YUCCA MOUNTAIN STRATIGRAPHIC AND MODEL UNIT CORRELATION CHART

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CONTENTS

Sectio	Pag	je
PLATE	S	iii
ACKN	DWLEDGMENTS	iv
1	BACKGROUND	1
2	PURPOSE	2
3	SCOPE	2
4	DESCRIPTION	2
5	REFERENCES	3
ATTA	CHMENT	

PLATES

Plate		Page
1	Yucca Mountain Stratigraphic and Model Unit Correlation Chart	Attachment

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QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: CNWRA data contained in this report meet quality assurance requirements described in the CNWRA Quality Assurance Manual. Data used in support of this report are taken from documents published by U.S. Department of Energy contractors and supporting organizations; the respective source of these non-CNWRA data should be consulted for determining the level of quality assurance.

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1 BACKGROUND

Yucca Mountain comprises a several kilometer-thick accumulation of volcanic tuff deposited on an irregular surface of eroded and deformed Paleozoic and Precambrian basement composed of highly faulted and folded sedimentary and metasedimentary rocks. The tuff originated from a series of Middle to Late Miocene (15–9 million years) calderas that collectively form what has been defined as the southwestern Nevada volcanic field. Rocks of the Paintbrush Group, principally the Tiva Canyon Tuff (12.7 million years), make up the main surface exposures of Yucca Mountain. Younger tuffs related to the Timber Mountain Group are locally exposed at Yucca Mountain in topographic lows between large block-bounding faults. Alluvium and colluvium, mainly derived from erosion of the Miocene tuffs exposed on fault-bound ridges, also fill the topographic lows and basins. The potential repository horizon is within the underlying Topopah Springs Tuff (12.8 million years) of the Paintbrush Group. The Paintbrush Group tuffs rest on a sequence of older tuffs, including the Prow Pass and Bullfrog formations of the Crater Flat Group.

The rock units of the southwestern Nevada volcanic field were first described by Ball (1907). Hinrichs and Orkild (1961) were the first to define stratigraphy relevant to Yucca Mountain. Their work, northeast of Yucca Mountain's present day surface facilities, led to the initial understanding of the volcanic stratigraphy and the geologic and tectonic evolution of the area. Their work also provided the basis for a series of detailed mapping efforts targeted specifically at the Yucca Mountain block, including the work of Scott and Bonk (1984). The nomenclature of Scott and Bonk (1984) is still included in correlation tables of model layer unit designations. Sawyer, et al. (1994) provide the most recent comprehensive regional stratigraphy of the Miocene volcanic rocks in the Yucca Mountain region. Potter, et al. (2002) and Dickerson and Drake (2006) provide the most recent detailed geologic maps of Yucca Mountain.

The Miocene volcanic strata at Yucca Mountain have been investigated extensively by the U.S. Department of Energy (DOE) and its subcontractors and consultants in order to fully characterize the rock units and as a basis for the development of detailed process-level and performance assessment models of the potential repository at Yucca Mountain. The initial efforts by the U.S. Geological Survey focused on detailed lithostratigraphy, which is a classification based on the age relationship and physical characteristics of rock units, such as layering, color, or composition. Since the development of the original lithostratigraphy, a variety of alternative classifications have been developed depending on the specific purpose and application of the classification to discipline-specific Yucca Mountain studies. These alternatives include (i) model layers for the Geologic Framework Model (Bechtel SAIC Company, LLC, 2004a); (ii) hydrostratigraphic units used in saturated zone flow and transport models, such as the DOE Hydrogeologic Framework Model for the Saturated Zone Site Scale Flow and Transport Model or HFM-27 (Bechtel SAIC Company, LLC, 2004b); (iii) rock units used in unsaturated flow and transport analyses models, such as Bechtel SAIC Company, LLC (2004c,d); and (iv) thermal-mechanical units for use in geomechanical analyses (Ortiz, et al., 1985). Because the nature of volcanic tuff strata is complex, these alternative stratigraphies do not easily correlate with the known lithostratigraphy. As a result, a comprehensive and transparent review of the DOE information may be complicated by potential inconsistencies or omissions among and between the various classifications.

2 PURPOSE

The purpose of this report is to (i) provide staff with the necessary information and tools to rapidly and effectively review and evaluate rock and model unit correlation across technical disciplines (e.g., stratigraphic, hydrologic, and geomechanical); (ii) provide a condensed and comprehensive summary of available DOE information related to the detailed classification of rock and model units at Yucca Mountain; and (iii) in the prelicense period, resolve discrepancies and clarify ambiguities among the numerous stratigraphic systems developed by the DOE and its supporting organizations. As a result of the synthesis, a Yucca Mountain Stratigraphic and Model Unit Correlation Chart (YMCC)¹ (plate 1) was developed. This chart provides a detailed summary of the most relevant and recent stratigraphic information used by DOE across the DOE program.

