unit, to pale-brown at the bottom. Pumice clasts are up to 2.36 inches (60 mm) in diameter in the lower part of the unit.

Compositional transition interval – 454.7 to 468.6 ft (138.63 to 142.87 m): The core changes gradually in composition downward through this transition interval from brown, crystal-rich quartz latite containing flattened and deformed cognate lithics of more-grey-colored, crystal-poor rhyolite to medium-gray crystal-poor rhyolite containing flattened and deformed clasts of brownish crystal-rich quartz latite.

Crystal transition interval – 448.2 to 485.2 ft (136.61 to 147.88 m): The phenocryst content of the matrix (excluding the deformed, cognate lithic clasts) changes from 10–20 percent at 448.2 ft (136.61 m) to only 3–5 percent at 485.2 ft (147.92 m). This change in phenocryst content corresponds to a change in rock type from crystal-rich quartz latite (Tptr) to crystal-poor rhyolite (Tptp). This 37-ft (11-m) thick interval contains the gradational contact between the crystal-rich and crystal-poor (informal) members of the Topopah Spring Tuff (table 2). Elsewhere at Yucca Mountain, the crystal transition between quartz latite and rhyolite occurs at different positions with respect to zonal structure produced by alteration phenomena, such as lithophysae development. In such locations, the crystal-rich lithophysal zone (Tptrl) may appear to be absent. In fact, lithophysal-style alteration is simply restricted to intervals below the crystal transition interval; zonal boundaries thus cross-cut the member boundaries.

Below 456.0 ft (139.02 m), lithophysae increase in abundance with the development of close-spaced, larger, ragged lithophysae that are weakly coated by vapor-phase minerals. Extensive broken or unrecovered intervals below 460.0 ft (140.24 m) are most likely caused by presence of lithophysal cavities that are several times larger than the drill-pipe diameter. The existence of large lithophysal cavities was confirmed by the down-hole video survey. The intensity of lithophysal development and vapor-phase alteration decreases downward below about 600 ft (183 m). The lithophysae gradually become thin, flattened, vuggy cavities with thin alteration halos at approximately 700 ft (213.41 m) depth.

Crystal-poor middle nonlithophysal zone (Tptpmn) 728.8–845.8 ft (222.2–257.87 m)

The contact of the crystal-poor upper lithophysal zone with the crystal-poor middle nonlithophysal zone (nonlithophysal and “brick” zones of Scott and Bonk) is notably gradational, and lithophysae are present through much of the so-called nonlithophysal interval. The contact is identified where the intensity of lithophysal-style alteration decreases and is observed to affect less than 10 percent of the rock mass. A 24-ft (7.4-m) lithophysal-bearing subzone (24 percent of the total interval) occurs within the middle nonlithophysal zone, extending from 788.1 to 812.5 ft (240.27 to 274.71 m).

The rock is composed of 1–2 percent feldspar phenocrysts, 0–10 percent flattened, vuggy lithophysae, and minor quantities of small, light-gray or red-brown lithic fragments; these lithic clasts are more prevalent lower in the zone. Sanidine is the most abundant phenocryst, with minor amounts of plagioclase and biotite; magnetite is present as an accessory mineral. The rock matrix is densely welded and devitrified, with a more compact, less-grainy texture than that present in overlying units. Two types of alteration can be distinguished: (1) a strong, pervasive, blue alteration with 17 percent fuzzy, white, 0.6 inch (15 mm) long vapor-phase streaks surrounding pumice clasts, lithophysae and islands of unaltered matrix; and (2) a more speckled or spotted type of alteration consisting of 1 percent white streaks and 0.28–0.31 inch (7–8 mm) spots in unaltered orange-pink devitrified matrix. Hairline vapor-phase silica veinlets make up as much as 2 percent of the rock volume. Welding foliation is not common except where the core has been distorted by the lithophysal-bearing subzone. Jointing is mostly vertical and joint surfaces are typically smooth.

Crystal-poor lower lithophysal zone (Tptpll) 845.8–1187.0 ft (257.87–361.89 m)

The top of the crystal-poor lower lithophysal zone of the Topopah Spring Tuff in SD-9 (simply called the lower lithophysal zone, with several color-based modifiers, by Scott and Bonk) is well defined by the presence of somewhat diffuse, granular-appearing vapor-phase alteration of the matrix, and by vapor-phase altered spots and small, pinched, oval-shaped lithophysae that are generally less than 0.8 inches (20 mm) in size; the spacing of these lithophysae is wider than that found in the upper lithophysal zone. Much of the core throughout this interval is highly fractured or has been lost. Fracturing and associated core loss are attributed to the presence of lithophysae several times larger than the drill-string diameter. These large lithophysae, which also occur at other depths where smaller lithophysae are not present, are well expressed in the down-hole video survey. The abundance of lithophysae decreases gradually downward.

The rock is densely welded, devitrified, and composed of 10–12 percent white vapor-phase replacement of flattened, wispy, former pumice sites within 1-inch (25-mm) diameter pale, pink-brown alteration spots, 1–2 percent sanidine phenocrysts, 0.5 percent biotite, trace plagioclase, and accessory magnetite. Small, pale-gray pumice clasts, and pale-gray rhyolitic lithic fragments are concentrated in lithic-rich zones from 1031.0–1075.4 ft (314.33–329.87 m) and 1107.7–1118.5 ft (337.71–341.01 m). Welding foliation is weakly to moderately developed in the lower two-thirds of the unit. The core is broken throughout the lithophysal zone and the fractures are irregular with rough surfaces.

Crystal-poor lower nonlithophysal zone (Tptpln) 1187.0–1365.0 ft (361.89–416.16 m)

The upper contact of the crystal-poor lower nonlithophysal zone (mottled zone of Scott and Bonk) is identified by a change of rock type to a dense, less grainy (less altered) matrix and a decrease in the abundance of lithophysae. As mesoscale lithophysae continue to decrease in abundance downward, the number of identifiable pumice clasts, which range in size from 0.08 to 0.59 inch (2 to 15 mm), increases to about 7 percent. The rock is composed of 2–4 percent phenocrysts, 2–15 percent pumice clasts, and 2–3 percent small, white rhyolite lithics. Sanidine is the dominant phenocryst with traces of plagioclase and biotite, and accessory magnetite. The number of rhyolitic lithic fragments increases to 4–5 percent of the rock at about 1253.0 ft (382.01m).

In general, the color of the matrix darkens with depth; the upper half of the unit is roughly equally divided between pale-red-purple and light-orange-gray; the third quarter of the unit is a medium-red-purple or red-brown, and the lowest quarter is dark-brown-gray. This variation in matrix color, particularly in the upper portion of the intervals produces a mottled appearance, leading to the older descriptive name, “mottled.” About 20 percent of the matrix is unaltered other than for early devitrification. In addition to producing light-pink alteration halos and wisps and pervasive blue alteration, vapor-phase alteration has healed microfractures throughout the rock with thin (millimeter-scale) selvages and created hairline coatings of silica and accessory minerals. For the most part, welding foliation is weakly developed. Nearly vertical and subhorizontal fractures predominate throughout the unit. High-angle, planar, smooth fractures are more prevalent in the lower part of the lower nonlithophysal zone.

Crystal-poor vitric zone

Densely welded (vitrophyre) subzone (Tptpv3) 1365.0–1418.7 ft (416.16–432.53 m)

The lower vitrophyre, or crystal-poor densely welded vitric subzone, of the Topopah Spring Tuff (vitrophyre zone of Scott and Bonk) is densely welded and vitric, with coarse, black vitric spots formed by relict cognate pumice clasts. Scattered through the vitrophyre are 3 to 5 percent small, rhyolitic lithics, 1 to 2 percent small, red-brown quartz latite lithics, and 3–4 percent phenocrysts. Sanidine dominates the phenocryst assemblage with traces of biotite and accessory magnetite. Lithic fragments are generally less than 0.08 inch (2 mm) in diameter. A distinctive rectilinear fracturing pattern is attributed to the glassy composition. The style of fracturing changes from predominantly subhorizontal fractures near the top of the unit to vertical fractures at 1404.0 ft (428.05 m) associated with an interval containing large blocks of vitric pumice. Strong, horizontal fracturing is present from 1414.0 to 1419.0 ft (431.10 to 432.62 m) depth. Pale-blue vapor-phase silica has been deposited on the major joint surfaces.

Moderately welded subzone (Tptpv2) 1418.7–1445.0 ft (432.53–440.55 m)

The moderately welded vitric subzone (partially welded zone of Scott and Bonk) is distinguished from the overlying vitrophyre in part by the presence of subangular, orange pumice fragments. This zone also is noticeably less welded than the vitrophyre. The matrix is glossy, vitric, and slightly more argillized lower in the unit.

The rock contains phenocrysts of sanidine, quartz and biotite, light-brown vitric pumice clasts about 0.39 inch (10 mm) in size, and small, light-gray rhyolitic lithics set in a matrix of vitric bubble-wall shards. A lithic-rich interval is present from 1431.5 to 1442.2 ft (436.43 to 439.70 m). Vitric quartz latite lithics averaging 0.39 to 0.59 inch (10–15 mm) are prevalent in the upper part of this interval and vitric, light-gray lithics are more common near the base of the lithic zone. Zeolitic alteration first appears at 1432.8 ft (436.83 m) as a waxy micro-recrystallization of the tuff matrix. Dominantly subhorizontal fracturing is less intense than in the overlying vitrophyre subzone. The intensity of welding decreases downward into the lower nonwelded subzone.

Nonwelded subzone (Tptpv1) 1445.0–1464.1 ft (440.55–446.37 m)

A gradational contact at about 1445.0 ft (440.55 m) separates the lower nonwelded vitric subzone (partially welded zone of Scott and Bonk) from its more welded overlying neighbor. The nonwelded subzone contains both vitric and zeolitic rocks composed of 35–40 percent light-pink or light-orange pumice fragments that average 0.20 to 0.28 inch (5 to 7 mm) in diameter. Pumice fragments locally contain spherulites. The rock also contains 2–3 percent red-brown, quartz latite lithics (0.20 inch diameter), and 2–3 percent phenocrysts in a zeolitized, formerly vitric matrix. Phenocrysts include 1–2 percent sanidine, 1–2 percent quartz eyes, traces of biotite and pyroxene, and accessory magnetite. The matrix is speckled by about 2 percent finely crystalline black spots of manganese oxide. A 0.6 inch (15 mm) thick, very fine-grained ash fall marks the base of the unit.

Pre-Topopah Spring Tuff bedded tuff (Tpbt1) 1464.1–1479.9 ft (445.46–451.19 m)

The pre-Topopah Spring Tuff bedded tuff is a zeolitized unit topped by a pumice fall containing 70 percent small, dense pumice clasts, 10–12 percent vesicular pumice, 1–2 percent zeolitic cognate pumice, and 5–7 percent small, dark lithics in an ashy matrix that grades downward into a bedded tuff. The bedded tuff exhibits a sandy, reworked texture, but retains a high ash content. The reworked tuffaceous material is composed of 25–30 percent pumiceous and non-pumiceous clasts. Many of the clasts have opaline color and conchoidal or angular shapes. Approximately 35–40 percent of the core is cognate pumice and 3 percent is dark, quartz latite lithic fragments. A coarse-grained pumice fall is present from a depth of 1477.0 to 1479.9 ft (450.30 to 451.19 m), becoming lithic-rich (20–30 percent lithic clasts) below 1478.7 ft (450.82 m).

Calico Hills Formation (Tac)

Calico Hills ash-flow unit 3 (Tac3) 1479.9–1764.4 ft (451.19–537.93 m)

The uppermost Calico Hills unit in this hole, ash-flow unit 3 of Moyer and Geslin (1995), is capped by a weakly reworked zone that probably represents a paleosol. This pyroclastic flow deposit is partially clast-supported and is composed of an altered matrix containing 35–40 percent partially zeolitized pumice clasts. The rock also contains 1–2 percent phenocrysts of feldspar, quartz with traces of biotite and sericite and up to 3–5 percent lithic fragments of mixed composition, mostly of quartz latite. Between 1483.7 and 1487.6 ft (452.35 to 453.54 m) in depth, the lithic content increases to around 5–7 percent. The diameter of these lithic fragments increases concurrently to an average of 0.31 inch (8 mm). Zeolitization increases downward, becoming noticeably more intense between a depth of 1572.0 and 1574.0 ft (479.27 to 479.88 m), associated with a crowded zone of larger lithics. A lithic-rich pumice fall, also exhibiting increased zeolitization, marks the bottom of unit 3.

Calico Hills ash-flow unit 2 (Tac2) 1586.1–1737.5 ft (483.57–529.73 m)

Ash-flow tuff unit 2 of the Calico Hills Formation is similar to the overlying unit 3, except that the pumice content decreases to 15–25 percent, and the lithic content also decreases to 1–2 percent red-brown and red-orange fragments of varying composition. Pumice fragments are generally smaller than 0.59 inch (15 mm) in diameter, but may be up to 2.56 inch (65 mm) across. Phenocrysts, including feldspar, quartz and minor amounts of biotite compose 1–2 percent of the core above about 1600 ft (487.80 m), and 2–4 percent below that depth. The matrix is heavily zeolitized, exhibiting an orange-pink, gray color; the intensity of alteration appears to increase downward. Subtle bedding breaks in the form of very thin ash or pumice falls are present at 1685.2 ft (513.78 m), 1704.0 ft (519.51 m), and 1708.5 ft (520.88 m). At 1735.0 ft (528.96 m), ash- and pumice-fall deposits form the base of the unit.

Calico Hills ash-flow unit 1 (Tac1) 1737.5–1764.4 ft (529.73–537.93 m)

Ash-flow unit 1 is a highly zeolitized pyroclastic-flow deposit containing 15–25 percent pumice fragments, 3–5 percent red-brown lithics of varying composition and texture, and 3–5 percent phenocrysts of feldspar, quartz and lesser biotite. The proportions of phenocrysts and red-brown lithics increase to 7–10 percent and 10–15 percent, respectively, below a very subtle bedding break at 1750.1 ft (533.57 m). Yellow-gray pumice clasts are generally smaller than 0.79 inches (20 mm) diameter and increase in abundance to 20–25 percent below 1750.1 ft. The matrix appears intensely altered to zeolites and is an orange-pink-gray color. The base of the unit is marked by a 2.4-inch (61 mm) thick pink ash bed.

Calico Hills bedded tuff unit (Tacbt) 1764.4–1803.4 ft (537.93–549.82 m)

The upper 3.8 ft (1.16 m) of the “bedded tuff” deposit that precedes the Calico Hills tuffs is a heavily zeolitized ash-flow tuff containing 7 to 10 percent white pumice fragments, 10–15 percent quartz, feldspar, and minor biotite phenocrysts, and 10 percent small, red-brown lithic clasts. The remainder of the deposit is composed of zeolitized pumice-fall or ash-fall deposits. The intensity of zeolitic alteration decreases downward toward the base of the unit. A fine-grained pumice fall containing distinctive pale-pink to yellow-gray pumice clasts is present from 1768.2 to 1775.1 ft (539.09 to 541.19 m), and is underlain by an altered, porcelaneous ash-fall deposit. Two coarse-grained pumice falls were cored between 1775.1 and 1799.4 ft (541.19 to 548.60 m). The upper pumice fall has a weakly reworked top, is heavily zeolitized from 1773.3 to 1780.6 ft (540.64 to 542.87 m). The unit is thinly bedded between 1776.7 and 1778.6 ft (541.68 to 545.26 m). The lower pumice fall, the upper 6-ft (1.83-m) of which appears to have been reworked, becomes coarser and more pumice- and biotite-rich downward. The base of the lower pumice-fall unit between 1797.8 and

1799.4 ft (548.11–548.60 m) appears bedded and has been intensely zeolitized. A thin, poorly sorted pumice fall with a thin, reworked top extends to the lower contact at 1803.4 ft (549.82 m).

Calico Hills basal tuffaceous sandstone (Tacbs) 1803.4–1820.7 ft (549.82–555.09 m)

The lowermost unit of the Calico Hills Formation was defined by Moyer and Geslin (1995) as a red-brown, immature, tuffaceous sandstone. This unit was encountered by the SD-9 drill hole between depths of 1803.4 and 1820.7 ft (549.82–555.09 m). The upper part of the unit to a depth of 1810.7 ft (552.04 m) is characterized by intervals of subrounded, reworked pumice clasts in a pale, red-brown sandstone. This interval is separated from the lower part of the unit by a thin, dark red-brown sandstone bed exhibiting load casts at 1811.5 ft (552.29 m). The lower sandstone interval (1811.5–1820.7 ft, 552.29–555.09 m) is pale-red-brown and contains 5–10 percent altered pumice fragments. A fine-grained, thinly bedded interval between 1813.9 and 1817.5 ft (553.02 –54.12 m) is devoid of pumice.

Prow Pass Tuff (Tcp)

Prow Pass ash-flow unit 4 (Tcp4) 1820.7–1868.7 ft (555.09–569.73 m)

Ash-flow unit 4 of the Prow Pass Tuff is a fine-grained, heavily zeolitized ash-flow tuff with yellow-gray mottling. A weak paleosol or weathering surface is developed in the uppermost 2.3 ft (0.70 m). The rock contains 2–3 percent white pumice clasts that are predominantly less than 0.39 inch (10 mm) in diameter; 3–5 percent phenocrysts of quartz, feldspar, traces of biotite, and rare pyroxene; and 2–3 percent small, lithic fragments that vary widely in composition. The percentage of pumice fragments increases at 1841.1 ft (561.31 m) to 7–10 percent pumice less than 0.59 inch (15 mm) in diameter; phenocrysts also increase to 5–7 percent. At 1845.8 ft (562.74 m) depth, pumice clasts increase in size to as much as 1.97 inch (50 mm) in diameter, and phenocrysts increase to 10–12 percent. Red-brown, angular siltstone lithic fragments are commingled with the more usual lithic assemblage below about 1845.8 ft. Bedding breaks are present at 1832.7 ft (558.75 m), 1835.8 ft (559.70 m), and 1836.0 ft (559.76 m). A slight increase in welding at 1860.2 (567.13 m) is possibly associated with weak vapor-phase silicification. Fracturing is dominantly subhorizontal, except in the upper 16 ft (4.89 m) of the unit where vertical joints are common.

Prow Pass ash-flow unit 3 (Tcp3) 1868.7–2015.8 ft (569.73–614.57 m)

Ash-flow unit 3 is distinguished principally by the presence of vapor-phase alteration and incipient welding. The rock is composed of 10–20 percent pumice clasts up to 1.38 inch (35 mm) diameter, 3–5 percent phenocrysts of quartz, feldspar, biotite, and pyroxene, and 2–3 percent small, mixed composition lithic fragments including a red siltstone variety. The upper 3 ft (1 m) of this heavily zeolitized ash-flow unit has been vapor-phase altered and contains clasts exhibiting vapor-phase replacement of cellular pumice. From about 1897 to 2012 ft (578.35–610.18 m), the tuff is partially welded with a heavily zeolitized, microgranular matrix. Large pumice fragments are slightly flattened and rimmed by vapor-phase alteration minerals surrounding a darker, typically vuggy core. Small angular lithics exhibit hazy halos of vapor-phase alteration products. The intensity of vapor-phase alteration decreases beginning at about 1930 ft (588.41 m). Below an interval of noticeably decreased welding and weaker vapor-phase alteration between 1989 and 2002 ft (606.22–610.18 m), welding and vapor-phase alteration are absent below 2012 ft (613.23 m). Irregularly spaced vertical joints are common.

Prow Pass ash-flow unit 2 (Tcp2) 2015.8–2985.3 ft (614.57–910.15 m)

Ash-flow unit 2 is a zeolitized, nonwelded ash-flow tuff similar to unit 3 except that the lithic content is higher, approximately 5 to 15 percent. A pale-orange matrix exhibits brown alteration, particularly along the margins of lithic clasts. Partially to totally zeolitized pumice fragments are 0.16 to 0.59 inch (4 to 15 mm) in diameter, undeformed, and constitute 20 to 40 percent of the rock. Most lithics are large, up to 0.98 inch (25 mm) in diameter, and of a dense, red-brown igneous rock or red siltstone. Two lithic-rich zones occur at 2018.1 ft and 2020.9 ft (615.27 and 616.13 m). A noticeable decrease in average lithic size occurs at 2022.8 ft

(616.71 m) and the size distribution is bimodal. Fragments 0.20–0.98 inches (5–25 mm) across compose 1–2 percent of the rock, and clasts less than 0.20 inch (5 mm) form approximately 2–4 percent). A subtle bedding break may be present at 2047.0 ft (624.09 m), where the phenocryst content changes abruptly downward from 5–10 percent to 10–12 percent. Phenocrysts include feldspar, quartz, oxybiotite, and pseudomorphs after pyroxene. The lower two-thirds of the unit is more intensely zeolitized, exhibiting patchy green-brown alteration of the bulk rock; green speckles of zeolite may be observed in the cores of pumice fragments.

Prow Pass ash-flow unit 1 (Tcp1)
2095.3–2223.1 ft (638.81–677.77 m)

Ash-flow unit 1 is an essentially nonwelded, heavily zeolitized unit, containing 25–27 percent altered, subangular pumice clasts in the 0.12 to 0.39 inch (3–10 mm) diameter size range. The pumice fragments are dense and laminated, and are almost completely altered to zeolite; some fragments retain relict froth structure. The rock also contains 1–3 percent small, angular, red-brown volcanic or red-siltstone lithics, and phenocrysts comprised of 2–3 percent quartz, 1–2 percent sanidine, 0.5 percent pyroxene, and 1.0 percent biotite. Secondary porosity increases downward with increasing zeolitic alteration. Two ash-flow boundaries located at 2122.8 ft (647.20 m) and 2125.8 ft (648.11 m) are marked by thin, ash-rich partings. The SD-9 drill hole stopped short of the base of ash-flow unit 1.

Appendix B: Geologic Core Logs

Geologic Core Logs

The geologic core logs in this appendix are reproduced in color at their original full scale of 1:120 (1 inch equals 10 feet). Full-size reproduction means that the log sheets that follow have not been formatted or numbered in the same manner as the remainder of this document, although the page count of this report is continuous and the log-sheet pages are themselves numbered consecutively. Copies of the original log forms may be retrieved from the Yucca Mountain Project records system under data-tracking number SNT02052794001.003.

The log form (figure B-1) contains a graphic representation of the actual geology of the core. Bedding within reworked units, clasts representing lithic fragments, lithophysal cavities, fractures, and similar textural features are drawn in a "cartoon," but still highly realistic, fashion. For example, large lithophysal cavities are drawn larger than small cavities, and flattened cavities in the core are represented as more oval features than spherical lithophysae. Near-vertical fracturing is represented by stylized fracture lines nearly parallel to the depth axis of the diagram, as such jointing is nearly parallel to the core axis in an essentially vertical drill hole, such as USW SD-9.

The degree of welding, devitrification, and the intensity of secondary alteration of the core is represented semiquantitatively by several parallel bars of vertically varying width. A blank column represents "no alteration" of the indicated type; a fully shaded column indicates "extremely intense alteration." This style of presentation can be very exact over short core distances (feet to tens of feet) and it allows relatively subtle, small-scale variation in these phenomena to be represented quite precisely. The gradational nature of several lithostratigraphic "contacts" becomes quite obvious in this manner. The representation, however, is not rigorously quantitative, and a 3-mm-wide bar at one depth should not be presumed to represent precisely the same intensity of that phenomenon as a 3-mm-wide bar several hundred feet away. Note that the type of alteration indicated by a particular column may change with depth to conserve space on the log form; the column headings are kept consistent over broad depth ranges, however.

Engineering and geologic information related to the core itself is also presented on the log sheets. Highly broken or rubblized zones are indicated by a shaded pattern in the fracturing column, and intervals of core loss are indicated by arrows extending through the indicated interval of non-recovery. The geology of these unrecovered intervals has been interpreted through the intervals of core loss where there is reasonable evidence for such an interpretation (for example, down-hole-video imagery or a relatively consistent lithology in a known, thick geologic unit). Large intervals of lost core in geologic units known from outcrop or other drill holes to be highly variable vertically have been left uninterpreted. Note that drilling support staff assigned lost-core intervals by convention to the bottom of the core run, whereas the actual core loss may have occurred at multiple levels during the drilling of a particular run. Quantitative information (varying from 0 to 100) for per-run core recovery and 10-ft-composite, drilling-support Deere RQD values (from tables C-1 and D-2) are presented in columns to the right of the geologic descriptions.

The framework material properties, porosity and bulk density, are presented in similar columnar-graphic form to the right of the core-recovery and RQD information. Saturated hydraulic conductivity information does not present well because the wide (orders-of-magnitude) variability of this framework property requires a logarithmic scale; these values have been omitted from the core log. Saturation values, however, have been included as this information may bear on the identification of geologic controls of perched-water bodies. These graphic representations of materials-property data contain quantitative information. Porosity values are scaled from 0 to 70 percent, bulk density values are scaled from 1.0 to 3.0 g/cm^3, and saturation is scaled from 0 to 1. The locations of changes in the porosity and density of core samples clearly indicate that the boundaries between material property units do not correspond exactly to the boundaries of the different formation-level lithostratigraphic units (Tiva Canyon Tuff, Topopah Spring Tuff).

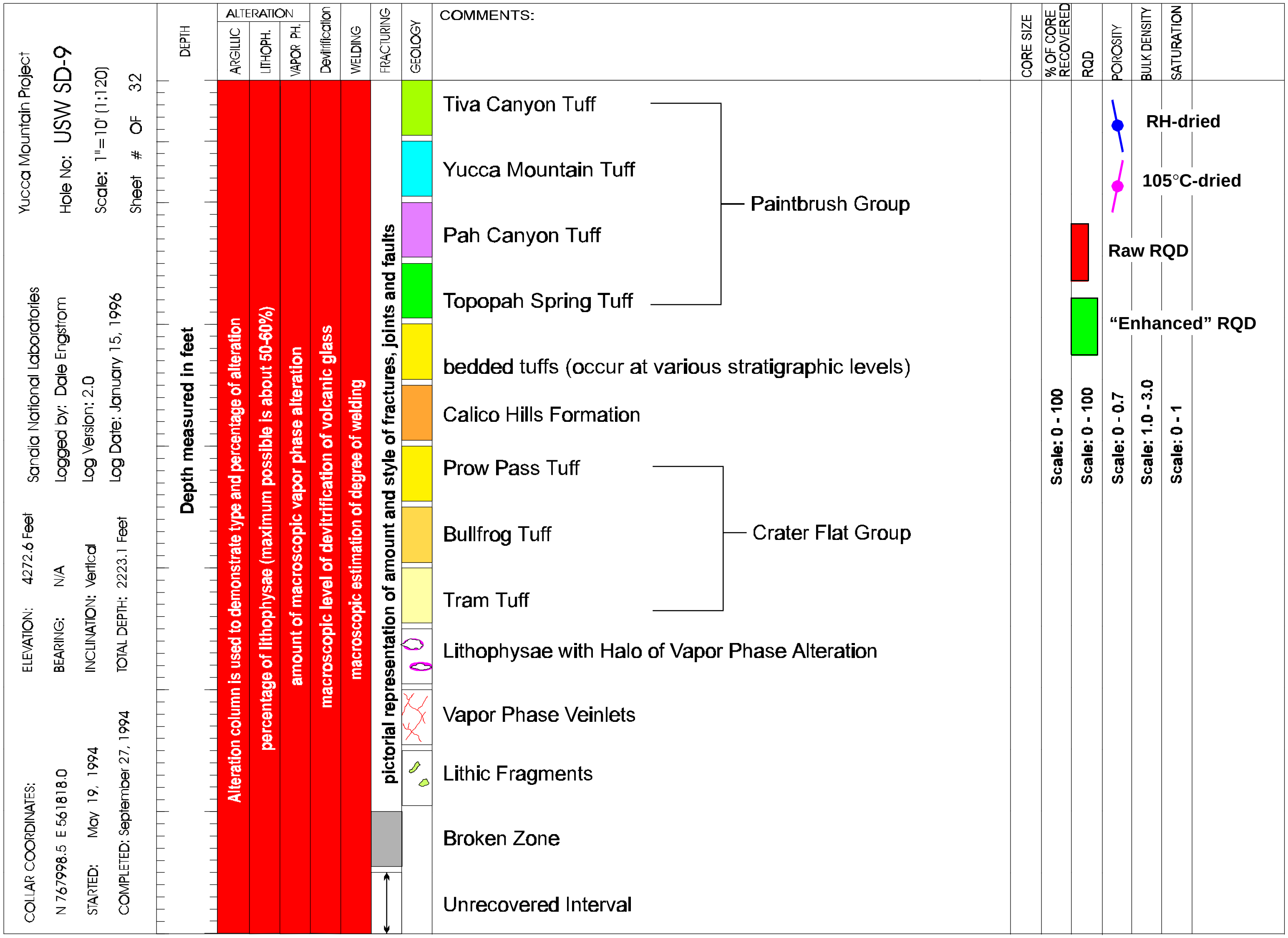

Figure B-1. Example geologic core log form with parallel columns for representing various geologic features and other quantitative and semiquantitative information as a function of depth. Actual geologic logs are reproduced in color.

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Note: The color geologic log sheets that follow are single sided.

Yucca Mountain Project

Hole No: USW SD-9

Scale: 1"=10' (1:120)

Sheet 1 OF 32

Sandia National Laboratories

Logged by: Dale Engstrom

Log Version: 2.01

Log Date: January 15, 1996

ELEVATION: 4272.6 feet

BEARING: N/A

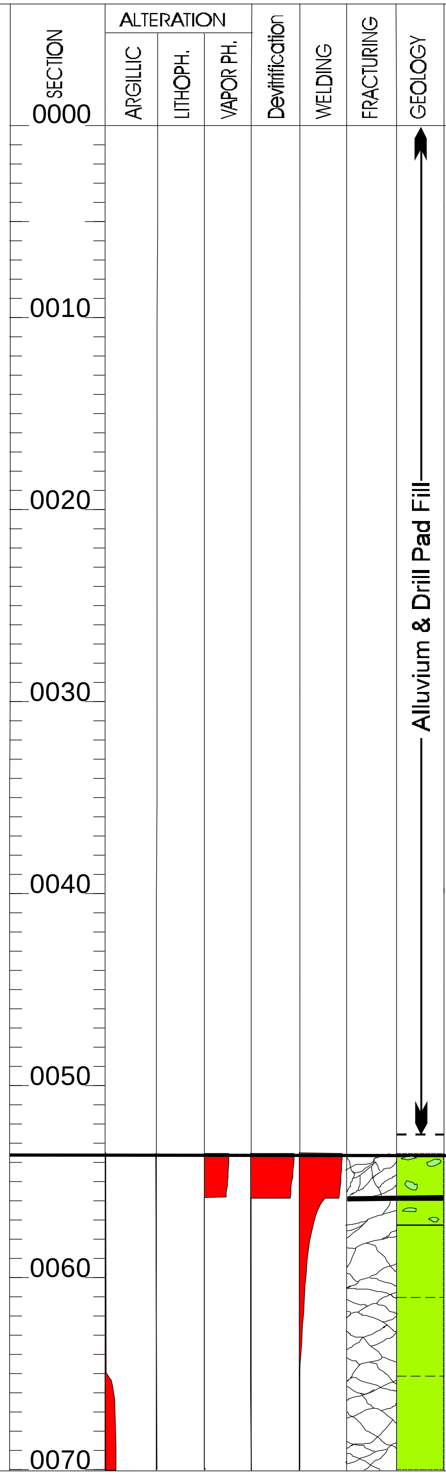
INCLINATION: Vertical

TOTAL DEPTH: 2223.1 feet

COLLAR COORDINATES: N 767998.5 E 561818.0

STARTED: May 19, 1994

COMPLETED: September 27, 1994



COMMENTS: SNT02052794001.003

AVE. CORE REC'Y/HOLE

SD-9 was hammer drilled to 53.6 feet before coring began. (Undifferentiated drill pad fill and alluvium to bedrock at 52.5 feet)

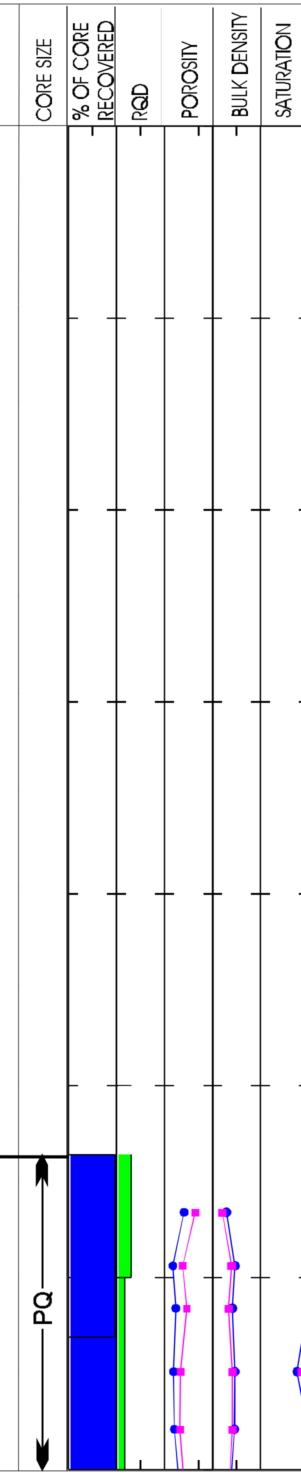
53.6 — ***Tiva Canyon Crystal-Poor Nonlithophysal zone, columnar subzone (Tpcplnc)*** *(53.6)* Light tan-gray (10YR7/2), moderately to densely welded, devitrified, 4-6% flattened (5:1) cognate pumice and 2% cognate lithics mostly very dark and vitric, 3-4% white sanidine phenos, rock badly fractured, healed with milled fragments from "shardy base" vitric zone in the fracture voids, pink clay (argillic) replacement of pumice extends into shardy base zone below minor fault zone at 55.7 feet depth.

55.7 — 0.1-foot thick clay gouge.

57.2 — ***Tiva Canyon Crystal-Poor Vitric Zone ("shardy base"), moderately welded subzone (Tpcpv2)*** *(55.7-65.0)* light orange-brown (5YR6/4) vitric, partially welded, 5-7% light pink-gray angular pumice 3-4 mm average size, 2-4% cognate pumice averages 5 mm but up to 40 mm, some are altered to orange clay (argillized) and 25% are black vitric, 1% hard brown lithics average 6-7 mm, 2-3% glassy sanidine phenos, vitric groundmass of weakly devitrified orange shards with 3-5% black microshards.

61.0 partially welded

65.0-79.6 — ***Tiva Canyon Vitric Zone, nonwelded subzone (Tpcpv1)*** gradational contact *(65.0-79.6)* to grades from 3-5% to 20% black shards, generally more altered (argillized?) than above.



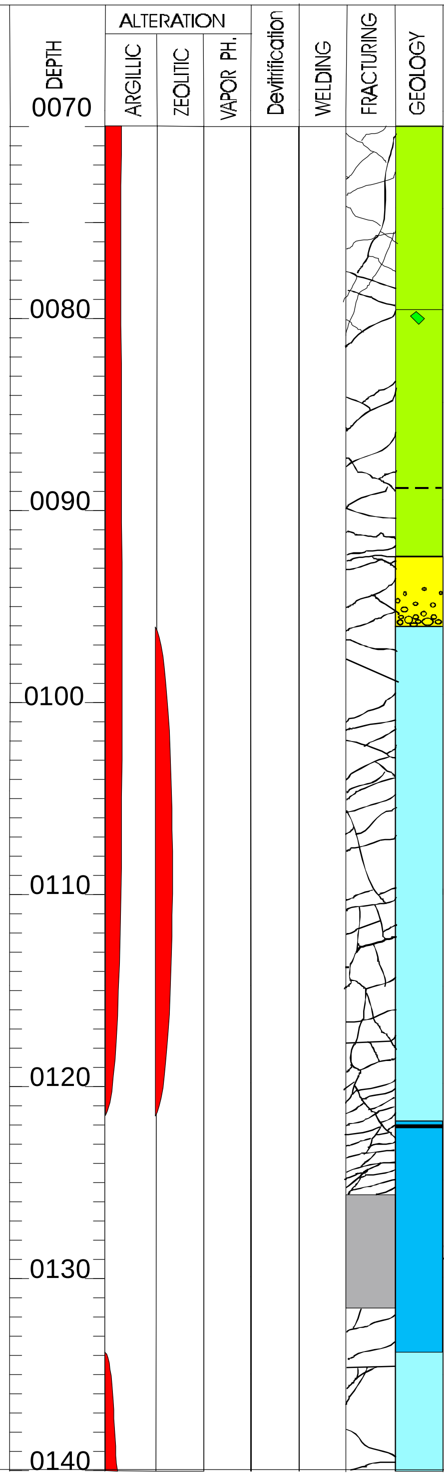
Yucca Mountain Project
Hole No: USW SD-9
Scale: 1"=10' (1:120)
Sheet 2 OF 32

Sandia National Laboratories
Logged by: Dale Engstrom
Log Version: 2.01
Log Date: January 15, 1996

ELEVATION: 4272.6 Feet
BEARING: N/A
INCLINATION: Vertical
TOTAL DEPTH: 2223.1 Feet

COLLAR COORDINATES: N 767998.5 E 561818.0
STARTED: May 19, 1994
COMPLETED: September 27, 1994

SNT02052794001.003



COMMENTS:

Tiva Canyon Vitric Zone ("shardy base"), nonwelded subzone, *cont. (65.0-92.3),* gradational contact 65.0-79.6, pale yellow-brown (10YR6/2) vitric, nonwelded, 7-10% pale brown pumice up to 28 mm, 3-4% white sanidine phenos, groundmass 20-25% black shards, rest is partially altered (argillic) orange shards, 1-2% quartz latite hard lithics averaging 10 mm, very straight smooth fractures coated by Mn-FeOx.

Same texture-different color, light gray (N7.5), pumiceous, vitric, nonwelded ashflow, mixed pumice of 80% light gray, 20% pale orange, 5% of groundmass is black shards, rare vitric hard lithic, 0.1-foot pumice fall at basal contact.

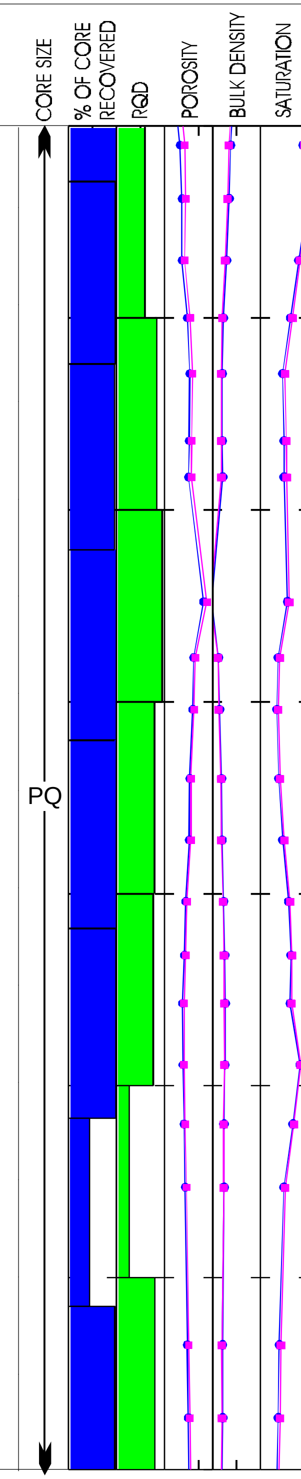
Pre-Tiva Canyon Tuff bedded tuff (Tptbt4) *(92.3-95.9)* weakly developed paleo-surface, pale red-orange (10R6/5), sandy-vitric texture, clast-supported, 5-7% small white angular pumice averaging 3-5 mm, 4-5% white sanidine phenos, grades downward into medium grain pumice fall becoming coarser downward, mixed pumice with 10-15% black vitric variety.

Yucca Mountain Tuff (Tpy) *(95.9-140.9)* pale red-gray (5R6/2) vitric, nonwelded ashflow tuff, 7-10% light pink zeolitic pumice fragments that average 3-4 mm, 3-4% light green-gray pumice, 1-2% white sanidine phenos, <1% oxybiotite, 1% hard angular quartz latite lithics averaging 4-5 mm, groundmass 5% black shards in red-brown argillized matrix, black shard content increases downward to 10-12%.

*Slightly welded interval (121.7-133.7)*light gray (N7) vitric, nonwelded to slightly welded, 7- 10% light pink zeolitic subangular pumice averaging 5 mm, 3-5% vitric cognate pumice that average 5 mm and are nearly invisible to groundmass, grading into black vitric pumice downward, 3-5% white sanidine phenos, 10-15% of groundmass is black shards in gray vitric matrix with hazy recrystallized spots (weakly vapor-phase altered?), 1-2% angular quartz latite hard lithics that average 5-6 mm.

Black shard content drops to 3-5% and decreasing downward.

AVE. CORE REC'Y/HOLE

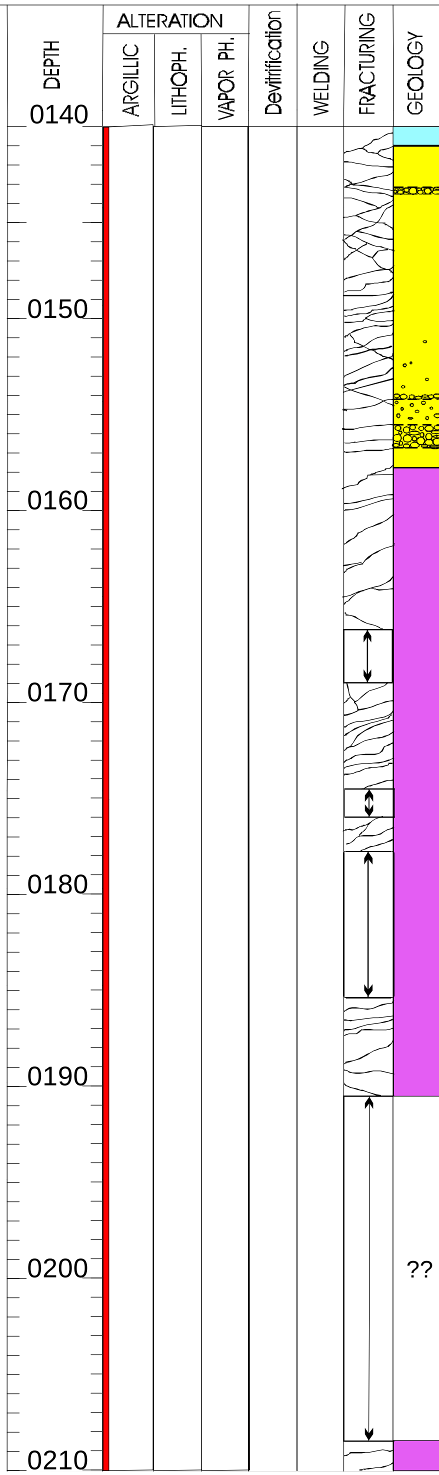


Yucca Mountain Project
Hole No: USW SD-9
Scale: 1"=10' (1:120)
Sheet 3 OF 32

Sandia National Laboratories
Logged by: Dale Engstrom
Log Version: 2.01
Log Date: January 15, 1996

ELEVATION: 4272.6 Feet
BEARING: N/A
INCLINATION: Vertical
TOTAL DEPTH: 2223.1 Feet

COLLAR COORDINATES:
N 767998.5 E 561818.0
STARTED: May 19, 1994
COMPLETED: September 27, 1994



COMMENTS:

DTN: SNT02052794001.003

AVE. CORE REC'Y/HOLE

140.9 — ***Pre-Yucca Mountain Tuff Bedded Tuff (Tptbt3)*** *(140.9-157.7)* light tan orange (5YR6/2) highly pumiceous, vitric, clast-supported, 25-35% light gray subangular pumice averaging 4-5 mm, 1-2% sanidine phenos, <1% biotite, 1% dark quartz latite hard lithics that average 3-4 mm, groundmass 2-3% black shards in muddy matrix, (moderately argillized?) 143.2-143.5 oscillatory 1-2 inch thick pumice beds (3X), below 143.5 15-20% pumice, slightly larger size up to 20 mm, pumice content increases downward.

143.2-143.5 pumice beds

154.2-154.8 pumice-rich

155.4-156.7 co.gr.pumice fall

156.7-157.7 reworked tuff

157.7 — ***Pah Canyon Tuff (Tpy)*** *(157.7-227.1)* light brick-red (10R7/2) nonwelded, vitric, pumiceous ashflow tuff, 25-30% light- med.gray vitric pumice 3-45 mm size range, bimodal: (1) light gray dense 3-15 mm pumice, (2) med. gray vesic. finely-laminated 12-45 mm pumice that becomes green variety (zeolite?) below 164.0, 1% dark red-brown quartz latite subangular hard lithics that average 8-10 mm, 3-5% fresh sanidine phenos, 1-2% black biotite flakes.

164.0

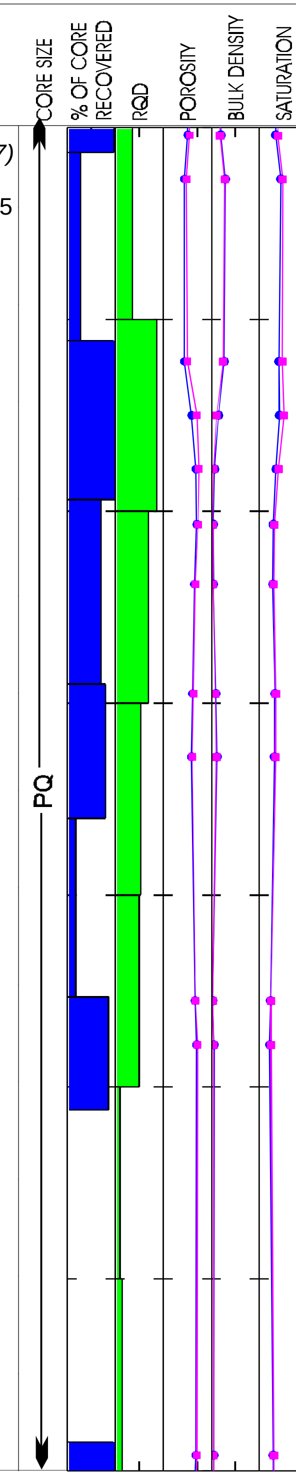
166.2-169.0 unrcvd

174.6-176.0 unrcvd

177.7-185.3 unrcvd

185.3 — Red-brown matrix with typical, large Pah Canyon vitric pumice that are yellow-orange in color.

190.4-208.5 unrcvd



Yucca Mountain Project

Hole No: USW SD-9

Scale: 1"=10' (1:120)

Sheet 4 OF 32

Sandia National Laboratories

Logged by: Dale Engstrom

Log Version: 2.01

Log Date: January 15, 1996

ELEVATION: 4272.6 Feet

BEARING: N/A

INCLINATION: Vertical

TOTAL DEPTH: 2223.1 Feet

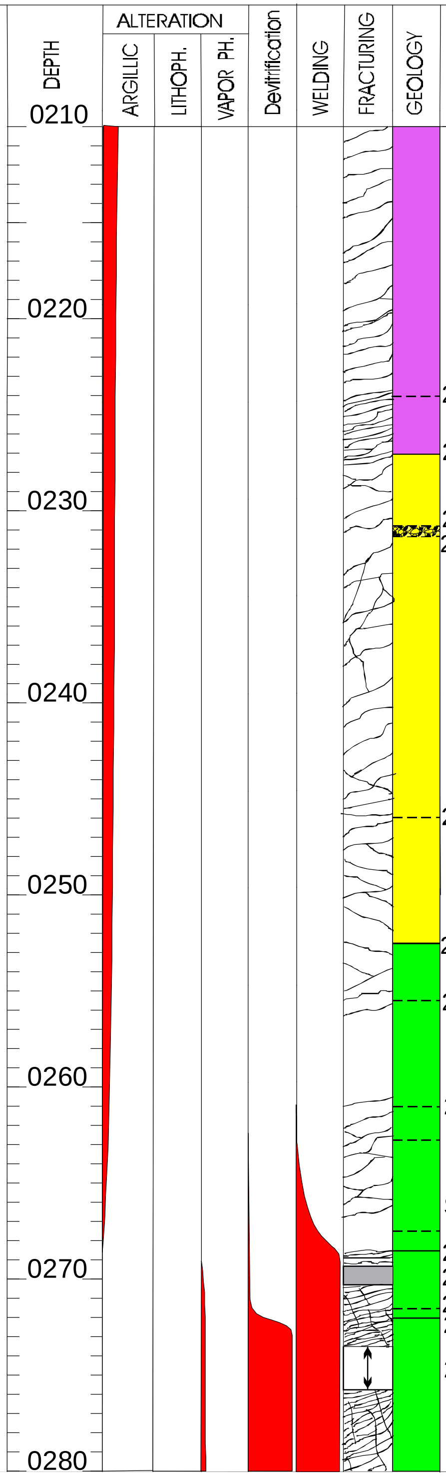
COLLAR COORDINATES: N 767998.5 E 561818.0

STARTED: May 19, 1994

COMPLETED: September 27, 1994

DTN: SNT02052794001.003

AVE. CORE REC'Y/HOLE



COMMENTS:

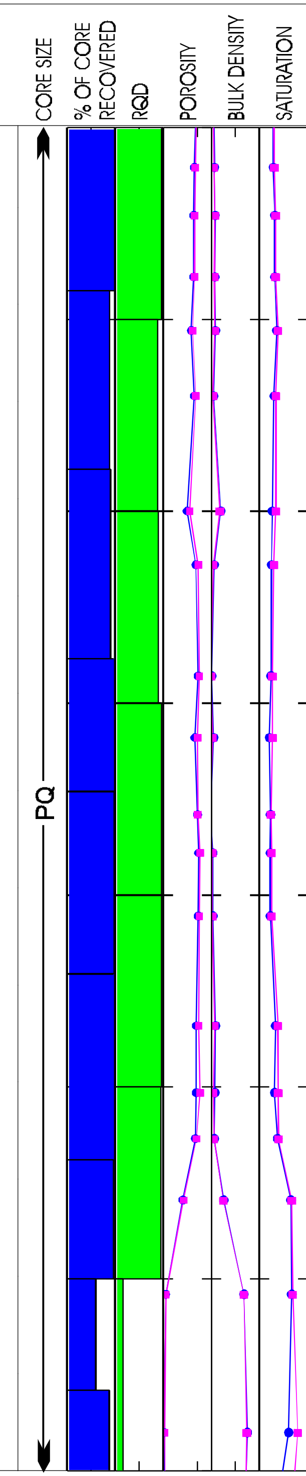
Pah Canyon Tuff, *cont. (157.7-227.1)* medium brick red-brown, nonwelded, vitric ashflow, 25-30% bright yellow-orange pumice, 1-2% dark 8-10 mm red-brown quartz latite hard lithics, 3-5% sanidine and 1% fresh black biotite phenos, 223.9-227.1 basal Pah Canyon white zone, softer and much more pumiceous than above.

Pre-Pah Canyon Tuff Bedded Tuff (Tptbt2) *(227.1-252.6)* light brown-gray (5Y7/1) vitric, nonwelded, pumiceous, 20-25% light gray-white pumice up to 8 mm, 2-4% subangular quartz latite lithics, sandy textured groundmass (possibly weakly reworked) 4-5% black shards in light brown argillic altered matrix, 3-5% sanidine and 2% biotite phenos, 227.1-231.3 reworked bedded pumiceous tuff grading down into pumice fall at 230.8, coarse grained pumice fall, 85-90% coarse white pumice 5-20 mm diameter, 245.9 poorly developed paleosol surface (weakly hematite stained).

Topopah Spring Crystal-Rich Vitric Zone, nonwelded subzone (Tptrv3) *(252.6-268.6)* med yellow-orange (10YR6/6) vitric, nonwelded, 12-15% light gray vitric pumice up to 15 mm, 2-3% 5-7 mm sub- angular red-brown quartz latite hard lithics, rare dark vitric lithics about 5 mm, 1-2% sanidine and 2% biotite phenos, 255.5 30 mm pink clay and pumice zone (palesol?), texture of rock same above and below, episodic hiatus, 261.1 more pumiceous with small angular fragments, 262.8 dominated by pumice fraction to 80-90% of large gray pumice and little matrix, weakly to moderately sintered, precursor to sintered interval belonging to ***moderately welded subzone (Tptrv2)*** at 266.1-268.6.

Topopah Spring "caprock vitrophyre" subzone (Tptrv1) *(268.6-272.1)* densely fused, vitric, crystal-rich with 15-20% feldspar and 1% oxybiotite phenos, red vitrophyre from 268.7-271.6, black vitrophyre from 271.6-272.1, thin pale blue vapor- phase coating on select joints.

Topopah Spring Crystal-Rich Nonlithophysal Zone (Tptrn) *("rounded") (272.1-439.2)* densely fused, vitric, incipient devitrification, with intensity increasing downward, no longer vitrophyre.



Yucca Mountain Project

Hole No: USW SD-9

Scale: 1"=10' (1:120)

Sheet 5 OF 32

Sandia National Laboratories

Logged by: Dale Engstrom

Log Version: 2.01

Log Date: January 15, 1996

ELEVATION: 4272.6 Feet

BEARING: N/A

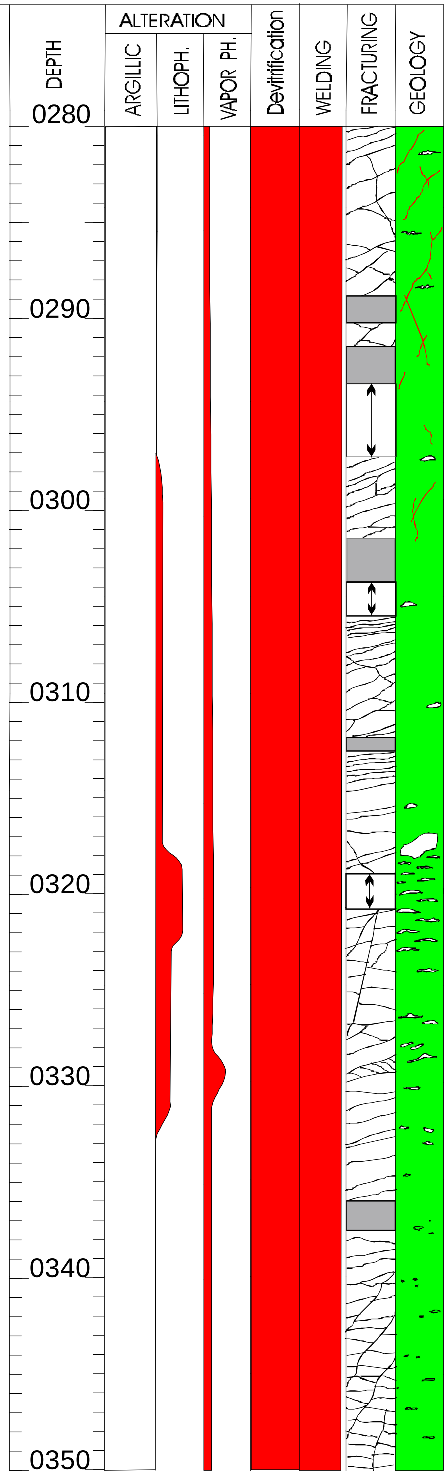
INCLINATION: Vertical

TOTAL DEPTH: 2223.1 Feet

COLLAR COORDINATES: N 767998.5 E 561818.0

STARTED: May 19, 1994

COMPLETED: September 27, 1994



COMMENTS:

DTN: SNT02052794001.003

AVE. CORE REC'Y/HOLE

weak SiO2 veinlets

Topopah Spring Crystal-Rich Nonlithophysal Zone, *cont. ("rounded") (281.0-439.2)* Med. red-brown (10R4/2) densely welded, devitrified, 3-5% cognate pumice visible only as weakly opened vugs, weakly recrystallized by light brown vapor- phase mineralization, 15-17% sanidine phenos, 1% oxybiotite flakes, weak vapor-phase SiO2 veinlets.

288.8-290.2 broken

291.6-293.4 broken

293.4-297.2 unrcvd

297.2 — Very weakly lithophysal pumice "reappear" as frothy cores but otherwise invisible to groundmass, lithophysal intensity increasing downward, vapor-phase alteration lightens the core color starting at depth of 298.0 feet.

301.5-303.7 broken

303.7-305.5 unrcvd

Light red-brown (5R5/2) densely welded, devitrified ash-flow tuff with flattened fabric, 15-17% sanidine phenos, 1% coppery oxybiotite, 25-30% cognate (nearly invisible) vesic. pumice weakly recrystallized by light brown vapor-phase mineralization, 10-15% exotic less vesic. quartz latite soft lithics are moderately recrystallized and crystal-rich, 2-3% light gray rhyolite soft lithics moderately-to-well replaced by vapor-phase mineralization, rhyolite soft lithic fraction increases downward toward the compositional transition zone, 318.0- 322.7 zone of increased lithophysal development, 317.0 >2-foot dia. lithophysae on borehole video, more intense below 318.4 ft.

311.8-312.4 broken

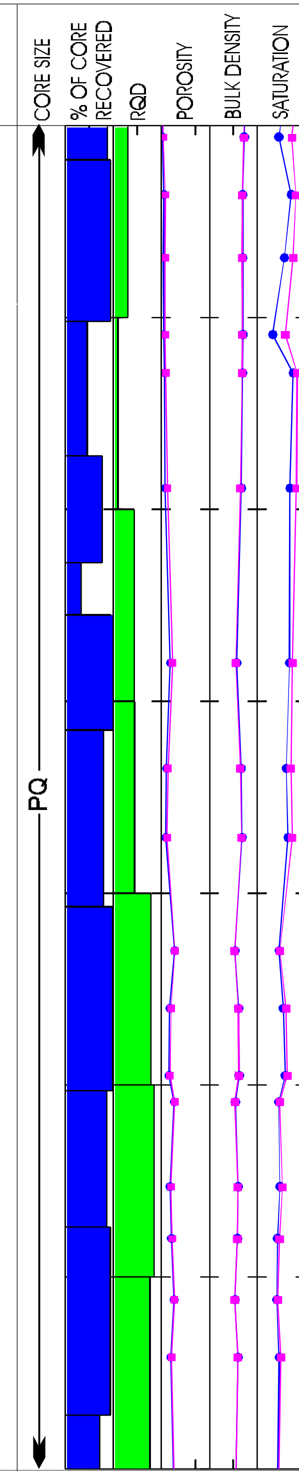
318.0

318.9-320.7 unrcvd

329.9 — Uppermost vapor-phase coating in flattened lithophysae.

333.0 — Lithophysae die, small vugs common below (very weakly lithophysal).

336.0-337.4 broken



Yucca Mountain Project

Hole No: USW SD-9

Scale: 1"=10' (1:120)

Sheet 6 OF 32

Sandia National Laboratories

Logged by: Dale Engstrom

Log Version: 2.01

Log Date: January 15, 1996

ELEVATION: 4272.6 fEET

BEARING: N/A

INCLINATION: Vertical

TOTAL DEPTH: 2223.1 Feet

COLLAR COORDINATES:

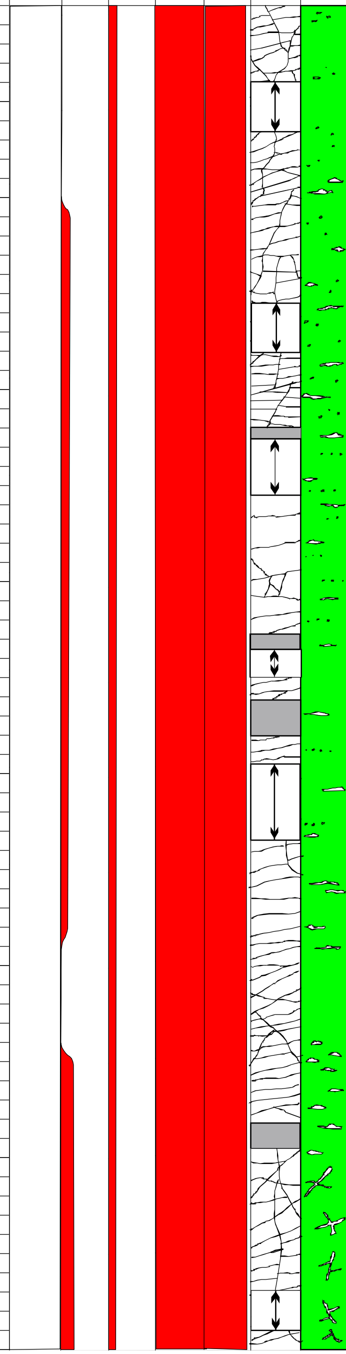
N 767998.5 E 561818.0

STARTED: May 19, 1994

COMPLETED: September 27, 1994

DEPTH | ALTERATION (ARGILLIC, LITHOPH., VAPOR PH.) | Devitrification | WELDING | FRACTURING | GEOLOGY | COMMENTS: | DTN: SNT02052794001.003 | AVE. CORE REC'Y/HOLE | CORE SIZE | % OF CORE RECOVERED | RQD | POROSITY | BULK DENSITY | SATURATION

0350
0360
0370
0380
0390
0400
0410
0420



353.9-356.5 unrcvd

359.8 — Very weakly opened lithophysal pumice.

Topopah Spring Crystal-Rich Nonlithophysal Zone *(cont.) ("rounded") (281.0-439.2)* light red-brown (5R5/2) densely welded, devitrified ashflow tuff with flattened rock texture, crystal- rich quartz latite groundmass, 25-30% cognate weakly opened (lithophysal) pumice weakly recrystallized by light brown vapor-phase mineralization, 10-15% exotic crystal-poor medium brown soft lithics moderately recrystallized by vapor-phase alteration, 2-3% light gray rhyolite soft lithics strongly altered by vapor-phase mineralization, rhyolite lithic fraction increases downward, 12-15% sanidine phenos, 1% coppery oxybiotite flakes.

365.4-368.1 unrcvd

371.9-372.4 broken

372.4-375.6 unrcvd

382.7-383.6 broken

383.6-384.9 unrcvd

386.2-388.1 broken

389.4-393.4 unrcvd

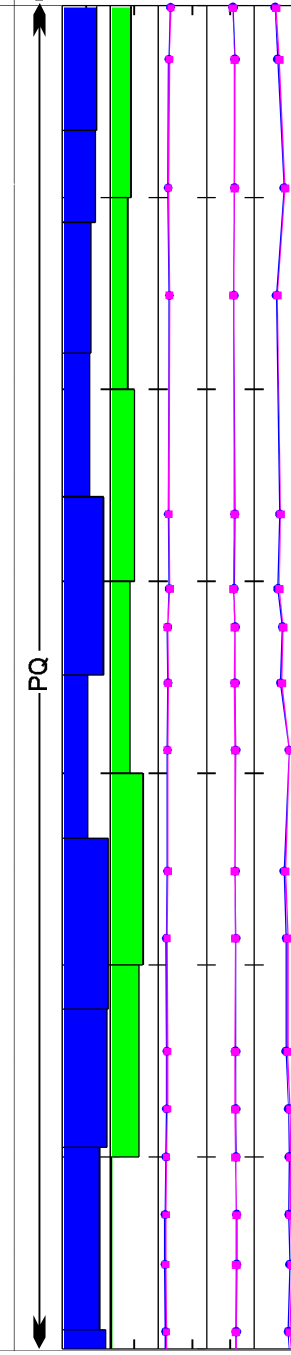
399.1-404.1 — Zone of limited lithophysal development.

404.1 — Small (1") oval recrystallized lithophysae each 2-6 inches.

408.2-409.5 broken

411.0-422.1 — Flat lithophysae developed on fractures.

416.9-419.0 unrcvd



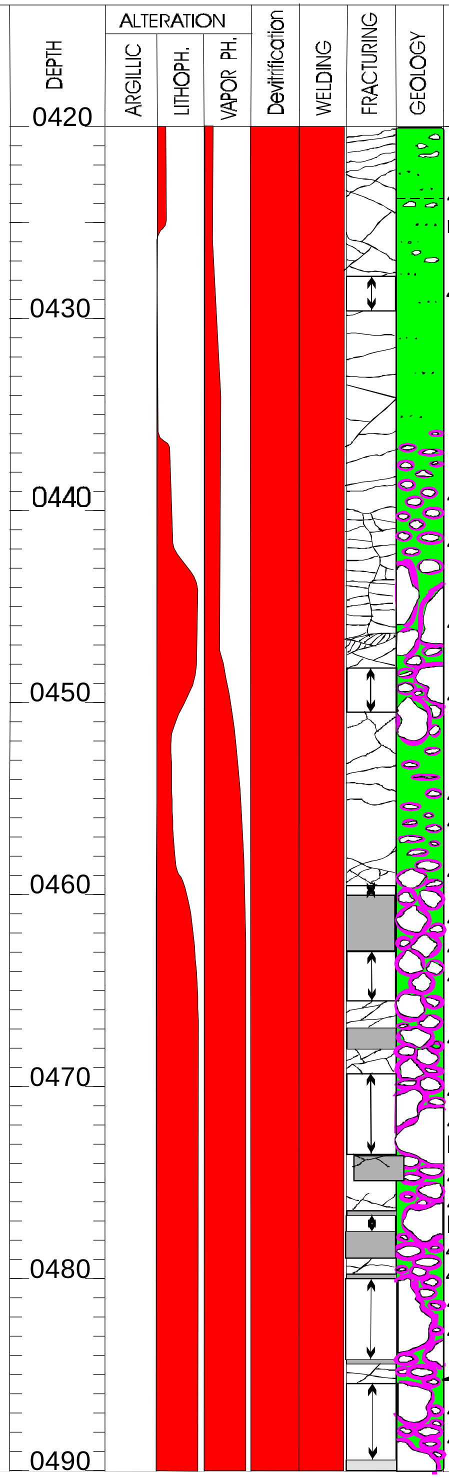
Yucca Mountain Project
Hole No: USW SD-9
Scale: 1"=10' (1:120)
Sheet 7 OF 32

Sandia National Laboratories
Logged by: Dale Engstrom
Log Version: 2.01
Log Date: January 15, 1996

ELEVATION: 4272.6 Feet
BEARING: N/A
INCLINATION: Vertical
TOTAL DEPTH: 2223.1 Feet

COLLAR COORDINATES: N 767998.5 E 561818.0
STARTED: May 19, 1994
COMPLETED: September 27, 1994

DTN: SNT02052794001.003



COMMENTS:

423.8 incr. rhyolite lithics
427.7-428.6 unrcvd
439.2
441.5-very large lithophysae
447.5 lithoph intensity increases
448.2
448.2-450.5 unrcvd
454.7
456.0 lithoph. zone
459.0-469.0 vapor phase increase
459.0 465.5 broken
459.5-460.1 unrcvd
463.0-465.5 unrcvd
466.9-468.0 broken
469.3-473.5 unrcvd
472.0-474.0 very large lithophysae
474.2-475.6 broken
477.0-498.0 very large lithophysae
476.8-477.6 unrcvd,
476.6-478.9 broken
479.8-484.4 broken
480.0-484.2 unrcvd
485.5-490.0 broken
485.5-489.4 unrcvd

Topopah Spring Crystal-Rich Nonlithophysal Zone, *cont. ("rounded") (281.0-439.2)* as described above, 423.8 rhyolite soft lithic fraction increases to 25-30%, nearing compositional transition zone, increase in vapor-phase recrystallization of pumiceous rhyolite

Topopah Spring Crystal-Rich Lithophysal zone (Tptrl) *(439.2-485.2)* pale red-purple (5RP6/2) densely welded, devitrified crystal-rich ashflow tuff,10%- 25% 10-30 mm lithophysae, with pink-gray alteration halos, 10% -15% exotic crystal-poor rhyolite soft lithics (deformed with fabric of groundmass), 10-12% feldspar phenos and 0.5% oxybiotite, <1% small red-brown hard lithics, borehole video shows very large (2-3 feet) lithophysal cavities, 447.5 increase in lithophysal intensity, lithophysae become small irregular, close-spaced, with 3-4 mm alteration rims.

Compositional transition interval *(454.7-468.6)* changes in composition from brown crystal-rich quartz latite with soft lithics of crystal-poor rhyolite, to medium gray crystal-poor rhyolite with soft lithics of crystal-rich quartz latite.

456.0 strong lithophysal zone, close-spaced larger ragged lithophysae weakly coated by vapor phase minerals, with none to 3 mm blue alteration rim.

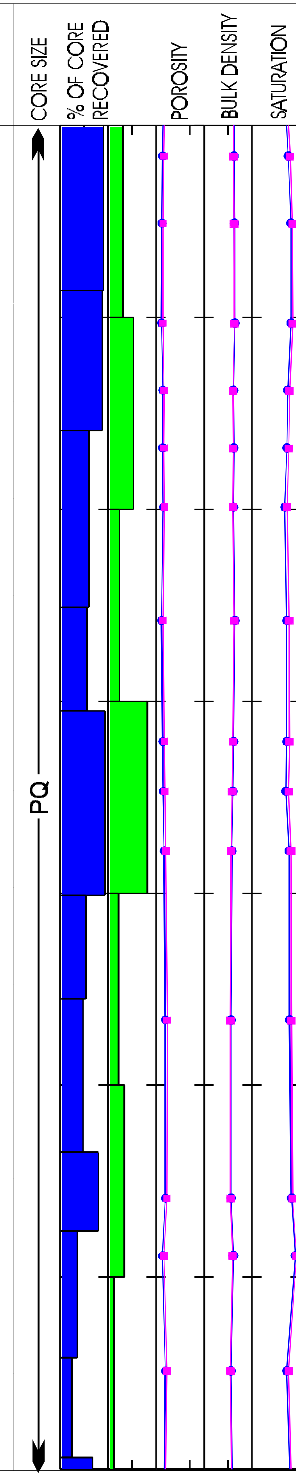
460.0-downward: extensive broken-unrecovered zones probable result of "cavernous" lithophysal cavities

Crystal transition interval *(448.2-485.2),* phenocryst content changes from 10-12% in crystal-rich quartz latite groundmass above to 3-5% in crystal-poor rhyolite groundmass below.

Approximate Contact:
Crystal-rich member to crystal-poor member

Topopah Spring Crystal-Poor Upper Lithophysal Zone (Tptpul) *(485.2-728.8)*

AVE. CORE REC'Y/HOLE



Sandia National Laboratories
Logged by: Dale Engstrom
Log Version: 2.01
Log Date: January 15, 1996

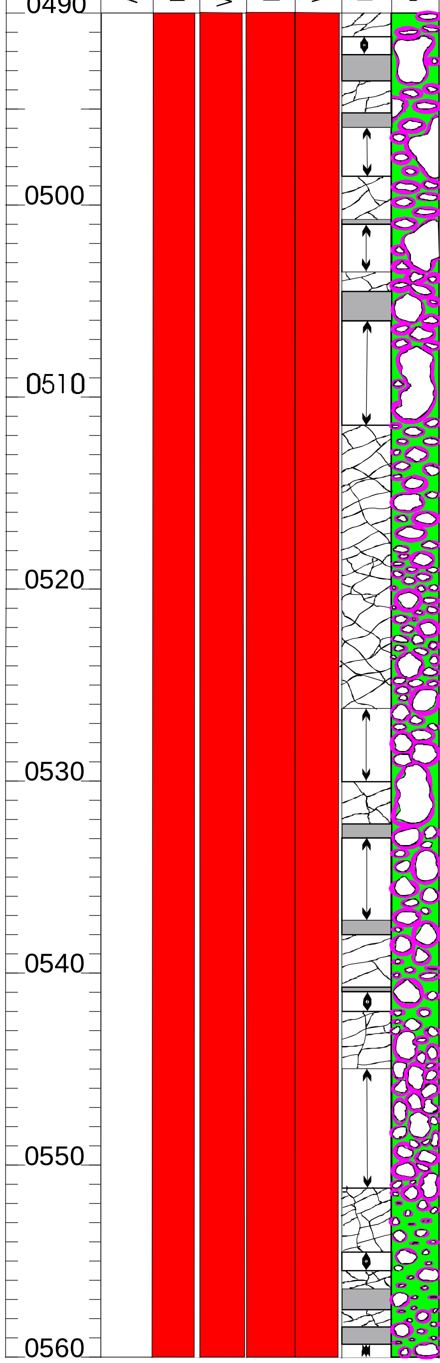
ELEVATION: 4272.6 Feet
BEARING: N/A
INCLINATION: Vertical
TOTAL DEPTH: 2223.1 Feet

COLLAR COORDINATES:
N 767998.5 E 561818.0
STARTED: May 19, 1994
COMPLETED: September 27, 1994

DEPTH | ALTERATION: ARGILLIC, LITHOPH., VAPOR PH. | Devitrification | WELDING | FRACTURING | GEOLOGY | COMMENTS:

DTN: SNT02052794001.003

AVE. CORE REC'Y/HOLE



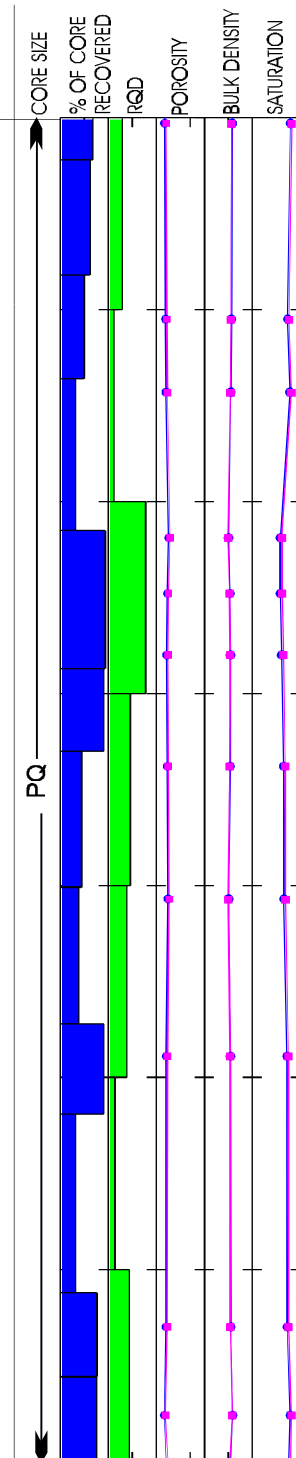
491.3-492.2 unrcvd
491.3-493.4 rubble
495.2-498.4 rubble
495.9-498.4 unrcvd
500.7-503.6 rubble
500.9-503.6 unrcvd
504.5-511.5 rubble
506.1-511.5 unrcvd

Topopah Spring Crystal-Poor Upper Lithophysal Zone (Tptpul), *cont. (485.2-728.8)* pale red-purple (5RP6/2) densely welded devitrified, 25%-30% close-spaced circular ragged small-to-medium sized lithophysae, abundant relicts of recrystallized frothy pumice cores rimmed by 3-5 mm white vapor-phase mineralized, most lithophysal interiors coated by vapor-phase minerals, all of groundmass pervasively blue altered, 7-10% quartz latite soft lithics up to 110 mm, 2% phenos of sanidine and biotite, 1% small dark hard lithics, extensive broken-unrecovered zones suggest "cavernous" lithophysae confirmed by down-hole video survey.

525.7-0.6' quartz latite lithic
526.2-530.1 unrcvd
530.0 — Very large lithophysae in borehole video.

532.3-537.9 rubble
532.9-537.2 unrcvd
540.7-540.9 rubble
540.9-541.9 unrcvd
543.0 -very crowded
544.9-551.2 unrcvd
554.6-555.6 unrcvd
556.6-557.6 rubble
558.4-560.5 rubble
559.3-560.5 unrcvd

15-17% of rock volume is lithophysal cavity in wide size range up to 60 mm, crowded circular cavities lined by crystalline vapor-phase SiO2 and accessory minerals, up to 15 mm light pink-gray vapor-phase alteration halo, 80% groundmass pervasively blue altered, 2-3% sanidine phenos, no biotite seen, <1% medium gray rhyolite angular hard lithics, brown crystal-rich quartz latite soft lithics up to 20-25 mm continue to 540.9, below 540.9 crystal-rich quartz latite soft lithics are smaller, more altered, less obvious.



Yucca Mountain Project

Hole No: USW SD-9

Scale: 1"=10' (1:120)

Sheet 9 OF 32

Sandia National Laboratories

Logged by: Dale Engstrom

Log Version: 2.01

Log Date: January 15, 1996

ELEVATION: 4272.6 Feet

BEARING: N/A

INCLINATION: Vertical

TOTAL DEPTH: 2223.1 Feet

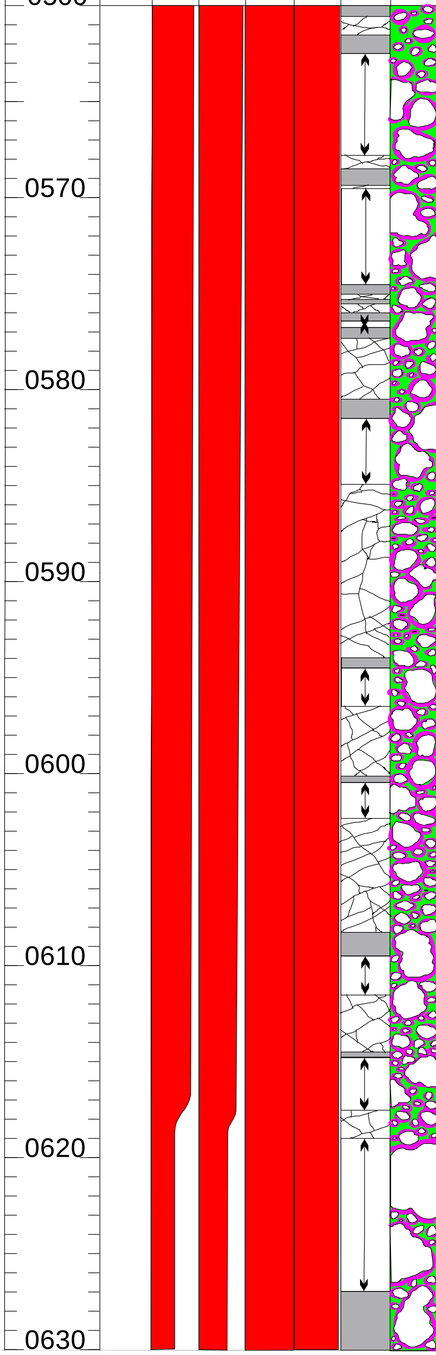
COLLAR COORDINATES: N 767998.5 E 561818.0

STARTED: May 19, 1994

COMPLETED: September 27, 1994

DTN: SNT02052794001.003

DEPTH	ALTERATION: ARGILLIC	LITHOPH.	VAPOR PH.	Devitrification	WELDING	FRACTURING	GEOLOGY	COMMENTS:	AVE. CORE REC'Y/HOLE



530.0-670.0 lg. lithoph.
561.6-567.8 rubble
562.5-567.8 unrcvd
568.4-569.3 rubble
569.5-574.6 unrcvd
574.6-575.1 rubble
575.3-575.6 rubble
576.1-577.3 rubble
576.4-576.8 unrcvd
580.5-584.9 rubble
581.4-584.9 unrcvd
593.9-596.4 rubble
594.4-596.4 unrcvd
600.2-602.4 rubble
600.6-602.3 unrcvd
608.3-611.6 rubble
609.5-611.6 unrcvd
614.5-617.6 rubble
614.7-617.6 unrcvd
617.6
619.0-626.9 unrcvd
619.0-630.0 rubble
627.7

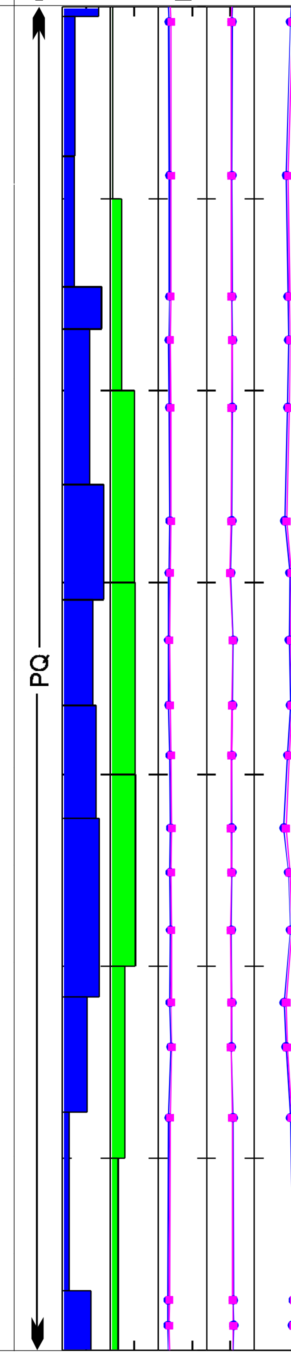
Topopah Spring Crystal-Poor Upper Lithophysal Zone, *cont. (485.2-728.8)* med. red-purple (5RP5/2) densely welded, devitrified, 15-17% crowded circular lithophysae in wide size range up to 60 mm, lined by white crystalline vapor-phase mineralization, rimmed by up to 15 mm light pink-gray alteration, 85% groundmass is pervasively blue altered, 3-5% quartz latite soft lithics, 2-3% white sanidine phenos, no biotite, <1% small light gray angular hard lithics (altered rhyolite?), very large lithophysae observed in borehole video from 530.0-711.3'.

Vapor-phase intensity gradually decreasing downward.

617.6 — Lithophysae smaller, close-spaced, vapor-phase intensity decreasing downward, borehole video contains very large lithophysae down to 711.3 feet.

627.7 — 10% of rock is unaltered, 30% is very light gray vapor-phase alteration halos, lithophysae intensity decreasing (less crowded) downward.

CORE SIZE	% OF CORE RECOVERED	RQD	POROSITY	BULK DENSITY	SATURATION



Yucca Mountain Project

Hole No: USW SD-9

Scale: 1"=10' (1:120)

Sheet 10 OF 32

Sandia National Laboratories

Logged by: Dale Engstrom

Log Version: 2.01

Log Date: January 15, 1996

ELEVATION: 4272.6 Feet

BEARING: N/A

INCLINATION: Vertical

TOTAL DEPTH: 2223.1 Feet

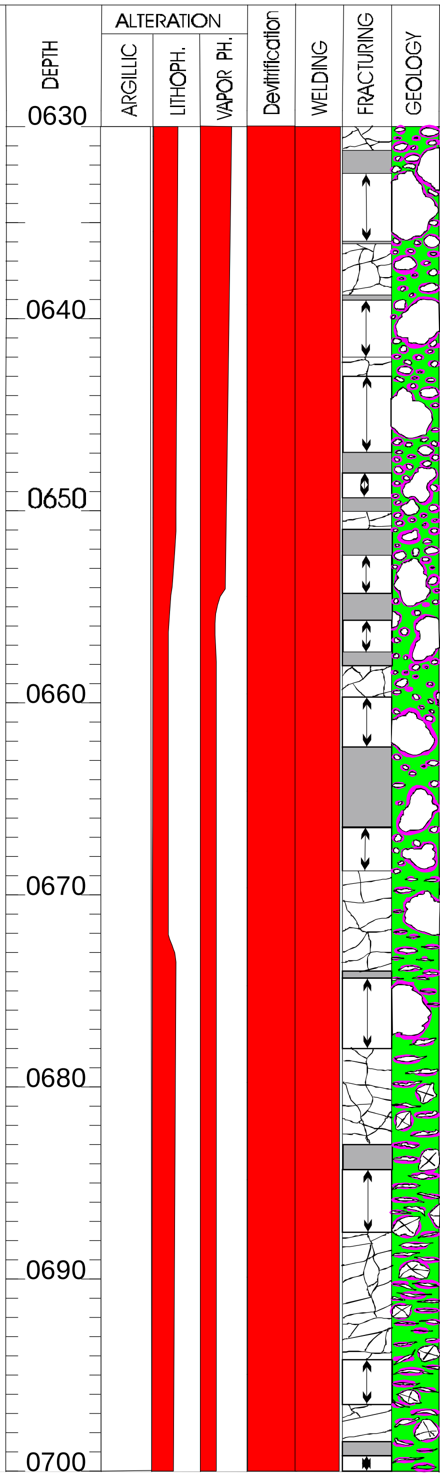
COLLAR COORDINATES:

N 767998.5 E 561818.0

STARTED: May 19, 1994

COMPLETED: September 27, 1994

DTN: SNT02052794001.003



COMMENTS:

AVE. CORE REC'Y/HOLE

631.2-636.1 rubble
632.4-636.0 unrcvd

Topopah Spring Crystal-Poor Upper Lithophysal Zone, *cont. (485.2-728.8)* medium red-purple (5RP5/2) densely welded, devitrified,15% to 20% crowded oval small to very small lithophysae lined by crystalline white vapor-phase mineralization, rimmed by 8-10 mm light gray alteration halo, weak 1-2 mm blue alteration border, rest of groundmass is medium orange grainy devitrified; lithophysal intensity decreasing downward, but very large lithophysae seen in borehole video from 530.0-711.3 feet.

638.7-642.0 rubble
639.1-642.0 unrcvd

634.0-650.1 rubble
643.0-646.9 unrcvd
648.1-649.3 unrcvd

650.9-658.1 rubble
652.3-654.3 unrcvd

654.3 — Lithophysae weaker, dramatic decrease in vapor phase intensity, 20% groundmass composed of blue alteration borders, 55% is unaltered.

655.7-657.3 unrcvd

658.2 — Lithophysae weaker, lithophysae barely opened or just vuggy, groundmass 75% unaltered.

659.7-668.7 rubble
659.7-662.3 unrcvd
666.5-668.7 unrcvd

672.9 — Lithophysae are less open, more flattened, and coated by coarse crystalline vapor-phase mineralization haloed by circular white alteration spots that make 30-35% of rock volume, 2-4% of rock is blue alteration border.

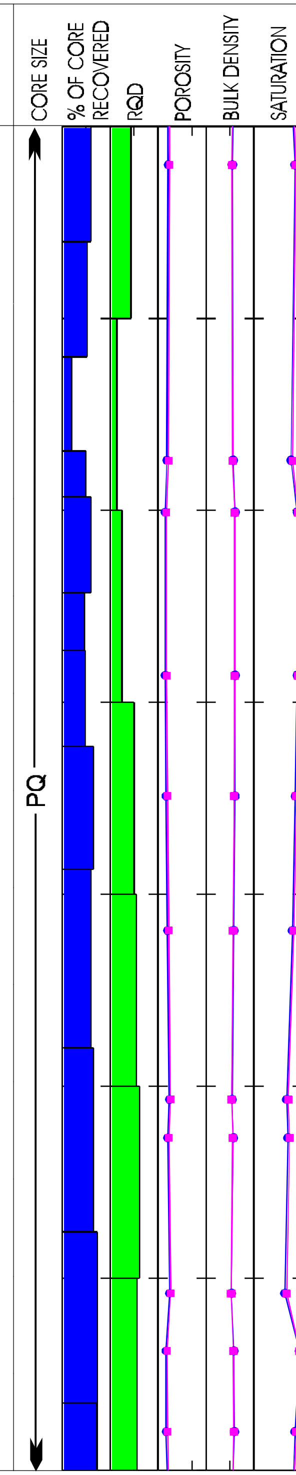
674.0-678.0 rubble
674.3-678.0 unrcvd

676.0 — Most lithophysae are closed to thin subhorizontal irregular line of vapor-phase minerals replacing flattened pumice, 15-17 mm diameter spots of pink-gray alteration, with 1 mm blue alteration border, grainy groundmass, occasional larger lithophysae that has been squeezed to vertical lens or "panelled" shape.