The DOE stratigraphic and model units have changed as new and more detailed lithostratigraphic information has developed and more detailed computer models have evolved. Therefore, this compilation is a status report, subject to further changes.

3 SCOPE

In order to focus specifically on the site of the potential Yucca Mountain repository, the scope of this report and associated YMCC focuses on the Miocene volcanic stratigraphy that make up the Yucca Mountain block. Younger Quaternary sedimentary and volcanic units, as well as older Paleozoic and Precambrian bedrock strata, are shown as superadjacent and subadjacent boundaries. Based on additional review and analysis of DOE information, these other geologic units may be included in future revisions of the YMCC.

In an effort to limit the size of the chart, only the detailed unit abbreviations from the 2000 Yucca Mountain Site Description (CRWMS M&O, 2000a) were used. These detailed unit abbreviations are used in DOE's various analyses and process models' stratigraphic correlation tables to indicate which units are considered part of that model's layers units. The YMCC's youngest unit used for correlation purposes is the Timber Mountain Group. This unit is also the youngest unit for most of the analyses and process models incorporated in the chart.

4 DESCRIPTION

The foundation of the YMCC is Table 7-1 and Table 7-9 from the Yucca Mountain Site Description (Bechtel SAIC Compay, LLC, 2004e). These tables are very much equivalent to Tables 4.5-1, 4.5-2, and 4.8-1 of the 2000 Yucca Mountain Site Description (CRWMS M&O, 2000a), but do not contain the same level of stratigraphic unit description. This level of detail is useful in determining the correlation of grouped units from DOE analysis and process model reports and was consulted when clarifying unit groupings. However, only the stratigraphic unit abbreviation of the 2000 Yucca Mountain Site Description (CRWMS M&O, 2000a) is included in the YMCC and is used for the correlation of the more recently released DOE analysis and process model reports. The informal unit nomenclature, based on Scott and Bonk (1984), was extracted from Table 7-9 and included in the YMCC as an independent column. The unit

¹Yucca Mountain Stratigraphic Model Unit Correlation Chart (YMCC) (plate 1) is referred to repeatedly in this report; consequently, the term YMCC will be used to designate the chart throughout this report.

symbols of Buesch, et al. (1996, Table 2) that proposed stratigraphic nomenclature were placed next to the Scott and Bonk (1984) column to initiate chronological order and to focus first on the geologic lithostratigraphy. These two columns form the foundation of lithostratigraphic descriptions and designations. Continuing the geologic stratigraphy, all columns from Table 6-2 of the GFM2000 (Bechtel SAIC Company, LLC, 2004a), the volcanic units and unit thicknesses based on borehole data from Table 3-1 of Yucca Mountain Site Description (Bechtel SAIC Company, LLC, 2004e), and the geologic stratigraphy of Table 7-9 in the Yucca Mountain Site Description (Bechtel SAIC Company, LLC, 2004e) were included in YMCC.

The next focus of the YMCC is unsaturated zone flow unit designations. Columns with either detailed and major hydrogeologic units or detailed and 2002 UZ Flow Model layer units [Tables 7-1 and 7-9 of the Yucca Mountain Site Description (Bechtel SAIC Company, LLC, 2004e), Table 6-5 from Development of Numercial Grids for UZ Flow and Transport Modeling (Bechtel SAIC Company, LLC, 2004c), and Table 1 from Flint, et al., (2006)], as well as the 2004 UZ model units and hydrogeologic units of Table 6.1-1 of the UZ Flow Models and Submodels (Bechtel SAIC Company, LLC, 2004d) were incorporated in the YMCC to illustrate the various interpretations of unit designations. The Thermal Mechanical Units column was added to the YMCC from Table 3-5 of the Yucca Mountain Site Description (Bechtel SAIC Company, LLC, 2004f) column and the Mineralogic Model Units (Bechtel SAIC Company, LLC, 2004g) column were also incorporated into the YMCC. The final column added, but placed as the first column in the YMCC, is the Unit Age column taken from Figure 2-8 in the Yucca Mountain Site Description (Bechtel SAIC Company, LLC, 2004e).

The detailed unit abbreviations column from the 2000 Yucca Mountain Site Description (CRWMS M&O, 2000a), described earlier, was inserted again at the end of the YMCC. The intention of repeating the column is to facilitate horizontal referencing across the chart. The unit abbreviations in these two columns are in red print as an aid for unit location. Colored shading of every other formation is also used to assist in horizontal correlation across the YMCC. Another benefit of using color in the YMCC is that the stratigraphic and model unit group designations are more obvious.