683.0-687.6 rubble
684.3-687.6 unrcvd

694.2-696.5 unrecvd

698.4-700.2 rubble
699.2-700.2 unrcvd



Yucca Mountain Project

Hole No: USW SD-9

Scale: 1"=10' (1:120)

Sheet 11 OF 32

Sandia National Laboratories

Logged by: Dale Engstrom

Log Version: 2.01

Log Date: January 15, 1996

ELEVATION: 4272.6 Feet

BEARING: N/A

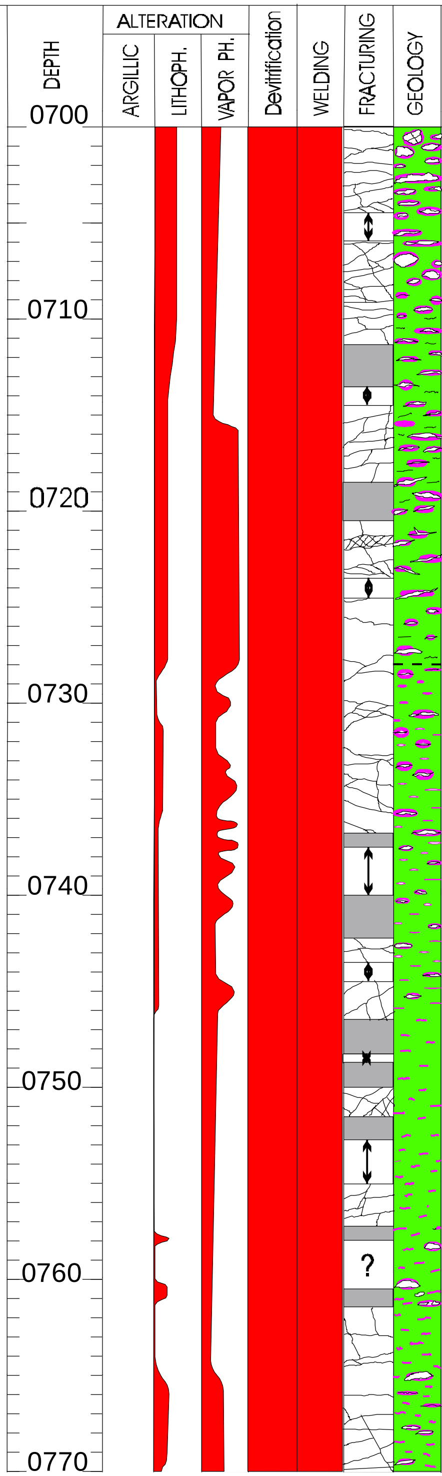
INCLINATION: Vertical

TOTAL DEPTH: 2223.1 Feet

COLLAR COORDINATES: N 767998.5 E 561818.0

STARTED: May 19, 1994

COMPLETED: September 27, 1994



COMMENTS:

DTN: SNT02052794001.003

AVE. CORE REC'Y/HOLE

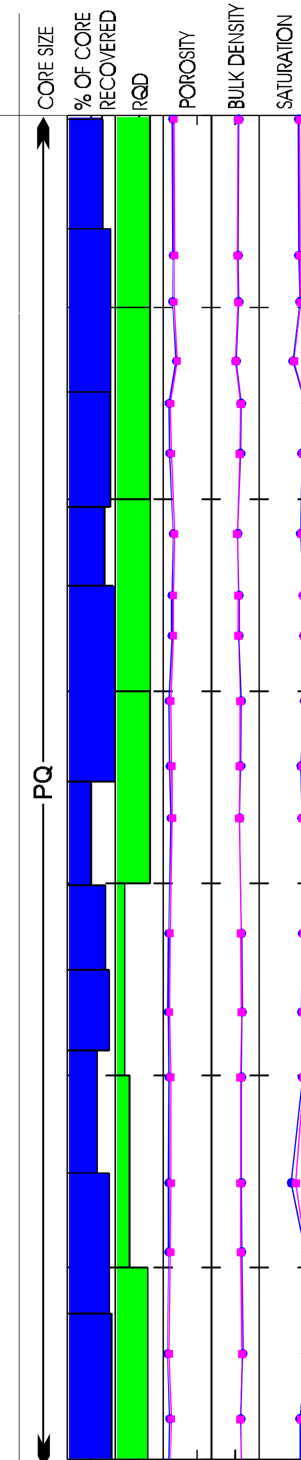
699.2-700.2 unrcvd
704.5-705.9 unrcvd
705.9-707.0
711.3-713.6 broken
713.6-714.4 unrcvd
714.0-724.5
715.3-728.8
718.6-720.4 broken
723.6-724.5 unrcvd
728.8
736.8-742.2 broken
737.4-740.1 unrcvd
743.6-744.5 unrcvd
746.4-750.1 broken
748.2-748.7 unrcvd
751.5-755.1 broken
752.7-755.1 unrcvd
757.2-757.9 broken
757.9-760.6 no core
760.6-761.3 broken
765.0
769.8-770.4 unrcvd

Topopah Spring Crystal-Poor Upper Lithophysal Zone, *cont. (439.2-728.8)* med. red-purple (5RP5/2) densely welded, groundmass is 85-90% grainy and devitrified, 8-10% light pink-gray vapor-phase alteration spots around lithophysae bordered by 1-2% blue alteration, replaced flattened litho- physae are seen as irregular 1-3 mm thick subhorizontal vapor-phase mineralization or barely opened, coated, vuggy, weakly developed lithophysae, rock is crystal-poor with 2-3% white sanidine phenos, 0.5% biotite flakes, lithophysae oriented along fractures at 705.9 and 714.0.

(714.0-724.5) 85% blue vapor-phase altered

(728.8) ***Topopah Spring Crystal-Poor Middle Nonlithophysal Zone (Tptpmn),*** *upper nonlithophysal subzone (728.8-788.1)* lithophysae number decrease to <10%, densely welded, devitrified, groundmass texture finer, more compact, less grainy, mixed alteration zone (first part) strong pervasive blue (5PB6/2) alteration and 17% white fuzzy 15 mm vapor-phase streaks around pumice and lithophysae with islands of unaltered groundmass vs. (second part) orange-pink zones of unaltered groundmass speckled by 10% white alteration streaks and 7-8 mm alteration spots, 17% white irregular hairline flattened pumice with 10 mm fuzzy alteration halo, 1-2% feldspar phenos, no biotite seen, most altered zones speckled by specular hematite, specks of dark olive green mineralization (pyroxene?) on post-oxidation surfaces.

(765.0) Medium-large lithophysae at 765.0, 768.2 (borehole video)

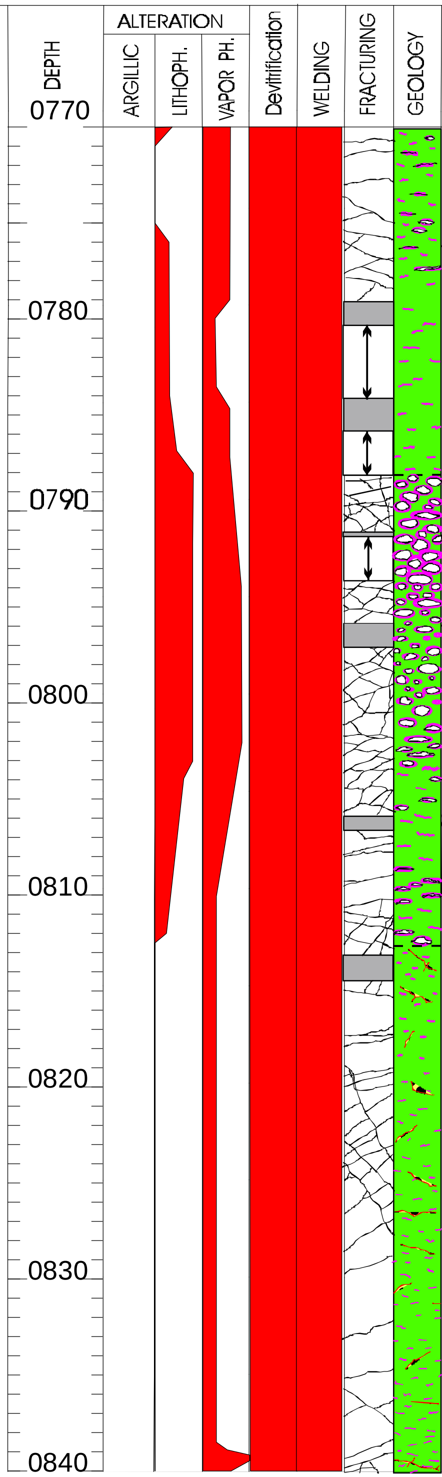


Yucca Mountain Project
Hole No: USW SD-9
Scale: 1"=10' (1:120)
Sheet 12 OF 32

Sandia National Laboratories
Logged by: Dale Engstrom
Log Version: 2.01
Log Date: January 15, 1996

ELEVATION: 4272.6 Feet
BEARING: N/A
INCLINATION: Vertical
TOTAL DEPTH: 2223.1 Feet

COLLAR COORDINATES:
N 767998.5 E 561818.0
STARTED: May 19, 1994
COMPLETED: September 27, 1994



COMMENTS:

DTN: SNT02052794001.003

AVE. CORE REC'Y/HOLE

776.4 — Pumice reduced to irregular subhorizontal recrystallized lines of vapor-phase mineralization.

779.0-784.1 broken
779.0-779.1 unrcvd
780.2-784.1 unrcvd
785.7-788.1 unrcvd

788.1 — ***Topopah Spring Crystal-Poor Middle Nonlithophysal Zone,*** *cont., lithophysae-bearing subzone (788.1-812.5)* characterized by small close-spaced circular lithophysae lined by crystalline vapor-phase mineralization after pumice, pumice often extending into cavity wall, in 15-20 mm light gray alteration spot with 1-2 mm blue alteration border, groundmass more intensely blue pervasively altered from 795.0-802.5, and much less altered below 803.3, lithophysae increase in size toward 803.3, then decrease in intensity downward.

791.0-793.5 broken
791.2-793.5 unrcvd
795.0 more altered
795.7-797.0 broken

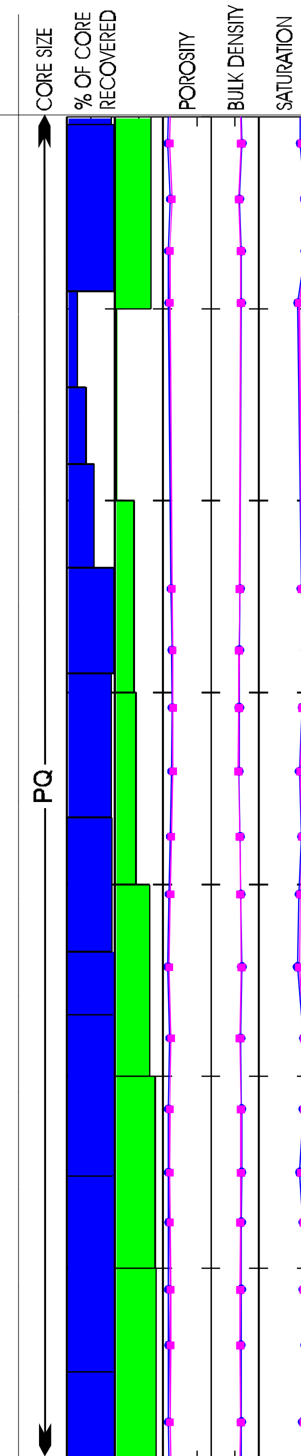
803.3 altn decreases

805.8-806.5 broken

812.5 — ***Topopah Spring Crystal-Poor Middle Nonlithophysal Zone,*** *cont., lower nonlithophysal subzone (812.5-845.8)* similar to above, dense compact texture, 10% speckled by hazy 5-10 mm vapor-phase streaks, some with weak blue border, 1-2% hairline vapor-phase silica veinlets with 20 mm blue alteration selvage each 2-3 feet, 2-3% white sanidine phenos, no biotite, 2% rhyolite and quartz latite hard lithics that average 5 mm.

813.1-814.3 broken

838.8
839.4 — 839.4 strong vertical joints coated by white vapor-phase silica, 4-6 mm pink-gray alteration halo and 1-2 mm blue alteration border, below 839.8 15-20% wispy blue alteration selvages around hairline silica veinlets with 1-2 mm medium gray alteration halos, vapor-phase vein mineralization includes SiO_2 and carbonate minerals.



Yucca Mountain Project

Hole No: USW SD-9

Scale: 1"=10' (1:120)

Sheet 13 OF 32

Sandia National Laboratories

Logged by: Dale Engstrom

Log Version: 2.01

Log Date: January 15, 1996

ELEVATION: 4272.6

BEARING: N/A

INCLINATION: Vertical

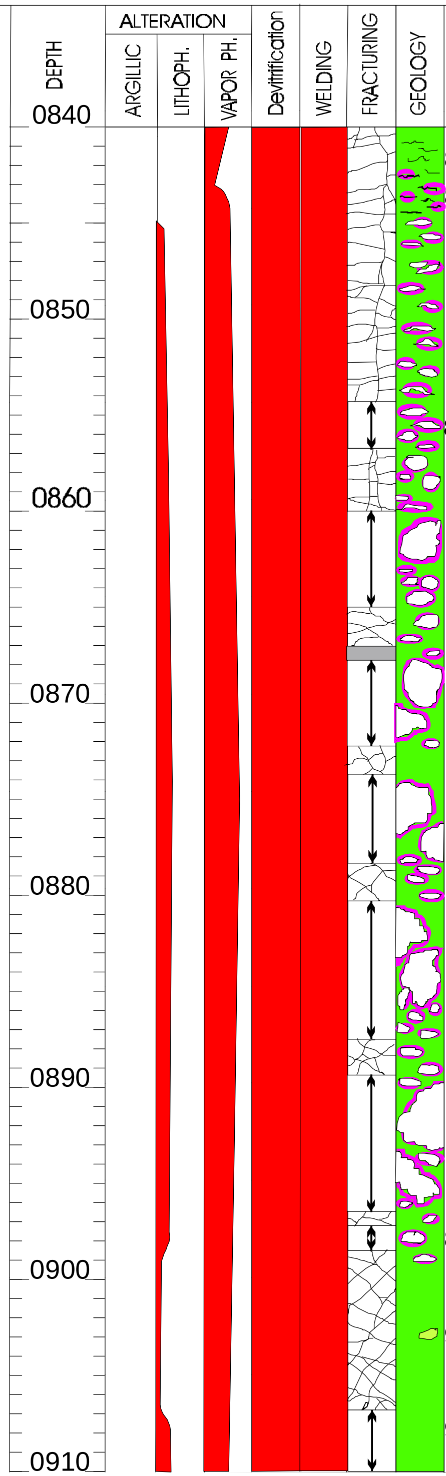
TOTAL DEPTH: 2223.1 Feet

COLLAR COORDINATES:

N 767998.5 E 561818.0

STARTED: May 19, 1994

COMPLETED: September 27,1994



COMMENTS:

DTN: SNT02052794001.003

AVE. CORE REC'Y/HOLE

841.4 — Upper limit of flat recrystallized pumice with blue alteration

843.5 — Alteration increases, light gray 10 mm alteration spot around micropumice each 1-2" rimmed by 2-3 mm blue alteration border, below 845 occasional partially open lithophysae.

845.8 — ***Topopah Spring Crystal-Poor Lower Lithophysal Zone, (Tptpll)*** *(845.8-1187.0)* medium red-brown (5YR6/3) 5% small pinched, oval lithophysae mostly < 20 mm, 2-7% light gray pumice less than 35 mm with thin brown alteration rims, 1-2% of wide variety of lithics with majority < 25 mm, 1-2% sanidine and 0.5% biotite phenocrysts, vertical jointing common.

854.3-856.8 unrcvd

860.0-865.0 unrcvd

866.5 — Rock fabric intensely contorted by activity of lithophysae.

867.1-928.7 — Rock between unrecovered zones broken to rubble (large lithophysae present?).

867.7-872.2 unrcvd

873.7-878.3 unrcvd

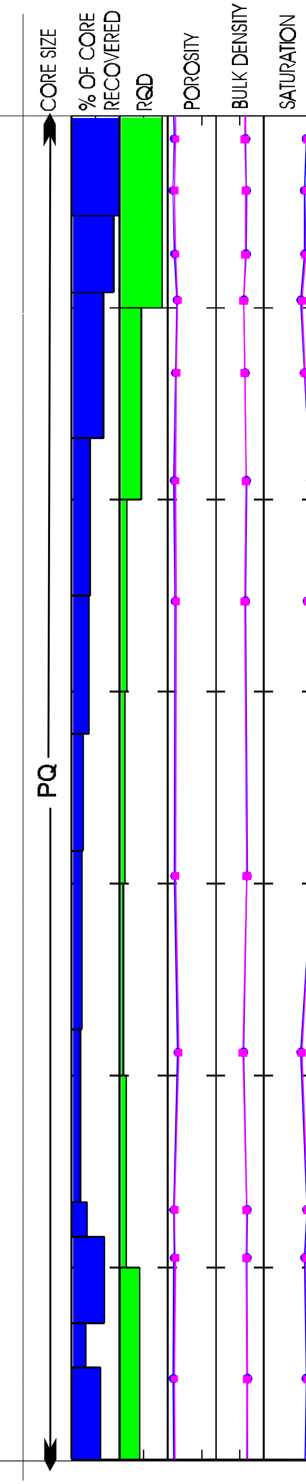
880.3-887.6 unrcvd

889.3-896.6 unrcvd

897.2-898.4 unrcvd

902.9 — 70mm pumice with relict froth texture.

906.8-921.2 unrcvd



Yucca Mountain Project
Hole No: USW SD-9
Scale: 1"=10' (1:120)
Sheet 14 OF 32

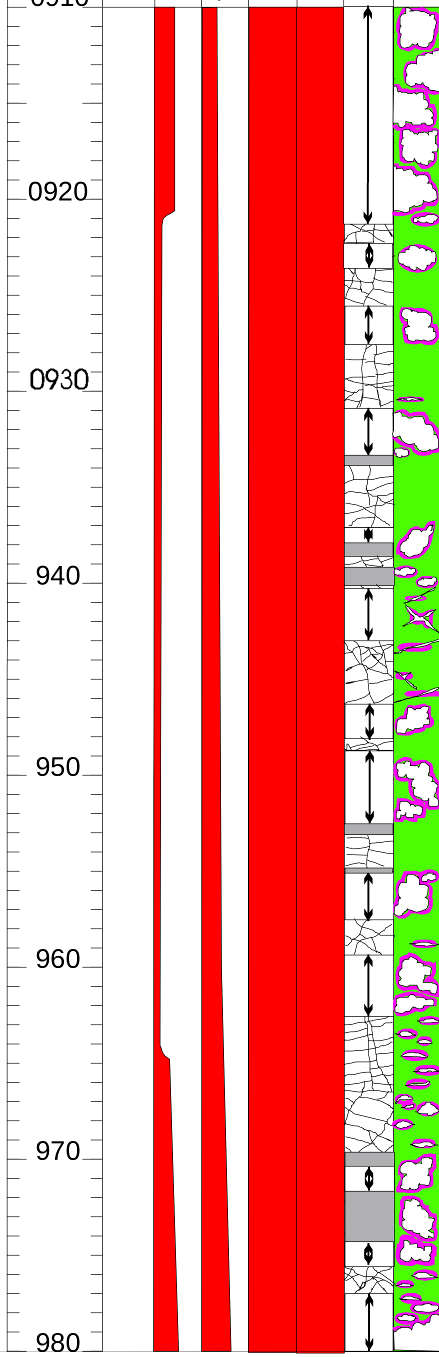
Sandia National Laboratories
Logged by: Dale Engstrom
Log Version: 2.01
Log Date: January 15, 1996

ELEVATION: 4272.6 Feet
BEARING: N/A
INCLINATION: Vertical
TOTAL DEPTH: 2223.1 Feet

COLLAR COORDINATES:
N 767998.5 E 561818.0
STARTED: May 19, 1994
COMPLETED: September 27, 1994

DEPTH | ALTERATION (ARGILLIC, LITHOPH., VAPOR PH.) | Devitrification | WELDING | FRACTURING | GEOLOGY | COMMENTS: | AVE. CORE REC'Y/HOLE

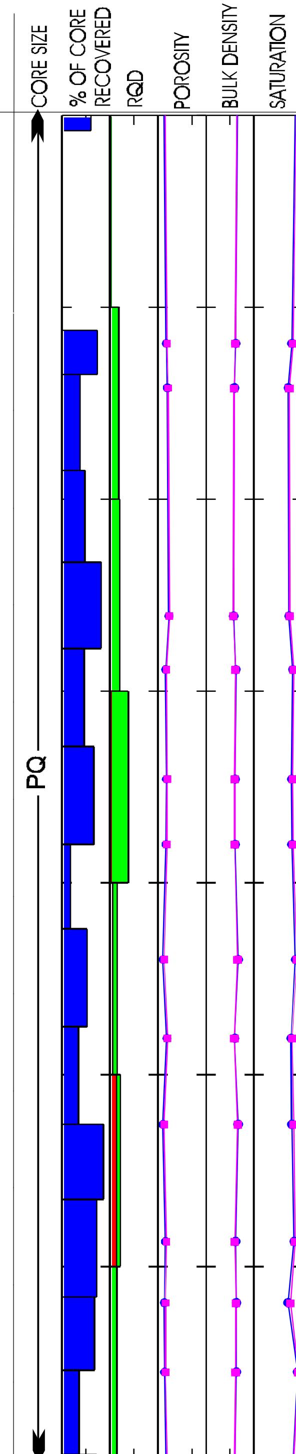
DTN: SNT02052794001.003



906.8-921.2 unrcvd

Topopah Spring Crystal-Poor Lower Lithophysal Zone, *cont. (845.8-1187.0)* pale red-gray (10R6/2) densely welded, devitrified, grainy groundmass texture, 10-12% very flat wispy pumice sites replaced by white crystalline vapor-phase mineralization in 25 mm very light brown vapor-phase alteration halo, 1-2% sanidine, 0.5% biotite, with majority of core broken due to very large lithophysae seen in borehole video, 900-975 vapor-phase intensity decrease downward, blue alteration of groundmass changes from 50% to 2-3%, and changes to 25% light pink-tan alteration spots around lithophysae of flat pumice fragments.

922.2-923.5 unrcvd
925.4-928.5 unrcvd
930.8-933.3 unrcvd
933.3-933.7 badly broken
937.0-938.4 badly broken, rubble
937.0-937.8 unrcvd
939.1-940.0 badly broken
940.2-942.9 unrcvd
946.3-948.0 unrcvd
948.8-953.0 broken
948.8-952.4 unrcvd
954.7-957.5 badly broken
955.1-957.5 unrcvd
959.3-962.6 unrcvd
962.6 ——— Lithophysae (visible in core) reappear.
969.5-975.5 broken
970.2-971.6 unrcvd
974.2-975.4 unrcvd



Yucca Mountain Project

Hole No: USW SD-9

Scale: 1"=10' (1:120)

Sheet 15 OF 32

Sandia National Laboratories

Logged by: Dale Engstrom

Log Version: 2.01

Log Date: January 15, 1996

ELEVATION: 4272.6 Feet

BEARING: N/A

INCLINATION: Vertical

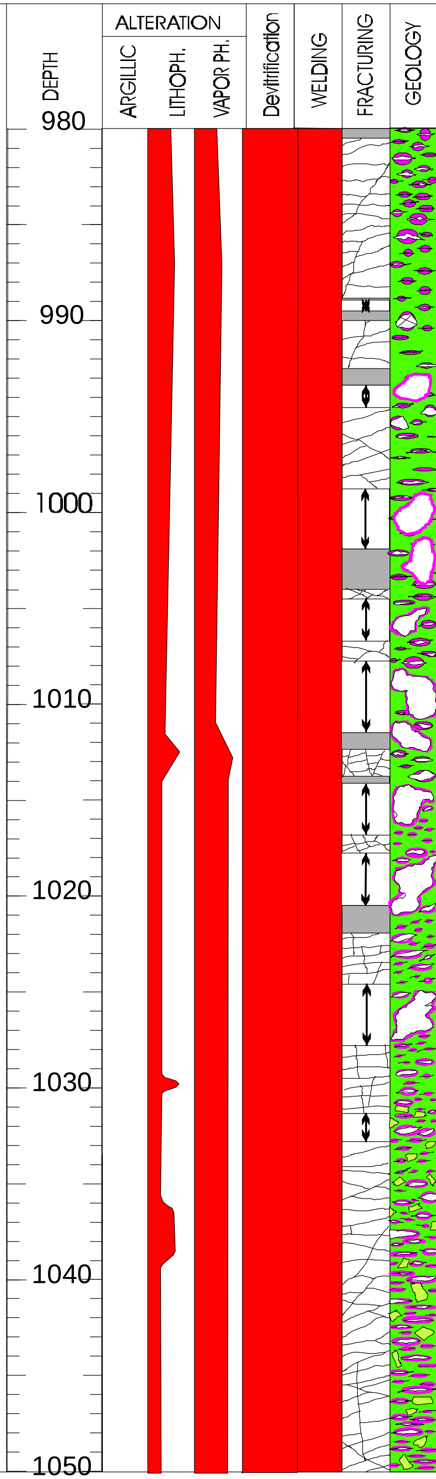
TOTAL DEPTH: 2223.1 Feet

COLLAR COORDINATES: N 767998.5 E 561818.0

STARTED: May 19, 1994

COMPLETED: September 27, 1994

DTN: SNT02052794001.003



COMMENTS:

Depth (ft)	Note
977.0-980.4	broken
988.8-990.0	broken
988.9-989.5	unrcvd
992.5-994.5	broken
993.3-994.5	unrcvd
998.5	
998.9-1001.9	unrcvd
998.8-1004.0	broken
1004.4-1006.7	unrcvd
1007.8-1012.3	broken
1007.8-1011.4	unrcvd
1013.2-	
1013.8-1016.8	broken
1014.1-1016.8	unrcvd
1015.0	
1017.8-1020.5	unrcvd
1017.8-1021.9	broken
1024.6-1027.7	unrcvd
1031.0	
1031.3-1032.8	unrcvd
1036.2	
1039.0	
1040.2	60mm rhyolite lithic

Topopah Spring Crystal-Poor Lower Lithophysal Zone, *cont.* pale red-gray (10R6/2) densely welded, devitrified, grainy groundmass texture,10-12% very flat wispy pumice replaced by white vapor-phase mineralization in 12-15 mm lt. gray vapor-phase alteration spot, below 990.0 closely-spaced lithophysae barely opened or not opened in 12-15 mm light gray alteration halo, weak "web" of blue alteration through groundmass (5-7%) otherwise groundmass is light orange and grainy, large broken or unrecovered zones suspected to be due to large lithophysae seen in borehole video, crystal-poor 1-2% sanidine and 0.5% biotite pheno.

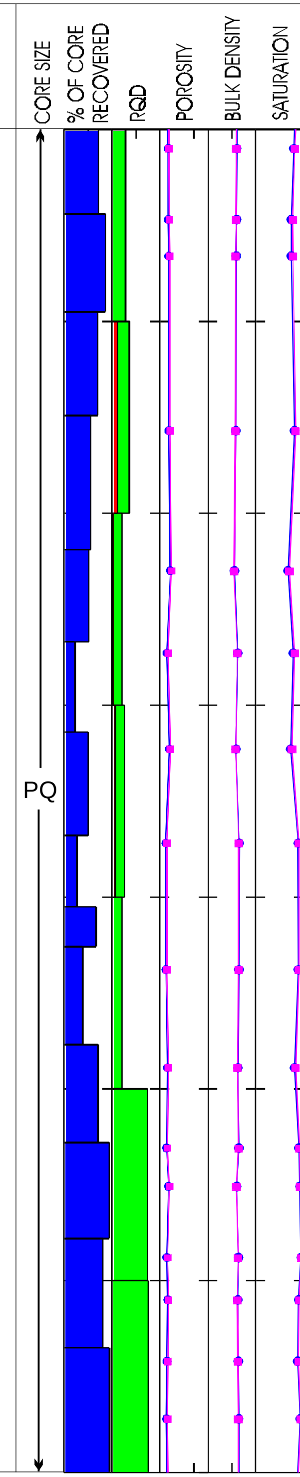
1013.2 lithophysae die out to very small flat cavities or vuggy and barely opened but vapor-phase spots continue down. 1015.0 vapor-phase alteration increases, 8% white vapor-phase alteration in small streaks and alteration around lithophysae, 20-25% of the groundmass is pervasively blue altered.

1031.0-1077.6 lithic zone, increase in 20-60 mm angular rhyolite lithics.

1036.2-1038.4 slight increase in lithophysal intensity,

1039.0-vapor-phase alteration changes to long subhorizontal streaks, 4-5 mm blue-lavender vapor-phase halos around hairline pumice sites now all crystalline vapor-phase mineralization (barely visible), 20-25% groundmass is pervasively blue altered, 2-3% sanidine phenos, rare cognate angular lithics average about 5-6 mm size.

AVE. CORE REC'Y/HOLE



Yucca Mountain Project
Hole No: USW SD-9
Scale: 1" = 10' (1:120)
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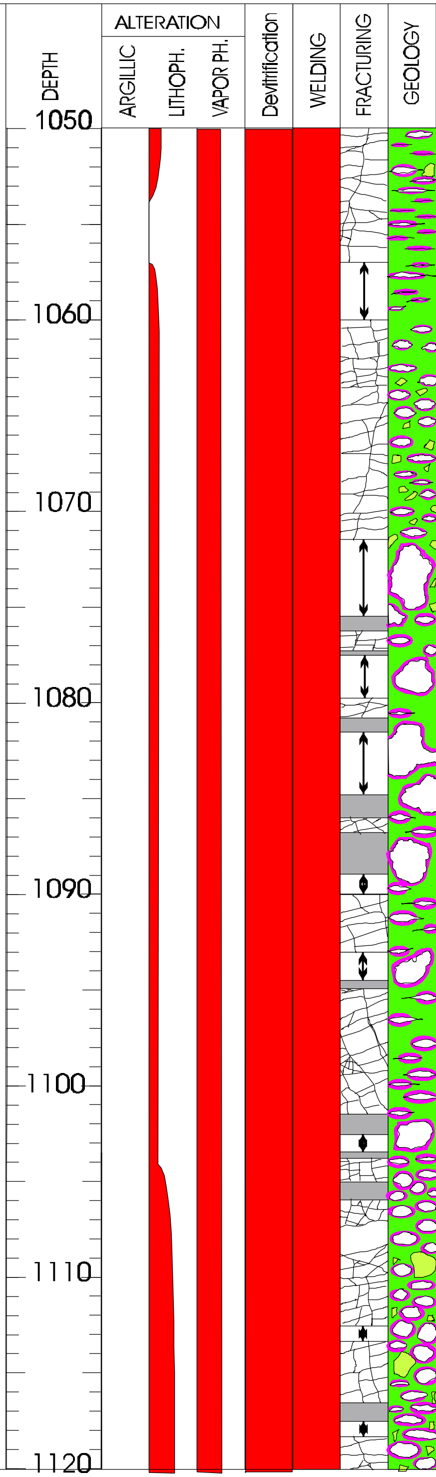
Drilling Contractor: Reeco
Logged by: Dale Engstrom
Log Version: 2.01
Log Date: January 15, 1996

Started: May 19, 1994
Completed: Sept. 27, 1994
Bearing: N/A (vertical)
Inclination: -90

Collar Coordinates:
N: 767998.5 E: 561818.0
Elevation: 4272.6 Feet
Total Depth: 2223.1 Feet



COMMENTS:

DTN: SNT02052794001.003

AVE. CORE REC'Y/HOLE

1050.0 v.lg.lithoph in borehole video
1052.0-50mm rhyolite lithic
1057.0-1059.7 unrcvd
1057.0-1060.0 broken
1060.0
1063.3-1075.4
1070.0
1071.4-1076.2 broken
1071.4-1075.4 unrcvd
1077.3-1079.8 broken
1077.6-1079.8 unrcvd
1080.8-1086.0 broken
1081.6-1084.8 unrcvd
1086.7-1090.0 broken
1088.9-1090.0 unrcvd
1093.0-1094.4 unrcvd
1093.0-1094.9 broken
1101.4-1103.7 broken
1102.5-1103.4 unrcvd
1104.4
1105.0-1105.9 broken
1107.7 lithic zone
1109.1-70mm rhyolite lithic
1110.0-1160.0 v.lg.lithoph in borehole video
1112.4-1113.3 unrcvd
1114.9-70mm rhyolite lithic
1116.4-1118.3 broken
1117.4-1118.3 unrcvd

Topopah Spring Crystal-Poor Lower Lithophysal Zone
cont. pale red-gray (10R6/2) densely welded, devitrified, 4-5 mm wide lavender-blue vapor-phase alteration streaks halo hairline pumice sites filled with crystalline vapor-phase mineralization, 20-25% of groundmass pervasively blue altered, 2-3% sanidine & 0.5% biotite phenos, rare angular 5-6 mm cognate lithics.

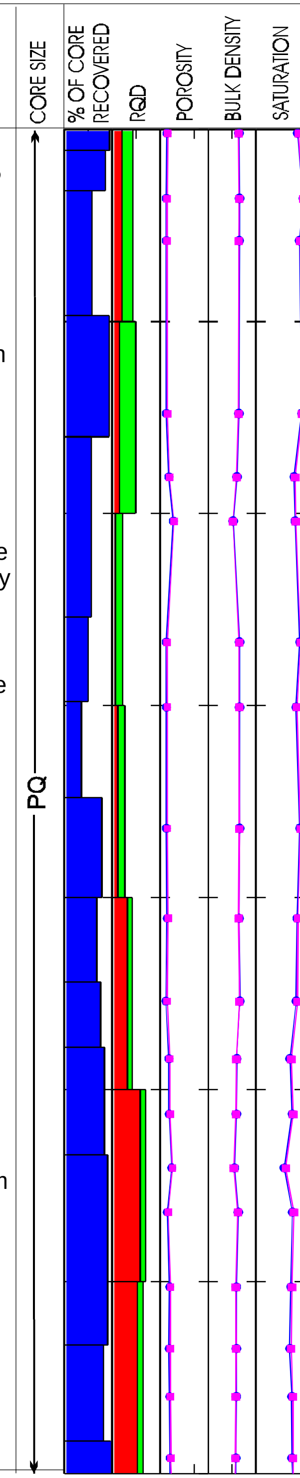
1060.0 ragged, angular small-to-mid size lithophysae,5-8 mm pink vapor-phase alteration halo, 1-2 mm blue alteration border.

1063.3-1075.4 lithic-rich zone, angular rhyolite lithics up to 25 mm size.

1070.0 ranges from very small flat moderately-spaced lithophysae to very flat (nearly invisible) hairline vapor-phase replacement of pumice sites in 20 mm circular light pink-gray alteration spot, 2-5 mm border blue alteration, 30-35% blue alteration "web" through groundmass, 1-2% sanidine phenos, 1-2% angular white (poss. altered) rhyolite lithics. unrecovered and broken zones suspected to be due to large lithophysae seen in borehole video.

1104.4 medium sized, well-opened, irregularly-shaped, moderately spaced, lithophysae with ragged interiors, 40-50% have no crystalline coating, regularly-spaced 60-70 mm circular light pink-gray alteration spots with/without lithophysae, weak to no blue alteration border.

1107.7-1118.5 lithic-rich zone, angular rhyolite lithics.



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SANDIA NATIONAL LABS
Logged by: Dale Engstrom
Log Version: 2.01
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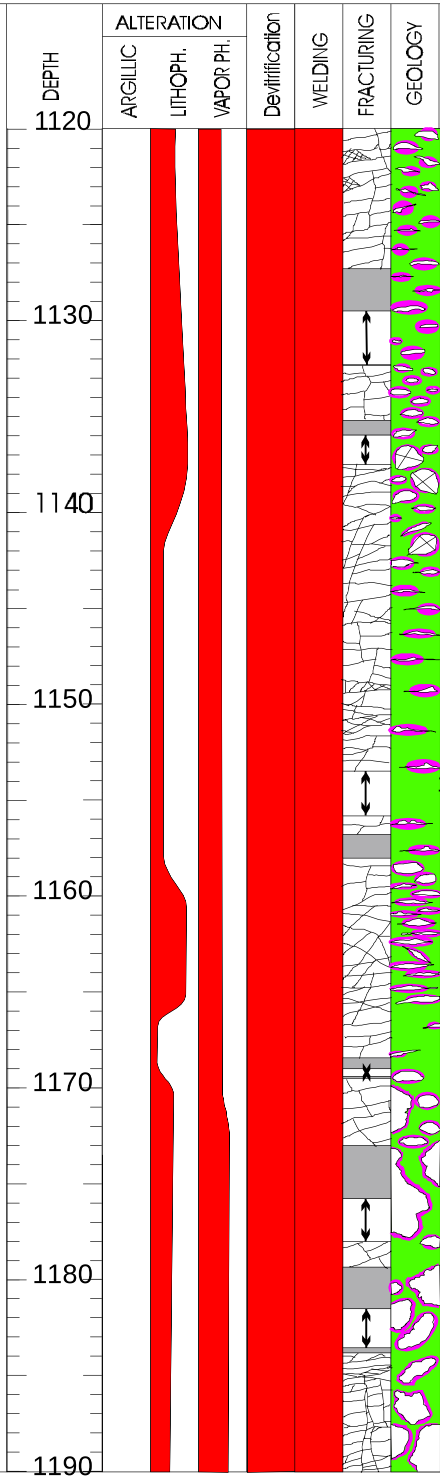
Started: May 19, 1994
Completed: Sept. 27, 1994
Bearing: N/A (vertical)
Inclination: -90

Collar Coordinates:
N: 767998.5 E: 561818.0
Elevation: 4272.6 Feet
Total Depth: 2223.12 Feet

DTN: SNT02052794001.003

AVE. CORE REC'Y/HOLE



COMMENTS:

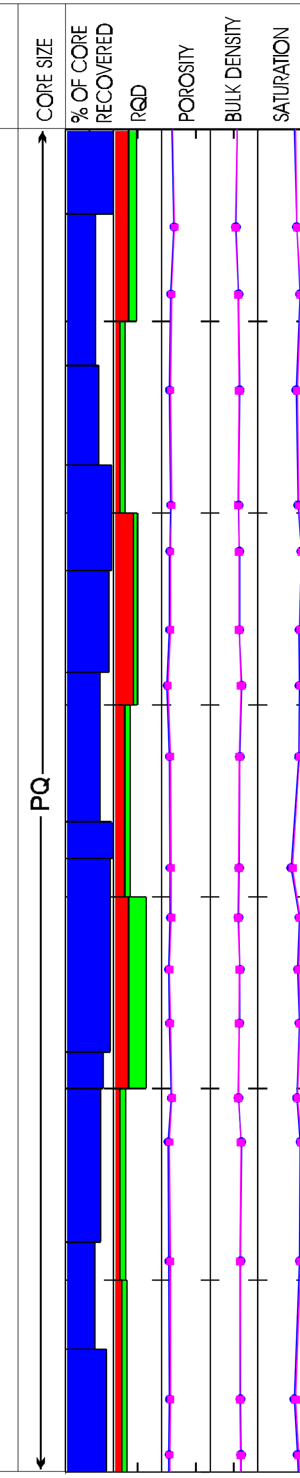
1125.0 groundmass 80-90% blue altered
1127.3-1132.3 broken
1129.4-1132.3 unrcvd
very small lithophysae
1135.2-1137.5 broken
1135.9-1137.5 unrcvd
1142.0
1153.6-1155.8 unrcvd
1156.8-1158.0 broken
1168.4-1169.5 broken
1168.9-1169.3 unrcvd
1174.0-1200.0 lg. lithophysae on borehole video
1173.0-1178.0 broken
1174.8-1178.0 unrcvd
1179.3-1183.8 broken
1181.4-1183.6 unrcvd
1187.0

Topopah Spring Crystal-Poor Lower Lithophysal Zone *cont.* light orange-pink (5YR7/2) densely welded, devitrified, 14-18% 40-50 mm circular pink-gray alteration spots, some nucleated by small lithophysae, interiors coated by crystalline vapor-phase mineralization, 20% other 20:1 flattened subhorizontal pumice, 2-3% sanidine phenos, no biotite seen.

1142.0- barely open lithophysal pumice occur in 50 mm light pink-gray alteration spots bordered by 2-4 mm blue alteration, blue alteration through groundmass following minor and micro-textural features giving groundmass subhorizontal micro-streak fabric, 0.5-1% specks of FeMnOx equally disseminated through rock.

1170.0 vapor-phase intensity increases slightly downward.

Topopah Spring Crystal-Poor Lower Nonlithophysal ("mottled") Zone (Tptpln) *(1187.0-1365.0),* pale orange-gray (5YR7/1) densely welded, devitrified, alteration character changes to slightly more dense, less grainy groundmass, subhorizontal wisps of light pink-gray alteration around very flattened pumice, groundmass 20% unaltered, rest is weakly pervasively blue altered, micro-fractures are hardened by mm-thick selvage and coating of vapor-phase SiO_2, 2-3% angular rhyolite lithics up to 40 mm, 3-4% sanidine phenos, no biotite observed, 0-0.5% MnOx specks throughout rock fabric.



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SANDIA NATIONAL LABS
Logged by: Dale Engstrom
Log Version: 2.01
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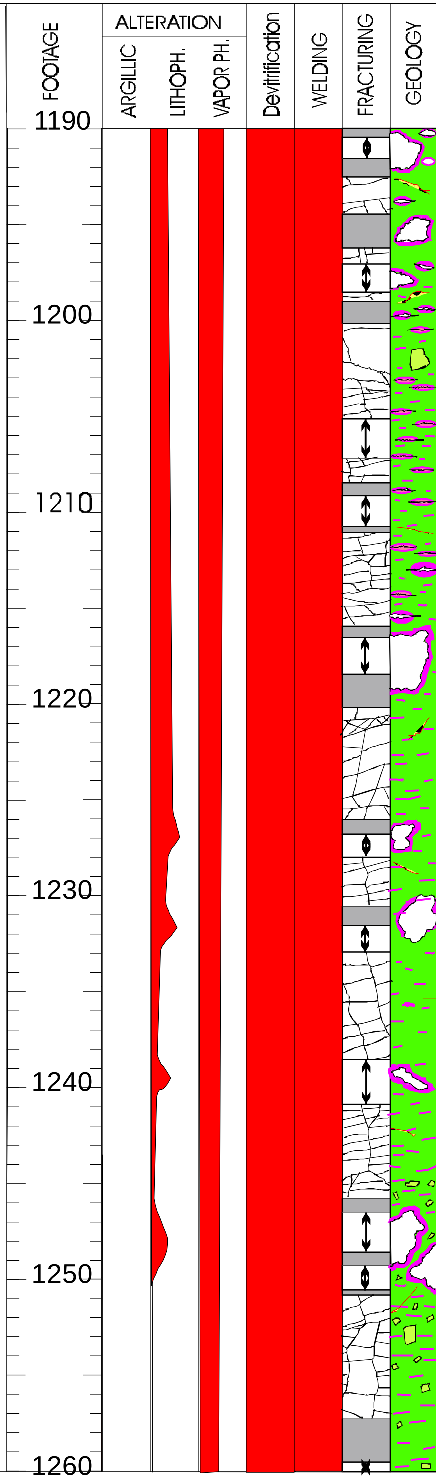
Started: May 19, 1994
Completed: Sept. 27, 1994
Bearing: N/A (vertical)
Inclination: -90

Collar Coordinates:
N: 767988.5 E: 561818.0
Elevation: 4272.6 Feet
Total Depth: 2223.1 Feet

DTN: SNT02052794001.003

AVE. CORE REC'Y/HOLE

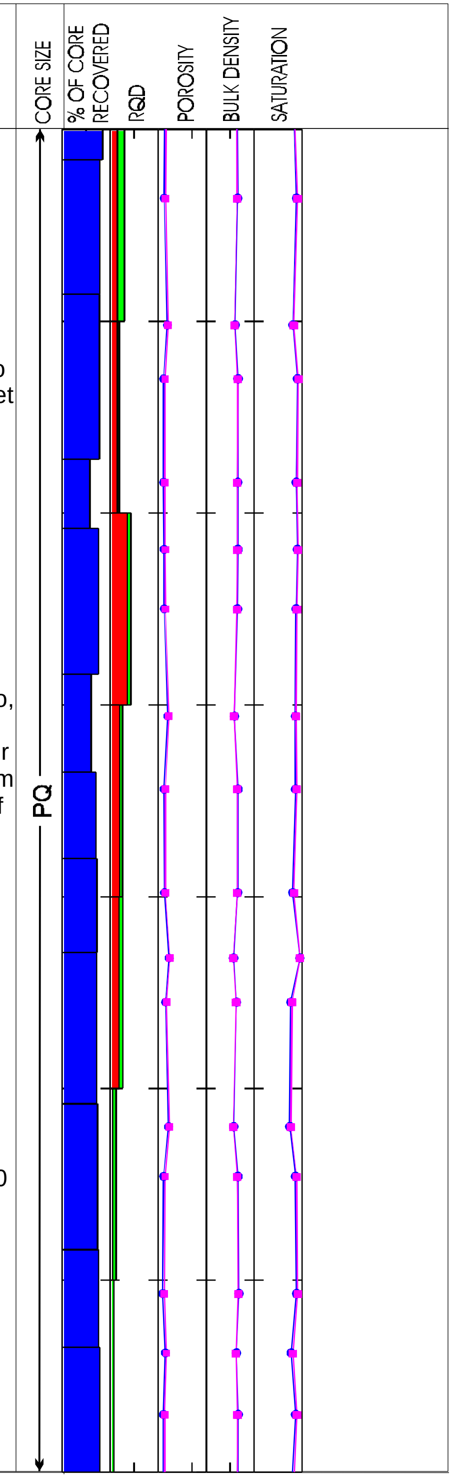


COMMENTS:

1189.9-1192.5 broken
1190.4-1191.6 unrcvd
1194.4-1196.2 broken
1197.1-1198.6 unrcvd
1199.1-1200.2 broken
1201.8-60mm rhyolite lithic
1205.2-1207.2 broken
1205.3-1207.2 unrcvd
1208.4-1211.1 broken
1209.2-1210.8 unrcvd
1215-1220 zone of v. lg. lithophysae (borehole video)
1215.9-1220.2 broken
1216.6-1218.4 unrcvd
1226.0-1228.0 broken
1226.7-1228.0 unrcvd
1230.0 v.lg.lithophysae
1230.5-1232.9 broken
1231.6-1232.9 unrcvd
1238.5-1240.8 unrcvd
1245.0 — Zone of angular rhyolite lithics, increases to 3-4% by 1253.0
1245.7-1250.7 broken
1246.4-1248.4 unrcvd
1249.3-1250.5 unrcvd
1257.3-1261.2 broken
1259.6-1261.2 unrcvd

Topopah Spring Crystal-Poor Lower Nonlithophysal ("mottled") Zone, *cont.* pale orange-gray (5YR7/1) densely welded, devitrified, small speckles of 10-12% lt. pink-gray alteration halos on very small, very flat pumice weakly replaced by crystalline vapor-phase mineralization, 90-95% groundmass pervasively blue altered, 2-3% white rhyolite subround lithics averaging 10 mm, 1-2% sanidine phenos, no biotite, 1% black MnOx specks, rare vapor-phase SiO_2 veinlet with hazy 4-5 mm lt. pink-gray alteration halo.