The YMCC units included from the Yucca Mountain Site Description (Bechtel SAIC Company, LLC, 2004e, Table 7-9) were formatted with the Group, Formation, and Member placed vertically, if space permitted, as well as horizontally. The dashed lines and arrows indicate that those units (group, formation, member, etc.) listed would be considered as one unit if the DOE report did not differentiate the individual units. The subgroup stratigraphic units in the YMCC have been indented to facilitate easy identification of associations between units. The group and formation stratigraphic units are in bold print for easy recognition. The amount of horizontal or vertical space given a stratigraphic or model unit does not represent the actual thickness of the unit. Unit thicknesses are located in the YMCC as a column from Table 3-1 of the Yucca Mountain Site Description (Bechtel SAIC Company, LLC, 2004e).

The authors of the YMCC did not add stratigraphic units to a YMCC column to make it consistent with the stratigraphic units included from a different table represented in another column [i.e., Rhyolite of Vent Pass is not listed as a unit in the Geologic Framework Model (Bechtel SAIC Company, LLC, 2004a)]. Stratigraphic and model unit correlations in the YMCC are made from the unit name used in the DOE report. If a unit name was not correlatable, a correlation using the unit description was considered (see plate 1 superscript description for ‡

and §). If the DOE analysis and process model report had a blank area in its stratigraphic or model unit table, that space in the YMCC contains a note to that effect. A space in the YMCC may also contain a note that the stratigraphic unit was (obviously) undifferentiated in the DOE stratigraphic table.

Model units may have the same unit abbreviation as the stratigraphic unit; however, the model unit will be either all capitalized letters or all lowercase letters as represented in the DOE table. These model units do not necessarily include the same subunits as indicated for the stratigraphic units. An example is the Tpy stratigraphic unit abbreviation for the Yucca Mountain Tuff Formation and the TPY hydrogeologic unit abbreviation.

Because one of the goals of the YMCC is to enable staff to easily identify source or reference information, each column header of the YMCC has an abbreviated reference callout, which corresponds to the complete reference information in the "Chart References" at the bottom of the YMCC. These complete references have listed beneath them, by table or figure title, the source reference cited in the DOE report. If full reference information was available for the cited source, it was also included (alphabetically) in the YMCC "Chart References."

Superscripts are used in the YMCC to inform the user of an uncertainty in the correlation of a unit or an explanation of the unit nomenclature [see ‡Tptf, Buesch, et al. (1996, Table 2)]. Had the correlation of hydrogeologic units been identical from one column to another in the YMCC, only the most recent report would be included and the later report recognized by a superscript in the column header information.

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Plate 1. Yucca Mountain Stratigraphic and Model Unit Correlation Chart

(Ma)	YM Site Description, 2004 (Bechtel SAIC, 2004e Table 7-9 PREVIOUSLY USE INFORMAL NOMENCLATUR	E SYMBOL	LITHO-		amework Model (GFM2000 echtel SAIC, 2004a) Table 6-2 UNIT ABBREV)) GFM2000 UNIT (RHH) and PTn	UNIT THICKNESS IN SITE AREA (m)	YM Site Descriptio (Bechtel SAIC, 20 Table 3-1 GROUP FORMATION / UNIT		GPOLIA FORMANOL	YM Site Description, 2004 (Bechtel SAIC, 2004e) (Table 7-9) STRATIGRAPHIC UNITS Order Order	YM Site Description, 20 (Bechtel SAIC, 2004e) Table 7-9 HYDROGEOLOGIC UI DETAILED (%) = matrix porosity	NITS			Numerical Grids (Bechtel SAlt Table (FY02 UZ MODEL LAYER	C, 2004c)	(Bechtel S	s and Submodels SAIC, 2004d) le 6.1-1 HYDRO- GEOLOGIC UNIT	Flint et al., 20 Table 1 DETAIL HYDRO UNIT (%) = matrix porosity	(Bechtel SAIC, Table 3-1	2004 Model (Bechtel SAIC, 20 Table 6.1-1	(Bechtel SAIC, 2004g) Table 1	YM Site Description, 2000 (CRWMS M&O, 2000) T4.5-1, T4.5-2, T4.8- LITHO- STRATIGRAPHI UNITS
<0.074 Not given 11.45 Not given 11.6 Not given		Units younge than the Paint brush Group not included Tp Unit not define ## Tpk ## Tpk ## Tpk (inform	Tmbt2 Tmr Tmbt1 Tp Tp Tpbt6 ## Tpk	Alluvium and Colluvium TIMBER MOUNTAIN GROUP Units not differentiated Rainier Mesa Tuff ## Not differentiated PAINTBRUSH GROUP ## Post-tuff unit "X" bedded tuff ## Tuff unit "X" Not differentiated	Qal, Q Tm Units not differentiated Tmr Not differentiated Tp Tpbt6 Not differentiated Tpki (informal) Not differentiated		Not Present in YM Area Generally <30	Timber Mountain Group Ammonia Tanks Tuff Rainier Mesa Tuff	Mountain Group not included Welded to nonwelded rhyolite tuff High-silica rhyolite and quartz latite tuffs Nonlithified pyroclastic flow deposits Rhyolite lava flows and related tephra; pyroclastic flow deposits	Units yo	ounger than the Paintbrush Group not included	Units your the Paintbru not inc	ush Group							Younger units	Undifferentia Overburda (UO)			Tm Tma Tmbt2 Tmr Tmbt1 Tp Tpk ¶¶ Tpbt6 Tpki Tpv
12.7	Units younger than Tiv Canyon vitrophyre not included vitrophyre (ccr) upper cliff (cuc) upper lithophysal (cul) clinkstone (cks), rounded step (crs) lower lithophysal (cll)	t Tpcrv Tpcrv Tpcrv Tpcrn Tpcrn4 Tpcrn4 Tpcrn3 Tpcrn3 Tpcrn2 Tpcr11 Tpcr1 Tpcr1 Tpcr14 Tpcr14 Tpcpul Tpcpul Tpcpul Tpcpul Tpcpun Tpcpmr Tpcpmr Tpcpmr Tpcpll Tpcpll	3p Tpcrv3p Tpcrv2 † Tpcrv1 1c † Tpcrn4 4d Tpcrn4 4d Tpcrn1 1c Tpcrn1 1c Tpcp 1c Tpcpp 1c Tpcpn1 1c Tpcppul 1c Tpcpmn3 1c Tpcpmn1 1c Tpcpll 1c Tpcpll 1c Tpcpllh 1c Tpcpllh	Pre-tuff unit "X" bedded tuff Tiva Canyon Tuff Units not differentiated Units not differentiated Units not differentiated Crystal-Rich Member Vitric zone Units not differentiated Monwelded subzone Units not differentiated Moderately welded subzone Units not differentiated Moderately welded subzone Units not differentiated Units not differentiated Units not differentiated Units not differentiated Units not differentiated Upper subzone Units not differentiated Units not differentiated Units not differentiated Upper subzone Units not differentiated Lithophysal zone Densely welded subzone Upper subzone Upper subzone Upper	Tpbt5 Tpc Units not differentiated Tpcr Tpcrv Tpcrv3 ated Units not differentiated Tpcrv2 Tpcrv1 ated Units not differentiated Tpcrv2 Tpcrv1 ated Units not differentiated Units not differentiated	Crystal-Rich Tiva and Post-Tiva	<50-175		F