By 1215.0, nonlithophysal tuff becomes pale red (2.5YR7/2) densely welded, devitrified,crystal-poor 2-3% sanidine pheno, <1% biotite, 1-2% average 4 mm white rhyolite subangular lithics, 15-20% vapor- phase streaks of varying intensity after flattened pumice and partially flat rhyolite lithics, <1% 2-3 mm medium red-brown quartz latite lithics, approximately 65% of groundmass is moderately blue altered, remainder grainy orange, 1% phyllo-MnOx (rancieite?) speckled on fracture surfaces especially near pumice sites.



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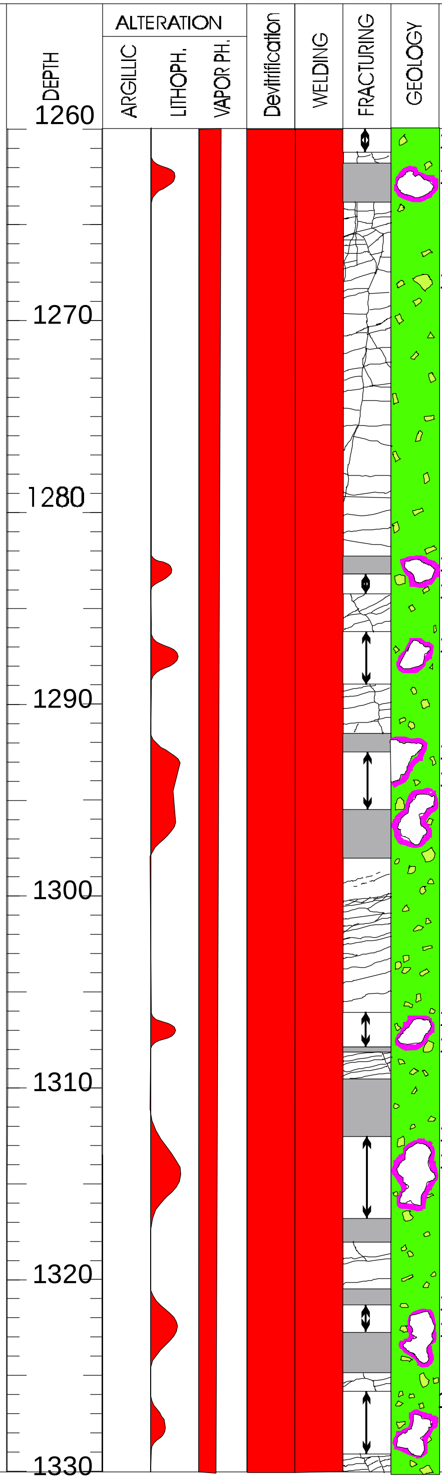
Started: May 27, 1994
Completed: Sept. 27, 1994
Bearing: N/A (vertical)
Inclination: -90

Collar Coordinates:
N: 767998.5 E: 561818.0
Elevation: 4272.6 Feet
Total Depth: 2223.12 Feet



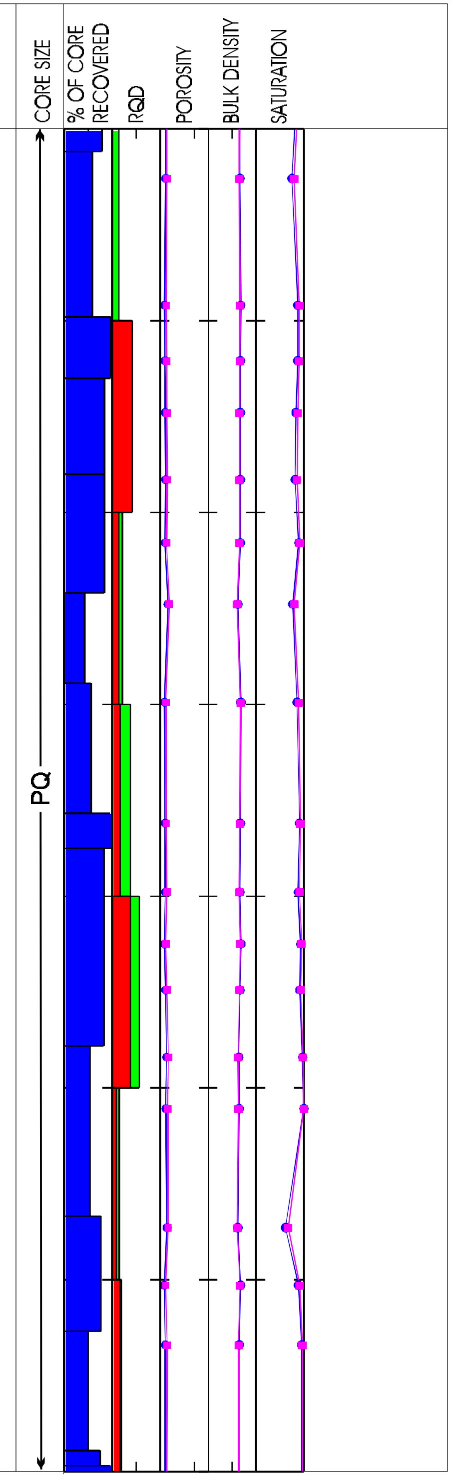
COMMENTS:

SNT02052794001.003

AVE. CORE REC'Y/HOLE

1159.6-1261.2 unrcvd
1261.7-1263.8 broken
1267.8-50mm rhyolite lithic
lithic-rich zone
1282.3-1284.2 broken
1283.2-1284.2 unrcvd
1286.2-1288.9 unrcvd
1291.5-1298.0 broken
1292.4-1295.4 unrcvd
1306.1-1308.1 broken
1307.8-1308.1 unrcvd
1309.5-1318.0 broken
1312.6-1316.7 unrcvd
1320.6-1324.8 broken
1321.3-1322.7 unrcvd
1325.8-1329.1 unrcvd

Topopah Spring Crystal-Poor Lower Nonlithophysal ("mottled") Zone, *cont.* pale red (2.5YR7/2) densely welded, devitrified, 15-20% vapor-phase alteration streaks of varying intensity after flattened pumice and partially flat rhyolite lithics, approximately 65% of groundmass moderately pervasively blue altered, rest is unaltered orange grainy textured, 3-4% angular 4 mm size rhyolite lithic fragments, increases to 5-10% in lithic-rich zone after 1267.8, <1% 2-3 mm med. red-brown quartz latite lithics, 2-3% sanidine <1% biotite phenos, <1% phyllo-MnOx specks on fracture surfaces especially around pumice sites.



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SANDIA NATIONAL LABS
Logged by: Dale Engstrom
Log Version: 2.01
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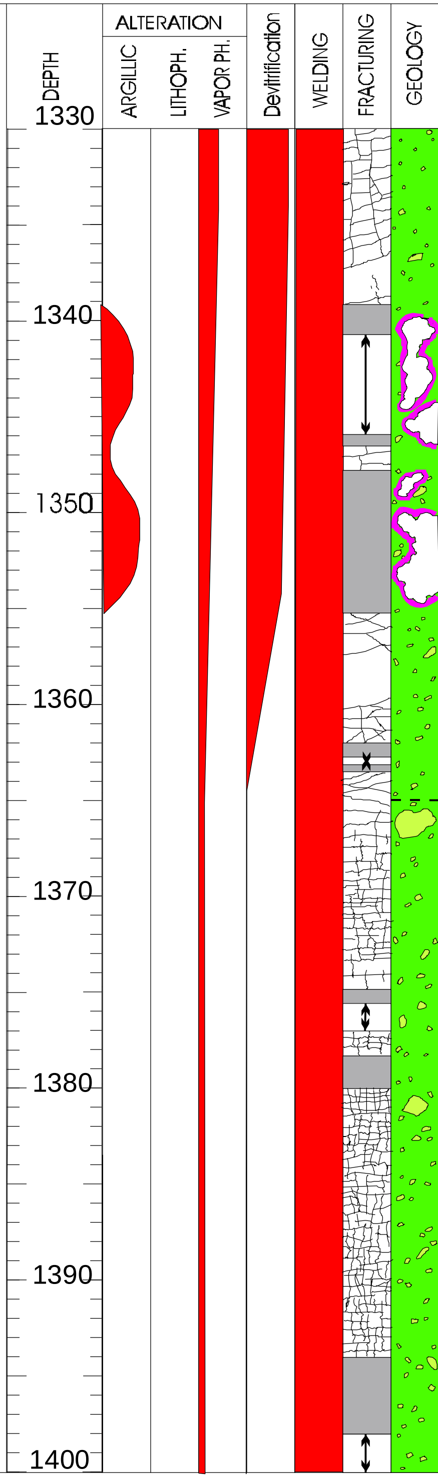
Started: May 19, 1994
Completed: Sept. 27, 1994
Bearing: N/A (vertical)
Inclination: -90

Collar Coordinates:
N: 767998.5 E: 561818.0
Elevation: 4272.6 Feet
Total Depth: 2223.1 Feet



COMMENTS:

SNT02052794001.003

AVE. CORE REC'Y/HOLE

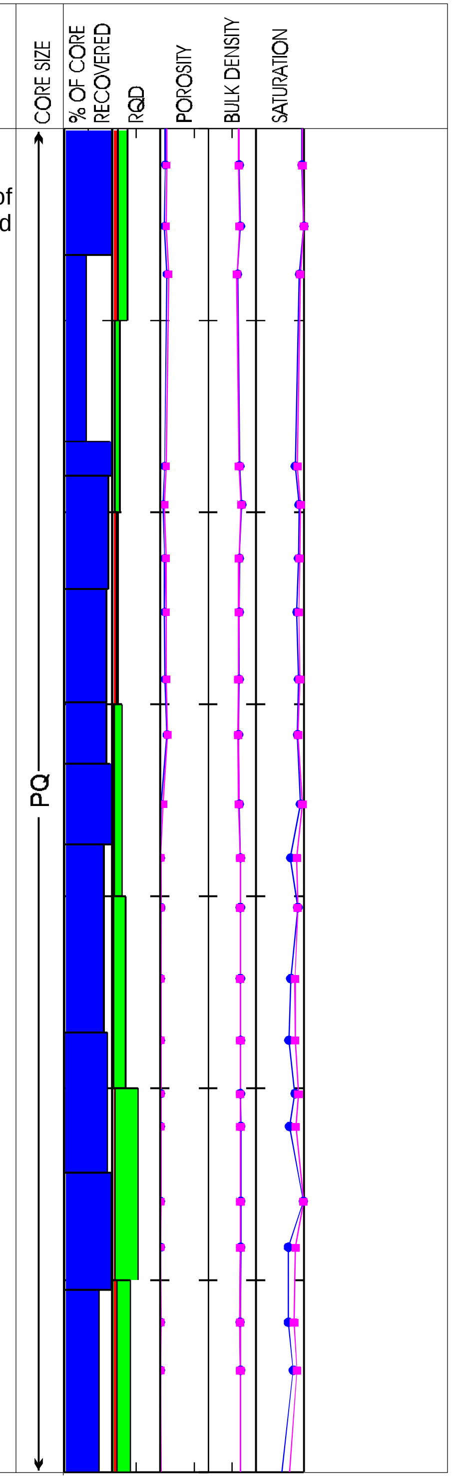
1334.0
1339.2-1346.5 broken
1340.7-1345.9 unrcvd
1347.8-1355.2 broken
1354.0
1362.0-1363.4 broken
1362.7-1363.1 unrcvd
1365.0-1426.0
1366.0-150mm QL lithic
1374.9-1377.0 broken
1375.4-1377.0 unrcvd
1378.0-1381.5 strong vertical fractures
1378.3-1380.3 broken
1382.0-40mm rhyolite lithic
1394.0-1400.3 broken
1397.7-1400.3 unrcvd

Topopah Spring Crystal-Poor Lower Nonlithophysal ("mottled") Zone, *cont.* pale red (2.5YR7/2) densely welded, devitrified, 15-20% vapor-phase alteration streaks of varying intensity after flattened pumice and partially flattened rhyolite lithics, approx 65% groundmass moderately pervasively blue altered, vapor-phase amount decreasing downward toward vitrophyre,5-10% angular rhyolite lithics, <1% med. red-brown quartz latite lithics, 2-3% sanidine and <1% biotite phenos, 1% phyllo-MnOx specks on fractures, especially near pumice sites.

334.0 change in alteration, light orange-brown (5YR6/4), orange clays and alteration minerals developed along microfracts and grain boundaries becoming more intense downward as vitrophyre is approached, rock is starting to become more vitric.

1354.0-blotchy vitric texture, precursor to vitrophyre, pale yellow-brown (10YR6/2) densely welded, 35% cognate pumice, 5% white subround rhyolite hard lithics averaging 5 mm, 3% red-brown subangular quartz latite hard lithics average 3-4 mm usually rimmed by MnOx mineralization.

Topopah Spring Crystal-Poor Vitric Zone, lower vitrophyre subzone (Tptpv3) *(1365.0-1418.7)* black vitric, densely welded, coarse black crystalline spots after cognate pumice, 4-5% subround rhyolite hard lithics, 1-2% red-brown quartz latite hard lithics, 3-4% white sanidine phenos, <1% biotite, rectilinear fracture reflecting glassy composition, pale blue vapor-phase SiO_2 deposited on major joint surfaces.



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SANDIA NATIONAL LABS
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Log Version: 2.01
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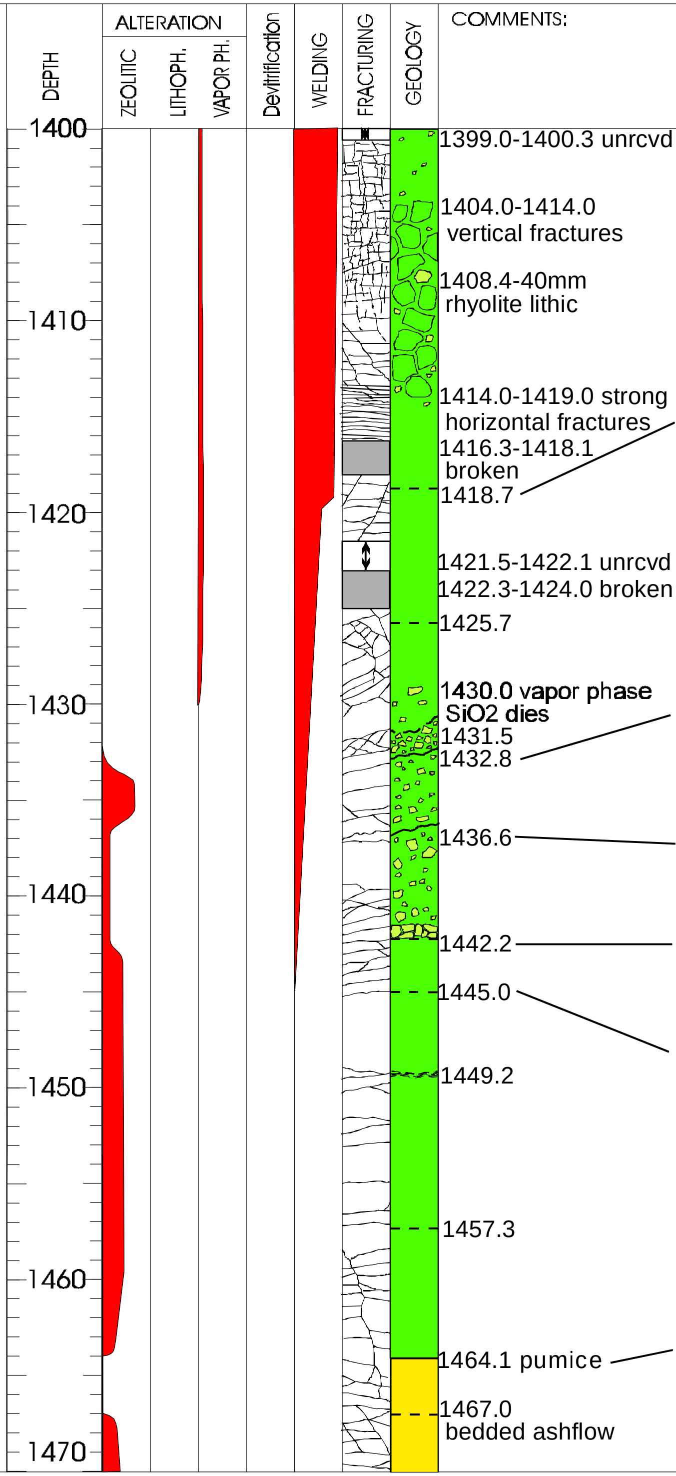
Started: May 19, 1994
Completed: Sept. 27, 1994
Bearing: N/A (vertical)
Inclination: -90

Collar Coordinates:
N: 767998.5 E: 561818.0
Elevation: 4272.6 Feet
Total Depth: 2223.1 Feet

SNT02052794001.003



COMMENTS:

Topopah Spring Crystal-Poor lower vitrophyre subzone *cont.* black, vitric, densely welded, coarse black crystalline spots after cognate pumice, 4-5% subround rhyolite hard lithics 1-2% red-brown quartz latite lithics, 3-4% sanidine and <1% biotite phenos, rectilinear fracture characteristic of glassy composition changes from dominantly horizontal to dominantly vertical orientation at 1404.0-1414.0 in zone populated by large blocks of pumice, strongly horizontal fracture from 1414.0-1419.0, creating "hocky puck" style core fragments.

Topopah Spring Vitric Zone, moderately welded subzone (Tptpv2) *(1418.7- 1464.1)* initial appearance of subangular orange pumice, less welded than above (partially), groundmass still vitric, slightly more altered (argillic?) downward, 15-17% pumice up to 30 mm, many larger pumice are vitric laminated and vesicular, 5-7% subangular dark quartz latite lithics average 5 mm, 1-3% sanidine phenos, no biotite seen.

1425.7 groundmass changes from 95% to 60% vitric content.

Crowded lithic-rich interval *(1431.5-1432.8)* 15-17% vitric subangular quartz latite lithics averaging 10-15 mm, groundmass 50% black shards.

Pink lithic-rich zeolitized inclusion *(1432.8-1436.6)* subround quartz latite lithics up to 45 mm wide, 3-4% small semiflattened rhyolite pumice lithics in very fine grained porcel. waxy textured matrix, areas of frothy texture in weakly spherulitic cognate pumice cores.

Lithic-rich vitric interval *(1436.6-1442.2)* light gray vitric lithics in groundmass of 65-75% dark gray shards with relict bubble walls, grainy intergranular fill (zeolitic?), 0.4 foot basal zone of 30% large all-vitric pumice blocks up to 10-12cm wide.

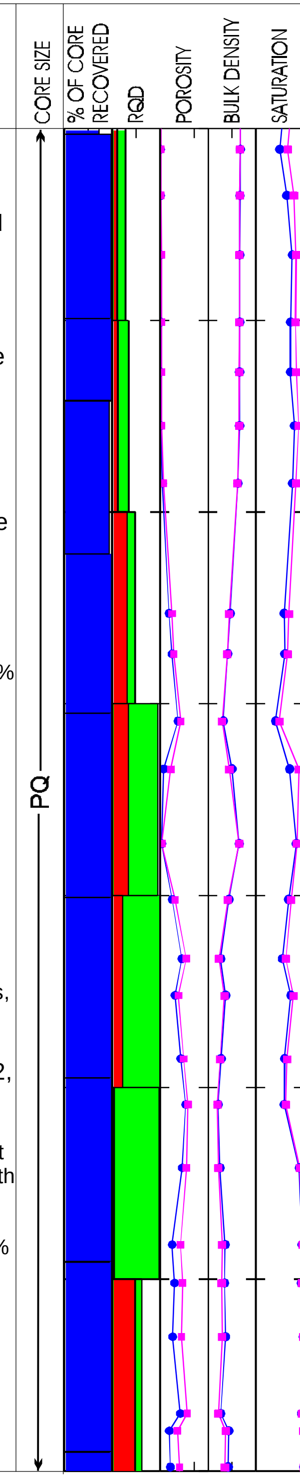
Light pink-gray vitric interval *(1442.2-1457.3)* (5R6.5/1) 20-25% lt. pink-tan dense pumice lithics in matrix of 65% black shards with original curved shape, and 35% grainy (zeolites?) fill between shards,

Topopah Spring Crystal-Poor Vitric Zone, nonwelded subzone (Tptpv1) grades to nonwelded at 1445.0, black shard content rapidly decreases downward to 1457.3, 1449.2, 0.4-foot zone of flat pumice.

1457.3 very pale orange (10YR8/2) nonwelded, 35-40% light pink subangular pumice averaging 5-7 mm, 35% cognate light yellow-light orange pumice invisible except for froth core texture, occasionally with spherulites, 2-3% dark red-brown subround quartz latite hard lithics averaging 5 mm, 1-2% quartz eyes, 1-2% clear euhedral sanidine, speckled 2% finely crystalline black spots of MnOx or magnetite, <1% biotite, rare pyroxene (?), basal 15 mm very fine grained ash fall.

Pre-Topopah Spring Tuff Bedded Tuff (Tptbt1) *1464.1-1479.9)* light orange-brown (5YR6/4), sandy reworked text but high ash content, 25-30% small clasts of pumice and non-pumice textures, many have opaline color, conchoidal or angular shapes, 3% dark 1-3 mm quartz latite hard llithics, 35-40% cognate pumice.

AVE. CORE REC'Y/HOLE



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SANDIA NATIONAL LABS
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Log Version: 2.01
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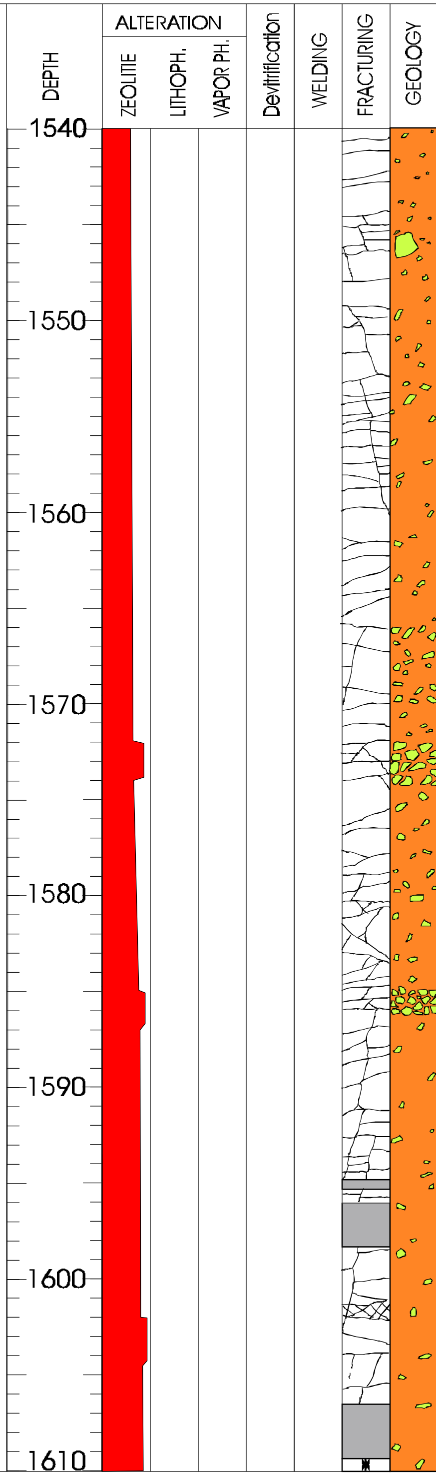
Completed: Sept. 27, 1994
Bearing: N/A (vertical)
Inclination: -90

Collar Coordinates:
N: 767998.5 E: 561818.0
Elevation: 4272.6 Feet
Total Depth: 2223.12 Feet



COMMENTS:

SNT02052794001.003

AVE. CORE REC'Y/HOLE

1546.0 30 mm quartz latite lithic

Calico Hills Fm., Ashflow Unit 3, cont., *(1479.9-1586.1)*
pale orange-pink (7.5YR8/2) nonwelded, zeolitic, 12-15% large very light pink pumice up to 35 mm, many pumice vitric with stretched texture, 40% smaller cellular pumice from very pale green to totally zeolitized, 2-5% dark red-brown angular crystal-rich quartz latite lithics average 5 mm size, groundmass <1% quartz or sanidine phenos and zeolitized to pink micro-crystalline which obliterates much of original texture but preserves cellular structure of pumice cores.

Zeolitization increases downward, noticeably stronger below 1572.0.

1572.0-1574.0

1572.0-1574.0 crowded large lithic subzone, slight increase in zeolitic alteration.

1584.9-1586.1 lithic-rich pumice fallout subzone, increase in zeolitic alteration to deep pink, lithics average 2-3 mm.

1584.9-1586.1
1586.1 unit 2

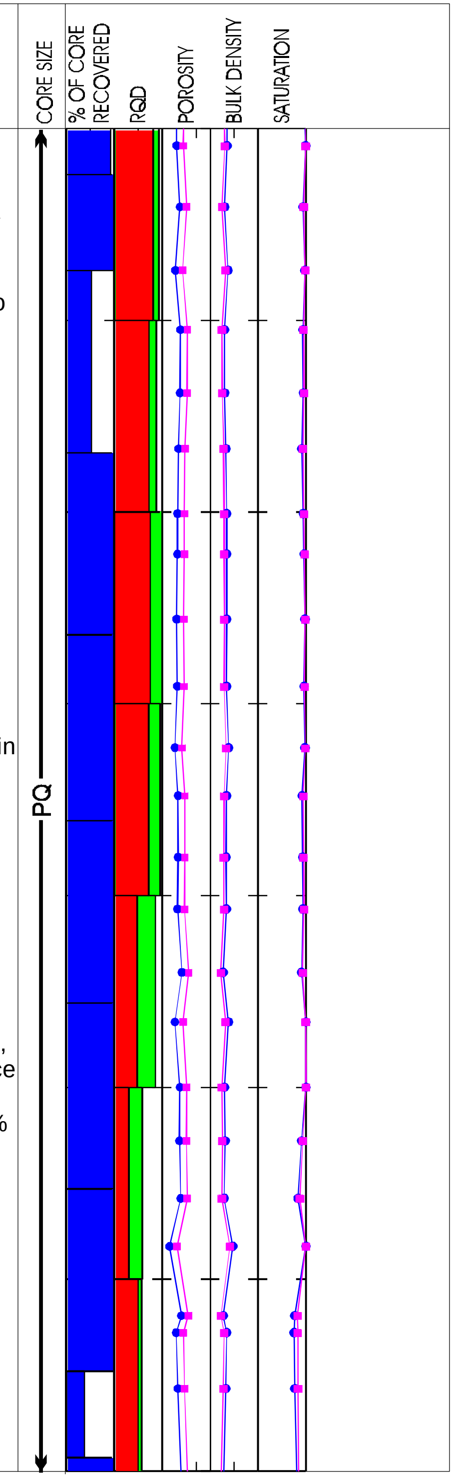
Calico Hills Fm., Ashflow Unit 2 (Tac2) *(1586.1-1737.5)*
pale orange- pink (5YR8/2) nonwelded, zeolitic altered matrix, 15%-25% light orange pumice up to 20 mm size, some pumice are vitric with stretched fabric, 1-2% lithics composed of red-brown or red-orange fragments of varying compositions, 1-2% quartz sanidine and lesser biotite phenocrysts.

1594.7-1595.3 broken
1596.1-1598.3 broken

1602.0-1604.5

Strongly zeolitized, especially pumice, groundmass pale green-yellow.

1606.5-1609.3 unrcvd
1609.3-1610.4 broken



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Scale: 1" = 10 ' (1:120)
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SANDIA NATIONAL LABS
Logged by: Dale Engstrom
Log Version: 2.01
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Started: Mat 19, 1994
Completed: Sept. 27, 1994
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Collar Coordinates:
N: 767998.5 E: 561818.0
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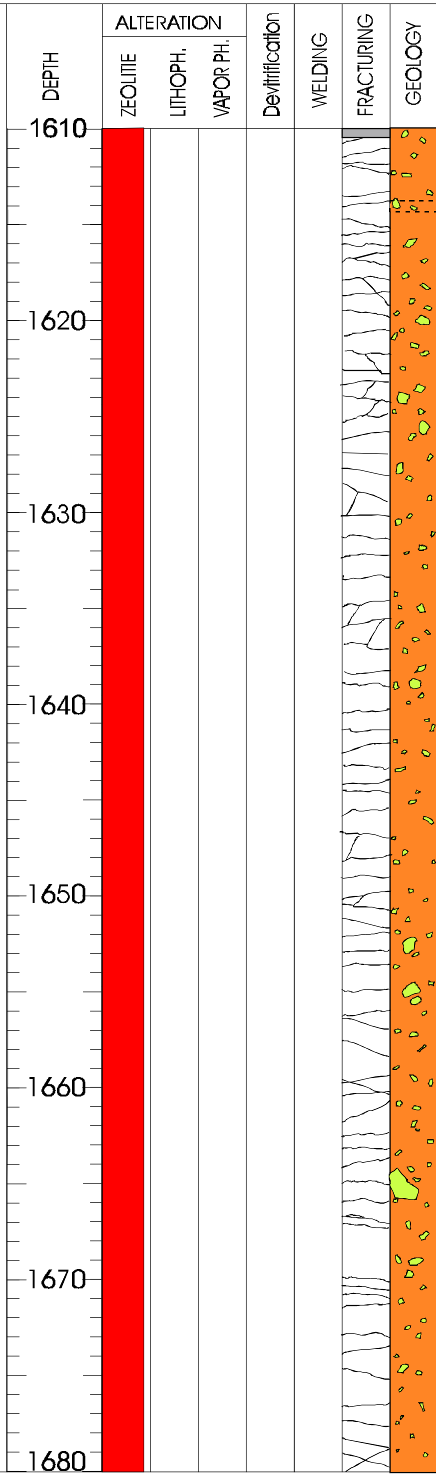
Total Depth: 2223.1 Feet



COMMENTS:

SNT02052794001.003

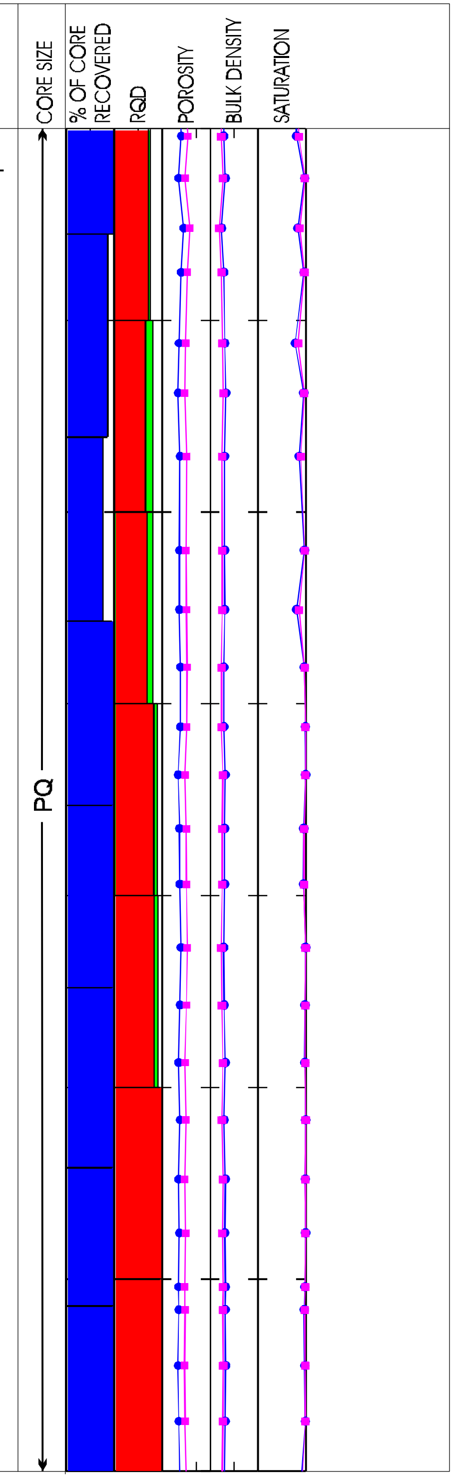
1613.7-0.6' altered zone (dark spot, silicified?)

1616.5-1617.0 heavily zeolitized

1665.0-32 mm red-brown quartz latite lithic

Calico Hills Fm., Ashflow Unit 2, *(cont.) (1586.1-1735.5)*
heavily zeolitized matrix, very pale red-gray (2.5YR8/2) non-welded, color darkens downward, 15-30% pale yellow-orange pumice generally <15 mm, but ranges from microscopic up to 65 mm, 2-4% red-brown lithics of varying compositions, 1-2% sanidine, quartz and lesser biotite phenos.

AVE. CORE REC'Y/HOLE



Yucca Mountain Project
Hole No: USW SD-9
Scale: 1" = 10' (1:120)
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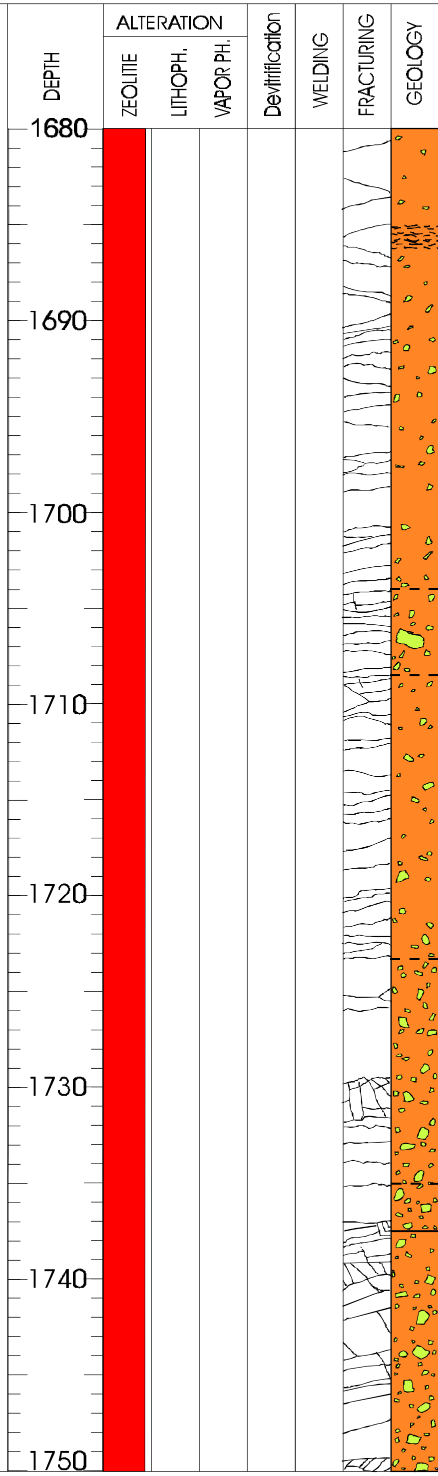
SANDIA NATIONAL LABS
Logged by: Dale Engstrom
Log Version: 2.01
Log Date: January 15, 1996

Started: May 19, 1994
Completed: Sept. 27, 1994
Bearing: N/A (vertical)
Inclination: -90

Collar Coordinates:
N: 767998.5 E: 561818.0
Elevation: 4272.6 Feet
Total Depth: 2223.1 Feet

SNT02052794001.003

AVE. CORE REC'Y/HOLE



COMMENTS:

1685.2-1686.2 very subtle bedding break

Calico Hills Fm., Ashflow Unit 2, *(cont.) (1586.1-1735.5)* very pale red-gray (7.5YR8/4) heavily zeolitized non-welded matrix,15-30% pale yellow to orange pumice generally 8 mm, but ranges from 2 to 35 mm, 2-3% red-brown subround quartz latite lithics of varying textures, 1-2% quartz, sanidine and biotite phenos, thin pumice or ashfall bedding breaks at 1685.2, 1704.0, 1708.5, 1723.3 and 1735.0.

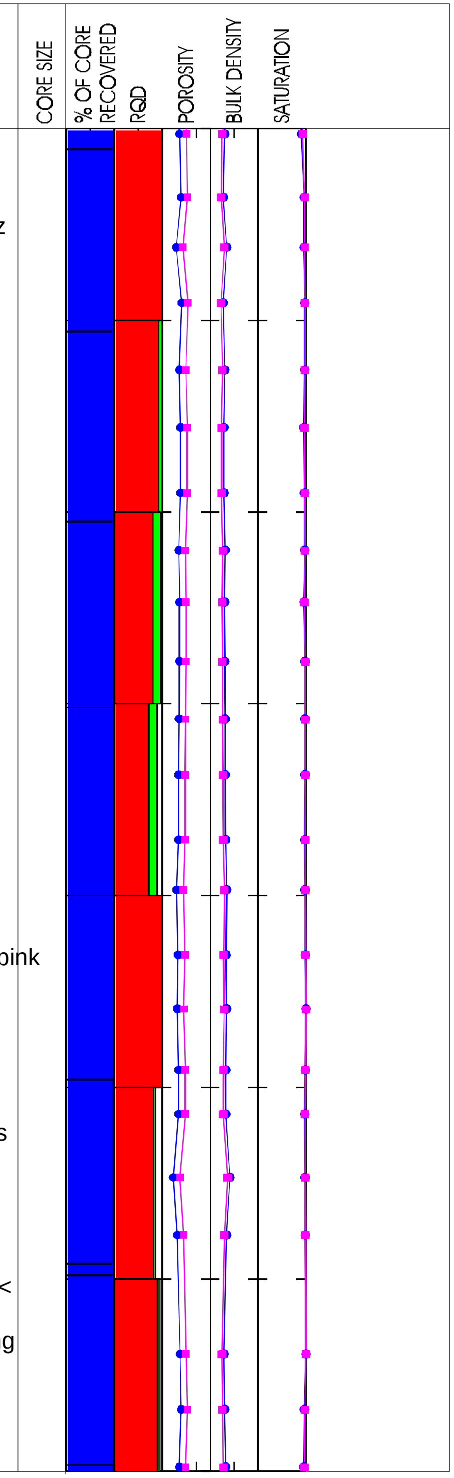
1704.0-1704.3 — Subtle **bedding** break, weakly **bedded**.

1708.5-1708.8 — Subtle **bedding** break, weakly **bedded**.

1723.3 — Bedding break, dense 30 mm weakly porcellaneous salmon-pink clay layer.

1735.0 — Basal ash falls and pumice falls; cm-thick beds, porcelaneous textured ash fall, clast-supported pumice fall with clasts <15 mm diameter, 3-5% lithics with up to 10% locally.

1737.5 unit 1 — ***Calico Hills Fm., Ashflow Unit 1 (Tac1)*** *(1735.0-1764.4),* pale gray-orange (5YR8/2) nonwelded, highly zeolitized altered matrix, 15-25% yellow-gray (5Y8/1) pumice generally < 20 mm, 3-5% phenocrysts of quartz, sanidine, biotite, 3-5% red-brown lithics of varying composition and texture, averaging < 5 mm but may be up to 18 mm.



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SANDIA NATIONAL LABS
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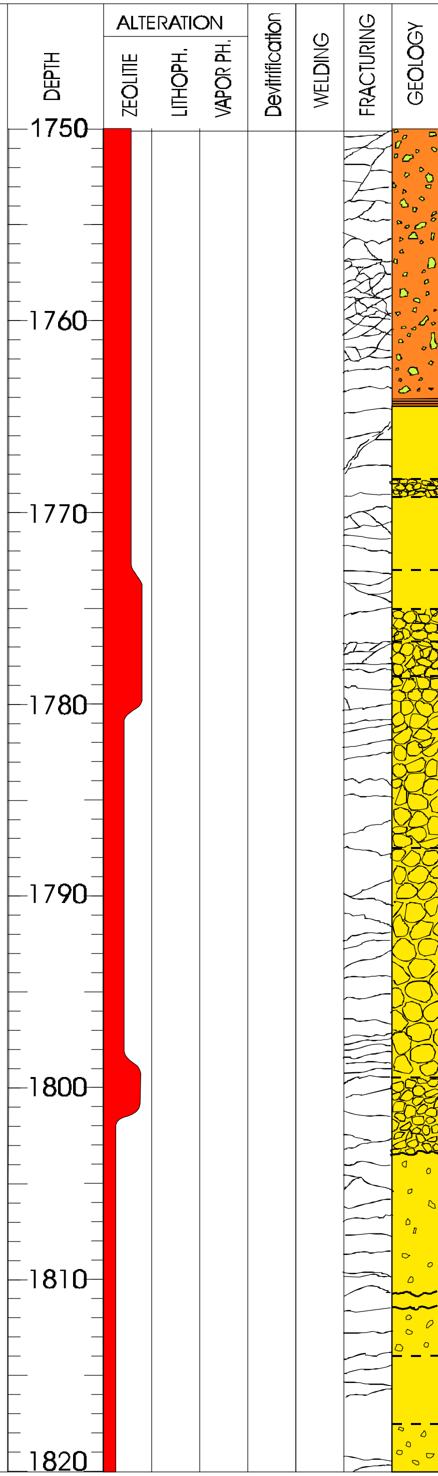


COMMENTS:

SNT02052794001.003

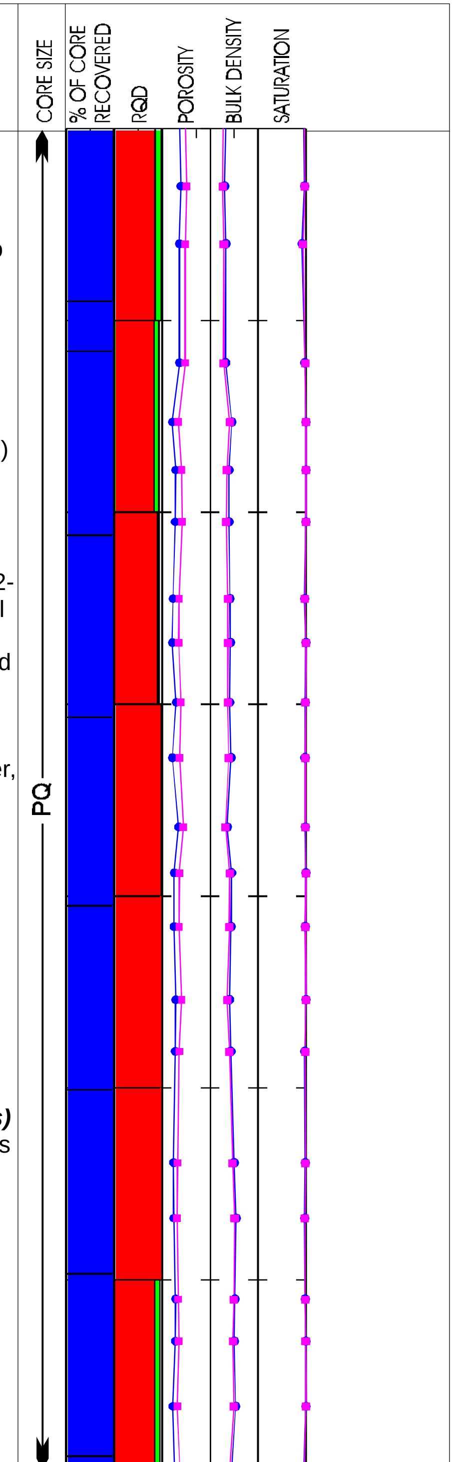
AVE. CORE REC'Y/HOLE

Basal orange-pink ashfall
1764.4 Ashflow tuff
1768.2- f.g. pumice fall
1769.2 -f.g. sugary texture
1775.1 -c.g. pumice fall
1776.7 -thinly bedded
1787.5 c.g. pumice fall
1799.4 pumice fall
1803.4 sandstone
1810.7 dark zone with load casts
1813.9 -f.g. thinly bedded zone

Calico Hills Fm., Ashflow Unit 1, *cont. (1737.5-1764.4)* pale gray-orange (5YR8/2) nonwelded, highly zeolitized altered matrix, 20-30% gray- yellow pumice generally < 20 mm, 7-10% quartz, sanidine, lesser biotite phenos, 10-15% medium red-brown lithics that average 8 mm but can be up to 20 mm.

Calico Hills Fm., Bedded Tuff Unit (Tacbt) *(1764.4-1820.7)*
Ashflow deposit (1764.4-1768.2) pale yellow-brown (10YR8/2) zeolitic altered matrix,7-10% white pumice,10-15% quartz, feldspar, biotite phenos,10% red-brown lithics averaging 5 mm.
Fine grained pumice fall (1768.2-1775.1) pale pink to yellow-gray pumice clasts, 1768.9-2" coarser pumice fall bed, 1769.2-1773.0 Fine-grained sugary textured matrix, followed by basal porcelaneous ashfall.
Coarse grained pumice fall (1775.1-1787.5) possibly reworked top, 1773.3-1780.6 strongly zeolitized to pale yellow-green (5Y8/2); 1776.7-1778.6 thinly bedded.
Coarse grained pumice fall (1787.5-1799.4) color changes to med. brown (7.5YR7/2), 6.3-foot reworked top, 1793.8 coarser, with increased pumice and biotite content downward, bedded and strongly zeolitized at bottom 1797.8-1799.4.
Pumice fall (1799.4-1803.4) thin reworked top, poorly sorted.