Pyroclastic flow & fallout tephra deposits Pyroclast flow & fallout tephyrol Pyroc	TIVA C T I V A C A N Y O N T U F F F O P	<i>r</i> Intopriyal zone <i>Crystal-poor Member</i> upper lithophysal zone <i>C</i> <i>r</i> middle nonlithophysal zone <i>y</i> <i>s</i> <i>t</i> lower lithophysal zone <i>I</i> lower nonlithophysal zone	Units younger than the subvitrophyre transition subzone (Tpcrn4) not included CCR (< 10%) Tiva Canyo (TC CUC (> 9%) CUL (< 20%) CW	on welded w)			Units younger than Member (Tpcr) to tcw 11			cCCR, CUC	included CCR (≤9%) CUC (>9%) CUL (<20%)	Canyon Ided Cw)	n	Sequence 22 (Layer 26) Alluvium - Tpc_un	Tpbt5 Tpc Units not differentiated Tpcr Tpcrv3 Tpcrv3 Tpcrv3 Tpcrv3 Tpcrv1 Tpcrv1 Tpcrv1 Tpcrn1 Tpcrl Tpcrl1 Tpcrl1 Tpcpl1 Tpcpmn3 Tpcpul1 Tpcppl1 Tpcpl1 Tpcp1 Tpcp1 Tpcp1 Tpcp1 Tpcp1 Tpcp1 <t< td=""></t<>
Not given	hackly (ch) columnar (cc) vitrophyre nonwelded base (ccs) Units not differentiated	Tpcv1 Tpcv1 Tpcv1	TpcpInc nc3 TpcpInc3 nc2 TpcpInc1 Tpcpv Tpcpv3 3v Tpcpv3v 3c Tpcpv2 Tpcpv1 Tpcpv1 p Tpcpv1	Hackley subzone Columnar subzone Units not differen Vitric zone Densely welded subzone Units not differen Moderately welded subzone Nonwelded subzone Units not diffieren Pre-Tiva Canyon bedded tuff Yucca Mountain Tuff Units not differentiated	iated Units not differentiated Tpcpv Tpcpv3 iated Units not differentiated Tpcpv2 Tpcpv1	TpcLD ////////////////////////////////////	<1-3 0-55 2-14 <250 (lava) <100 (ash flows) Not given <10	Pre-Tiva Canyon Tuff bedded tu Pre-Tiva Canyon Tuff bedded tu Yucca Mountain Tuff Rhyolite of Black Glass Canyon Rhyolite of Delirium Canyon Not differentiated Rhyolite of Zig Zag Hill	Nonwelded to densely welded pyroclastic flow deposit	P A I N	p o o columnar subzone o argillic puinterval M vitric zone e densely welded subzone b densely welded subzone p non to partially welded subzone Pre-Tiva Canyon Tuff bedded tuff A MOUNTAIN TUFF FORMATION Units not differentiated	CMW (>15%)		CNW # BT4 # # TPY #	tcw13 ptn21 # ptn22 # ptn23 # ptn24	tcw13 ptn21 # ptn22 # ptn23 # ptn24	CMW CNW # BT4 # TPY # BT3	tcw13 ptn21 # ptn22 # ptn23 # ptn24	СМW СNW # ВТ4 # ТРҮ # ВТ3	CMW (>15%) CNW (>28%) BT4 TPY (≤30%)		Blank space Table 6.1-1		Tpcplnh Tpcplnc3 Tpcplnc1 Tpcpv Tpcpv3 Tpcpv2 Tpcvln Tpcpv1 Tpcpv1 Tpcvlp Tpcvln Tpcvln <t< td=""></t<>
Not given 12.8		Tpb13 Tpbt3 Tpp Tpbt2 Tptd Tptx Tpbt Tptr Tptrv Tptrv3	Tpb2 Tpbt3 Tpp Tpbt2 Tpt Units not differentiated Tpbt Tptr Tptr Tptrv Tptrv3	Pre-Yucca Mountain bedded tuff Pah Canyon Tuff Pre-Pah Canyon bedded tuff Topopah Spring Tuff Units not differentiated Crystal-Rich Member Vitric zone Nonwelded subzone	Tpbt3 Tpp Tpbt2 Tpt Units not differentiated Tptr Tptrv Tptrv3	Tpbt3_dc Pah ‡‡ (≤65% porosity) Tpbt2 ////////////////////////////////////	<1-46 0-79 3-10	Pre-Yucca Mtn Tuff bedded tuff Pah Canyon Tuff Pre-Pah Canyon Tuff bedded tu	Pyroclastic flow deposits; abundant large pumice clasts	R U S	Pre-Yucca Mountain Tuff bedded tuff CANYON TUFF FORMATION Pre-Pah Canyon Tuff bedded tuff PAH SPRING TUFF FORMATION Crystal-rich Member C r	BT3 Paintbrush (PT BT2	nonwelded ' n)	ТРР	ptn25	ptn25 ptn26	TPP BT2	ptn24	TPP BT2	non	tbrush velded Tn) Paintbrus nonwelde (PTn)		Sequence 20 (Layer 24) Tpcpv1 - Tptrv2	Tpbt3 Tpp Tpbt2 Tpt Units not differentiated Tpbt Tptr Tptrv Tptrv3
	vitrophyre (tc) rounded (tr) Not differentiated	Tptrv3 Tptrv1 Tptrv1 Tptrv1 Tptrv1 Tptrv1 Tptrv1 Tptrv2 Tptrv1 Tptrv1 Tptrv1 Tptrn3 Tptrn1 Tptrl1 Tptrf Tptrf	p Tptrv3p Tptrv2 Tptrv1 c TptrvIc	Units not differer Moderately welded subzone Densely welded subzone Units not differer Nonlithophysal zone Dense subzone Vapor-phase corroded subzone Crystal transition subzone Lithophysal zone	tiated Units not differentiated Tptrv2 Tptrv1 tiated Units not differentiated Tptrn Tptrn3 Tptrn3 Tptrn2 Tptrn1 Tptrl1	Tptrv3 Tptrv2 Tptrv1 Tptrn Tptrn Tptrl		(>1 cry fre	A A A A A A A A A A A A A A A A A A A	К О U Р Т О Р О Р А Н		TC (<9%)			[#] tsw31 [#] tsw32	[#] tsw31 [#] tsw32	# TC # TR	[#] tsw31 [#] tsw32	# TC # TR	TC (<9%) TR	Topopah Sp welded			Tptrv3n Tptrv3p Tptrv2 Tptrv1 † Tptrvlc † Tptrvlv Tptrn Tptrn3 Tptrn2 Tptrn1 Tptrl Tptrl1 tptrl1 tptrf Tptrf
	upper lithophysal (tul) middle nonlithophysal (tm lower lithophysal (tll)	n)	Tptrfl Tptp Tptfl Tptp Tptpf Tptpfl Tptpul Tptpulc Tptpuls Tptpmn Tptpmn2 Tptpmn2	Units not differen Crystal-Poor Member Lithic-rich zone Units not different Upper lithophysal zone Units not differentiate Middle nonlithophysal zone Nonlithophysal subzone Lithophysal subzone Lower lithophysal zone Not differentiated Lower nonlithophysal zone	tiated Tptp Tptp/Tptrf Units not differentiated Tptpul	Totoll	0-381	Topopah Spring Tuff	Compositionally zoned (rhyolite to quartz latite) tuff sequence; each member divided into several zones and subzones. Repository host rock is within crystal-poor member.	SPRING TUFF FORMA	e r Crystal-poor Member upper lithophysal zone C r y Imiddle nonlithophysal zone s t a Iower lithophysal zone l	TUL Topopah weld (TS TMN TLL TM2	bed	TMN TLL	tsw33 tsw34 tsw35 tsw36	tsw33 tsw34 tsw35	TUL TMN TLL TM2	tsw33 Blank space in Table 6.1-1 tsw34 tsw35	TUL Blank space in Table 6.1-1 TMN TLL TM2	- S	Topopah Sp welded Sw) Topopah Sp welded lithophysae- (TSw2)	ing TSw	Tptrn - ‡ Tptf ////////////////////////////////////	IptrfTptrflTptp‡ TptfTptpfTptpflTptpulTptpulTptpulsTptpulsTptpmnTptpmn1TptpllTptpllTptpllTptpllTptpllTptpllTptpllTptpllhTptplnTptpln
-	mottled (tm) Units not differentiated basal vitrophyre (tv) Units not differentiated	TptpInc Tptplin Tptplin Tptplin Tptpin Tptpin Tptpin Tptpin Tptpin Tptpin Tptpv Tptpv3 Tptpv Tptpv Tptpv2 Tptpv1	TptpInc C3 TptpInc3 c2 TptpInc2 c1 TptpV Tptpv3 Tptpv3v 3v Tptpv2 Tptpv1 Tptpv1 1p Tptpvlpv1 Tptpv1 Tptpv1 Tptpv1 Tptpv1 Tptpt1 Tptpv1	Units not differen Vitric zone Densely welded subzone Units not differen Moderately welded subzone Nonwelded subzone Units not differen Pre-Topopah Spring bedded tuff Calico Hills Formation	tiated Tptpv Tptpv3 Units not differentiated Tptpv2 Tptpv1	Tptpln ////////////////////////////////////	0-17	(< cry fra me <i>Pre-Topopah Spring Tuff bedded</i>	5% 5% stal g- nts) tuff Bedded tuffaceous deposits	T I O N	P 0 Iower nonlithophysal zone 0 r Iower nonlithophysal zone M vitric zone Idensely welded subzone B Idensely welded subzone Imoderately welded subzone r Imoderately welded subzone Inonwelded subzone Pre-Topopah Spring Tuff bedded tuff Imoderately welded subzone	(upper 2/3) TM1 (lower 1/3) PV3		(upper 2/3) TM1 (lower 1/3) PV3 PV2 tsw BT1 or BT1a (altered)	ch1 (vit, zeo) # ch2	[#] ch2	(upper 2/3) TM1 (lower 1/3) PV3 PV2 BT1 or BT1a (altered)	tsw36 tsw37 tsw38 tsw39 (vit, zeo) ch1 (vit, zeo) # ch2	Im2 (upper 2/3) TM1 (lower 1/3) PV3 PV2 BT1 or BT1a (altered)	Im2 (upper 2/3) TM1 (lower 1/3) PV3 PV2 BT1a or BT1	Topopah Sp welded vitrophyr (TSw3)	Blank space Table 6.1-1		Tptplnc Tptplnc3 Tptplnc2 Tptpv Tptpv3v Tptpv2 Tptpv1 Tptpvln Tptpv1 Tptptv1 Tptptv1 Tptptv1 Tptptv1 Tptptv1 Tptpt1 Tptpt1 Tptpt1