Calico Hills Fm., Basal Tuffaceous Sandstone Unit (Tacbs) *(1803.4-1820.7)* pale red-brown (10R5/4) immature tuffaceous sandstone, upper part characterized by reworked pumice clasts, 1810.7- 1811.5 central part darker (10R4/4) with load casts, 5-10% altered subround pumice clasts in lower part, 1813.9-1817.5 fine grained thinly bedded zone with no pumice.



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SANDIA NATIONAL LABS
Logged by: Dale Engstrom
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Inclination: -90

Collar Coordinates:
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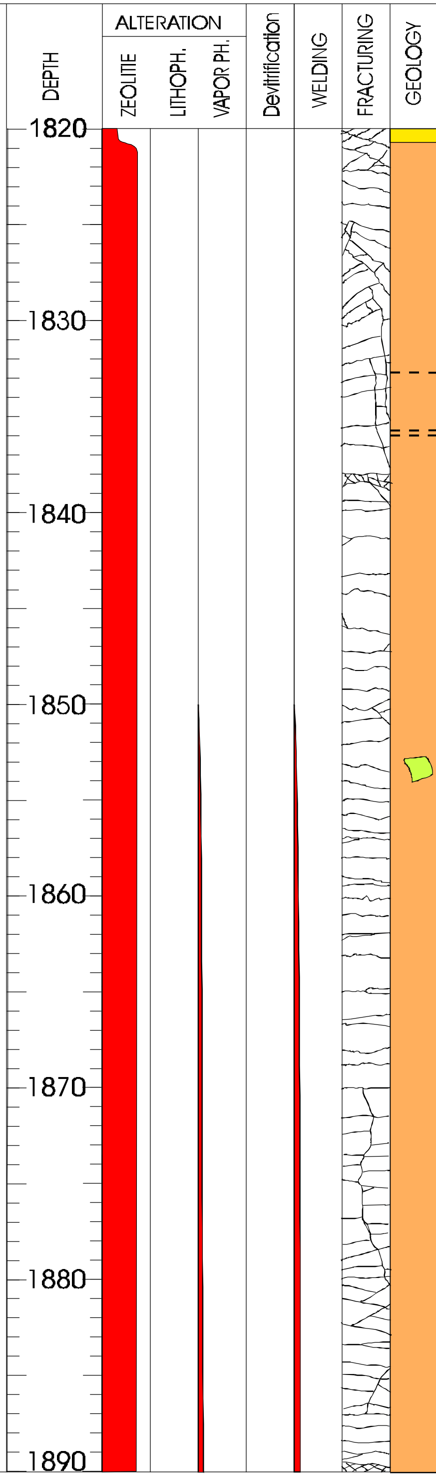


COMMENTS:

SNT02052794001.003

AVE. CORE REC'Y/HOLE

1820.7 Unit 4 — ***Prow Pass Tuff, Unit 4 (Tcp4)*** *(1820.7-1868.7)* pale orange-pink (7.5YR8/2) with yellow-gray mottling, nonwelded, fine-grained, zeolitic altered, upper 2.3 feet weathered (paleosol), 2-3% white pumice mostly <10 mm, 2-3% lithics from a wide range of compositions <3 mm, 3-5% quartz, feldspar, biotite, and rare pyroxenite phenos, irregular high-angle fractures 1820.7- 1837.0, 1828.3 3-foot pink slightly more pumiceous altered zone, ashflow deposit tops at 1832.7, 1835.8 & 1836.0.

1832.7 Ashflow top

1835.8 Ashflow top

1836.0 Ashflow top

1841.1 — 1841.1-1845.8 light orange-brown (7.5YR8/2), nonwelded, zeolitized matrix, 7-10% pale orange pumice <15 mm, 2-3% red-brown lithics <5 mm, 5-7% feldspar, quartz, biotite and pyroxene phenos,

1845.8 — 1845.8-1868.7 very pale orange (10YR8/2), nonwelded, zeolitized matrix, 15-25% pale pink pumice averaging 20 mm and up to 50 mm, 2-3% lithics in 3-5 mm size range, including cognate, red-brown exotic and red-brown angular siltstone fragments with alteration rim, 1860.2 slight increase in welding, possibly associated with very weak silicification (vapor-phase?)

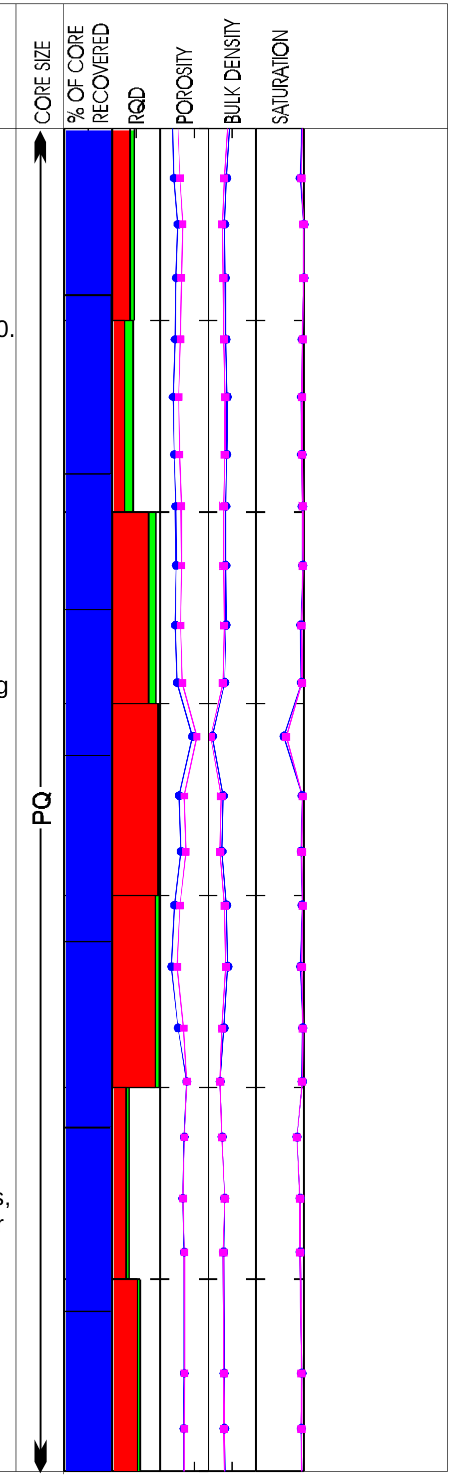
1852.0-1852.6 rubble

1853.5-60 mm angular lithic

1860.2 increased welding, increased silicification

1865.0 color lightens to very pale orange-gray (7.5YR8/1)

1868.7 Unit 3 — ***Prow Pass Tuff, Unit 3 (Tcp3)*** *(1868.7-2015.8)*, very pale brown, (10YR8/1) nonwelded, zeolitized matrix, 10-20% red-brown cellular-vuggy subangular pumice up to 35 mm across, many rexlzd by zeolitic alteration (or vapor-phase?), groundmass is white, soft, zeolitized (argillized?), 2-3% cognate, red-brown, and alteration-rimmed red siltstone lithics, 33-5% feldspar, quartz, biotite and pyroxene phenos, irregular vertical joints



SANDIA NATIONAL LABS
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Log Version: 2.01
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Started: May 19, 1994
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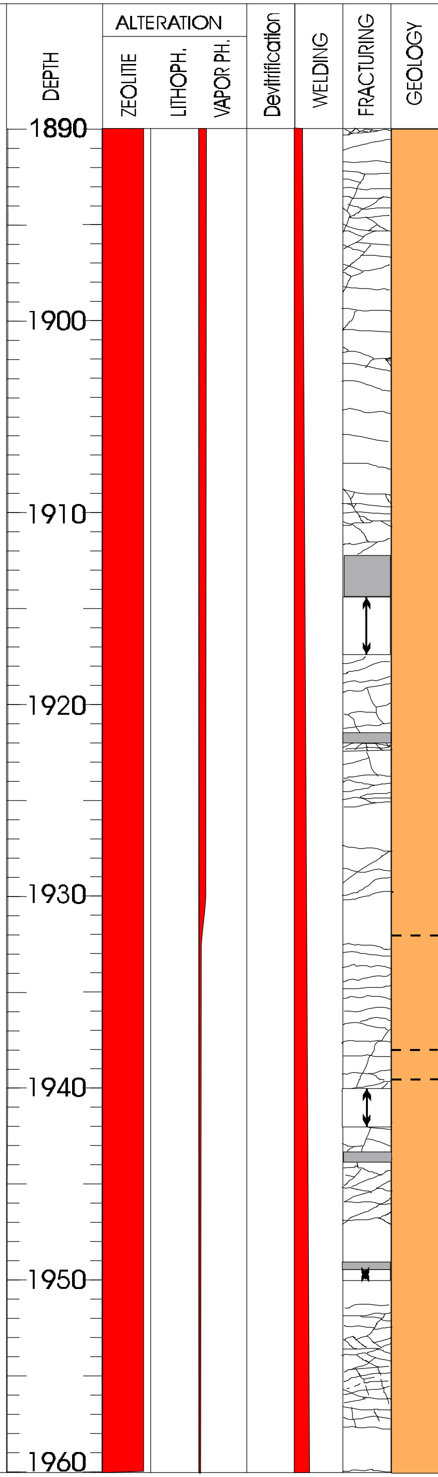
Inclination: -90

Collar Coordinates:
N: 767998.5 E: 561818.0
Elevation: 4272.6 Feet
Total Depth: 2223.1 Feet



COMMENTS:

SNT02052794001.003

AVE. CORE REC'Y/HOLE

Prow Pass Tuff, Unit 3, *cont. (1868.7-2015.8),* pale red-gray (7.5R8/2) weakly welded, zeolitic altered, dense microgranular groundmass, 10-20% pale vapor-phase altered subangular pumice, large ones rimmed by white vapor-phase around dark often vuggy recrystallized core, 1-3% 1-4 mm subangular lithics, equal parts cognate composition and red siltstone, often with halos of white vapor-phase alteration, 3-4% feldspar, quartz, biotite and rare pyroxene phenos, very irregular horizontal joints.

1910.0-1916.1 Vapor-phase alteration decreases slightly.

1912.2-1917.4 rubble
1914.4-1917.4 unrcvd

1916.1

1921.5-1922.0 rubble

1932.0 Around 1932.0, gradational decrease in vapor-phase intensity and decrease in lithics to 1-2%.

1934.7-1938.0 oily drill dust obscures core

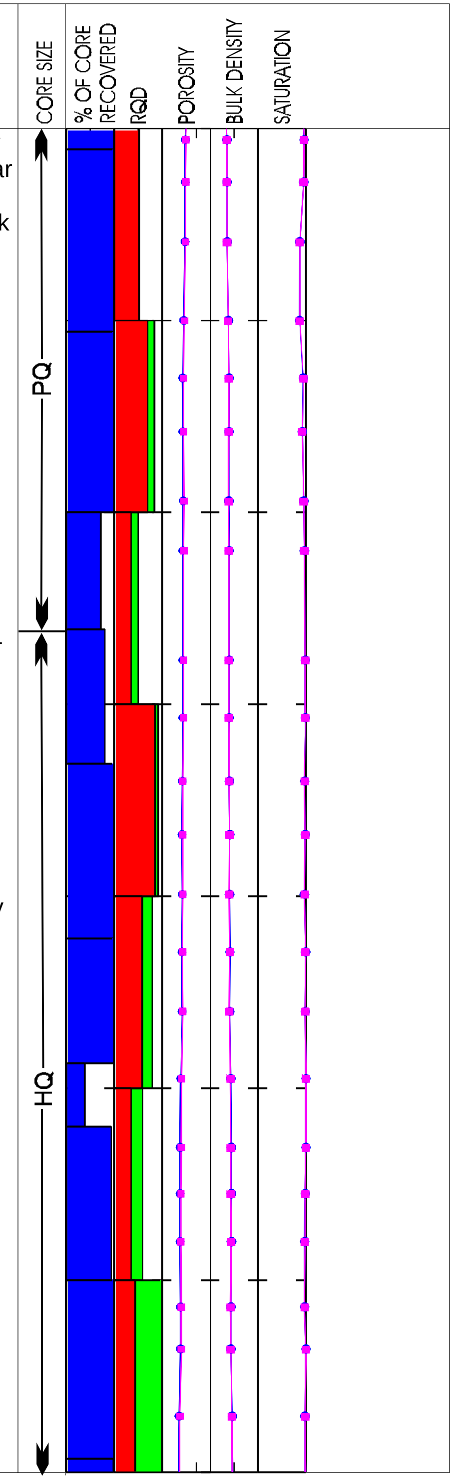
1938.0 Around 1938.0, vapor-phase decreases to small tight white halos (no longer large fuzzy halos and recrystallization).

1939.5

1940.0-1942.0 unrcvd — 1939.5, slightly darker colored (5R7/2.5) less fuzzy more defined, small tight vapor-phase halos, slightly more welded, highly zeolitized matrix.

1943.3-1943.7 rubble

1949.1-1949.9 rubble
1949.4-1949.9 unrcvd



Yucca Mountain Project
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Scale: 1" = 10 ' (1:120)
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SANDIA NATIONAL LABS
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Log Version: 2.01
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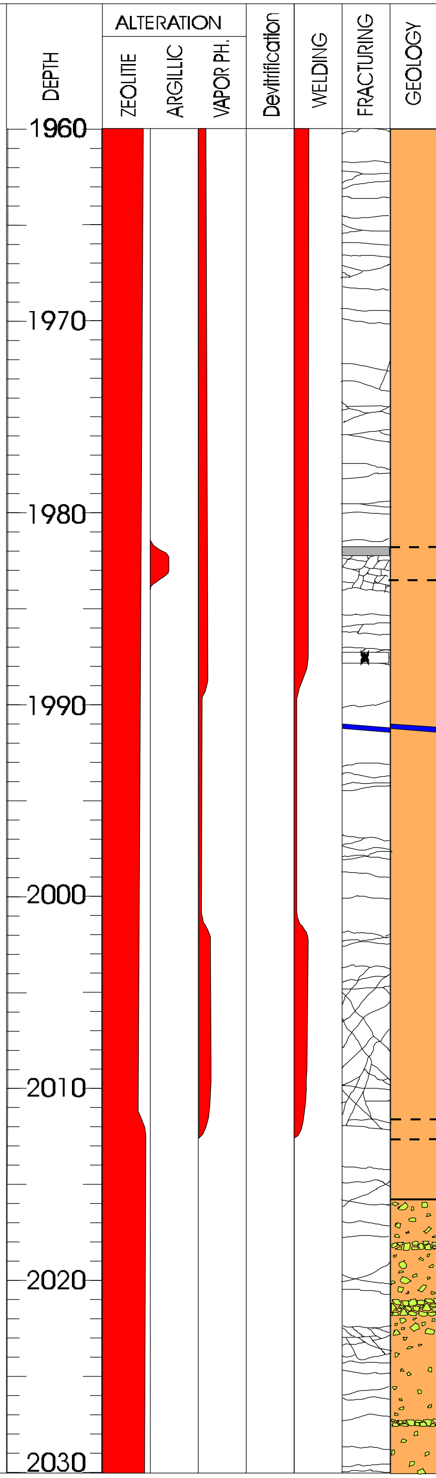


COMMENTS:

SNT02052794001.003

1980.0 vapor-phase decreases
1981.8-1982.2 rubble zone
1982.2-1983.5 soft, broken (argillized?)
1987.2-1987.8 unrcvd
1991.0 fault
1994.8 matrix hem stained
2002.2 more welded, altered
2011.6 alt increases
2012.5 alt increases
2015.8 Unit 2
2018.1 lithic-rich zone
2020.9 lithic-rich zone
2022.8 lg. lithics die
2027.3 lithic-rich zone

Prow Pass Tuff, Unit 3, *cont. (1868.7-2015.8),* pale red-gray (5R7/2.5) partially welded, highly zeolitic altered dense micro-granular groundmass, 7-10% small moderately flattened pumice recrystallized by vapor phase alteration, larger ones with vuggy interiors after laminated pumice texture, 1% 1-4 mm subangular lithics, equal parts cognate composition and red siltstone, some Fe-rich lithics heavily zeolitized with heavy hematite halo, 3-4% feldspar, quartz, biotite and rare pyroxene, around 1980.0, vapor-phase mineralization decreases, confined to replacement or recryallized of small angular pumice.

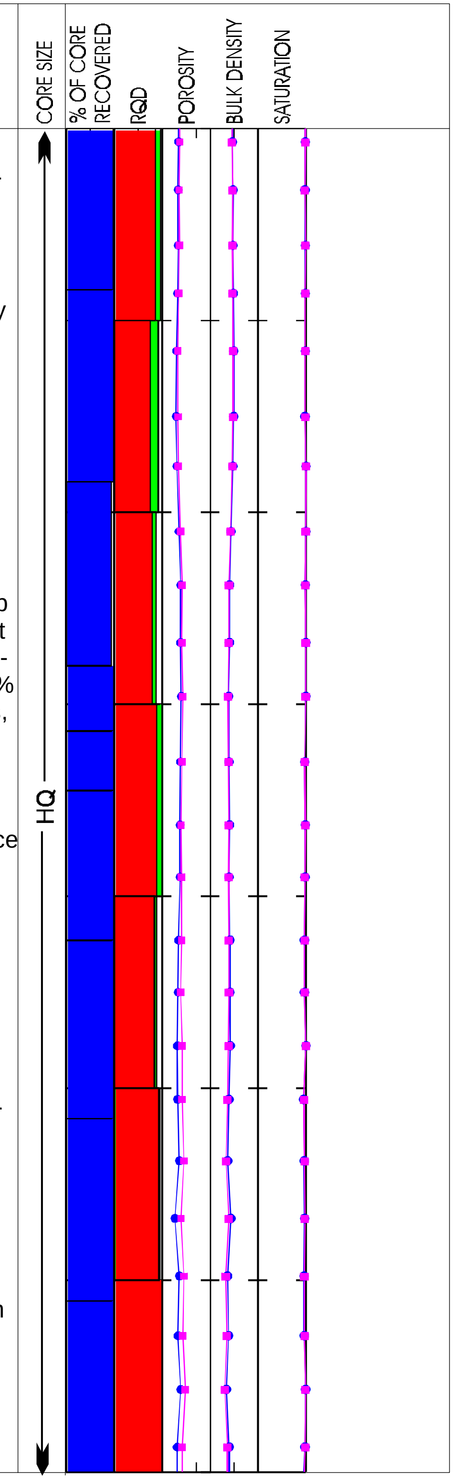
1991.0-1991.2 plastic fault gouge, rough est. 62.7 feet dip-slip offset at 75-70° to core axis, rock much less dense below fault (less welded?), pale pink-gray (5R8/4) moderately zeolitic, 80-85% recrystallized, 7-10% small weakly flattened pumice,1-2% small red siltstone lithics zeolitized with strong hematite halos, occas. coarse crystalline lithic (probably pumiceous), 3-5% quartz, feldspar, biotite and rare pyroxene phenocrysts.

2002.2 returns to partially welded, dense, microcrystalline more zeolitized groundmass, 15-17% small subangular pumice replaced by vapor phase mineralization, 10-20 mm large pumice are cellular and recrystallized, usually plucked by drilling, 2-3% cognate or red siltstone lithic fragments less altered than above, 3-5% quartz, feldspar, biotite and rare pyroxene phenos, irregular joints at 30° to core axis.

2007.8-2011.6 gradational contact zone (10YR7.5/2) finer grained, denser groundmass.
2012.5 green zeolite patches in large pumices, all pumice recrystallized to very fine grain white powdery state (argillic or zeolitic alteration?), Fe remobilized as magnetite.
2012.5 welding and vapor-phase alteration ends.

Prow Pass Tuff, Unit 2 (Tcp2), lithic-rich unit *(2015.8-2095.3),* similar to above except lithic content increases to 5-15%, 2118.1 0.3-foot lithic-rich zone, large lithics up to 25 mm most of dense red-brown composition or red siltstone, 2020.9 0.8-foot lithic-rich zone, large lithics mostly die by 2022.8; 1-2% 5-25 mm size and 2-4% small <5 mm size, 2027.3 slight increase in lithic content 0.2-foot zone.

AVE. CORE REC'Y/HOLE



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Scale: 1" = 10' (1:120)
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SANDIA NATIONAL LABS
Logged by: Dale Engstrom
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Started: May 19, 1994
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Bearing: N/A (vertical)
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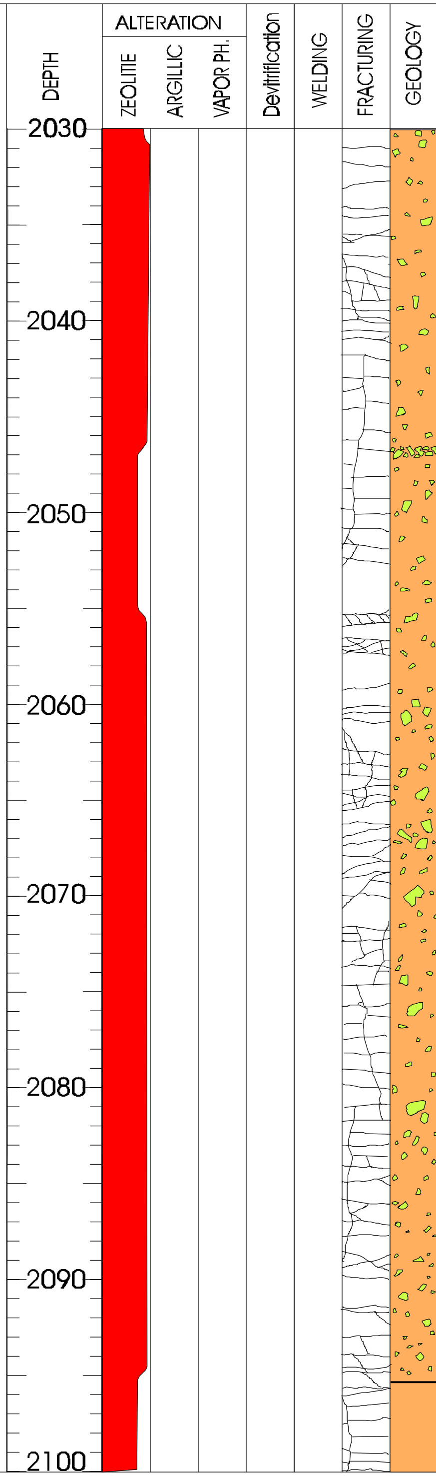
Collar Coordinates:
N: 767998.5 E: 561818.0
Elevation: 4272.6 Feet
Total Depth: 2223.1 Feet

SNT02052794001.003



COMMENTS:

2030.6-2046.6 heavy zeolitic alteration

2047.0 lithic-rich zone

2055.4 heavily zeolitized

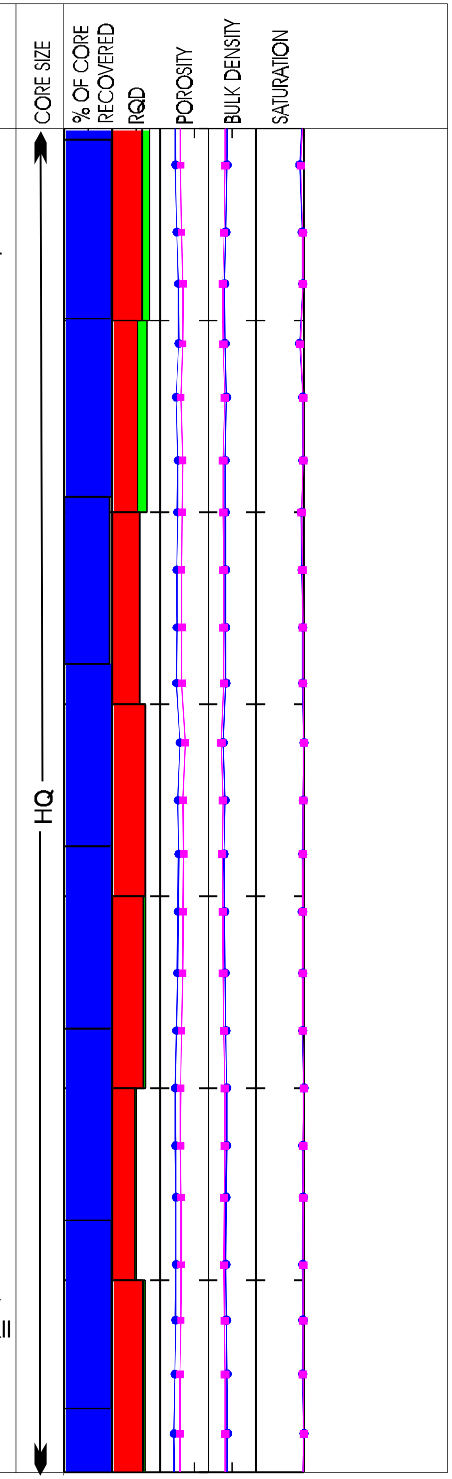
2095.3 Unit 1

Prow Pass Tuff, Unit 2, lithic-rich unit, *cont. (2015.8-2095.3),* pale red-gray (5R8/2) nonwelded, zeolitic altered groundmass, 10-15% small angular pumice, 5-15% small subangular cognate or red siltstone lithics less altered than in Unit 3, large lithics up to 25 mm mostly of dense red-brown or red siltstone composition, patchy strong zeolitic alteration discolors core brown, produces green zeolite blobs in large pumices, all pumice zeolitized to large degree, 3-5% quartz, feldspar, biotite and rare pyroxene phenocrysts.
2030.6-2046.6 increase in zeolitic alteration makes core brown, 25-35% pumice replaced by green zeolite, sinuous micro-wavefronts of harder resistant material forms "web" through totally altered microgranular groundmass, large laminated pumices recrystallized into coarse grained quartz-feldspar-zeolite mass with residual magnetite.

2055.4 dark patches of green-brown zeolitic alteration, very light pink-gray microcrystalline matrix, barely discernable altered pumice (75-80% zeolitized), rock is speckled by green (zeolitized) pumice cores, Fe remobilized into magnetite.

Prow Pass Tuff, Unit 1 (Tcp1), lithic-poor unit *(2095.3-TD)* pale yellow-white (2.5Y8/2) weakly to nonwelded, heavily zeolitic altered, 6-8% olive green zeolite in matrix after micro-shards of black glass(?), 25-27% 3-10 mm subangular pale-colored sometimes laminated dense pumice fragments nearly totally zeolitized but some retain relict core texture, 1-3% small 2-4 mm angular dense red-brown volcanic or red siltstone lithics, 1-2% sanidine, trace-.5% pyroxene, 2-3% euhedral quartz phenos, 0.5-1% biotite flakes.

AVE. CORE REC'Y/HOLE



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SANDIA NATIONAL LABS
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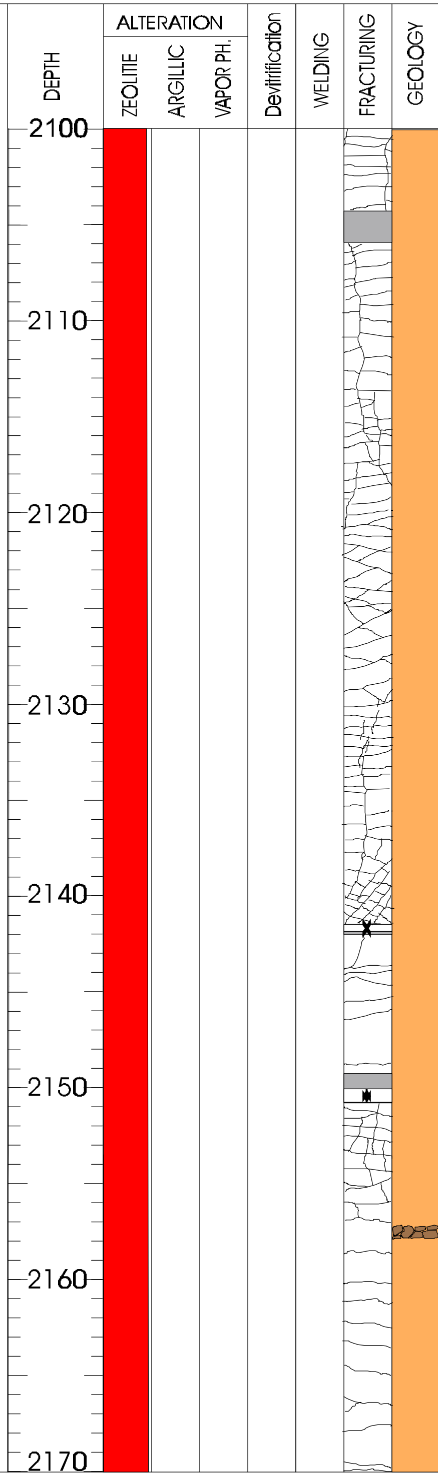


COMMENTS:

SNT02052794001.003

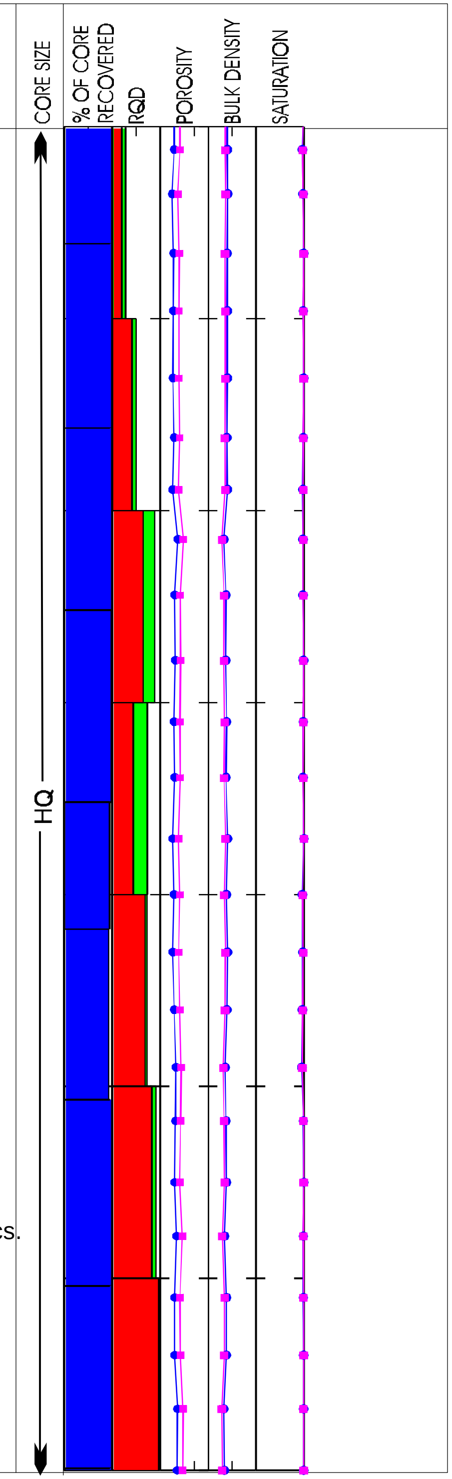
2104.3-2105.9 rubble

Prow Pass Tuff, Unit 1, lithic-poor unit, *cont. (2095.3-TD)*
pale yellow-white (2.5Y8/2) weakly to nonwelded, heavy zeolitic alteration, 6-8% olive green zeolite in matrix after microshards of black glass(?), 25-27% 3-10 mm subangular pale- colored sometimes laminated dense pumice fragments nearly totally zeolitized but some retain relict core texture, 1-3% small 2-4 mm angular dense red-brown volcanic or red siltstone lithics, 1-2% sanidine, trace-.5% pyroxene, 2-3% euhedral quartz phenos, 0.5-1% biotite flakes.

2141.5-2141.8 unrcvd
2121.5-2142.0 rubble

2149.2-2150.7 rubble
2150.1-2150.7 unrcvd

2157.3-2157.8 zone of large (up to 5 cm) medium brown porcelaneous altered lithics.



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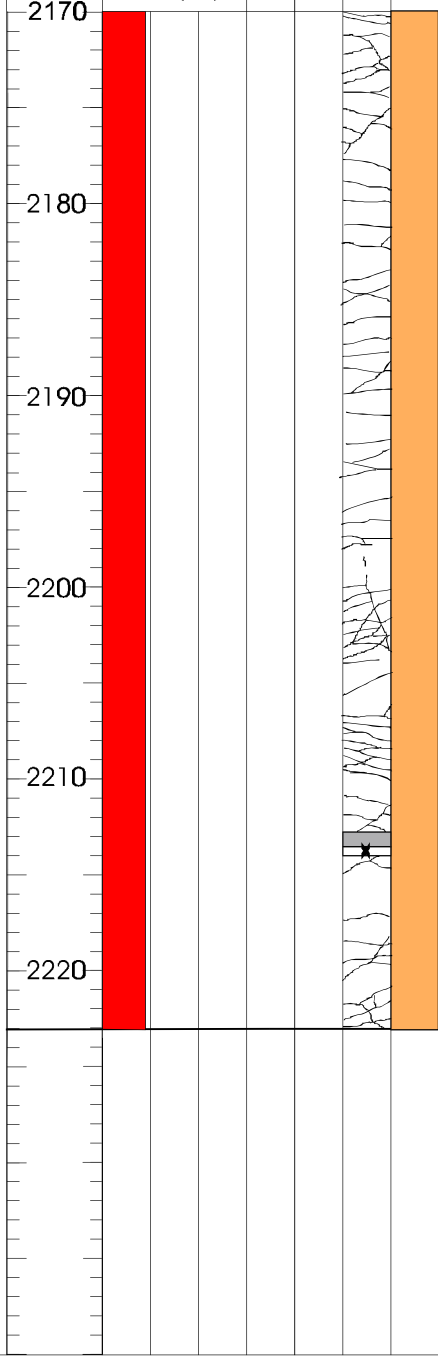
DEPTH | ALTERATION (ZEOLITE, ARGILLIC, VAPOR PH.) | Devitrification | WELDING | FRACTURING | GEOLOGY



COMMENTS:

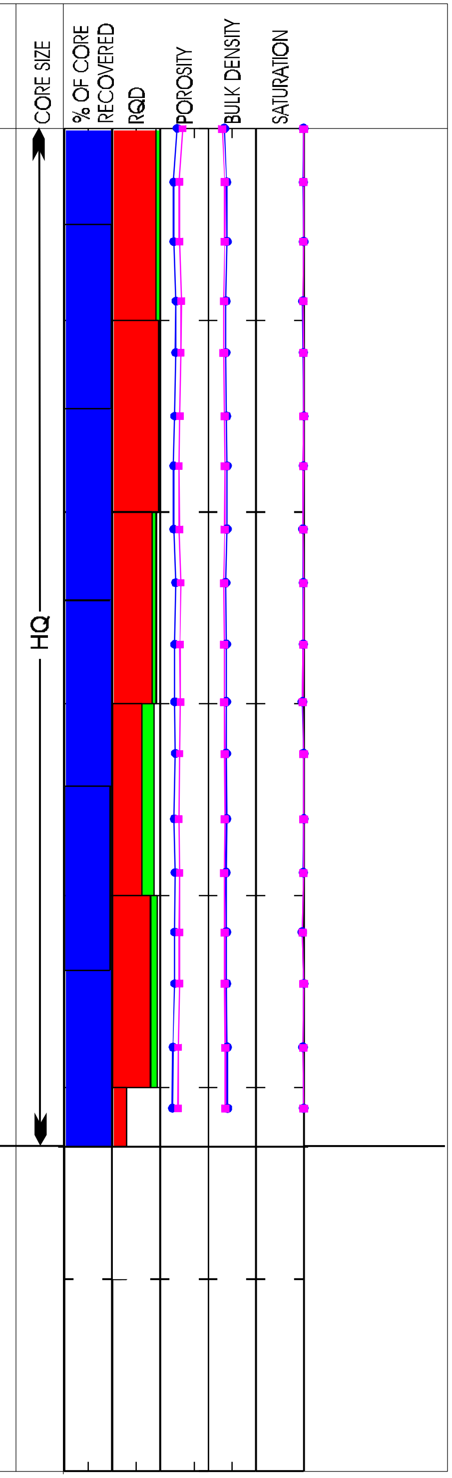
SNT02052794001.003

AVE. CORE REC'Y/HOLE

Prow Pass Tuff, Unit 1, lithic-poor unit, *cont. (2095.3-TD)*
pale yellow-white (2.5Y8/2) weakly to nonwelded, heavy zeolitic alteration, 6-8% olive green zeolite in matrix after microshards of black glass(?), 25-27% 3-10 mm subangular pale-colored sometimes laminated dense pumice fragments nearly totally zeolitized but some retain relict core texture, 1-3% small 2-4 mm angular dense red-brown volcanic or red siltstone lithics, 1-2% sanidine, trace-0.5% pyroxene, 2-3% euhedral quartz phenos, 0.5-1% biotite flakes.

2212.8-2213.9 rubble
2213.5-2213.9 unrcvd

2223.12 - Foot of Hole



Appendix C: Core Recovery Data

Table C-1: Core Recovery Data

[Sources (Data-tracking numbers, DTNs): 1–TM0000000SD9RS.001; 2–TM0000000SD9RS.002; 3–TM0000000SD9RS.003; 4–TM0000000SD9RS.004]

Run No.	Interval Bottom (feet)	Drilled (feet)	Recovered (feet)	Core Recovery (percent)	Source	Page No.
0	53.6	--	--	--	1	1
1	63.1	9.5	9.3	98	1	2
2	72.9	9.8	9.8	100	1	4
3	82.4	9.5	9.3	98	1	6
4	92.1	9.7	9.3	96	1	7
5	102.0	9.9	9.9	100	1	8
6	111.8	9.8	9.8	100	1	9
7	121.7	9.9	9.8	99	1	11
8	131.5	9.8	4.3	44	1	12
9	141.3	9.8	9.5	97	1	13
10	151.1	9.8	2.7	28	1	13
11	159.4	8.3	8.3	100	1	14
12	16.09	9.6	6.8	71	1	15
13	176.0	7.0	5.6	80	1	16
14	185.3	9.3	1.7	18	1	16
15	191.2	5.9	5.1	86	1	17
16	199.2	8.0	0.0	0	1	17
17	208.5	9.3	0.0	0	1	18
18	218.5	10.0	10.0	100	1	19
19	227.8	9.3	8.3	89	1	19
20	237.7	9.9	9.0	91	1	20
21	244.6	6.9	6.9	100	1	21
22	254.1	9.5	9.4	99	1	22
23	263.8	9.7	9.7	100	1	22
24	270.0	6.2	6.0	97	1	23
25	275.8	5.8	3.5	60	1	24
26	281.8	6.0	5.3	88	1	26
27	290.2	8.4	8.0	95	1	29
28	297.2	7.0	3.2	46	1	30
29	302.8	5.6	4.3	77	1	31
30	305.5	2.7	0.9	33	1	31

Table C-1: Core Recovery Data (Continued)

[Sources (Data-tracking numbers, DTNs): 1–TM0000000SD9RS.001; 2–TM0000000SD9RS.002; 3–TM0000000SD9RS.003; 4–TM0000000SD9RS.004]

Run No.	Interval Bottom (feet)	Drilled (feet)	Recovered (feet)	Core Recovery (percent)	Source	Page No.
31	311.5	6.0	6.0	100	1	32
32	320.7	9.2	7.4	80	1	33
33	330.3	9.6	9.5	99	1	34
34	337.4	7.1	6.2	87	1	35
35	347.2	9.8	9.2	94	1	36
36	356.5	9.3	6.7	72	1	38
37	361.3	4.8	3.3	69	1	39
38	368.1	6.8	4.1	60	1	41
39	375.6	7.5	4.3	57	1	42
40	384.9	9.3	8.0	86	1	44
41	393.4	8.5	4.5	53	1	45
42	402.3	8.9	8.5	96	1	46
43	409.5	7.2	6.7	93	1	47
44	419.0	9.5	7.4	78	1	47
45	428.6	9.6	8.7	91	1	47
46	435.9	7.3	6.4	88	1	48
47	445.1	9.2	5.6	61	1	49
48	450.5	5.4	3.1	57	1	50
49	460.1	9.6	9.0	94	1	51
50	465.5	5.4	2.9	54	1	51
51	473.5	8.0	3.8	48	1	52
52	477.6	4.1	3.3	80	1	53
53	484.2	6.6	2.4	36	1	53
54	489.4	5.2	1.3	25	1	54
55	492.2	2.8	1.9	68	1	54
56	498.2	6.0	3.7	62	1	55
57	503.6	5.4	2.7	50	1	56
58	511.5	7.9	2.5	32	1	56
59	518.7	7.2	6.8	94	1	57
60	523.0	4.3	3.9	91	1	58
61	530.1	7.1	3.2	45	1	59

Table C-1: Core Recovery Data (Continued)

[Sources (Data-tracking numbers, DTNs): 1–TM0000000SD9RS.001; 2–TM0000000SD9RS.002; 3–TM0000000SD9RS.003; 4–TM0000000SD9RS.004]

Run No.	Interval Bottom (feet)	Drilled (feet)	Recovered (feet)	Core Recovery (percent)	Source	Page No.
62	537.2	7.1	2.8	39	1	59
63	541.9	4.7	4.3	91	1	60
64	551.2	9.3	3.0	32	1	60
65	555.6	4.4	3.4	77	1	61
66	560.5	4.9	3.7	76	1	62
67	567.8	7.3	2.0	27	1	62
68	574.6	6.8	1.7	25	1	63
69	576.8	2.2	1.8	82	1	63
70	584.9	8.1	4.6	57	1	64
71	590.9	6.0	5.2	87	1	66
72	596.4	5.5	3.5	64	1	66
73	602.3	5.9	4.2	71	1	68
74	611.6	9.3	7.2	77	1	69
75	617.6	6.0	3.1	52	1	70
76	626.9	9.3	1.4	15	1	70
77	636.0	9.1	5.5	60	1	71
78	642.0	6.0	3.1	52	1	72
79	646.9	4.9	1.0	20	1	72
80	649.3	2.4	1.2	50	1	73
81	654.3	5.0	3.0	60	1	73
82	657.3	3.0	1.4	47	1	74
83	662.3	5.0	2.4	48	1	74
84	668.7	6.4	4.2	66	1	75
85	678.0	9.3	5.6	60	1	76
86	687.6	9.6	6.3	66	1	78
87	696.5	8.9	6.6	74	1	79
88	700.2	3.7	2.7	73	1	80
89	705.9	5.7	4.3	75	1	81
90	714.4	8.5	7.7	91	1	83
91	720.4	6.0	5.4	90	1	84
92	724.5	4.1	3.2	78	1	85

Table C-1: Core Recovery Data (Continued)

[Sources (Data-tracking numbers, DTNs): 1–TM0000000SD9RS.001; 2–TM0000000SD9RS.002; 3–TM0000000SD9RS.003; 4–TM0000000SD9RS.004]

Run No.	Interval Bottom (feet)	Drilled (feet)	Recovered (feet)	Core Recovery (percent)	Source	Page No.
93	734.7	10.2	10.2	100	1	87
94	740.1	5.4	2.7	50	1	87
95	744.5	4.4	3.5	80	1	88
96	748.7	4.2	3.7	88	1	89
97	755.1	6.4	4.0	63	1	90
98	762.4	7.3	6.4	88	1	92
99	770.4	8.0	7.4	93	1	93
100	779.1	8.7	8.6	99	1	94
101	784.1	5.0	1.1	22	1	94
102	788.1	4.0	1.6	40	1	95
103	793.5	5.4	3.1	57	1	95
104	799.0	5.5	5.4	98	1	97
105	806.5	7.5	7.0	93	1	98
106	813.5	7.0	6.6	94	1	100
107	816.8	3.3	3.3	100	1	100
108	825.2	8.4	8.4	100	1	102
109	835.4	10.2	10.2	100	1	103
110	845.2	9.8	9.8	100	1	105
111	849.2	4.0	3.5	88	1	106
112	856.8	7.6	5.1	67	1	107
113	865.0	8.2	3.2	39	1	108
114	872.2	7.2	2.7	37	1	109
115	878.3	6.1	1.5	25	1	110
116	887.6	9.3	2.0	22	1	110
117	896.6	9.0	1.7	19	1	111
118	898.4	1.8	0.6	33	1	111
119	902.9	4.5	3.1	69	1	112
120	905.2	2.3	0.7	30	1	112
121	910.8	5.6	3.4	61	1	113
122	921.2	10.4	0.0	0	1	113
123	923.5	2.3	1.7	74	1	114

Table C-1: Core Recovery Data (Continued)

[Sources (Data-tracking numbers, DTNs): 1–TM0000000SD9RS.001; 2–TM0000000SD9RS.002; 3–TM0000000SD9RS.003; 4–TM0000000SD9RS.004]