-	(CHv) §§ Calico Hills zeolitized (CHz) Units older than Calico H zeolitized not included	ills	Tac3 Tac2 Tac1 Tacbt Tacbs Tc Tcp	Units not differentiated Bedded tuff Not differentiated CRATER FLAT GROUP Prow Pass Tuff	Units not differentiated Tacbt Not differentiated Tc Tcp	Calico Calicobt	15–457 9–39 Not given	Calico Hills Formation Pre-Calico Hills Formation bedded tuff CRATER FLAT GROUP	Rhyolite tuffs and lavas; contains five pyroclastic units Pyroclastic flow and coarse-grained fallout deposits	CRATER FLA	Member Unit 4—Pumiceous pyroclastic flow Not given Unit 3—Lithic-rich pyroclastic flow Unit 2—Pumiceous pyroclastic flow Unit 1—Lithic-rich pyroclastic flow Bedded Tuff Basal Sandstone AT GROUP PASS TUFF FORMATION			CHV (vitric) or CHZ (zeolitic) # cl # cl # cl		(vit, zeo) # ch3 (vit, zeo) # ch4 vit, zeo # ch5 vit, zeo ch6 (vit, zeo)	CHV (vitric) or CHZ (zeolitic) BT	(vit, zeo) # ch3 (vit, zeo) # ch4 vit, zeo ch5 vit, zeo ch6 (vit, zeo)	CHV (vitric) or CHZ (zeolitic) BT	CHV (vitric) CHZ (zeolitic) BT	Calico Hil nonwelde (CHn)		Tac (subdivided into 4 layers of equal thickness) Sequence 10, (Layer 10) Tacbt	<pre>/ Tac5 Tac4 Tac3 Tac2 Tac1 Tacbt Tacbs Tc Tc Tcp</pre>
			Tcp4 § Tcpuv (altered ash) § Tcpuv (1-4 altered ash flows; 3-12 mm pumice) § Tcpuv (1-2 altered ash flows with pumice) Tcp3 § Tcpuc (vapor phase altered) § Tcpuc (upper nonwelded) § Tcpuc (upper moderately welded) § Tcpuc (middle nonwelded) § Tcpuc (lower moderately welded)	Prow Pass Tuff upper vitric nonwelded zone Prow Pass Tuff upper crystalline nonwelded zone Prow Pass Tuff moderately to den welded zone	¶ Тсриv ¶ Тсрис eely ¶ Тсриd	Prowuv Prowuc Prowmd	15–194	Prow Pass Tuff		P		PP4 (zeolitic)		PP4 (zeolitic) PP3 (devitrified) PP2	pp4	рр4	PP4 (zeolitic) PP3 (devitrified) PP2	рр4	PP4 (zeolitic) PP3 (devitrified) PP2	BTa (zeolitic) PP3 PP2 Cali	to Hills Hn)		# Sequence 9 (Layer 9) Tcpuv Sequence 8 (Layer 8) Tcpuc - Tcplc	Tcp4 § Tcpuv (altered ash) § Tcpuv (1-4 altered ash flows 3-12 mm pumice) § Tcpuv (1-2 altered ash flows with pumice) Tcp3 § Tcpuc (vapor phase altered) § Tcpuc (upper nonwelded) § Tcpuc (upper moderately welded) § Tcpuc (upper moderately welded) § Tcpuc (upper moderately welded) § Tcpuc (middle nonwelded) § Tcpuc (middle nonwelded)
			§ Tcplc (lower nonwelded) Tcp2 § Tcplv (upper pyroclastic flow; altered, 3–7% lithics, pumice) § Tcplv (lower pyroclastic flow; abundant lithics, pumice) § Tcplv (lower pyroclastic flow; abundant lithics, pumice) § Tcplv (basal ash flow deposit) Tcp1 § Tcplv (10–40 mm pumice, <3% lithic clasts)	Prow Pass Tuff lower crystalline nonwelded zone Prow Pass Tuff lower vitric nonwelded zone	¶ Tcplc	Prowlc			Includes four variably welded pyroclastic flow deposits	OW PASS TUFF FORMATION CRATER FLAT G	t g i v e n Unit 2—Lithic-rich pyroclastic flow	PP1 (zeolitic) Calico Hills I (CH	⊢	(devitrified)	pp2	рр2 # pp1	(devitrified) # PP1 (zeolitic)	рр2 # pp1	(devitrified) # PP1 (zeolitic)	# PP1 (upper part)		Tcp (Table 6.1-1 h Tcbbt abbreviat