Run No.	Interval Bottom (feet)	Drilled (feet)	Recovered (feet)	Core Recovery (percent)	Source	Page No.
124	928.5	5.0	1.9	38	1	114
125	933.3	4.8	2.3	48	1	115
126	937.8	4.5	3.7	82	1	116
127	942.9	5.1	2.4	47	1	117
128	948.0	5.1	3.4	67	1	118
129	952.4	4.4	0.8	18	1	118
130	957.5	5.1	2.7	53	1	119
131	962.6	5.1	1.8	35	1	120
132	966.5	3.9	3.4	87	1	121
133	971.6	5.1	3.7	73	1	121
134	975.4	3.8	2.6	68	1	122
135	979.8	4.4	1.6	36	1	123
136	984.4	4.6	3.3	72	1	124
137	989.5	5.1	4.4	86	1	125
138	994.9	5.4	3.8	70	1	125
139	1001.9	7.0	3.9	56	1	126
140	1006.7	4.8	2.5	52	1	127
141	1011.4	4.7	1.1	23	1	127
142	1016.8	5.4	2.7	50	1	128
143	1020.5	3.7	1.0	27	1	129
144	1022.6	2.1	1.4	67	1	129
145	1027.7	5.1	2.0	39	1	130
146	1032.8	5.1	3.6	71	1	131
147	1037.8	5.0	4.7	94	1	132
148	1043.5	5.7	4.6	81	1	133
149	1051.1	7.6	7.2	95	1	134
150	1053.2	2.1	1.8	86	1	134
151	1059.7	6.5	3.8	58	1	135
152	1066.0	6.3	5.9	94	1	136
153	1075.4	9.4	5.4	57	1	137
154	1079.8	4.4	2.2	50	1	138

Table C-1: Core Recovery Data (Continued)

[Sources (Data-tracking numbers, DTNs): 1–TM0000000SD9RS.001; 2–TM0000000SD9RS.002; 3–TM0000000SD9RS.003; 4–TM0000000SD9RS.004]

Run No.	Interval Bottom (feet)	Drilled (feet)	Recovered (feet)	Core Recovery (percent)	Source	Page No.
155	1084.8	5.0	1.8	36	1	139
156	1090.0	5.2	4.1	79	1	140
157	1094.4	4.4	3.0	68	1	140
158	1097.8	3.4	2.6	76	1	141
159	1103.4	5.6	4.7	84	1	142
160	1113.3	9.9	9.0	91	1	143
161	1118.3	5.0	4.1	82	1	144
162	1124.4	6.1	6.1	100	1	145
163	1132.3	7.9	5.0	63	1	146
164	1137.5	5.2	3.6	69	1	147
165	1143.0	5.5	5.3	96	1	148
166	1148.3	5.3	4.8	91	1	149
167	1156.1	7.8	5.6	72	1	150
168	1158.0	1.9	1.9	100	1	151
169	1168.1	10.1	9.4	93	1	153
170	1170.0	1.9	1.5	79	1	153
171	1178.0	8.0	5.8	73	1	155
172	1183.6	5.6	3.4	61	1	156
173	1191.6	8.0	6.8	85	1	158
174	1198.6	7.0	5.5	79	1	159
175	1207.2	8.6	6.7	78	1	160
176	1210.8	3.6	2.1	58	1	161
177	1218.4	7.6	5.8	76	1	162
178	1223.5	5.1	3.1	61	1	163
179	1228.0	4.5	3.2	71	1	163
180	1232.9	4.9	3.6	73	1	164
181	1240.8	7.9	5.7	72	1	165
182	1248.4	7.6	5.6	74	1	166
183	1253.5	5.1	3.9	76	1	167
184	1261.2	7.7	6.1	79	1	169
185	1269.8	8.6	5.1	59	1	170

Table C-1: Core Recovery Data (Continued)

[Sources (Data-tracking numbers, DTNs): 1–TM0000000SD9RS.001; 2–TM0000000SD9RS.002; 3–TM0000000SD9RS.003; 4–TM0000000SD9RS.004]

Run No.	Interval Bottom (feet)	Drilled (feet)	Recovered (feet)	Core Recovery (percent)	Source	Page No.
186	1273.0	3.2	3.1	97	1	171
187	1278.0	5.0	4.2	84	1	172
188	1284.2	6.2	5.2	84	1	173
189	1288.9	4.7	2.0	43	1	174
190	1295.7	6.8	3.8	56	1	175
191	1297.5	1.8	1.8	100	1	175
192	1307.8	10.3	8.6	83	1	177
193	1316.7	8.9	4.8	54	1	178
194	1322.7	6.0	4.6	77	1	179
195	1328.9	6.2	3.1	50	1	180
196	1329.7	0.8	0.6	75	1	180
197	1336.6	6.9	6.9	100	1	183
198	1346.3	9.7	4.5	46	1	183
199	1348.1	1.8	1.8	100	1	184
200	1354.0	5.9	5.4	92	1	186
201	1359.9	5.9	5.2	88	1	187
202	1363.1	3.2	2.8	88	1	188
203	1367.3	4.2	4.2	100	1	189
204	1377.1	9.8	8.1	83	1	191
205	1384.4	7.3	6.6	90	1	193
206	1390.5	6.1	6.0	98	1	194
207	1400.3	9.8	7.2	73	1	196
208	1409.9	9.6	9.4	98	1	198
209	1414.2	4.3	4.3	100	1	199
210	1422.2	8.0	7.5	94	1	201
211	1430.5	8.3	8.3	100	1	202
212	1440.1	9.6	9.6	100	1	203
213	1449.5	9.4	9.4	100	1	204
214	1459.1	9.6	9.6	100	1	205
215	1469.0	9.9	9.9	100	1	206
216	1474.2	5.2	5.2	100	1	207

Table C-1: Core Recovery Data (Continued)

[Sources (Data-tracking numbers, DTNs): 1–TM0000000SD9RS.001; 2–TM0000000SD9RS.002; 3–TM0000000SD9RS.003; 4–TM0000000SD9RS.004]

Run No.	Interval Bottom (feet)	Drilled (feet)	Recovered (feet)	Core Recovery (percent)	Source	Page No.
217	1479.3	5.1	5.1	100	1	207
218	1484.2	4.9	4.9	100	1	208
219	1489.2	5.0	5.0	100	1	209
220	1490.7	1.5	0.2	13	2	209
221	1491.7	1.0	0.9	90	2	209
222	1492.0	0.3	0.3	100	2	209
223	1497.9	5.9	5.9	100	2	210
224	1507.2	9.3	9.3	100	2	211
225	1516.7	9.5	9.5	100	2	212
226	1526.4	9.7	9.7	100	2	214
227	1536.6	10.2	10.2	100	2	215
228	1542.4	5.8	5.4	93	2	215
229	1547.4	5.0	5.8	116	2	216
230	1556.9	9.5	5.0	53	2	217
231	1566.4	9.5	9.5	100	2	218
232	1576.1	9.7	9.7	100	2	219
233	1585.6	9.5	9.5	100	2	221
234	1595.3	9.7	9.7	100	2	222
235	1604.8	9.5	9.5	100	2	224
236	1609.3	4.5	1.7	38	2	224
237	1615.5	6.2	7.2	116	2	225
238	1626.1	10.6	9.2	87	2	227
239	1635.7	9.6	7.4	77	2	228
240	1645.3	9.6	9.6	100	2	228
241	1654.8	9.5	9.5	100	2	229
242	1664.2	9.4	9.4	100	2	230
243	1671.4	7.2	7.2	100	2	231
244	1681.1	9.7	9.7	100	2	232
245	1690.6	9.5	9.5	100	2	232
246	1700.5	9.9	9.9	100	3	233
247	1710.2	9.7	9.7	100	3	234

Table C-1: Core Recovery Data (Continued)

[Sources (Data-tracking numbers, DTNs): 1–TM0000000SD9RS.001; 2–TM0000000SD9RS.002; 3–TM0000000SD9RS.003; 4–TM0000000SD9RS.004]

Run No.	Interval Bottom (feet)	Drilled (feet)	Recovered (feet)	Core Recovery (percent)	Source	Page No.
248	1720.0	9.8	9.8	100	3	235
249	1729.6	9.6	10.1	105	3	235
250	1739.2	9.6	9.5	99	3	237
251	1739.8	0.6	0.6	100	3	237
252	1749.7	9.9	9.9	100	3	238
253	1759.0	9.3	9.2	99	3	239
254	1761.6	2.6	2.6	100	3	239
255	1771.2	9.6	9.6	100	3	240
256	1780.7	9.5	9.5	100	3	241
257	1790.5	9.8	9.8	100	3	241
258	1800.1	9.6	9.6	100	3	242
259	1809.7	9.6	9.6	100	3	243
260	1819.2	9.5	9.5	100	3	243
261	1828.7	9.5	9.5	100	3	244
262	1838.0	9.3	9.2	99	3	246
263	1845.1	7.1	7.1	100	3	246
264	1852.7	7.6	7.6	100	3	247
265	1862.4	9.7	9.7	100	3	247
266	1872.1	9.7	9.7	100	3	249
267	1881.7	9.6	9.6	100	3	250
268	1891.1	9.4	9.4	100	3	251
269	1900.6	9.5	9.5	100	3	252
270	1910.0	9.4	9.4	100	3	252
271	1916.1	6.1	4.4	72	3	254
272	1923.1	7.0	5.7	81	3	254
273	1932.2	9.1	9.1	100	3	255
274	1938.7	6.5	6.5	100	3	256
275	1942.0	3.3	1.3	39	3	256
276	1950.0	8.0	7.5	94	3	257
277	1959.3	9.3	9.3	100	3	259
278	1968.4	9.1	8.9	98	3	259

Table C-1: Core Recovery Data (Continued)

[Sources (Data-tracking numbers, DTNs): 1–TM0000000SD9RS.001; 2–TM0000000SD9RS.002; 3–TM0000000SD9RS.003; 4–TM0000000SD9RS.004]

Run No.	Interval Bottom (feet)	Drilled (feet)	Recovered (feet)	Core Recovery (percent)	Source	Page No.
279	1978.4	10.0	10.0	100	3	260
280	1988	9.6	9.0	94	3	261
281	1991.4	3.4	3.4	100	3	261
282	1994.5	3.1	3.1	100	3	262
283	2002.3	7.8	7.8	100	3	262
284	2011.6	9.3	9.3	100	3	263
285	2021.1	9.5	9.5	100	3	263
286	2030.6	9.5	9.5	100	3	263
287	2039.9	9.3	9.2	99	4	264
288	2049.2	9.3	9.3	100	4	265
289	2057.9	8.7	8.3	95	4	266
290	2067.4	9.5	9.5	100	4	267
291	2076.9	9.5	9.5	100	4	268
292	2086.9	10.0	10.0	100	4	269
293	2096.7	9.8	9.7	99	4	270
294	2106.1	9.4	9.4	100	4	271
295	2115.7	9.6	9.6	100	4	272
296	2125.2	9.5	9.5	100	4	273
297	2135.2	10.0	9.9	99	4	275
298	2141.8	6.6	6.3	95	4	276
299	2150.7	8.9	8.3	93	4	276
300	2160.4	9.7	9.7	100	4	277
301	2169.9	9.5	9.5	100	4	277
302	2175.0	5.1	5.1	100	4	278
303	2184.6	9.6	9.5	99	4	278
304	2194.6	10.0	10.0	100	4	279
305	2204.3	9.7	9.7	100	4	280
306	2213.9	9.6	9.2	96	4	281
307	2223.1	9.2	9.2	100	4	

Appendix D: Rock Quality Designation (RQD) Data

Table D-1: Core-Run RQD Data

[Source (DTN): TM0000SD9SUPER.002]

Run No.	Interval Bottom [feet]	Drilled [feet]	Raw		Adjusted		Page No.
			Length [feet]†	RQD†	Length [feet]	RQD	
0	53.6	--	--	--	--	--	1
1	63.1	9.5	--	--	4.59	48	1
2	72.9	9.8	--	--	0.40	4	2
3	82.4	9.5	--	--	7.85	83	4
4	92.1	9.7	--	--	8.20	85	6
5	102.0	9.9	--	--	9.80	99	7
6	111.8	9.8	--	--	7.30	74	8
7	121.7	9.9	--	--	7.70	78	9
8	131.5	9.8	--	--	1.60	16	11
9	141.3	9.8	--	--	9.00	92	12
10	151.1	9.8	--	--	2.70	28	13
11	159.4	8.3	--	--	8.00	96	13
12	169.0	9.6	--	--	6.60	69	14
13	176.0	7.0	--	--	5.40	77	15
14	185.3	9.3	--	--	1.70	18	16
15	191.2	5.9	--	--	5.10	86	16
16	199.2	8.0	--	--	0.00	0	17
17	208.5	9.3	--	--	0.00	0	17
18	218.5	10.0	--	--	9.90	99	18
19	227.8	9.3	--	--	8.30	89	19
20	237.7	9.9	--	--	8.76	88	19
21	244.6	6.9	--	--	6.50	94	20
22	254.1	9.5	--	--	9.40	99	21
23	263.8	9.7	--	--	9.30	96	22
24	270.0	6.2	--	--	5.90	95	22
25	275.8	5.8	--	--	0.85	15	23
26	281.8	6.0	--	--	1.20	20	24
27	290.2	8.4	--	--	2.80	33	26
28	297.2	7.0	--	--	0.00	0	29
29	302.8	5.6	--	--	1.90	34	30
30	305.5	2.7	--	--	0.60	22	31
31	311.5	6.0	--	--	3.80	63	31
32	320.7	9.2	--	--	3.80	41	32

Table D-1: Core-Run RQD Data (Continued)

[Source (DTN): TM0000SD9SUPER.002]

Run No.	Interval Bottom [feet]	Drilled [feet]	Raw		Adjusted		Page No.
			Length [feet]†	RQD†	Length [feet]	RQD	
33	330.3	9.6	--	--	7.80	81	33
34	337.4	7.1	--	--	6.10	86	34
35	347.2	9.8	--	--	8.20	84	35
36	356.5	9.3	--	--	5.40	58	36
37	361.3	4.8	--	--	0.80	17	38
38	368.1	6.8	--	--	2.70	40	39
39	375.6	7.5	--	--	3.00	40	41
40	384.9	9.3	--	--	6.00	65	42
41	393.4	8.5	--	--	1.60	19	44
42	402.3	8.9	--	--	8.40	94	45
43	409.5	7.2	--	--	3.80	53	46
44	419.0	9.5	--	--	0.00	0	47
45	428.6	9.6	--	--	2.40	25	47
46	435.9	7.3	--	--	5.30	73	47
47	445.1	9.2	--	--	2.40	26	48
48	450.5	5.4	--	--	1.25	23	49
49	460.1	9.6	--	--	8.20	85	50
50	465.5	5.4	--	--	0.40	7	51
51	473.5	8.0	--	--	3.10	39	51
52	477.6	4.1	--	--	2.10	51	52
53	484.2	6.6	--	--	0.00	0	53
54	489.4	5.2	--	--	1.00	19	53
55	492.2	2.8	--	--	1.40	50	54
56	498.2	6.0	--	--	1.20	20	54
57	503.6	5.4	--	--	1.90	35	55
58	511.5	7.9	--	--	0.00	0	56
59	518.7	7.2	--	--	6.70	93	56
60	523.0	4.3	--	--	0.39	9	57
61	530.1	7.1	--	--	1.96	28	58
62	537.2	7.1	--	--	1.78	25	59
63	541.9	4.7	--	--	3.58	76	59
64	551.2	9.3	--	--	0.00	0	60
65	555.6	4.4	--	--	2.97	68	60

Table D-1: Core-Run RQD Data (Continued)

[Source (DTN): TM0000SD9SUPER.002]

Run No.	Interval Bottom [feet]	Drilled [feet]	Raw		Adjusted		Page No.
			Length [feet]†	RQD†	Length [feet]	RQD	
66	560.5	4.9	--	--	1.61	33	61
67	567.8	7.3	--	--	0.00	0	62
68	574.6	6.8	--	--	1.00	15	62
69	576.8	2.2	--	--	1.00	45	63
70	584.9	8.1	--	--	1.90	23	63
71	590.9	6.0	--	--	4.60	77	64
72	596.4	5.5	--	--	2.90	53	66
73	602.3	5.9	--	--	2.70	46	66
74	611.6	9.3	--	--	5.10	55	68
75	617.6	6.0	--	--	2.23	37	69
76	626.9	9.3	--	--	0.00	0	70
77	636.0	9.1	--	--	4.90	54	70
78	642.0	6.0	--	--	1.81	30	71
79	646.9	4.9	--	--	0.59	12	72
80	649.3	2.4	--	--	0.00	0	72
81	654.3	5.0	--	--	1.90	38	73
82	657.3	3.0	--	--	0.00	0	73
83	662.3	5.0	--	--	1.70	34	74
84	668.7	6.4	--	--	3.56	56	74
85	678.0	9.3	--	--	5.03	54	75
86	687.6	9.6	--	--	5.83	61	76
87	696.5	8.9	--	--	6.00	67	78
88	700.2	3.7	--	--	1.40	38	79
89	705.9	5.7	--	--	3.80	67	80
90	714.4	8.5	--	--	7.10	84	81
91	720.4	6.0	--	--	3.90	65	83
92	724.5	4.1	--	--	1.80	44	84
93	734.7	10.2	--	--	9.90	97	85
94	740.1	5.4	--	--	2.80	52	87
95	744.5	4.4	--	--	0.40	9	87
96	748.7	4.2	--	--	1.30	31	88
97	755.1	6.4	--	--	1.30	20	89
98	762.4	7.3	--	--	3.00	41	90

Table D-1: Core-Run RQD Data (Continued)

[Source (DTN): TM0000SD9SUPER.002]

Run No.	Interval Bottom [feet]	Drilled [feet]	Raw		Adjusted		Page No.
			Length [feet]†	RQD†	Length [feet]	RQD	
99	770.4	8.0	--	--	6.17	77	92
100	779.1	8.7	--	--	7.24	83	93
101	784.1	5.0	--	--	0.00	0	94
102	788.1	4.0	--	--	0.00	0	94
103	793.5	5.4	--	--	1.00	19	95
104	799.0	5.5	--	--	3.06	56	95
105	806.5	7.5	--	--	2.74	37	97
106	813.5	7.0	--	--	4.20	60	98
107	816.8	3.3	--	--	2.40	73	100
108	825.2	8.4	--	--	7.45	89	100
109	835.4	10.2	--	--	8.10	79	102
110	845.2	9.8	--	--	9.25	94	103
111	849.2	4.0	--	--	3.50	88	105
112	856.8	7.6	--	--	4.70	62	106
113	865.0	8.2	--	--	0.90	11	107
114	872.2	7.2	--	--	1.50	21	108
115	878.3	6.1	--	--	0.50	8	109
116	887.6	9.3	--	--	1.00	11	110
117	896.6	9.0	--	--	0.00	0	110
118	898.4	1.8	--	--	0.40	22	111
119	902.9	4.5	--	--	2.90	64	111
120	905.2	2.3	--	--	1.10	48	112
121	910.8	5.6	--	--	1.50	27	112
122	921.2	10.4	--	--	0.00	0	113
123	923.5	2.3	--	--	0.58	25	113
124	928.5	5.0	--	--	1.00	20	114
125	933.3	4.8	--	--	0.92	19	114
126	937.8	4.5	--	--	1.26	28	115
127	942.9	5.1	--	--	0.50	10	116
128	948.0	5.1	--	--	3.36	66	117
129	952.4	4.4	0.46	10	0.46	10	118
130	957.5	5.1	0.37	7	0.80	16	118
131	962.6	5.1	0.00	0	1.11	22	119

Table D-1: Core-Run RQD Data (Continued)

[Source (DTN): TM0000SD9SUPER.002]

Run No.	Interval Bottom [feet]	Drilled [feet]	Raw Length [feet]†	Raw RQD†	Adjusted Length [feet]	Adjusted RQD	Page No.
132	966.5	3.9	1.39	36	1.00	26	120
133	971.6	5.1	--	--	0.90	18	121
134	975.4	3.8	--	--	1.15	30	121
135	979.8	4.4	--	--	0.00	0	122
136	984.4	4.6	0.00	0	1.49	32	123
137	989.5	5.1	0.00	0	1.23	24	124
138	994.9	5.4	0.75	14	2.30	43	125
139	1001.9	7.0	0.69	10	2.18	31	125
140	1006.7	4.8	0.00	0	1.21	25	126
141	1011.4	4.7	0.00	0	0.50	11	127
142	1016.8	5.4	0.73	14	1.80	33	127
143	1020.5	3.7	--	--	0.80	22	128
144	1022.6	2.1	--	--	0.00	0	129
145	1027.7	5.1	--	--	0.70	14	129
146	1032.8	5.1	--	--	2.88	56	130
147	1037.8	5.0	--	--	4.11	82	131
148	1043.5	5.7	--	--	4.60	81	132
149	1051.1	7.6	--	--	5.59	74	133
150	1053.2	2.1	0.00	0	0.93	44	134
151	1059.7	6.5	1.99	31	2.45	38	134
152	1066.0	6.3	1.14	18	3.81	60	135
153	1075.4	9.4	1.09	12	3.06	33	136
154	1079.8	4.4	0.00	0	0.40	9	137
155	1084.8	5.0	0.90	18	0.90	18	138
156	1090.0	5.2	0.36	7	1.80	35	139
157	1094.4	4.4	1.59	36	1.80	41	140
158	1097.8	3.4	0.80	24	1.10	32	140
159	1103.4	5.6	2.16	39	3.35	60	141
160	1113.3	9.9	6.91	70	7.40	75	142
161	1118.3	5.0	2.15	43	3.04	61	143
162	1124.4	6.1	2.96	49	3.52	58	144
163	1132.3	7.9	1.41	18	3.19	40	145
164	1137.5	5.2	0.00	0	0.00	0	146

Table D-1: Core-Run RQD Data (Continued)

[Source (DTN): TM0000SD9SUPER.002]

Run No.	Interval Bottom [feet]	Drilled [feet]	Raw Length [feet]†	Raw RQD†	Adjusted Length [feet]	Adjusted RQD	Page No.
165	1143.0	5.5	2.07	38	3.23	59	147
166	1148.3	5.3	2.56	48	2.67	50	148
167	1156.1	7.8	2.02	26	2.43	31	149
168	1158.0	1.9	0.00	0	0.00	0	150
169	1168.1	10.1	3.92	39	7.86	78	151
170	1170.0	1.9	0.00	0	0.50	26	153
171	1178.0	8.0	1.21	15	2.07	26	153
172	1183.6	5.6	0.38	7	1.33	24	155
173	1191.6	8.0	1.85	23	2.45	31	156
174	1198.6	7.0	1.00	14	2.30	33	158
175	1207.2	8.6	1.20	14	1.70	20	159
176	1210.8	3.6	0.73	20	0.73	20	160
177	1218.4	7.6	3.38	44	3.90	51	161
178	1223.5	5.1	0.40	8	1.00	20	162
179	1228.0	4.5	1.25	28	1.40	31	163
180	1232.9	4.9	1.24	25	1.40	29	163
181	1240.8	7.9	1.35	17	2.10	27	164
182	1248.4	7.6	0.45	6	0.70	9	165
183	1253.4	5.0	0.00	0	1.19	24	166
184	1261.2	7.8	0.00	0	0.00	0	167
185	1269.8	8.6	0.00	0	1.41	16	169
186	1273.0	3.2	0.78	24	1.50	47	170
187	1278.0	5.0	2.38	48	2.86	57	171
188	1284.2	6.2	1.44	23	1.44	23	172
189	1288.9	4.7	0.40	9	0.90	19	173
190	1295.7	6.8	0.58	9	1.89	28	174
191	1297.5	1.8	0.00	0	0.46	26	175
192	1307.8	10.3	5.10	50	7.26	70	175
193	1316.7	8.9	0.00	0	0.75	8	177
194	1322.7	6.0	1.70	28	1.70	28	178
195	1328.9	6.2	0.90	15	1.10	18	179
196	1329.7	0.8	0.00	0	0.00	0	180
197	1336.6	6.9	1.09	16	3.08	45	180

Table D-1: Core-Run RQD Data (Continued)

[Source (DTN): TM0000SD9SUPER.002]

Run No.	Interval Bottom [feet]	Drilled [feet]	Raw		Adjusted		Page No.
			Length [feet]†	RQD†	Length [feet]	RQD	
198	1346.3	9.7	0.49	5	0.75	8	183
199	1348.1	1.8	0.00	0	0.80	44	183
200	1354.0	5.9	0.85	14	1.20	20	184
201	1359.9	5.9	0.40	7	0.40	7	186
202	1363.1	3.2	0.00	0	0.00	0	187
203	1367.3	4.2	0.40	10	1.50	36	188
204	1377.1	9.8	0.00	0	2.20	22	189
205	1384.4	7.3	1.00	14	3.20	44	191
206	1390.5	6.1	0.00	0	3.86	63	193
207	1400.3	9.8	1.08	11	3.60	37	194
208	1409.9	9.6	1.04	11	2.68	28	196
209	1414.2	4.3	0.40	9	2.70	63	198
210	1422.2	8.0	1.19	15	1.19	15	199
211	1430.5	8.3	3.00	36	4.81	58	201
212	1440.1	9.6	3.27	34	9.38	98	202
213	1449.5	9.4	2.17	23	9.40	100	203
214	1459.1	9.6	8.28	86	9.90	103	204
215	1469.0	9.9	4.40	44	5.80	59	205
216	1474.2	5.2	4.45	86	5.04	97	206
217	1479.3	5.1	3.90	76	5.30	104	207
218	1484.2	4.9	0.40	8	0.40	8	207
219	1489.2	5.0	3.10	62	3.60	72	208
220	1490.7	1.5	0.00	0	0.00	0	209
221	1491.7	1.0	0.00	0	0.90	90	209
222	1492.0	0.3	0.00	0	0.00	0	209
223	1497.9	5.9	3.92	66	5.40	92	209
224	1507.2	9.3	6.79	73	8.85	95	210
225	1516.7	9.5	0.00	0	0.00	0	211
226	1526.4	9.7	6.20	64	6.92	71	212
227	1536.6	10.2	8.60	84	8.80	86	214
228	1542.4	5.8	4.96	86	5.42	93	215
229	1547.4	5.0	4.22	84	5.00	100	215
230	1556.9	9.5	7.01	74	7.80	82	216

Table D-1: Core-Run RQD Data (Continued)

[Source (DTN): TM0000SD9SUPER.002]

Run No.	Interval Bottom [feet]	Drilled [feet]	Raw		Adjusted		Page No.
			Length [feet]†	RQD†	Length [feet]	RQD	
231	1566.4	9.5	6.90	73	9.70	102	217
232	1576.1	9.7	7.77	80	9.53	98	218
233	1585.6	9.5	5.78	61	8.80	93	219
234	1595.3	9.7	3.22	33	7.58	78	221
235	1604.8	9.5	2.69	28	3.52	37	222
236	1609.3	4.5	3.23	72	3.50	78	224
237	1616.5	7.2	4.98	69	4.98	69	224
238	1626.1	9.6	7.41	77	8.50	89	225
239	1635.7	9.6	4.65	48	6.60	69	227
240	1645.3	9.6	9.37	98	9.43	98	228
241	1654.8	9.5	6.30	66	7.77	82	228
242	1664.2	9.4	9.39	100	9.39	100	229
243	1671.4	7.2	7.81	108	7.81	108	230
244	1680.8	9.4	9.55	102	9.70	103	231
245	1690.3	9.5	9.50	100	9.50	100	232
246	1700.5	10.2	9.45	93	10.20	100	232
247	1710.2	9.7	7.80	80	9.43	97	233
248	1720.0	9.8	7.10	72	8.80	90	234
249	1729.6	9.6	9.55	99	10.03	104	235
250	1739.2	9.6	7.99	83	8.41	88	235
251	1739.8	0.6	0.40	67	0.40	67	237
252	1749.7	9.9	9.00	91	9.43	95	237
253	1759.0	9.3	8.30	89	9.10	98	238
254	1761.6	2.6	1.46	56	2.64	102	239
255	1771.2	9.6	8.54	89	8.86	92	239
256	1780.7	9.5	8.68	91	8.94	94	240
257	1790.5	9.8	9.70	99	9.80	100	241
258	1800.1	9.6	9.70	101	9.73	101	241
259	1809.7	9.6	9.60	100	9.60	100	242
260	1819.2	9.5	8.50	89	9.50	100	243
261	1828.7	9.5	3.90	41	4.60	48	243
262	1838.0	9.3	1.43	15	2.90	31	244
263	1845.1	7.1	4.93	69	6.90	97	246

Table D-1: Core-Run RQD Data (Continued)
[Source (DTN): TM0000SD9SUPER.002]

Run No.	Interval Bottom [feet]	Drilled [feet]	Raw		Adjusted		Page No.
			Length [feet]†	RQD†	Length [feet]	RQD	
264	1852.7	7.6	6.30	83	6.52	86	246
265	1862.4	9.7	9.81	101	9.85	102	247
266	1872.1	9.7	8.47	87	9.50	98	247
267	1881.7	9.6	1.41	15	1.80	19	249
268	1891.1	9.4	5.70	61	6.30	67	250
269	1900.6	9.5	4.80	51	4.90	52	251
270	1910.0	9.4	6.70	71	8.10	86	252
271	1916.1	6.1	1.40	23	2.10	34	252
272	1923.1	7.0	3.90	56	5.30	76	254
273	1932.2	9.1	9.06	100	9.14	100	254
274	1938.7	6.5	3.40	52	5.15	79	255
275	1942.0	3.3	0.76	23	1.52	46	256
276	1950.0	8.0	3.12	39	5.00	63	256
277	1959.3	9.3	3.80	41	9.28	100	257
278	1968.4	9.1	8.02	88	8.87	97	259
279	1978.4	10.0	7.52	75	9.36	94	259
280	1988.0	9.6	7.30	76	8.32	87	260
281	1991.4	3.4	3.16	93	3.16	93	261
282	1994.5	3.1	2.38	77	3.38	109	261
283	2002.3	7.8	7.40	95	7.70	99	262
284	2011.6	9.3	7.60	82	8.00	86	262
285	2021.1	9.5	9.10	96	9.20	97	263
286	2030.6	9.5	9.50	100	9.50	100	263
287	2039.9	9.3	5.63	61	7.15	77	263
288	2049.2	9.3	4.91	53	6.90	74	264
289	2057.9	8.7	4.80	55	4.95	57	265
290	2067.4	9.5	6.10	64	6.10	64	266
291	2076.9	9.5	7.80	82	8.27	87	267
292	2086.9	10.0	3.00	30	3.30	33	268
293	2096.7	9.8	8.38	86	8.68	89	269
294	2106.1	9.4	2.00	21	2.70	29	270
295	2115.7	9.6	1.90	20	2.70	28	271
296	2125.2	9.5	6.70	71	7.62	80	272

Table D-1: Core-Run RQD Data (Continued)
[Source (DTN): TM0000SD9SUPER.002]

Run No.	Interval Bottom [feet]	Drilled [feet]	Raw		Adjusted		Page No.
			Length [feet]†	RQD†	Length [feet]	RQD	
297	2135.2	10.0	5.93	59	9.82	98	273
298	2141.8	6.6	1.90	29	3.10	47	275
299	2150.7	8.9	6.95	78	7.00	79	276
300	2160.4	9.7	8.10	84	9.00	93	276
301	2169.9	9.5	9.32	98	9.32	98	277
302	2175.0	5.1	4.30	84	5.10	100	277
303	2184.6	9.6	9.47	99	9.50	99	278
304	2194.6	10.0	9.58	96	9.62	96	278
305	2204.3	9.7	7.15	74	8.71	90	279
306	2213.9	9.6	5.15	54	8.27	86	280
307	2223.1	9.2	9.00	98	9.14	99	281

†Data for core runs numbered less than 163 (1124.4 ft) are either missing or incomplete because the technical procedures in place during the time these intervals were drilled did not call for recording raw piece length.

Table D-2: RQD Values by 10-foot Intervals

[Sources: Drilling Support values computed from table D-1; values for Study 8.3.1.14.2 –DTN:. SNF29041993002.069]

Interval Bottom [feet]	Drilling Support		Study 8.3.1.14.2	
	Raw RQD	Adj. RQD	Core RQD	Enhanced RQD
10	--	--	--	--
20	--	--	--	--
30	--	--	--	--
40	--	--	--	--
50	--	--	--	--
60	--	31	--	--
70	--	18	11	24
80	--	60	64	65
90	--	84	67	81
100	--	96	69	91
110	--	79	73	77
120	--	77	28	53
130	--	27	2	21
140	--	81	60	85
150	--	36	19	37
160	--	87	79	86
170	--	70	35	70
180	--	54	21	44
190	--	50	0	45
200	--	10	0	4
210	--	15	7	15
220	--	98	99	100
230	--	89	55	60
240	--	90	67	86
250	--	97	94	99
260	--	97	91	97
270	--	95	77	89
280	--	17	0	9
290	--	31	5	23
300	--	10	6	16
310	--	44	40	49
320	--	45	41	76

Table D-2: RQD Values by 10-foot Intervals (Continued)

[Sources: Drilling Support values computed from table D-1; values for Study 8.3.1.14.2 –DTN:. SNF29041993002.069]

Interval Bottom [feet]	Drilling Support		Study 8.3.1.14.2	
	Raw RQD	Adj. RQD	Core RQD	Enhanced RQD
330	--	78	51	84
340	--	85	38	66
350	--	77	29	83
360	--	44	10	41
370	--	37	7	27
380	--	51	4	44
390	--	41	9	30
400	--	69	7	66
410	--	60	19	74
420	--	2	12	68
430	--	32	38	77
440	--	54	36	77
450	--	25	5	17
460	--	82	63	79
470	--	22	19	32
480	--	35	3	13
490	--	13	0	0
500	--	29	1	39
510	--	13	5	5
520	--	79	39	68
530	--	47	16	43
540	--	39	20	38
550	--	14	4	7
560	--	44	20	36
570	--	5	4	10
580	--	24	18	22
590	--	51	5	45
600	--	52	8	60
610	--	53	14	52
620	--	31	4	19
630	--	17	3	26
640	--	44	22	36

Table D-2: RQD Values by 10-foot Intervals (Continued)

[Sources: Drilling Support values computed from table D-1; values for Study 8.3.1.14.2 –DTN:. SNF29041993002.069]

Interval Bottom [feet]	Drilling Support		Study 8.3.1.14.2	
	Raw RQD	Adj. RQD	Core RQD	Enhanced RQD
650	--	15	3	5
660	--	26	7	34
670	--	50	4	31
680	--	55	14	62
690	--	62	19	55
700	--	57	6	39
710	--	73	9	76
720	--	73	16	54
730	--	74	41	60
740	--	73	28	56
750	--	20	7	17
760	--	30	12	32
770	--	68	62	72
780	--	75	64	72
790	--	4	0	0
800	--	41	8	31
810	--	45	19	50
820	--	73	52	63
830	--	84	48	60
840	--	86	78	92
850	--	89	18	39
860	--	46	16	49
870	--	16	0	8
880	0	11	5	7
890	0	8	0	0
900	0	14	3	6
910	0	43	4	18
920	0	2	0	0
930	0	19	1	1
940	0	21	3	22
950	2	39	8	34
960	6	16	4	15

Table D-2: RQD Values by 10-foot Intervals (Continued)

[Sources: Drilling Support values computed from table D-1; values for Study 8.3.1.14.2 –DTN:. SNF29041993002.069]

Interval Bottom [feet]	Drilling Support		Study 8.3.1.14.2	
	Raw RQD	Adj. RQD	Core RQD	Enhanced RQD
970	14	22	10	22
980	0	15	0	4
990	1	29	0	22
1000	12	37	11	48
1010	2	22	0	16
1020	7	26	4	14
1030	0	21	2	17
1040	0	75	30	67
1050	0	76	49	53
1060	20	44	20	32
1070	15	49	15	61
1080	7	22	5	9
1090	12	27	0	0
1100	32	42	18	34
1110	59	70	41	71
1120	53	65	49	67
1130	31	48	34	59
1140	14	24	16	18
1150	41	50	38	53
1160	24	35	13	37
1170	31	68	33	69
1180	13	25	12	33
1190	17	28	0	20
1200	16	31	9	40
1210	16	20	19	23
1220	37	44	32	38
1230	20	27	8	21
1240	19	27	8	19
1250	6	13	5	11
1260	0	8	4	32
1270	1	15	0	20
1280	43	41	24	27

Table D-2: RQD Values by 10-foot Intervals (Continued)

[Sources: Drilling Support values computed from table D-1; values for Study 8.3.1.14.2 –DTN:. SNF29041993002.069]

Interval Bottom [feet]	Drilling Support Raw RQD	Drilling Support Adj. RQD	Study 8.3.1.14.2 Core RQD	Study 8.3.1.14.2 Enhanced RQD
1290	15	22	15	16
1300	17	38	14	32
1310	39	57	21	47
1320	9	15	16	24
1330	17	20	5	17
1340	12	32	14	45
1350	6	17	0	0
1360	10	12	--	--
1370	4	21	--	--
1380	4	29	--	--
1390	6	55	--	--
1400	10	38	--	--
1410	11	29	--	--
1420	13	35	--	--
1430	31	48	--	--
1440	34	96	--	--
1450	22	100	--	--
1460	4	99	--	--
1470	49	62	--	--
1480	76	94	--	--
1490	34	39	--	--
1500	55	83	--	--
1510	53	69	--	--
1520	21	24	--	--
1530	71	77	--	--
1540	85	89	--	--
1550	82	94	--	--
1560	73	88	--	--
1570	75	101	--	--
1580	73	96	--	--
1590	49	86	--	--
1600	31	59	--	--

Table D-2: RQD Values by 10-foot Intervals (Continued)

[Sources: Drilling Support values computed from table D-1; values for Study 8.3.1.14.2 –DTN:. SNF29041993002.069]

Interval Bottom [feet]	Drilling Support Raw RQD	Drilling Support Adj. RQD	Study 8.3.1.14.2 Core RQD	Study 8.3.1.14.2 Enhanced RQD
1610	51	58	--	--
1620	72	76	--	--
1630	66	81	--	--
1640	70	81	--	--
1650	83	91	--	--
1660	84	91	--	--
1670	105	105	--	--
1680	103	104	--	--
1690	100	100	--	--
1700	93	100	--	--
1710	81	97	--	--
1720	73	90	--	--
1730	104	99	--	--
1740	82	87	--	--
1750	91	95	--	--
1760	86	98	--	--
1770	84	94	--	--
1780	91	94	--	--
1790	98	100	--	--
1800	101	101	--	--
1810	100	100	--	--
1820	86	96	--	--
1830	38	46	--	--
1840	26	44	--	--
1850	76	92	--	--
1860	96	97	--	--
1870	91	99	--	--
1880	30	35	--	--
1890	53	59	--	--
1900	52	53	--	--
1910	70	84	--	--
1920	36	51	--	--

Table D-2: RQD Values by 10-foot Intervals (Continued)

[Sources: Drilling Support values computed from table D-1; values for Study 8.3.1.14.2 –DTN:. SNF29041993002.069]

Interval Bottom [feet]	Drilling Support		Study 8.3.1.14.2	
	Raw RQD	Adj. RQD	Core RQD	Enhanced RQD
1930	86	93	--	--
1940	59	80	--	--
1950	36	59	--	--
1960	44	100	--	--
1970	86	97	--	--
1980	75	92	--	--
1990	79	88	--	--
2000	89	101	--	--
2010	85	89	--	--
2020	94	95	--	--
2030	100	100	--	--
2040	63	78	--	--
2050	53	73	--	--
2060	57	58	--	--
2070	69	70	--	--
2080	66	70	--	--
2090	47	50	--	--
2100	64	69	--	--
2110	21	28	--	--
2120	42	51	--	--
2130	65	89	--	--
2140	45	74	--	--
2150	69	73	--	--
2160	83	92	--	--
2170	97	98	--	--
2180	91	99	--	--
2190	97	97	--	--
2200	84	93	--	--
2210	62	88	--	--
2220	81	94	--	--
2230	30	31	--	--

Appendix E: Lithophysal Cavity Data

Table E-1: Measured Lithophysal Cavity Abundances for 10-foot Composite Intervals

[NM – not meaningful; < – less than. Source: DTN SNF29041993002.069]

Depth to Base of Interval (feet)	Estimated Cavity Content (percent)
60	Drilled Interval, no core
70	0
80	0
90	0
100	0
110	0
120	0
130	0
140	0
150	0
160	0
170	0
180	0
190	0
200	0
210	0
220	0
230	0
240	0
250	0
260	0
270	0
280	0
290	<1
300	<1
310	<1
320	<1
330	1
340	<1
350	<1
360	<1
370	<1
380	<1
390	<1
400	<1
410	<1
420	<1
430	<1
440	<1
450	<1
460	3
470	2
480	2
490	NM
500	3
510	3
520	10
530	5
540	5
550	12
560	5
570	13
580	11
590	12
600	9
610	9
620	6
630	3
640	3
650	2
660	1
670	1
680	2
690	2
700	2
710	2
720	1
730	1
740	1
750	<1
760	<1
770	1
780	1
790	NM
800	2
810	1
820	<1
830	<1
840	<1
850	<1
860	<1
870	<1
880	<1
890	NM
900	NM
910	NM
920	NM
930	<1
940	<1
950	<1
960	1
970	3
980	5
990	2
1000	2

Table E-1: Measured Lithophysal Cavity Abundances for 10-foot Composite Intervals (Continued)

[NM – not meaningful; < – less than. Source: DTN SNF29041993002.069]

Depth to Base of Interval (feet)	Estimated Cavity Content (percent)
1010	1
1020	NM
1030	<1
1040	<1
1050	1
1060	<1
1070	1
1080	<1
1090	0
1100	<1
1110	1
1120	2
1130	1
1140	1
1150	<1
1160	<1
1170	<1
1180	<1
1190	<1
1200	<1
1210	<1
1220	<1
1230	<1
1240	<1
1250	<1
1260	<1
1270	<1
1280	<1
1290	<1
1300	<1
1310	<1
1320	<1
1330	<1
1340	<1
1350	<1

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Appendix F: Fracture Information

Table F-1: Measured Fracture Data for 10-foot Composite Intervals

[N–natural, I–indeterminate, C–coring-induced, V–vug or void; dip classes are 10-degree intervals ending with the indicated value. Source: DTN SNF29041993002.069]

Depth to Base of Interval (feet)	Type of Fracture				Dip of Fracture (degrees)									Lost Core (feet)	Rubble (feet)
	N	I	C	V	10	20	30	40	50	60	70	80	90		
60	Drilled Interval, No Core													0.2	1.1
70	52	2	2	--	32	9	7	3	--	--	--	--	3	0.0	0.1
80	11	10	2	--	8	4	3	1	1	2	--	--	2	0.2	0.2
90	3	12	10	--	10	2	--	--	1		--	--	2	0.4	0.5
100	1	1	10	--	1	--	--	--	--	1	--	--	--	0.0	--
110	4	5	11	--	4	--	2	2	--	--	--	--	1	0.0	--
120	3	6	22	--	4	1	1	--	--	--	--	1	2	4.2	1.4
130	1	17	8	--	8	3	3	--	--	3	--	1	--	1.5	--
140	1	--	18	--	--	--	--	--	--	--	--	1	--	6.3	--
150	--	--	13	--	--	--	--	--	--	--	--	--	--	1.1	0.3
160	--	--	12	--	--	--	--	--	--	--	--	--	--	2.8	0.2
170	--	2	21	--	--	--	--	--	--	--	--	--	2	3.7	--
180	--	12	8	--	11	--	--	--	--	--	--	1	--	5.3	--
190	--	1	19	--	1	--	--	--	--	--	--	--	--	9.6	--
200	--	--	2	--	--	--	--	--	--	--	--	--	--	8.5	--
210	--	--	5	--	--	--	--	--	--	--	--	--	--	0.0	--
220	--	--	13	--	--	--	--	--	--	--	--	--	--	1.0	--
230	--	18	10	--	18	--	--	--	--	--	--	--	--	0.9	0.3
240	--	3	11	--	3	--	--	--	--	--	--	--	--	0.0	0.1
250	--	--	8	--	--	--	--	--	--	--	--	--	--	0.1	0.2
260	--	--	6	--	--	--	--	--	--	--	--	--	--	0.2	0.6
270	--	2	11	--	2	--	--	--	--	--	--	--	--	2.3	2.0
280	41	5	7	--	34	4	3	--	1	1	--	1	2	0.9	3.6
290	15	9	16	--	10	6	3	1	--	1	--	2	1	4.0	2.0
300	12	6	5	--	11	--	1	1	--	--	--	2	3	3.1	1.1
310	2	12	6	--	7	3	1	--	1	1	--	1	--	1.1	0.6
320	9	4	20	--	8	3	1	--	1	--	--	--	--	0.7	0.1
330	3	--	20	--	2	--	--	--	--	--	--	--	1	1.0	1.0
340	--	2	23	--	--	--	--	--	--	--	--	1	1	0.6	0.5
350	--	2	36	--	--	--	--	--	1	--	--	1	--	2.8	1.9
360	1	4	26	--	2	--	--	--	--	--	--	3	--	4.0	1.4
370	--	4	23	--	--	--	--	--	--	1	1	--	2	2.9	1.7
380	1	4	28	--	--	1	--	--	--	--	--	1	3	1.9	4.7
390	--	--	19	--	--	--	--	--	--	--	--	--	--	3.4	--
400	--	--	27	--	--	--	--	--	--	--	--	--	--	0.9	1.1
410	--	1	37	--	--	1	--	--	--	--	--	--	--	2.1	0.2
420	1	1	35	--	1	--	--	--	--	--	--	--	1	0.9	1.2
430	2	3	26	--	2	--	1	--	1	--	--	--	1	0.9	0.7
440	2	2	28	--	2	--	--	--	--	2	--	--	--	5.4	1.7
450	1	3	14	--	--	--	--	--	--	--	--	2	2	1.1	0.8
460	--	1	17	--	--	--	--	--	--	--	--	--	1	3.1	3.7
470	--	--	15	--	--	--	--	--	--	--	--	--	--	4.3	3.3
480	1	1	12	--	--	--	1	--	--	--	--	--	1	8.1	1.7
490	--	--	2	--	--	--	--	--	--	--	--	--	--	3.2	2.6
500	--	1	20	--	1	--	--	--	--	--	--	--	--	6.6	2.9
510	--	--	1	--	--	--	--	--	--	--	--	--	--	1.9	0.8
520	--	1	23	--	--	--	--	--	--	--	--	--	1	4.2	1.5

Table F-1: Measured Fracture Data for 10-foot Composite Intervals (Continued)

[N–natural, I–indeterminate, C–coring-induced, V–vug or void; dip classes are 10-degree intervals ending with the indicated value. Source: DTN SNF29041993002.069]

Depth to Base of Interval (feet)	Type of Fracture				Dip of Fracture (degrees)									Lost Core (feet)	Rubble (feet)
	N	I	C	V	10	20	30	40	50	60	70	80	90		
530	--	--	19	--	--	--	--	--	--	--	--	--	--	4.4	1.1
540	--	2	16	--	--	--	--	--	--	--	--	--	2	5.5	3.8
550	--	--	2	--	--	--	--	--	--	--	--	--	--	2.9	2.1
560	--	3	16	--	--	--	--	--	--	--	--	--	3	6.3	2.5
570	--	--	9	--	--	--	--	--	--	--	--	--	--	5.0	2.5
580	--	--	10	--	--	--	--	--	--	--	--	--	--	3.5	1.4
590	--	1	22	--	1	--	--	--	--	--	--	--	--	2.8	1.1
600	--	1	26	--	--	--	--	--	--	--	--	--	1	2.2	2.4
610	--	--	26	--	--	--	--	--	--	--	--	--	--	5.5	2.4
620	--	--	13	--	--	--	--	--	--	--	--	--	--	6.9	0.3
630	--	2	13	2	--	--	--	--	1	--	--	--	1	4.5	1.7
640	--	2	16	--	1	--	--	--	--	--	--	--	1	7.1	1.9
650	--	3	1	--	2	--	--	--	--	--	1	--	--	3.9	2.4
660	--	3	17	--	--	--	1	--	--	--	1	--	1	4.5	1.2
670	--	4	16	3	--	--	1	--	2	--	--	--	1	3.7	0.1
680	1	--	23	1	--	--	--	--	--	1	--	--	--	3.3	0.8
690	--	3	25	--	--	--	--	--	1	--	--	--	2	3.1	1.6
700	1	1	21	1	--	--	--	--	--	--	--	--	2	1.6	0.6
710	--	2	35	--	1	--	--	--	--	--	--	--	1	1.0	2.4
720	--	6	26	2		--	--	--	--	--	--	--	6	1.3	1.4
730	3	2	23	1	1	--	--	1	--	--	--	1	2	3.1	0.8
740	--	4	18	--	1	1	--	--	--	--	--	2	--	1.5	3.5
750	13	10	9	--	4	1	2	1	6	5	--	3	1	2.4	2.3
760	8	8	12	--	5	--	--	1	1	3	2	2	2	1.1	0.5
770	10	4	6	2	7	1	2	--	--	--	1	1	2	0.5	1.8
780	6	1	7	1	2	1	--	1	2	--	--	1	--	6.3	2.9
790	1	--	2	--	--	--	--	--	--	--	--	--	1	2.4	2.0
800	4	1	24	1	--	--	--	--	1	--	--	--	4	0.5	1.9
810	5	4	21	--	1	--	--	3	2	--	--	1	2	0.6	1.6
820	2	5	22	--	--	--	--	--	--	--	2	3	2	0.0	0.4
830	9	3	10	--	2	1	--	--	--	1	3	3	2	0.0	0.3
840	6	2	8	--	2	--	--	--	--	--	2	2	2	0.5	0.3
850	4	--	19	--	1	1	--	--	--	--	--	--	2	2.5	0.2
860	8	5	18	--	3	1	1	--	1	1	--	1	5	7.3	1.6
870	1	1	6	--	--	--	--	--	--	--	--	1	1	6.8	1.8
880	2	--	10	--	--	--	--	--	--	--	--	1	1	8.0	1.5
890	--	--	3	--	--	--	--	--	--	--	--	--	--	7.8	0.8
900	--	1	9	--	1	--	--	--	--	--	--	--	--	4.4	2.6
910	1	3	18	--	--	--	--	--	--	--	1	--	3	10.0	--
920	--	--	--	--	--	--	--	--	--	--	--	--	--	4.9	2.6
930	1	5	15	--	3	--	--	--	--	--	--	--	3	3.3	2.6
940	3	2	18	--	2	--	--	--	--	--	1	2		5.6	0.6
950	--	2	18	--	--	--	--	--	--	--	--	1	1	5.5	1.3
960	4	1	17	--	1	--	--	--	--	--	--	1	3	3.1	1.4
970	1	4	21	--	2	--	--	--	--	--	--	--	3	5.4	3.2
980	1	1	10	--	--	--	--	--	--	--	--	--	2	2.0	1.8
990	2	4	26	--	--	--	--	--	--	1	1	2	2	2.8	2.1

Table F-1: Measured Fracture Data for 10-foot Composite Intervals (Continued)

[N–natural, I–indeterminate, C–coring-induced, V–vug or void; dip classes are 10-degree intervals ending with the indicated value. Source: DTN SNF29041993002.069]

Depth to Base of Interval (feet)	Type of Fracture				Dip of Fracture (degrees)									Lost Core (feet)	Rubble (feet)
	N	I	C	V	10	20	30	40	50	60	70	80	90		
1000	--	--	25	--	--	--	--	--	--	--	--	--	--	6.4	1.0
1010	--	1	19	--	1	--	--	--	--	--	--	--	--	6.3	1.1
1020	--	2	17	1	--	--	--	--	--	--	--	--	2	4.3	2.0
1030	2	1	16	4	--	--	--	--	--	--	--	--	3	1.8	1.0
1040	--	3	27	--	1	--	1	--	--	--	--	1	--	1.1	1.6
1050	5	4	15	2	5	1	--	--	--	1	2	--	--	3.4	1.5
1060	4	--	19	1	--	--	--	1	--	--	1	--	2	0.4	2.2
1070	2	7	28	--	2	--	1	1	--	--	1	1	3	6.2	1.5
1080	1	2	11	--	--	--	1	--	--	--	--	1	1	4.3	4.4
1090	2	2	9	--	2	--	--	--	--	--	--	--	2	2.2	2.9
1100	4	5	18	--	3	--	--	--	1	--	1	2	2	0.9	1.6
1110	1	6	15	--	3	1	--	--	--	--	1	1	1	1.8	1.3
1120	--	--	18	1	--	--	--	--	--	--	--	--	--	0.6	3.1
1130	2	3	17	1	1	--	--	--	3	--	--	--	1	3.9	1.7
1140	4	5	14	--	1	--	--	--	--	1	--	--	7	0.7	1.5
1150	4	3	30	--	3	1	--	--	--	--	--	--	3	2.2	2.8
1160	7	1	22	--	1	--	--	--	--	--	1	--	6	1.0	1.2
1170	1	3	27	2	--	--	--	--	--	2	1	--	1	2.2	2.5
1180	--	10	20	--	--	--	--	1	3	--	1	--	5	2.2	3.3
1190	1	5	21	--	1	1	--	--	--	--	1	--	3	2.7	2.5
1200	4	3	17	--	1	1	--	1	--	--	--	2	2	2.6	1.2
1210	8	8	14	--	1	7	1	--	--	--	--	--	7	2.6	2.1
1220	7	7	7	--	1	2	4	--	--	--	3	1	3	3.3	2.2
1230	6	3	13	1	4	--	1	--	--	--	--	--	4	2.7	2.4
1240	5	2	24	--	3	--	--	--	--	--	--	2	2	2.8	2.3
1250	1	4	23	--	4	--	--	--	--	--	--	--	1	1.6	0.3
1260	8	2	25	--	2	--	--	--	--	--	--	2	6	4.7	1.8
1270	7	2	13	--	2	--	1	--	--	--	--	2	4	0.9	2.3
1280	13	3	16	--	10	1		--	--	--	1	1	3	3.7	1.6
1290	8	2	9	2	3	--	2	--	1	1	--	--	3	3.0	2.0
1300	5	3	16	2	2	--	1	--	--	--	1	--	4	1.7	1.4
1310	5	9	28	--	5	--	--	--	--	--	3	4	2	4.1	1.8
1320	5	14	2	--	14	1	2	--	--	--	--	1	1	4.8	2.6
1330	2	8	3	--	7	--	--	1	--	--	--	1	1	0.0	2.9
1340	5	13	22	--	6	1	1	1	3	1	1	2	2	5.2	2.6
1350	1	3	10	--	--	--	1	--	--	--	--	--	3	--	--

Appendix G: Laboratory Material Properties

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of "SD9-" plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.
56.6	1.59	0.286	2.22	0.173	0.275	0.962	1.42	0.452	2.59	0.310	0.441	0.976
59.4	1.95	0.121	2.22	0.062	0.120	0.992	1.80	0.268	2.46	0.148	0.267	0.996
61.6	1.83	0.167	2.20	0.089	0.163	0.974	1.67	0.328	2.49	0.194	0.324	0.987
64.9	1.94	0.133	2.24	0.053	0.102	0.767	1.84	0.237	2.41	0.112	0.206	0.869
67.9	1.92	0.146	2.25	0.076	0.146	0.994	1.84	0.228	2.38	0.123	0.227	0.996
71.0	1.76	0.227	2.28	0.114	0.201	0.886	1.69	0.299	2.41	0.161	0.273	0.914
73.8	1.69	0.256	2.27	0.149	0.252	0.985	1.63	0.311	2.37	0.188	0.307	0.988
77.0	1.58	0.255	2.13	0.129	0.205	0.802	1.54	0.297	2.19	0.159	0.246	0.829
80.0	1.45	0.335	2.19	0.145	0.211	0.629	1.41	0.376	2.26	0.178	0.252	0.670
82.9	1.41	0.372	2.25	0.121	0.171	0.460	1.37	0.413	2.34	0.155	0.212	0.514
86.4	1.41	0.362	2.21	0.127	0.179	0.495	1.37	0.398	2.28	0.156	0.215	0.540
88.3	1.43	0.351	2.20	0.122	0.174	0.494	1.38	0.396	2.28	0.158	0.218	0.551
94.8	0.97	0.569	2.24	0.333	0.322	0.566	0.92	0.619	2.40	0.406	0.372	0.601
97.7	1.26	0.427	2.20	0.125	0.158	0.369	1.23	0.453	2.25	0.149	0.184	0.406
100.4	1.29	0.413	2.20	0.109	0.141	0.341	1.27	0.433	2.24	0.127	0.161	0.372
104.0	1.38	0.367	2.18	0.102	0.141	0.383	1.36	0.387	2.22	0.118	0.161	0.415
107.2	1.40	0.363	2.19	0.121	0.169	0.465	1.37	0.387	2.24	0.140	0.192	0.497
110.4	1.47	0.310	2.13	0.125	0.184	0.592	1.45	0.332	2.17	0.142	0.205	0.619
113.2	1.51	0.292	2.13	0.124	0.187	0.638	1.49	0.311	2.16	0.138	0.205	0.660
115.7	1.53	0.262	2.07	0.106	0.162	0.618	1.50	0.289	2.11	0.126	0.189	0.654
118.9	1.53	0.270	2.09	0.147	0.224	0.830	1.51	0.290	2.12	0.162	0.244	0.841
122.0	1.49	0.287	2.08	0.131	0.195	0.679	1.47	0.304	2.11	0.144	0.212	0.697
125.3	1.49	0.304	2.15	0.100	0.149	0.489	1.48	0.323	2.18	0.114	0.168	0.519
133.5	1.42	0.335	2.13	0.093	0.132	0.395	1.39	0.357	2.17	0.111	0.154	0.432
137.3	1.43	0.347	2.19	0.090	0.128	0.370	1.40	0.373	2.24	0.111	0.155	0.415
140.4	1.40	0.357	2.18	0.088	0.123	0.345	1.37	0.384	2.23	0.109	0.150	0.390
142.7	1.59	0.310	2.30	0.088	0.139	0.448	1.56	0.337	2.35	0.106	0.165	0.491
152.2	1.54	0.308	2.23	0.082	0.126	0.409	1.50	0.353	2.32	0.114	0.171	0.484
155.0	1.31	0.412	2.23	0.133	0.174	0.423	1.23	0.493	2.42	0.208	0.255	0.518
157.8	1.14	0.477	2.19	0.146	0.167	0.350	1.10	0.518	2.29	0.188	0.208	0.401
160.7	1.09	0.490	2.13	0.132	0.144	0.294	1.07	0.508	2.17	0.152	0.162	0.320

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of "SD9-" plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.
163.8	1.09	0.456	2.01	0.117	0.128	0.281	1.08	0.470	2.04	0.132	0.142	0.302
169.5	1.19	0.427	2.07	0.117	0.139	0.325	1.17	0.440	2.10	0.129	0.152	0.345
172.8	1.23	0.411	2.09	0.106	0.131	0.318	1.22	0.426	2.12	0.119	0.145	0.342
185.5	1.07	0.463	1.99	0.102	0.108	0.234	1.06	0.471	2.00	0.110	0.116	0.247
187.8	1.11	0.485	2.16	0.095	0.106	0.218	1.10	0.501	2.20	0.112	0.122	0.244
209.2	1.11	0.478	2.12	0.124	0.138	0.289	1.10	0.490	2.15	0.137	0.151	0.307
212.1	1.13	0.452	2.06	0.115	0.130	0.288	1.11	0.468	2.09	0.132	0.147	0.314
214.6	1.16	0.445	2.10	0.123	0.143	0.321	1.15	0.460	2.13	0.137	0.158	0.343
217.8	1.14	0.442	2.05	0.124	0.142	0.321	1.13	0.458	2.08	0.139	0.157	0.343
220.6	1.17	0.410	1.99	0.127	0.149	0.364	1.15	0.429	2.02	0.145	0.168	0.392
224.0	1.10	0.452	2.01	0.125	0.138	0.305	1.08	0.478	2.07	0.153	0.165	0.344
230.0	1.40	0.347	2.15	0.067	0.093	0.269	1.36	0.389	2.23	0.099	0.135	0.347
232.8	1.13	0.478	2.16	0.108	0.121	0.254	1.09	0.512	2.24	0.143	0.156	0.305
238.6	1.02	0.508	2.08	0.123	0.125	0.247	1.00	0.527	2.12	0.144	0.144	0.274
241.8	1.10	0.460	2.04	0.087	0.096	0.208	1.06	0.503	2.13	0.131	0.139	0.276
245.8	0.98	0.501	1.97	0.120	0.118	0.235	0.97	0.509	1.99	0.130	0.126	0.248
247.8	1.06	0.516	2.20	0.109	0.116	0.225	1.04	0.539	2.26	0.134	0.139	0.258
251.1	1.06	0.509	2.17	0.109	0.116	0.229	1.05	0.527	2.21	0.129	0.135	0.256
256.8	1.18	0.480	2.28	0.137	0.162	0.337	1.14	0.520	2.38	0.177	0.202	0.388
260.3	1.16	0.479	2.22	0.131	0.151	0.316	1.10	0.540	2.38	0.194	0.213	0.394
262.7	1.13	0.470	2.13	0.159	0.180	0.383	1.11	0.485	2.16	0.175	0.195	0.402
265.9	1.52	0.284	2.13	0.122	0.186	0.657	1.51	0.298	2.15	0.133	0.201	0.674
270.8	2.37	0.038	2.46	0.011	0.025	0.675	2.36	0.040	2.46	0.012	0.028	0.698
278.0	2.50	0.011	2.52	0.003	0.007	0.611	2.49	0.022	2.54	0.007	0.017	0.802
280.6	2.46	0.015	2.50	0.003	0.007	0.451	2.44	0.031	2.52	0.009	0.022	0.722
283.6	2.40	0.041	2.50	0.012	0.029	0.712	2.38	0.061	2.53	0.021	0.049	0.806
286.9	2.40	0.033	2.48	0.008	0.019	0.565	2.37	0.058	2.52	0.018	0.043	0.750
290.9	2.40	0.034	2.49	0.005	0.011	0.321	2.38	0.056	2.52	0.014	0.033	0.587
292.9	2.39	0.045	2.50	0.014	0.034	0.751	2.37	0.068	2.54	0.024	0.057	0.836
298.9	2.34	0.054	2.47	0.016	0.037	0.681	2.30	0.094	2.54	0.034	0.077	0.819
308.0	2.14	0.133	2.47	0.042	0.090	0.675	2.11	0.166	2.53	0.058	0.122	0.739

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of “SD9-” plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.
313.5	2.32	0.076	2.51	0.020	0.046	0.606	2.30	0.100	2.55	0.031	0.070	0.702
317.1	2.37	0.064	2.54	0.017	0.041	0.644	2.35	0.085	2.57	0.026	0.062	0.731
323.0	2.07	0.193	2.57	0.043	0.088	0.456	2.06	0.201	2.58	0.046	0.095	0.476
326.0	2.23	0.125	2.55	0.031	0.068	0.546	2.21	0.143	2.58	0.039	0.086	0.602
329.5	2.25	0.112	2.53	0.029	0.065	0.583	2.24	0.126	2.56	0.036	0.080	0.631
330.9	2.09	0.188	2.57	0.040	0.084	0.445	2.08	0.197	2.59	0.044	0.092	0.468
335.3	2.21	0.129	2.54	0.028	0.061	0.476	2.20	0.142	2.56	0.034	0.075	0.525
338.0	2.18	0.148	2.56	0.029	0.063	0.423	2.17	0.160	2.58	0.034	0.074	0.464
341.2	2.08	0.186	2.56	0.036	0.075	0.405	2.07	0.195	2.57	0.040	0.084	0.430
344.2	2.21	0.141	2.57	0.029	0.065	0.458	2.20	0.152	2.59	0.034	0.076	0.497
350.1	2.12	0.178	2.58	0.037	0.078	0.435	2.11	0.186	2.59	0.040	0.085	0.457
352.8	2.19	0.155	2.60	0.035	0.076	0.491	2.19	0.165	2.62	0.039	0.086	0.521
359.5	2.18	0.143	2.55	0.041	0.090	0.627	2.18	0.150	2.56	0.044	0.096	0.642
365.1	2.15	0.161	2.56	0.035	0.075	0.464	2.14	0.168	2.57	0.038	0.082	0.487
376.5	2.19	0.148	2.57	0.036	0.079	0.534	2.18	0.155	2.58	0.039	0.086	0.554
380.4	2.15	0.158	2.56	0.036	0.078	0.493	2.14	0.169	2.58	0.041	0.089	0.526
382.4	2.20	0.135	2.55	0.036	0.080	0.591	2.20	0.138	2.55	0.038	0.083	0.602
385.3	2.20	0.140	2.56	0.035	0.077	0.551	2.19	0.148	2.57	0.039	0.085	0.576
388.8	2.22	0.132	2.55	0.043	0.096	0.728	2.21	0.138	2.57	0.046	0.102	0.739
395.1	2.21	0.132	2.54	0.037	0.082	0.622	2.20	0.143	2.56	0.042	0.092	0.649
398.6	2.23	0.117	2.53	0.035	0.079	0.670	2.22	0.130	2.55	0.041	0.091	0.701
404.5	2.22	0.124	2.54	0.037	0.083	0.665	2.21	0.137	2.56	0.043	0.095	0.696
407.5	2.23	0.118	2.52	0.038	0.084	0.714	2.21	0.134	2.55	0.046	0.101	0.749
410.0	2.24	0.110	2.52	0.036	0.080	0.730	2.23	0.122	2.54	0.041	0.092	0.757
413.0	2.27	0.098	2.52	0.031	0.071	0.721	2.26	0.113	2.54	0.038	0.085	0.756
415.6	2.27	0.096	2.51	0.031	0.071	0.747	2.25	0.111	2.54	0.039	0.087	0.782
419.1	2.25	0.108	2.52	0.034	0.077	0.709	2.23	0.123	2.55	0.041	0.092	0.744
421.6	2.26	0.096	2.49	0.032	0.073	0.759	2.24	0.115	2.53	0.041	0.092	0.800
425.1	2.28	0.087	2.49	0.031	0.071	0.814	2.26	0.106	2.53	0.040	0.090	0.848
430.3	2.29	0.083	2.50	0.030	0.068	0.820	2.27	0.101	2.53	0.038	0.086	0.852
433.8	2.24	0.102	2.49	0.034	0.077	0.750	2.22	0.120	2.52	0.043	0.094	0.787

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of “SD9-” plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.
436.8	2.25	0.097	2.49	0.032	0.071	0.728	2.23	0.115	2.52	0.040	0.089	0.770
439.9	2.23	0.106	2.50	0.033	0.073	0.687	2.21	0.125	2.53	0.042	0.092	0.734
445.8	2.29	0.083	2.50	0.026	0.060	0.725	2.27	0.103	2.53	0.035	0.080	0.779
452.1	2.24	0.099	2.48	0.032	0.072	0.727	2.21	0.125	2.53	0.045	0.098	0.785
454.7	2.20	0.104	2.46	0.034	0.074	0.708	2.18	0.130	2.50	0.046	0.100	0.765
457.8	2.17	0.118	2.46	0.042	0.092	0.776	2.14	0.145	2.50	0.055	0.118	0.817
466.6	2.13	0.139	2.47	0.051	0.109	0.785	2.10	0.168	2.53	0.066	0.138	0.823
475.9	2.13	0.138	2.47	0.053	0.114	0.826	2.11	0.162	2.51	0.065	0.138	0.852
478.9	2.23	0.097	2.47	0.040	0.088	0.911	2.21	0.120	2.51	0.050	0.111	0.928
484.9	2.12	0.139	2.47	0.048	0.101	0.728	2.10	0.163	2.51	0.060	0.125	0.768
490.3	2.17	0.123	2.48	0.045	0.098	0.797	2.15	0.144	2.51	0.055	0.119	0.826
500.5	2.14	0.138	2.48	0.048	0.102	0.740	2.12	0.157	2.52	0.057	0.121	0.772
504.3	2.12	0.144	2.47	0.054	0.114	0.791	2.10	0.166	2.51	0.065	0.136	0.819
511.9	2.02	0.183	2.48	0.053	0.107	0.585	2.00	0.202	2.51	0.063	0.126	0.624
514.8	2.08	0.164	2.48	0.046	0.096	0.586	2.06	0.181	2.51	0.055	0.113	0.625
518.0	2.10	0.153	2.48	0.045	0.094	0.613	2.08	0.171	2.51	0.054	0.112	0.655
523.8	2.08	0.162	2.49	0.051	0.106	0.657	2.07	0.179	2.52	0.060	0.123	0.689
530.7	2.03	0.172	2.45	0.056	0.114	0.662	2.01	0.192	2.49	0.067	0.134	0.697
538.9	2.10	0.146	2.46	0.051	0.106	0.727	2.08	0.166	2.50	0.061	0.126	0.759
553.0	2.11	0.143	2.47	0.049	0.104	0.728	2.09	0.164	2.50	0.060	0.125	0.763
557.6	2.19	0.119	2.49	0.043	0.095	0.794	2.17	0.137	2.52	0.052	0.113	0.821
560.8	2.07	0.156	2.46	0.057	0.118	0.755	2.04	0.188	2.51	0.073	0.150	0.797
568.8	2.07	0.164	2.48	0.053	0.110	0.669	2.05	0.188	2.52	0.065	0.134	0.712
575.1	2.08	0.164	2.48	0.055	0.115	0.703	2.05	0.186	2.52	0.067	0.137	0.738
577.36	2.10	0.154	2.48	0.053	0.110	0.716	2.08	0.177	2.52	0.064	0.133	0.753
580.9	2.08	0.163	2.49	0.055	0.114	0.697	2.06	0.184	2.53	0.065	0.134	0.731
586.8	2.07	0.167	2.48	0.052	0.107	0.639	2.04	0.188	2.52	0.062	0.128	0.680
589.5	2.02	0.156	2.39	0.058	0.116	0.747	2.00	0.176	2.43	0.069	0.137	0.776
593	2.13	0.147	2.49	0.050	0.107	0.729	2.10	0.167	2.53	0.061	0.128	0.763
596.4	2.10	0.153	2.48	0.055	0.116	0.757	2.08	0.174	2.52	0.066	0.137	0.787
599.0	2.07	0.168	2.49	0.057	0.118	0.699	2.05	0.188	2.53	0.067	0.137	0.731

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of “SD9-” plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.
602.8	2.06	0.178	2.50	0.054	0.110	0.620	2.04	0.199	2.54	0.064	0.131	0.660
605.1	2.07	0.167	2.49	0.057	0.119	0.713	2.05	0.189	2.53	0.069	0.141	0.747
608.1	2.05	0.174	2.48	0.064	0.131	0.752	2.02	0.196	2.52	0.076	0.153	0.780
611.9	2.07	0.170	2.49	0.051	0.106	0.623	2.05	0.191	2.53	0.062	0.127	0.664
614.2	2.05	0.182	2.51	0.059	0.121	0.661	2.03	0.201	2.54	0.068	0.139	0.692
617.9	2.11	0.153	2.49	0.055	0.116	0.758	2.09	0.174	2.53	0.066	0.137	0.788
627.4	2.13	0.142	2.48	0.054	0.115	0.812	2.11	0.163	2.52	0.065	0.137	0.837
628.7	2.15	0.140	2.50	0.052	0.111	0.794	2.13	0.162	2.54	0.062	0.133	0.822
632.0	2.10	0.150	2.48	0.061	0.129	0.858	2.08	0.172	2.51	0.072	0.150	0.875
647.4	2.14	0.130	2.46	0.047	0.100	0.774	2.12	0.155	2.51	0.060	0.126	0.811
650.1	2.22	0.105	2.48	0.043	0.095	0.901	2.20	0.125	2.52	0.052	0.115	0.917
658.6	2.22	0.106	2.48	0.043	0.095	0.902	2.20	0.127	2.52	0.053	0.117	0.919
664.9	2.20	0.117	2.49	0.046	0.100	0.861	2.18	0.137	2.53	0.055	0.121	0.882
671.9	2.15	0.140	2.50	0.052	0.112	0.805	2.13	0.159	2.54	0.062	0.132	0.829
680.7	2.09	0.166	2.51	0.055	0.114	0.686	2.08	0.184	2.54	0.063	0.132	0.716
682.7	2.15	0.142	2.50	0.047	0.101	0.711	2.13	0.161	2.53	0.056	0.120	0.746
690.8	2.07	0.168	2.49	0.052	0.108	0.645	2.05	0.187	2.52	0.062	0.127	0.681
693.8	2.17	0.116	2.45	0.051	0.110	0.946	2.14	0.137	2.48	0.061	0.131	0.955
698.0	2.18	0.119	2.48	0.047	0.103	0.860	2.16	0.142	2.52	0.058	0.126	0.882
700.2	2.15	0.138	2.49	0.053	0.114	0.823	2.13	0.157	2.53	0.062	0.133	0.845
707.3	2.13	0.146	2.49	0.057	0.122	0.832	2.10	0.167	2.53	0.068	0.142	0.853
709.7	2.15	0.137	2.50	0.054	0.117	0.851	2.13	0.158	2.53	0.065	0.138	0.870
712.8	2.04	0.192	2.53	0.066	0.136	0.707	2.03	0.208	2.56	0.075	0.152	0.730
715	2.26	0.084	2.47	0.036	0.081	0.965	2.24	0.108	2.51	0.047	0.105	0.972
717.6	2.23	0.096	2.46	0.038	0.086	0.892	2.20	0.123	2.51	0.051	0.113	0.916
721.8	2.11	0.147	2.48	0.060	0.128	0.870	2.09	0.170	2.52	0.072	0.151	0.888
725.0	2.16	0.129	2.48	0.055	0.119	0.918	2.14	0.153	2.52	0.067	0.142	0.930
727.1	2.16	0.130	2.48	0.056	0.121	0.932	2.14	0.153	2.52	0.068	0.144	0.943
730.5	2.25	0.087	2.47	0.037	0.082	0.945	2.22	0.115	2.51	0.049	0.110	0.958
733.9	2.23	0.100	2.48	0.039	0.087	0.874	2.20	0.127	2.52	0.052	0.115	0.901
736.6	2.20	0.115	2.48	0.047	0.103	0.896	2.18	0.135	2.52	0.057	0.123	0.911

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of "SD9-" plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.
742.6	2.28	0.081	2.48	0.032	0.073	0.904	2.25	0.106	2.52	0.044	0.098	0.926
746.7	2.30	0.075	2.49	0.029	0.066	0.886	2.28	0.098	2.52	0.039	0.089	0.913
750.1	2.27	0.085	2.48	0.034	0.077	0.911	2.24	0.113	2.52	0.047	0.105	0.933
755.6	2.27	0.083	2.47	0.025	0.056	0.675	2.23	0.116	2.53	0.040	0.089	0.766
759.2	2.28	0.081	2.48	0.034	0.078	0.966	2.25	0.108	2.52	0.047	0.105	0.974
764.5	2.32	0.062	2.48	0.026	0.060	0.971	2.30	0.087	2.52	0.037	0.086	0.980
767.9	2.24	0.098	2.49	0.037	0.083	0.854	2.22	0.121	2.53	0.048	0.107	0.882
771.4	2.30	0.076	2.49	0.028	0.066	0.867	2.28	0.101	2.53	0.040	0.091	0.901
774.3	2.20	0.110	2.47	0.048	0.105	0.958	2.17	0.135	2.51	0.060	0.130	0.966
777.0	2.27	0.083	2.48	0.035	0.080	0.967	2.25	0.105	2.52	0.045	0.102	0.974
779.7	2.27	0.089	2.49	0.032	0.072	0.813	2.25	0.107	2.52	0.040	0.091	0.846
794.6	2.23	0.120	2.53	0.048	0.107	0.890	2.21	0.137	2.56	0.056	0.123	0.904
797.8	2.20	0.133	2.53	0.059	0.131	0.980	2.18	0.147	2.56	0.066	0.145	0.982
800.8	2.19	0.135	2.53	0.056	0.122	0.906	2.17	0.151	2.56	0.064	0.139	0.916
804.1	2.18	0.131	2.51	0.051	0.112	0.851	2.16	0.149	2.54	0.060	0.129	0.868
807.5	2.23	0.111	2.51	0.044	0.099	0.892	2.21	0.128	2.53	0.052	0.116	0.907
810.5	2.26	0.092	2.49	0.034	0.078	0.842	2.24	0.112	2.52	0.044	0.098	0.870
814.3	2.30	0.073	2.48	0.026	0.059	0.807	2.28	0.094	2.52	0.035	0.080	0.850
818.0	2.24	0.099	2.49	0.041	0.092	0.934	2.22	0.121	2.53	0.052	0.115	0.946
821.7	2.28	0.078	2.48	0.032	0.073	0.931	2.26	0.104	2.52	0.044	0.098	0.948
825.0	2.28	0.080	2.48	0.030	0.068	0.855	2.26	0.103	2.52	0.040	0.091	0.887
827.6	2.27	0.086	2.48	0.035	0.079	0.921	2.24	0.110	2.52	0.046	0.103	0.939
831.1	2.27	0.083	2.47	0.034	0.076	0.922	2.24	0.113	2.52	0.048	0.107	0.943
834.0	2.26	0.084	2.47	0.036	0.082	0.966	2.23	0.115	2.52	0.050	0.112	0.975
838.0	2.28	0.080	2.48	0.032	0.074	0.914	2.25	0.107	2.52	0.044	0.100	0.935
841.2	2.24	0.096	2.48	0.038	0.085	0.889	2.22	0.120	2.52	0.049	0.109	0.911
843.9	2.28	0.077	2.48	0.029	0.066	0.851	2.26	0.103	2.52	0.040	0.091	0.888
847.2	2.26	0.100	2.52	0.038	0.085	0.852	2.25	0.118	2.55	0.046	0.103	0.875
849.6	2.18	0.135	2.52	0.048	0.104	0.775	2.16	0.149	2.54	0.055	0.119	0.797
853.4	2.23	0.113	2.51	0.043	0.095	0.843	2.21	0.130	2.54	0.051	0.112	0.863
859.0	2.28	0.094	2.52	0.040	0.092	0.974	2.27	0.112	2.55	0.048	0.110	0.978

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of “SD9-” plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.
865.3	2.24	0.108	2.51	0.044	0.098	0.907	2.22	0.126	2.54	0.052	0.116	0.920
879.6	2.31	0.102	2.57	0.045	0.104	1.020	2.30	0.117	2.60	0.052	0.119	1.017
888.8	2.16	0.148	2.53	0.053	0.115	0.774	2.14	0.163	2.56	0.061	0.130	0.794
897.0	2.30	0.089	2.53	0.035	0.080	0.898	2.29	0.103	2.55	0.041	0.094	0.913
899.5	2.30	0.096	2.54	0.036	0.082	0.854	2.28	0.113	2.57	0.044	0.099	0.877
905.8	2.33	0.083	2.54	0.032	0.074	0.886	2.31	0.100	2.57	0.039	0.091	0.905
921.9	2.25	0.121	2.56	0.043	0.096	0.794	2.23	0.137	2.58	0.050	0.112	0.818
924.2	2.20	0.136	2.54	0.044	0.098	0.717	2.18	0.150	2.57	0.051	0.112	0.743
936.1	2.16	0.160	2.57	0.054	0.116	0.728	2.15	0.173	2.59	0.060	0.129	0.748
938.9	2.25	0.113	2.54	0.041	0.092	0.812	2.24	0.127	2.57	0.047	0.106	0.833
944.6	2.22	0.125	2.54	0.044	0.099	0.787	2.20	0.139	2.56	0.051	0.113	0.809
948.0	2.22	0.118	2.52	0.042	0.094	0.796	2.21	0.134	2.55	0.050	0.110	0.821
954.0	2.35	0.074	2.53	0.027	0.064	0.865	2.33	0.093	2.57	0.036	0.083	0.893
958.1	2.20	0.129	2.53	0.045	0.100	0.776	2.18	0.145	2.55	0.053	0.116	0.801
962.6	2.35	0.071	2.53	0.024	0.056	0.791	2.33	0.090	2.56	0.032	0.075	0.835
968.7	2.23	0.109	2.50	0.041	0.091	0.837	2.21	0.127	2.54	0.049	0.109	0.860
971.9	2.28	0.095	2.52	0.030	0.068	0.716	2.26	0.114	2.55	0.039	0.087	0.764
975.5	2.26	0.096	2.50	0.038	0.087	0.910	2.25	0.114	2.53	0.047	0.106	0.925
981.0	2.21	0.120	2.51	0.043	0.095	0.793	2.19	0.137	2.54	0.051	0.112	0.819
984.7	2.20	0.120	2.50	0.041	0.089	0.742	2.19	0.138	2.53	0.049	0.107	0.775
986.6	2.19	0.126	2.50	0.043	0.094	0.744	2.17	0.144	2.53	0.052	0.112	0.776
995.7	2.17	0.131	2.50	0.049	0.106	0.809	2.16	0.148	2.53	0.057	0.123	0.832
1003.0	2.12	0.153	2.50	0.049	0.103	0.672	2.10	0.170	2.53	0.057	0.120	0.704
1007.3	2.25	0.102	2.51	0.035	0.079	0.781	2.23	0.121	2.54	0.044	0.099	0.816
1012.3	2.18	0.140	2.53	0.047	0.102	0.731	2.16	0.156	2.56	0.055	0.119	0.759
1017.2	2.31	0.085	2.53	0.033	0.076	0.886	2.29	0.104	2.56	0.041	0.094	0.906
1023.8	2.30	0.087	2.52	0.034	0.078	0.890	2.28	0.104	2.55	0.041	0.094	0.908
1028.9	2.26	0.111	2.54	0.040	0.090	0.810	2.24	0.128	2.57	0.048	0.107	0.834
1033.1	2.30	0.095	2.54	0.037	0.086	0.903	2.28	0.112	2.57	0.045	0.103	0.917
1035.1	2.21	0.126	2.53	0.052	0.116	0.922	2.20	0.142	2.56	0.060	0.132	0.931
1038.8	2.28	0.100	2.54	0.042	0.095	0.950	2.27	0.117	2.57	0.050	0.112	0.957

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of "SD9-" plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.
1041.0	2.25	0.113	2.54	0.045	0.102	0.895	2.23	0.130	2.57	0.053	0.118	0.908
1044.2	2.27	0.101	2.53	0.039	0.088	0.874	2.26	0.118	2.56	0.047	0.105	0.892
1047.2	2.29	0.096	2.53	0.039	0.089	0.932	2.27	0.112	2.56	0.047	0.106	0.942
1050.2	2.29	0.099	2.54	0.038	0.086	0.871	2.27	0.115	2.57	0.045	0.103	0.889
1053.6	2.32	0.087	2.54	0.037	0.086	0.985	2.30	0.105	2.57	0.045	0.104	0.987
1055.8	2.31	0.087	2.53	0.034	0.079	0.909	2.29	0.105	2.56	0.042	0.097	0.924
1064.8	2.29	0.091	2.52	0.038	0.087	0.958	2.28	0.109	2.55	0.046	0.105	0.965
1068.1	2.21	0.126	2.53	0.046	0.101	0.798	2.19	0.142	2.56	0.053	0.117	0.821
1070.4	2.05	0.193	2.54	0.077	0.158	0.821	2.04	0.206	2.57	0.084	0.171	0.833
1076.7	2.32	0.089	2.54	0.035	0.082	0.920	2.30	0.106	2.57	0.043	0.099	0.933
1080.1	2.31	0.090	2.54	0.032	0.075	0.837	2.30	0.107	2.57	0.040	0.092	0.863
1086.4	2.32	0.091	2.56	0.036	0.084	0.918	2.31	0.107	2.59	0.043	0.100	0.930
1091.1	2.30	0.103	2.56	0.039	0.089	0.863	2.28	0.118	2.59	0.046	0.104	0.881
1095.4	2.33	0.085	2.55	0.031	0.071	0.840	2.31	0.105	2.58	0.039	0.091	0.870
1098.4	2.21	0.128	2.53	0.041	0.091	0.712	2.19	0.145	2.56	0.049	0.108	0.744
1101.3	2.19	0.133	2.52	0.046	0.100	0.757	2.17	0.148	2.55	0.053	0.115	0.781
1104.1	2.10	0.169	2.53	0.048	0.101	0.596	2.09	0.183	2.55	0.055	0.114	0.625
1106.4	2.27	0.105	2.53	0.035	0.080	0.761	2.25	0.121	2.56	0.043	0.096	0.793
1110.3	2.18	0.140	2.53	0.047	0.102	0.729	2.16	0.155	2.56	0.054	0.117	0.755
1113.5	2.19	0.134	2.53	0.043	0.094	0.706	2.17	0.150	2.56	0.051	0.110	0.737
1116.0	2.18	0.138	2.53	0.048	0.104	0.749	2.16	0.154	2.55	0.055	0.119	0.775
1119.2	2.16	0.143	2.52	0.050	0.108	0.755	2.15	0.158	2.55	0.057	0.123	0.778
1125.1	2.09	0.177	2.54	0.068	0.142	0.806	2.08	0.190	2.56	0.075	0.156	0.819
1128.6	2.20	0.130	2.53	0.052	0.114	0.877	2.19	0.145	2.56	0.059	0.129	0.890
1133.6	2.24	0.113	2.53	0.040	0.090	0.799	2.23	0.129	2.56	0.048	0.107	0.825
1139.6	2.20	0.131	2.53	0.050	0.110	0.840	2.19	0.146	2.56	0.057	0.125	0.856
1142.0	2.24	0.116	2.53	0.047	0.105	0.903	2.22	0.131	2.56	0.054	0.120	0.914
1146.1	2.24	0.114	2.53	0.044	0.098	0.863	2.22	0.130	2.56	0.052	0.115	0.880
1149.0	2.33	0.076	2.52	0.028	0.065	0.865	2.31	0.094	2.55	0.036	0.083	0.891
1152.7	2.25	0.111	2.53	0.042	0.095	0.855	2.23	0.127	2.56	0.050	0.111	0.874
1158.5	2.22	0.120	2.53	0.037	0.083	0.690	2.21	0.135	2.55	0.044	0.098	0.724

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of “SD9-” plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.
1161.1	2.20	0.126	2.52	0.049	0.109	0.864	2.18	0.141	2.54	0.057	0.124	0.879
1163.8	2.26	0.100	2.51	0.037	0.083	0.828	2.24	0.117	2.54	0.044	0.100	0.853
1166.6	2.23	0.112	2.51	0.043	0.096	0.862	2.22	0.128	2.54	0.051	0.112	0.879
1170.5	2.20	0.140	2.56	0.052	0.114	0.813	2.19	0.153	2.58	0.058	0.127	0.830
1172.8	2.32	0.092	2.55	0.035	0.081	0.880	2.30	0.113	2.59	0.045	0.103	0.903
1179.0	2.29	0.103	2.55	0.039	0.090	0.868	2.26	0.124	2.58	0.049	0.110	0.890
1186.2	2.28	0.113	2.57	0.038	0.086	0.758	2.26	0.129	2.59	0.045	0.101	0.787
1189.1	2.30	0.104	2.56	0.037	0.086	0.827	2.28	0.120	2.59	0.045	0.102	0.850
1193.6	2.32	0.091	2.55	0.035	0.081	0.886	2.30	0.114	2.60	0.045	0.104	0.908
1200.2	2.21	0.137	2.56	0.050	0.111	0.812	2.20	0.151	2.58	0.057	0.125	0.829
1203.0	2.34	0.082	2.55	0.032	0.074	0.906	2.32	0.105	2.59	0.042	0.097	0.926
1208.4	2.32	0.083	2.54	0.032	0.073	0.878	2.30	0.102	2.57	0.040	0.092	0.901
1211.9	2.33	0.089	2.56	0.034	0.080	0.906	2.31	0.106	2.59	0.042	0.098	0.921
1215.0	2.32	0.091	2.55	0.034	0.079	0.876	2.30	0.111	2.58	0.043	0.100	0.899
1220.6	2.19	0.142	2.55	0.056	0.123	0.864	2.17	0.159	2.58	0.064	0.139	0.878
1224.4	2.33	0.089	2.56	0.033	0.077	0.867	2.31	0.111	2.59	0.043	0.099	0.893
1229.8	2.32	0.095	2.57	0.033	0.077	0.805	2.31	0.111	2.59	0.040	0.093	0.834
1233.2	2.15	0.161	2.56	0.072	0.154	0.959	2.14	0.175	2.59	0.079	0.169	0.963
1235.5	2.28	0.110	2.56	0.037	0.084	0.764	2.26	0.128	2.59	0.045	0.102	0.796
1242.0	2.16	0.154	2.55	0.053	0.115	0.745	2.14	0.170	2.58	0.061	0.131	0.769
1244.6	2.33	0.084	2.54	0.031	0.072	0.865	2.31	0.104	2.58	0.040	0.093	0.892
1250.7	2.37	0.069	2.55	0.026	0.061	0.886	2.35	0.093	2.59	0.036	0.085	0.916
1253.8	2.27	0.105	2.54	0.036	0.081	0.777	2.25	0.125	2.57	0.045	0.102	0.813
1257.0	2.34	0.077	2.54	0.029	0.067	0.869	2.32	0.099	2.57	0.038	0.089	0.898
1262.6	2.33	0.084	2.54	0.027	0.063	0.751	2.31	0.102	2.57	0.035	0.082	0.797
1269.2	2.37	0.067	2.54	0.025	0.059	0.874	2.34	0.091	2.58	0.035	0.083	0.907
1272.1	2.35	0.075	2.54	0.028	0.066	0.873	2.33	0.099	2.59	0.038	0.090	0.904
1274.8	2.35	0.078	2.55	0.028	0.065	0.837	2.32	0.102	2.59	0.038	0.089	0.875
1278.3	2.35	0.080	2.55	0.028	0.065	0.818	2.32	0.104	2.59	0.039	0.090	0.861
1281.6	2.35	0.074	2.54	0.028	0.066	0.893	2.33	0.098	2.58	0.039	0.090	0.919
1284.8	2.24	0.117	2.54	0.040	0.090	0.769	2.22	0.136	2.57	0.049	0.109	0.801

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of “SD9-” plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.
1289.9	2.38	0.065	2.55	0.024	0.056	0.860	2.36	0.085	2.58	0.032	0.076	0.892
1296.2	2.36	0.071	2.54	0.027	0.065	0.910	2.34	0.092	2.57	0.036	0.085	0.930
1299.8	2.33	0.077	2.53	0.029	0.068	0.882	2.31	0.102	2.57	0.040	0.092	0.910
1302.5	2.37	0.062	2.53	0.024	0.058	0.935	2.35	0.084	2.57	0.034	0.080	0.953
1304.9	2.34	0.079	2.54	0.031	0.072	0.917	2.31	0.103	2.58	0.042	0.096	0.936
1308.4	2.29	0.096	2.53	0.041	0.094	0.976	2.26	0.124	2.58	0.054	0.121	0.981
1311.1	2.30	0.085	2.52	0.038	0.087	1.020	2.28	0.112	2.56	0.050	0.114	1.015
1317.3	2.24	0.101	2.49	0.028	0.063	0.620	2.22	0.118	2.52	0.036	0.080	0.674
1320.3	2.36	0.061	2.52	0.023	0.054	0.886	2.34	0.082	2.55	0.032	0.075	0.914
1323.4	2.31	0.078	2.50	0.032	0.074	0.958	2.28	0.104	2.55	0.044	0.101	0.969
1331.9	2.31	0.077	2.50	0.032	0.074	0.962	2.29	0.099	2.54	0.042	0.096	0.971
1335.1	2.35	0.066	2.51	0.029	0.069	1.034	2.32	0.090	2.55	0.040	0.092	1.025
1337.6	2.23	0.103	2.49	0.042	0.093	0.907	2.21	0.127	2.53	0.053	0.117	0.925
1347.6	2.32	0.069	2.49	0.024	0.056	0.821	2.30	0.092	2.53	0.035	0.080	0.866
1349.6	2.41	0.043	2.52	0.016	0.039	0.904	2.39	0.065	2.56	0.025	0.061	0.936
1352.4	2.31	0.067	2.48	0.026	0.060	0.888	2.29	0.088	2.51	0.035	0.081	0.915
1355.2	2.31	0.064	2.47	0.024	0.055	0.856	2.28	0.091	2.51	0.036	0.081	0.897
1358.7	2.30	0.073	2.48	0.028	0.065	0.891	2.27	0.095	2.51	0.038	0.087	0.917
1361.6	2.27	0.101	2.53	0.038	0.087	0.867	2.26	0.114	2.55	0.045	0.101	0.883
1365.2	2.31	0.019	2.36	0.008	0.018	0.932	2.28	0.047	2.40	0.020	0.045	0.972
1368.0	2.36	0.007	2.38	0.002	0.005	0.723	2.35	0.013	2.38	0.005	0.011	0.855
1370.6	2.35	0.014	2.38	0.005	0.012	0.875	2.35	0.014	2.38	0.005	0.012	0.873
1374.3	2.35	0.010	2.38	0.003	0.008	0.725	2.35	0.016	2.38	0.006	0.013	0.819
1377.5	2.36	0.007	2.38	0.002	0.005	0.686	2.35	0.013	2.38	0.004	0.011	0.823
1380.3	2.36	0.009	2.38	0.003	0.007	0.815	2.35	0.015	2.39	0.006	0.014	0.891
1382.0	2.36	0.007	2.38	0.002	0.005	0.704	2.36	0.012	2.38	0.004	0.010	0.833
1385.9	2.36	0.008	2.38	0.003	0.008	0.991	2.35	0.015	2.39	0.006	0.015	0.995
1388.3	2.36	0.006	2.38	0.002	0.004	0.679	2.36	0.011	2.38	0.004	0.009	0.824
1392.2	2.34	0.010	2.37	0.003	0.007	0.678	2.34	0.016	2.38	0.006	0.013	0.798
1394.7	2.36	0.007	2.38	0.002	0.005	0.776	2.36	0.011	2.38	0.004	0.010	0.858
1401.1	2.36	0.009	2.38	0.002	0.005	0.500	2.35	0.014	2.38	0.004	0.009	0.668

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of “SD9-” plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.
1403.5	2.34	0.008	2.36	0.002	0.005	0.646	2.33	0.015	2.37	0.005	0.012	0.799
1406.6	2.33	0.015	2.36	0.005	0.011	0.761	2.32	0.022	2.38	0.008	0.019	0.844
1410.1	2.33	0.015	2.37	0.005	0.011	0.726	2.32	0.023	2.38	0.008	0.019	0.830
1412.7	2.33	0.014	2.36	0.004	0.010	0.722	2.32	0.025	2.38	0.009	0.021	0.844
1415.5	2.32	0.014	2.36	0.005	0.012	0.811	2.31	0.027	2.37	0.010	0.024	0.897
1418.5	2.26	0.036	2.34	0.012	0.028	0.764	2.24	0.054	2.37	0.020	0.046	0.842
1425.3	1.94	0.132	2.23	0.040	0.079	0.594	1.89	0.177	2.30	0.065	0.123	0.696
1427.4	1.84	0.176	2.23	0.059	0.108	0.612	1.81	0.204	2.27	0.075	0.135	0.665
1430.9	1.64	0.266	2.24	0.067	0.111	0.416	1.60	0.308	2.31	0.095	0.152	0.495
1433.4	2.01	0.053	2.12	0.019	0.037	0.708	1.90	0.158	2.26	0.075	0.143	0.903
1437.3	2.31	0.028	2.38	0.010	0.023	0.846	2.31	0.031	2.38	0.011	0.026	0.861
1440.2	1.89	0.181	2.30	0.066	0.125	0.687	1.85	0.222	2.37	0.089	0.165	0.744
1443.3	1.53	0.322	2.26	0.117	0.180	0.559	1.47	0.385	2.39	0.166	0.244	0.632
1445.2	1.75	0.219	2.24	0.092	0.161	0.735	1.70	0.271	2.33	0.126	0.213	0.786
1448.5	1.56	0.305	2.24	0.118	0.183	0.602	1.51	0.349	2.33	0.151	0.228	0.653
1450.9	1.44	0.375	2.30	0.155	0.222	0.592	1.40	0.410	2.37	0.183	0.257	0.626
1454.2	1.51	0.326	2.24	0.196	0.296	0.907	1.45	0.389	2.37	0.248	0.359	0.922
1458.2	1.73	0.177	2.10	0.099	0.171	0.966	1.60	0.301	2.29	0.184	0.295	0.980
1460.2	1.70	0.213	2.16	0.119	0.202	0.947	1.58	0.332	2.37	0.203	0.321	0.966
1463.0	1.74	0.185	2.13	0.105	0.183	0.988	1.61	0.314	2.34	0.194	0.312	0.993
1467.0	1.54	0.297	2.20	0.185	0.285	0.960	1.44	0.400	2.40	0.269	0.388	0.970
1467.9	1.87	0.135	2.16	0.072	0.134	0.998	1.75	0.257	2.35	0.147	0.257	0.999
1469.8	1.85	0.153	2.18	0.088	0.162	1.063	1.71	0.286	2.40	0.173	0.295	1.034
1473.0	1.84	0.158	2.19	0.087	0.160	1.008	1.72	0.282	2.39	0.165	0.284	1.005
1478.8	1.75	0.200	2.19	0.109	0.191	0.955	1.64	0.309	2.38	0.183	0.300	0.971
1481.8	1.95	0.106	2.18	0.055	0.107	1.008	1.82	0.232	2.37	0.128	0.233	1.004
1485.1	1.75	0.186	2.15	0.105	0.184	0.990	1.63	0.308	2.35	0.188	0.307	0.994
1488.5	1.55	0.282	2.16	0.161	0.249	0.884	1.44	0.392	2.37	0.250	0.360	0.917
1493.1	1.65	0.233	2.15	0.138	0.227	0.973	1.53	0.348	2.35	0.223	0.342	0.982
1496.5	1.62	0.242	2.14	0.146	0.236	0.977	1.51	0.355	2.34	0.232	0.349	0.984
1499.6	1.54	0.276	2.13	0.164	0.253	0.915	1.43	0.388	2.34	0.255	0.365	0.940

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of “SD9-” plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.
1501.2	1.58	0.271	2.16	0.157	0.248	0.913	1.47	0.378	2.36	0.241	0.354	0.937
1504.9	1.70	0.218	2.17	0.124	0.210	0.965	1.58	0.329	2.36	0.203	0.321	0.977
1508.2	1.67	0.237	2.19	0.137	0.229	0.963	1.56	0.341	2.37	0.212	0.332	0.974
1511.4	1.63	0.255	2.19	0.150	0.246	0.963	1.53	0.358	2.38	0.228	0.349	0.974
1514.1	1.77	0.168	2.13	0.095	0.168	1.000	1.65	0.281	2.30	0.170	0.281	1.000
1517.7	1.65	0.244	2.18	0.147	0.242	0.990	1.54	0.351	2.38	0.226	0.349	0.993
1521.7	1.63	0.249	2.18	0.147	0.240	0.961	1.53	0.356	2.37	0.227	0.346	0.973
1523.5	1.63	0.250	2.17	0.154	0.250	1.000	1.52	0.355	2.36	0.233	0.355	1.000
1526.4	1.63	0.249	2.17	0.145	0.236	0.949	1.53	0.352	2.35	0.222	0.339	0.964
1529.7	1.64	0.240	2.16	0.139	0.227	0.946	1.53	0.349	2.35	0.219	0.336	0.963
1532.1	1.57	0.283	2.19	0.157	0.246	0.871	1.47	0.383	2.38	0.236	0.347	0.905
1538.6	1.70	0.217	2.17	0.124	0.210	0.970	1.60	0.322	2.35	0.198	0.315	0.979
1540.9	1.72	0.211	2.18	0.123	0.211	1.000	1.62	0.312	2.35	0.192	0.312	1.000
1544.1	1.61	0.261	2.18	0.153	0.246	0.943	1.51	0.361	2.36	0.229	0.346	0.959
1547.4	1.76	0.195	2.18	0.108	0.190	0.977	1.65	0.302	2.36	0.181	0.298	0.985
1550.5	1.60	0.268	2.19	0.157	0.251	0.937	1.50	0.370	2.38	0.236	0.353	0.955
1553.8	1.62	0.266	2.20	0.156	0.251	0.947	1.51	0.368	2.39	0.234	0.354	0.961
1556.7	1.67	0.238	2.19	0.131	0.218	0.916	1.57	0.337	2.37	0.202	0.317	0.940
1560.1	1.70	0.227	2.20	0.127	0.215	0.946	1.60	0.325	2.37	0.196	0.313	0.962
1562.2	1.70	0.226	2.19	0.128	0.218	0.962	1.60	0.327	2.37	0.199	0.318	0.974
1565.6	1.70	0.215	2.17	0.124	0.211	0.981	1.60	0.317	2.34	0.195	0.313	0.987
1569.1	1.70	0.221	2.18	0.126	0.213	0.963	1.59	0.325	2.36	0.199	0.316	0.975
1572.3	1.78	0.189	2.19	0.104	0.185	0.982	1.68	0.289	2.36	0.170	0.285	0.988
1574.8	1.69	0.235	2.21	0.128	0.217	0.923	1.59	0.335	2.40	0.199	0.317	0.946
1578.0	1.68	0.236	2.20	0.131	0.220	0.932	1.58	0.333	2.37	0.201	0.317	0.952
1580.7	1.69	0.229	2.19	0.128	0.216	0.943	1.59	0.328	2.36	0.199	0.315	0.961
1584.0	1.55	0.292	2.19	0.171	0.265	0.909	1.45	0.390	2.38	0.250	0.363	0.932
1586.6	1.78	0.188	2.19	0.106	0.188	0.997	1.65	0.309	2.40	0.187	0.309	0.998
1590.0	1.60	0.261	2.17	0.163	0.262	1.001	1.50	0.360	2.35	0.239	0.360	1.000
1592.8	1.63	0.255	2.18	0.143	0.232	0.911	1.52	0.356	2.37	0.219	0.333	0.936
1595.8	1.60	0.272	2.19	0.143	0.228	0.838	1.50	0.367	2.37	0.216	0.323	0.880

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of “SD9-” plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.
1598.3	1.95	0.110	2.19	0.061	0.119	1.082	1.84	0.220	2.36	0.124	0.229	1.041
1601.9	1.55	0.285	2.17	0.141	0.219	0.767	1.46	0.382	2.36	0.216	0.315	0.826
1602.8	1.70	0.208	2.15	0.092	0.157	0.754	1.60	0.312	2.32	0.163	0.260	0.835
1605.7	1.66	0.231	2.16	0.108	0.178	0.771	1.56	0.328	2.33	0.176	0.275	0.838
1610.4	1.57	0.282	2.19	0.145	0.228	0.807	1.47	0.379	2.37	0.220	0.324	0.856
1612.6	1.64	0.241	2.16	0.143	0.235	0.974	1.55	0.336	2.33	0.213	0.330	0.982
1615.2	1.48	0.315	2.17	0.177	0.263	0.836	1.39	0.406	2.34	0.255	0.354	0.873
1617.5	1.57	0.279	2.18	0.170	0.268	0.961	1.48	0.372	2.36	0.244	0.361	0.971
1621.2	1.62	0.247	2.15	0.119	0.192	0.777	1.52	0.345	2.32	0.191	0.290	0.840
1623.8	1.66	0.235	2.17	0.135	0.224	0.955	1.57	0.331	2.34	0.205	0.320	0.968
1627.1	1.60	0.262	2.17	0.141	0.226	0.863	1.50	0.358	2.35	0.214	0.323	0.900
1632.0	1.61	0.255	2.16	0.154	0.248	0.971	1.52	0.352	2.34	0.227	0.344	0.979
1635.1	1.62	0.253	2.17	0.126	0.204	0.805	1.52	0.356	2.35	0.203	0.307	0.861
1638.1	1.58	0.271	2.16	0.166	0.262	0.966	1.48	0.365	2.34	0.240	0.356	0.975
1641.2	1.58	0.266	2.16	0.167	0.264	0.992	1.49	0.362	2.33	0.242	0.360	0.994
1643.7	1.64	0.238	2.15	0.144	0.236	0.994	1.54	0.336	2.32	0.217	0.335	0.996
1646.5	1.61	0.256	2.17	0.152	0.245	0.954	1.51	0.354	2.34	0.226	0.342	0.966
1649.4	1.61	0.258	2.17	0.152	0.245	0.949	1.51	0.356	2.35	0.226	0.343	0.963
1652.7	1.57	0.275	2.17	0.174	0.273	0.996	1.48	0.368	2.34	0.249	0.367	0.997
1655.7	1.60	0.262	2.16	0.161	0.257	0.982	1.50	0.357	2.34	0.235	0.353	0.987
1658.7	1.64	0.241	2.16	0.144	0.235	0.979	1.54	0.338	2.33	0.216	0.333	0.985
1661.7	1.59	0.262	2.16	0.164	0.261	0.996	1.50	0.353	2.32	0.234	0.351	0.997
1664.8	1.64	0.239	2.16	0.144	0.236	0.985	1.55	0.332	2.32	0.212	0.328	0.989
1667.6	1.62	0.252	2.17	0.155	0.251	0.994	1.53	0.345	2.33	0.225	0.344	0.996
1670.4	1.64	0.238	2.15	0.142	0.233	0.980	1.55	0.333	2.32	0.212	0.328	0.986
1671.6	1.63	0.246	2.17	0.145	0.238	0.967	1.54	0.338	2.33	0.214	0.330	0.976
1674.5	1.65	0.235	2.16	0.139	0.230	0.980	1.56	0.328	2.32	0.207	0.323	0.985
1677.4	1.63	0.245	2.16	0.148	0.242	0.989	1.54	0.338	2.32	0.218	0.336	0.992
1680.3	1.61	0.257	2.17	0.144	0.233	0.906	1.51	0.357	2.35	0.220	0.333	0.933
1683.6	1.57	0.277	2.17	0.171	0.268	0.968	1.47	0.372	2.34	0.247	0.363	0.976
1686.2	1.70	0.209	2.15	0.118	0.201	0.962	1.61	0.305	2.31	0.185	0.297	0.974

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of "SD9-" plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.
1689.1	1.55	0.286	2.17	0.180	0.279	0.977	1.46	0.379	2.35	0.255	0.372	0.982
1692.6	1.62	0.254	2.17	0.153	0.248	0.976	1.52	0.349	2.34	0.225	0.343	0.982
1695.6	1.58	0.270	2.17	0.164	0.259	0.959	1.48	0.370	2.35	0.242	0.358	0.970
1699.0	1.59	0.269	2.17	0.165	0.262	0.972	1.49	0.367	2.35	0.242	0.360	0.979
1702.0	1.63	0.246	2.16	0.148	0.240	0.976	1.54	0.341	2.33	0.218	0.335	0.983
1704.7	1.61	0.256	2.17	0.152	0.246	0.961	1.52	0.351	2.34	0.225	0.341	0.972
1707.8	1.62	0.254	2.17	0.154	0.249	0.980	1.52	0.351	2.34	0.227	0.346	0.986
1710.8	1.63	0.249	2.16	0.150	0.244	0.982	1.53	0.344	2.33	0.222	0.340	0.987
1713.7	1.64	0.244	2.17	0.146	0.239	0.980	1.54	0.340	2.34	0.217	0.335	0.986
1717.1	1.65	0.239	2.17	0.142	0.234	0.979	1.55	0.339	2.35	0.215	0.334	0.985
1719.7	1.70	0.215	2.16	0.124	0.211	0.981	1.60	0.312	2.33	0.193	0.308	0.987
1723.1	1.68	0.232	2.18	0.137	0.229	0.990	1.57	0.337	2.37	0.213	0.334	0.993
1725.9	1.69	0.223	2.18	0.132	0.224	1.005	1.60	0.319	2.35	0.200	0.320	1.003
1729.1	1.66	0.241	2.19	0.144	0.239	0.988	1.56	0.341	2.37	0.216	0.338	0.991
1731.4	1.66	0.239	2.18	0.141	0.234	0.976	1.56	0.340	2.36	0.214	0.334	0.983
1734.7	1.84	0.164	2.20	0.088	0.161	0.981	1.74	0.261	2.36	0.148	0.258	0.988
1737.7	1.69	0.223	2.18	0.130	0.220	0.987	1.60	0.315	2.34	0.195	0.312	0.991
1743.9	1.59	0.266	2.16	0.170	0.270	1.017	1.50	0.351	2.31	0.236	0.355	1.013
1746.8	1.61	0.282	2.24	0.170	0.274	0.971	1.52	0.371	2.42	0.239	0.363	0.978
1749.8	1.66	0.254	2.22	0.147	0.243	0.957	1.57	0.342	2.38	0.211	0.331	0.968
1753.0	1.61	0.277	2.23	0.167	0.270	0.975	1.53	0.359	2.39	0.230	0.353	0.981
1756.0	1.67	0.254	2.24	0.140	0.234	0.921	1.58	0.340	2.40	0.202	0.319	0.941
1762.2	1.65	0.257	2.23	0.152	0.251	0.979	1.57	0.341	2.38	0.214	0.336	0.984
1765.3	1.92	0.150	2.26	0.080	0.153	1.017	1.83	0.239	2.40	0.132	0.241	1.011
1767.8	1.79	0.202	2.24	0.113	0.202	1.003	1.71	0.287	2.39	0.168	0.287	1.002
1770.5	1.79	0.192	2.22	0.112	0.200	1.044	1.69	0.296	2.40	0.180	0.304	1.028
1774.5	1.84	0.162	2.19	0.086	0.157	0.972	1.75	0.251	2.33	0.141	0.246	0.982
1776.8	1.85	0.150	2.18	0.082	0.153	1.014	1.76	0.245	2.33	0.141	0.248	1.009
1779.9	1.82	0.205	2.29	0.112	0.203	0.989	1.75	0.275	2.41	0.156	0.273	0.992
1782.8	1.88	0.152	2.22	0.080	0.150	0.984	1.78	0.255	2.39	0.142	0.253	0.990
1786.4	1.72	0.243	2.28	0.139	0.240	0.985	1.65	0.312	2.40	0.186	0.308	0.989

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of "SD9-" plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.
1788.8	1.90	0.177	2.31	0.094	0.179	1.011	1.83	0.252	2.44	0.139	0.254	1.008
1791.6	1.88	0.176	2.29	0.092	0.173	0.986	1.81	0.252	2.42	0.138	0.249	0.990
1795.4	1.81	0.201	2.27	0.114	0.207	1.031	1.72	0.288	2.42	0.171	0.294	1.021
1798.1	1.87	0.192	2.32	0.100	0.188	0.979	1.81	0.254	2.43	0.138	0.250	0.984
1803.9	2.01	0.166	2.42	0.082	0.165	0.989	1.95	0.229	2.53	0.116	0.227	0.992
1806.8	2.09	0.171	2.52	0.080	0.167	0.977	2.04	0.220	2.62	0.106	0.216	0.982
1811.0	2.05	0.196	2.55	0.094	0.193	0.985	2.00	0.239	2.63	0.118	0.237	0.988
1813.2	2.01	0.194	2.50	0.096	0.194	1.000	1.96	0.248	2.61	0.127	0.248	1.000
1816.6	2.08	0.159	2.47	0.078	0.161	1.015	2.01	0.227	2.60	0.114	0.229	1.010
1822.6	1.77	0.204	2.23	0.107	0.189	0.928	1.68	0.293	2.38	0.165	0.279	0.950
1825.0	1.68	0.258	2.27	0.154	0.258	1.000	1.61	0.334	2.41	0.208	0.333	1.000
1827.8	1.72	0.233	2.24	0.135	0.233	0.999	1.64	0.312	2.39	0.190	0.312	0.999
1831.0	1.75	0.220	2.24	0.122	0.213	0.965	1.67	0.298	2.38	0.174	0.290	0.974
1834.0	1.81	0.191	2.23	0.100	0.181	0.949	1.73	0.273	2.37	0.153	0.263	0.964
1837.0	1.78	0.208	2.25	0.112	0.199	0.956	1.70	0.284	2.38	0.161	0.275	0.968
1839.7	1.74	0.229	2.26	0.128	0.222	0.969	1.66	0.313	2.41	0.184	0.305	0.977
1842.8	1.74	0.237	2.28	0.133	0.232	0.977	1.66	0.316	2.43	0.187	0.310	0.983
1845.9	1.76	0.224	2.27	0.119	0.210	0.938	1.68	0.302	2.41	0.172	0.289	0.954
1848.9	1.70	0.252	2.27	0.141	0.239	0.949	1.62	0.326	2.41	0.193	0.313	0.961
1851.7	1.18	0.474	2.24	0.236	0.277	0.585	1.11	0.538	2.41	0.306	0.341	0.634
1854.8	1.63	0.279	2.27	0.165	0.270	0.966	1.56	0.356	2.42	0.222	0.346	0.973
1857.7	1.58	0.308	2.28	0.184	0.291	0.946	1.51	0.381	2.44	0.241	0.364	0.956
1860.5	1.77	0.215	2.25	0.117	0.208	0.967	1.69	0.292	2.39	0.168	0.285	0.976
1863.7	1.83	0.169	2.20	0.086	0.158	0.936	1.75	0.254	2.34	0.139	0.243	0.957
1866.9	1.67	0.264	2.27	0.155	0.258	0.978	1.58	0.346	2.42	0.215	0.341	0.983
1869.7	1.51	0.390	2.48	0.249	0.376	0.966	1.51	0.395	2.49	0.253	0.381	0.967
1872.6	1.59	0.354	2.47	0.191	0.304	0.858	1.59	0.357	2.47	0.193	0.307	0.859
1875.8	1.70	0.332	2.55	0.179	0.306	0.921	1.70	0.337	2.56	0.183	0.310	0.922
1878.6	1.65	0.352	2.55	0.198	0.326	0.926	1.65	0.358	2.56	0.202	0.332	0.927
1884.9	1.67	0.354	2.59	0.201	0.337	0.952	1.67	0.360	2.61	0.206	0.343	0.953
1887.8	1.68	0.347	2.58	0.196	0.329	0.947	1.67	0.355	2.59	0.201	0.337	0.948

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of "SD9-" plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.
1890.6	1.71	0.340	2.59	0.192	0.328	0.963	1.70	0.350	2.61	0.199	0.337	0.964
1892.8	1.72	0.338	2.59	0.188	0.323	0.956	1.71	0.346	2.61	0.194	0.331	0.957
1895.9	1.72	0.333	2.59	0.169	0.291	0.872	1.71	0.343	2.61	0.175	0.301	0.876
1900.0	1.77	0.315	2.59	0.155	0.274	0.869	1.76	0.327	2.62	0.162	0.285	0.874
1903.0	1.80	0.302	2.58	0.159	0.286	0.947	1.79	0.315	2.61	0.167	0.299	0.950
1905.8	1.79	0.303	2.57	0.156	0.280	0.924	1.78	0.315	2.60	0.164	0.292	0.927
1909.4	1.79	0.309	2.58	0.165	0.295	0.956	1.78	0.320	2.61	0.173	0.306	0.958
1912	1.80	0.305	2.59	0.164	0.296	0.969	1.79	0.316	2.62	0.172	0.307	0.970
1917.7	1.80	0.304	2.59	0.166	0.299	0.986	1.79	0.315	2.62	0.174	0.311	0.986
1920.7	1.80	0.303	2.58	0.166	0.300	0.990	1.79	0.314	2.61	0.174	0.311	0.991
1924.0	1.82	0.295	2.58	0.158	0.287	0.973	1.81	0.305	2.60	0.164	0.297	0.974
1926.8	1.83	0.291	2.58	0.157	0.286	0.985	1.82	0.301	2.60	0.163	0.297	0.986
1929.9	1.82	0.296	2.58	0.158	0.287	0.971	1.81	0.305	2.60	0.164	0.297	0.972
1932.9	1.84	0.289	2.58	0.156	0.287	0.993	1.83	0.297	2.60	0.161	0.295	0.993
1936.0	1.83	0.293	2.58	0.158	0.289	0.987	1.82	0.303	2.60	0.165	0.299	0.987
1939.5	1.87	0.274	2.57	0.148	0.277	1.008	1.85	0.288	2.60	0.157	0.290	1.008
1943.1	1.89	0.266	2.58	0.150	0.283	1.065	1.88	0.281	2.61	0.159	0.298	1.062
1945.5	1.89	0.263	2.57	0.137	0.259	0.985	1.88	0.279	2.60	0.146	0.275	0.985
1948.0	1.90	0.261	2.57	0.135	0.255	0.979	1.88	0.276	2.60	0.144	0.270	0.980
1951.4	1.88	0.269	2.57	0.140	0.262	0.974	1.86	0.284	2.60	0.149	0.277	0.975
1953.6	1.88	0.269	2.57	0.145	0.273	1.014	1.86	0.284	2.61	0.155	0.288	1.013
1957.1	1.93	0.247	2.56	0.126	0.243	0.984	1.91	0.263	2.60	0.135	0.259	0.985
1960.7	1.94	0.242	2.56	0.123	0.240	0.990	1.92	0.258	2.59	0.133	0.256	0.991
1963.2	1.96	0.233	2.56	0.116	0.228	0.981	1.95	0.250	2.59	0.126	0.245	0.982
1966.1	1.96	0.235	2.56	0.119	0.233	0.992	1.94	0.252	2.59	0.129	0.250	0.992
1968.6	1.97	0.228	2.55	0.114	0.225	0.987	1.95	0.245	2.59	0.124	0.242	0.988
1971.6	1.99	0.213	2.53	0.106	0.210	0.986	1.97	0.232	2.57	0.116	0.229	0.987
1975.0	1.99	0.206	2.51	0.102	0.202	0.982	1.96	0.234	2.57	0.117	0.230	0.984
1977.6	1.96	0.218	2.50	0.117	0.229	1.052	1.93	0.239	2.54	0.129	0.250	1.048
1981.0	1.88	0.249	2.50	0.132	0.249	0.998	1.86	0.270	2.54	0.145	0.270	0.998
1983.8	1.81	0.273	2.50	0.149	0.271	0.991	1.79	0.294	2.54	0.163	0.292	0.992

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of "SD9-" plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.
1986.8	1.81	0.268	2.48	0.148	0.268	0.997	1.79	0.290	2.52	0.162	0.289	0.998
1989.6	1.78	0.282	2.48	0.158	0.281	0.997	1.76	0.303	2.52	0.172	0.303	0.997
1993.0	1.80	0.268	2.45	0.146	0.262	0.977	1.77	0.292	2.50	0.162	0.286	0.979
1996.3	1.81	0.261	2.45	0.143	0.258	0.988	1.79	0.279	2.48	0.154	0.275	0.988
1999.0	1.80	0.265	2.44	0.145	0.260	0.982	1.78	0.283	2.48	0.157	0.278	0.983
2002.3	1.84	0.240	2.41	0.127	0.233	0.971	1.79	0.286	2.51	0.156	0.279	0.975
2005.0	1.83	0.234	2.39	0.124	0.227	0.969	1.79	0.274	2.47	0.149	0.267	0.974
2007.8	1.84	0.222	2.37	0.122	0.224	1.009	1.77	0.295	2.51	0.168	0.297	1.007
2010.6	1.80	0.228	2.33	0.120	0.217	0.952	1.73	0.294	2.45	0.163	0.283	0.963
2013.8	1.74	0.252	2.33	0.140	0.244	0.967	1.67	0.321	2.46	0.187	0.312	0.974
2016.8	1.88	0.189	2.32	0.098	0.184	0.973	1.79	0.280	2.48	0.154	0.275	0.982
2019.8	1.73	0.253	2.31	0.141	0.243	0.962	1.66	0.320	2.44	0.187	0.310	0.970
2022.9	1.78	0.231	2.31	0.126	0.223	0.967	1.70	0.303	2.45	0.174	0.296	0.975
2025.7	1.68	0.273	2.32	0.161	0.271	0.994	1.62	0.339	2.45	0.209	0.338	0.995
2028.7	1.81	0.221	2.32	0.120	0.217	0.983	1.73	0.296	2.46	0.169	0.293	0.987
2031.9	1.79	0.226	2.31	0.115	0.207	0.917	1.72	0.297	2.45	0.162	0.279	0.937
2035.4	1.74	0.244	2.31	0.135	0.236	0.970	1.67	0.314	2.44	0.183	0.307	0.977
2038.1	1.69	0.271	2.32	0.157	0.265	0.977	1.62	0.339	2.45	0.205	0.333	0.982
2041.2	1.71	0.272	2.34	0.145	0.248	0.910	1.64	0.335	2.47	0.189	0.311	0.927
2044.0	1.77	0.236	2.32	0.131	0.231	0.980	1.70	0.304	2.45	0.176	0.299	0.984
2047.3	1.70	0.262	2.31	0.151	0.258	0.984	1.64	0.332	2.45	0.200	0.327	0.987
2050.0	1.72	0.255	2.31	0.140	0.242	0.949	1.65	0.324	2.45	0.188	0.311	0.960
2053.0	1.73	0.246	2.30	0.136	0.236	0.960	1.66	0.316	2.43	0.184	0.306	0.969
2056.0	1.73	0.247	2.29	0.139	0.241	0.977	1.66	0.318	2.43	0.189	0.313	0.982
2058.9	1.75	0.243	2.31	0.136	0.237	0.976	1.67	0.319	2.45	0.187	0.313	0.982
2062.0	1.63	0.293	2.30	0.188	0.306	1.043	1.55	0.368	2.46	0.245	0.380	1.034
2065.0	1.70	0.261	2.31	0.151	0.257	0.984	1.63	0.336	2.46	0.204	0.332	0.988
2067.8	1.68	0.273	2.30	0.159	0.266	0.975	1.60	0.345	2.45	0.211	0.338	0.980
2070.8	1.70	0.264	2.30	0.151	0.256	0.971	1.62	0.336	2.45	0.202	0.329	0.977
2074.0	1.71	0.257	2.30	0.146	0.250	0.973	1.63	0.331	2.44	0.198	0.324	0.979
2077.0	1.75	0.241	2.30	0.135	0.235	0.973	1.67	0.316	2.44	0.185	0.310	0.980

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of "SD9-" plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.	Dry Bulk Density (g/cm³)	Porosity (cm³/cm³)	Particle Density (g/cm³)	Grav. Water Content (g/g)	Vol. Water Content (cm³/cm³)	Relative Satn.
2080.0	1.78	0.223	2.29	0.127	0.226	1.010	1.70	0.301	2.43	0.178	0.303	1.008
2083.0	1.78	0.224	2.29	0.123	0.219	0.979	1.70	0.300	2.43	0.173	0.295	0.984
2085.7	1.76	0.234	2.29	0.131	0.230	0.985	1.68	0.308	2.43	0.181	0.305	0.988
2089.2	1.75	0.235	2.28	0.131	0.230	0.980	1.67	0.311	2.43	0.183	0.307	0.985
2092.1	1.77	0.227	2.29	0.126	0.222	0.981	1.69	0.307	2.44	0.179	0.303	0.986
2094.9	1.79	0.216	2.29	0.117	0.210	0.973	1.72	0.293	2.43	0.167	0.287	0.980
2098.0	1.81	0.204	2.27	0.115	0.207	1.019	1.72	0.292	2.43	0.172	0.296	1.013
2101.2	1.81	0.210	2.30	0.112	0.204	0.970	1.73	0.291	2.44	0.165	0.285	0.979
2103.5	1.83	0.178	2.22	0.095	0.174	0.981	1.74	0.263	2.36	0.149	0.259	0.987
2106.6	1.80	0.198	2.24	0.110	0.198	0.998	1.72	0.281	2.39	0.163	0.280	0.999
2109.6	1.81	0.194	2.25	0.106	0.191	0.988	1.72	0.280	2.40	0.161	0.278	0.991
2113.1	1.81	0.189	2.24	0.104	0.189	1.000	1.73	0.275	2.38	0.159	0.275	1.000
2116.2	1.79	0.205	2.25	0.114	0.203	0.988	1.71	0.287	2.39	0.167	0.285	0.991
2118.9	1.81	0.184	2.22	0.099	0.180	0.979	1.72	0.270	2.36	0.154	0.266	0.986
2121.5	1.67	0.260	2.26	0.153	0.256	0.982	1.59	0.341	2.41	0.212	0.337	0.986
2124.4	1.76	0.213	2.23	0.119	0.208	0.981	1.68	0.296	2.38	0.174	0.292	0.986
2127.8	1.75	0.221	2.25	0.126	0.220	0.993	1.67	0.302	2.39	0.180	0.300	0.995
2131.0	1.78	0.203	2.23	0.112	0.200	0.986	1.69	0.292	2.39	0.171	0.290	0.991
2133.9	1.76	0.214	2.24	0.120	0.210	0.981	1.68	0.296	2.38	0.174	0.292	0.986
2137.1	1.82	0.187	2.24	0.103	0.188	1.002	1.74	0.271	2.38	0.157	0.272	1.001
2140.0	1.77	0.204	2.22	0.112	0.198	0.971	1.68	0.290	2.37	0.169	0.285	0.980
2143.0	1.82	0.184	2.23	0.099	0.180	0.980	1.73	0.272	2.38	0.155	0.269	0.986
2146.0	1.79	0.207	2.26	0.112	0.201	0.972	1.71	0.289	2.41	0.165	0.283	0.980
2149.0	1.72	0.231	2.24	0.128	0.221	0.957	1.64	0.310	2.38	0.183	0.301	0.968
2151.8	1.75	0.225	2.26	0.127	0.222	0.990	1.68	0.302	2.40	0.179	0.299	0.992
2155.0	1.77	0.211	2.25	0.119	0.210	0.998	1.70	0.289	2.39	0.171	0.289	0.999
2157.8	1.69	0.241	2.23	0.140	0.237	0.984	1.61	0.325	2.38	0.200	0.321	0.988
2161.0	1.77	0.211	2.25	0.118	0.209	0.992	1.69	0.293	2.39	0.172	0.291	0.994
2164.0	1.77	0.215	2.25	0.121	0.214	0.996	1.68	0.298	2.40	0.176	0.297	0.997
2166.8	1.66	0.255	2.23	0.152	0.253	0.992	1.58	0.338	2.38	0.213	0.336	0.994
2170.0	1.68	0.249	2.24	0.147	0.248	0.995	1.60	0.332	2.40	0.207	0.331	0.996

Table G-1: Laboratory Material Properties and Water Contents Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950408312231.004. J. Curtis and C. Vidano, analysts. Sample number consists of “SD9-” plus depth in feet]

Depth (feet)	Relative Humidity Oven Dried						105°C Oven-Dried					
	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.	Dry Bulk Density (g/cm^3)	Porosity (cm^3/cm^3)	Particle Density (g/cm^3)	Grav. Water Content (g/g)	Vol. Water Content (cm^3/cm^3)	Relative Satn.
2172.8	1.78	0.197	2.22	0.110	0.195	0.989	1.70	0.281	2.36	0.164	0.278	0.992
2175.9	1.78	0.201	2.23	0.112	0.200	0.993	1.70	0.285	2.38	0.167	0.284	0.995
2179.0	1.74	0.231	2.27	0.130	0.226	0.979	1.66	0.312	2.42	0.184	0.307	0.984
2181.7	1.74	0.229	2.25	0.131	0.227	0.991	1.66	0.307	2.39	0.184	0.305	0.993
2185.0	1.77	0.210	2.24	0.118	0.209	0.997	1.69	0.291	2.38	0.172	0.290	0.998
2187.6	1.80	0.197	2.24	0.108	0.195	0.989	1.72	0.278	2.38	0.161	0.276	0.992
2190.9	1.78	0.199	2.23	0.110	0.196	0.983	1.70	0.282	2.37	0.163	0.278	0.988
2193.7	1.74	0.229	2.26	0.130	0.227	0.990	1.67	0.305	2.40	0.181	0.303	0.993
2196.9	1.77	0.215	2.25	0.120	0.212	0.988	1.69	0.294	2.39	0.172	0.291	0.991
2199.9	1.77	0.215	2.25	0.118	0.209	0.970	1.68	0.298	2.40	0.173	0.292	0.978
2202.6	1.77	0.222	2.27	0.125	0.222	0.999	1.70	0.288	2.39	0.169	0.288	0.999
2206.0	1.78	0.206	2.24	0.116	0.206	1.000	1.71	0.275	2.36	0.161	0.275	1.000
2208.8	1.75	0.221	2.25	0.125	0.219	0.990	1.69	0.287	2.37	0.169	0.285	0.992
2211.9	1.77	0.214	2.25	0.117	0.207	0.966	1.70	0.283	2.37	0.162	0.275	0.974
2214.6	1.77	0.211	2.25	0.119	0.211	0.999	1.70	0.283	2.37	0.166	0.283	0.999
2217.9	1.81	0.188	2.22	0.102	0.184	0.983	1.73	0.267	2.36	0.153	0.264	0.988
2221.1	1.81	0.180	2.21	0.099	0.179	0.995	1.73	0.264	2.35	0.152	0.263	0.996

Table G-2: Porosity and Saturated Hydraulic Conductivity Values Measured on Core Samples from Drill Hole USW SD-9

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950608312231.006. Ksat - saturated hydraulic conductivity. Sample number consists of "SD9-" plus depth in feet. nf–no measurable flow]

Depth (feet)	Porosity (cm^3/cm^3)	Ksat (m/ sec)	Notes
56.9	0.177	8.63E-11	
61.8	0.171	1.06E-11	
71.3	0.210	1.85E-10	(a)
77.2	0.270	9.60E-09	
83.1	0.357	8.79E-07	
88.6	0.359	4.87E-07	
100.7	0.379	3.66E-07	
107.5	0.310	2.01E-07	
113.4	0.281	5.87E-08	
116.0	0.265	2.45E-08	
122.3	0.297	4.32E-08	
133.0	0.346	1.02E-06	
137.6	0.333	8.19E-07	
151.7	0.324	1.20E-06	
154.5	0.403	1.41E-06	
160.9	0.465	1.74E-06	
173.0	0.426	1.61E-06	
209.5	0.489	1.74E-06	
217.3	0.438	7.62E-07	
232.3	0.483	5.06E-07	
238.1	0.592	1.87E-06	
246.0	0.581	7.46E-06	
247.4	0.491	5.68E-06	
259.7	0.538	2.19E-06	
278.3	0.016	2.33E-08	(b)
287.1	0.041	nf	
291.1	0.030	nf	
308.3	0.140	4.77E-10	
323.2	0.133	1.83E-09	
335.6	0.117	9.43E-10	
359.1	0.109	2.04E-09	
385.6	0.124	1.99E-08	

Table G-2: Porosity and Saturated Hydraulic Conductivity Values Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950608312231.006. Ksat - saturated hydraulic conductivity. Sample number consists of "SD9-" plus depth in feet. nf–no measurable flow]

Depth (feet)	Porosity (cm^3/cm^3)	Ksat (m/ sec)	Notes
388.1	0.143	5.04E-09	
395.4	0.125	2.30E-10	
405.1	0.098	8.30E-11	
415.0	0.114	6.14E-11	
429.8	0.091	4.22E-09	(b)
439.5	0.082	nf	
455.0	0.096	nf	
479.1	0.094	nf	
512.4	0.146	1.07E-10	
552.6	0.115	1.31E-10	
577.6	0.114	1.17E-10	
599.2	0.132	6.82E-11	
627.0	0.130	3.39E-10	
650.1	0.108	2.07E-09	
658.2	0.094	3.87E-11	
672.2	0.117	3.65E-11	
682.9	0.145	8.53E-11	
697.4	0.110	7.12E-11	
707.6	0.105	2.34E-11	
721.2	0.090	1.71E-11	
730.8	0.094	nf	
746.9	0.073	nf	
777.2	0.081	nf	
798.0	0.112	8.31E-10	(c)
818.2	0.069	nf	
834.3	0.086	nf	
849.8	0.186	3.99E-09	
865.5	0.092	6.71E-11	
899.9	0.085	5.22E-11	
944.9	0.087	5.43E-11	
975.8	0.070	1.18E-11	

Table G-2: Porosity and Saturated Hydraulic Conductivity Values Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950608312231.006. Ksat - saturated hydraulic conductivity. Sample number consists of “SD9-” plus depth in feet. nf–no measurable flow]

Table G-2: Porosity and Saturated Hydraulic Conductivity Values Measured on Core Samples from Drill Hole USW SD-9 (Continued)

[Measurements reported by L.E. Flint, U.S. Geological Survey Hydrologic Research Facility; DTN No. GS950608312231.006. Ksat - saturated hydraulic conductivity. Sample number consists of “SD9-” plus depth in feet. nf–no measurable flow]

Depth (feet)	Porosity (cm^3/cm^3)	Ksat (m/ sec)	Notes
1012.6	0.092	6.94E-11	
1035.5	0.085	nf	
1086.0	0.090	nf	
1105.9	0.104	3.94E-11	
1142.2	0.109	4.38E-10	
1166.2	0.085	nf	
1200.5	0.082	nf	
1224.6	0.092	8.08E-09	(d)
1256.5	0.087	nf	
1285.0	0.097	5.61E-10	(d)
1308.1	0.083	nf	
1335.3	0.067	nf	
1440.5	0.139	1.04E-10	
1444.7	0.277	8.70E-08	
1459.7	0.173	nf	
1466.7	0.215	nf	
1473.3	0.178	nf	
1478.3	0.118	nf	
1501.8	0.266	6.57E-11	
1488.0	0.325	nf	
1513.6	0.213	1.78E-11	
1526.7	0.267	nf	
1547.9	0.248	2.12E-11	
1569.3	0.245	7.23E-12	
1583.5	0.226	1.27E-11	
1617.8	0.278	3.00E-11	
1643.9	0.258	1.44E-11	
1671.9	0.249	5.68E-11	
1698.4	0.335	8.86E-11	
1720.0	0.229	nf	
1768.1	0.216	nf	
1789.0	0.177	nf	
1811.2	0.170	8.88E-11	
1837.2	0.198	nf	(e)
1851.0	0.303	2.45E-10	
1860.8	0.261	5.94E-11	
1896.1	0.333	1.16E-07	
1927.0	0.314	3.04E-09	
1956.5	0.252	2.05E-09	
1977.1	0.212	1.08E-10	
1989.8	0.294	4.40E-10	
2017.0	0.260	5.37E-11	
2040.6	0.247	3.43E-11	
2077.2	0.233	1.90E-11	
2095.1	0.206	1.92E-11	
2118.4	0.173	nf	(e)
2145.5	0.214	1.02E-11	
2158.0	0.216	4.83E-11	
2179.2	0.222	8.79E-11	
2206.2	0.217	1.34E-10	

a. Sample thinner than specification; Ksat may not be valid
b. Sample exhibited high flow but low porosity; pumice or lithophysae may be conducting flow
c. Anomalously high porosity sample
d. Sample is fractured; Ksat is probably too high for matrix
e. Anomalously low flow for high-porosity sample