for the Pre-Pro Pass bedded to should be Tcp	on w ff;	§ Tcplc (lower nonwelded) Tcp2 § Tcplv (upper pyroclastic flow altered, 3–7% lithics, pumice) § Tcplv (lower pyroclastic flow abundant lithics, pumice) § Tcplv (lower pyroclastic flow abundant lithics, pumice) § Tcplv (basal ash flow deposit Tcp1 § Tcplv (basal ash flow deposit) § Tcplv (10–40 mm pumice, <3% lithic clasts) § Tcplv (4–30 mm pumice, <5% lithic clasts) § Tcplv (5–25 mm pumice, <3% lithic clasts) § Tcpbt (upper pumiceous tuff ≤70% pumice, biotite ra § Tcpbt § Tcpbt
13.35			(upper pyroclastic flow; 3–5% lithics, subordinate biotite) § <i>Tcpbt</i> (lower pyroclastic flow; 10–15% lithics, abundant biotite) § <i>Tcpbt</i> (lower pumiceous tuff; ≤80% pumice, biotite, and breccia) Tcb § Tcbuv (upper pyroclastic flow; variably welded, <2% lithics) § Tcbuc/Tcbmd	Pre-Prow Pass Tuff bedded tuff Bullfrog Tuff Bullfrog Tuff Bullfrog Tuff upper vitric nonwelded zone Bullfrog Tuff upper crystalline	Tcpbt Tcpbt Tcb ¶ Tcbuv	Prowbt	<1–3.5	Pre-Prow Pass Tuff bedded tu	ff Pumiceous tuffs and pyroclastic flow deposits flow deposits flow deposits	R O U P	Pre-Prow Pass bedded tuff FROG TUFF FORMATION M e # Unit 4 m b e e	# BF3 (welded)		#BF3 (welded)										(upper pyroclastic flow 3–5% lithics, subordina biotite) § <i>Tcpbt</i> (lower pyroclastic flow 10–15% lithics, abunda biotite) § <i>Tcpbt</i> (lower pumiceous tuff; ≤80% pumice, biotite, and breccia) <i>Tcb</i> § <i>Tcbuv</i> (upper pyroclastic flow variably welded, <2% lithics) § <i>Tcbuc/Tcbmc</i>
13.9			(pumiceous fallout; partially to moderately welded, clast supported) § Tcblc/Tcblv (lower pyroclastic flow; moderately welded, pumice with phenocrysts) § Tcbbt (pre-Tcb bedded tuffs; reworked pyroclastic deposits) Tct § Tctuv	nonwelded zone Bullfrog Tuff welded zone Bullfrog Tuff lower crystalline nonwelded zone Bullfrog Tuff lower vitric nonwelded zone Pre-Bullfrog Tuff bedded tuff Tram Tuff Tram Tuff upper vitric nonwelded zone	¶ Tcbmd ¶ Tcblc ¶ Tcblv ¶ Tcblv Tcbbt Tct one	Bullfrogmd Bullfroglc Bullfroglv Bullfrogbt Tramuv	15–366	Bullfrog Tuff Pre-Bullfrog Tuff bedded tuff	Includes two pyroclastic flow deposits separated by a pumiceous fallout unit Pyroclastic flow deposits with thin zones of fallout tephra	FR RM OA GT I TO UN F F	<pre> # Unit 3 n o t g # Unit 2 </pre>			# ===	[#] bf3	[#] bf3	<pre># BF3 (welded) # BF2 (nonwelded)</pre>	[#] bf3	# BF3 (welded) # BF2 (nonwelded)	# BF2 (nonwelded)	Fu)	Not Modeled	# Sequence 6 (Layer 6) Tcbuc - Tcblc # Sequence 5 (Layer 5) Tcblv - Tctuv	(pumiceous fallout; partially to moderately welded, clast supported § Tcblc/Tcblv (lower pyroclastic flow moderately welded, pumice with phenocryst § Tcbbt (pre-Tcb beddet tuffs; reworked pyroclastic deposits) Tct § Tctuv (littic-poor unit variable
			(lithic-poor unit, variable welding, altered pumice) § Tctuc/Tctmd/ Tctlc/Tctlv (lithic-rich unit; 10–60% altered lithic clasts) § Tctbt (pre-Tct bedded tuffs; altered pyroclastic fallout deposits) I TII (dacitic flow breccia with interbedded thin lava flows) I TIIbt (bedded tuff deposit;	Tram Tuff upper crystalline nonwelded zone Tram Tuff moderately to densely welded zone Tram Tuff lower crystalline nonwel Tram Tuff lower vitric nonwelded zone Pre-Tram Tuff bedded tuff *** Lava and flow breccia (informal) *** Bedded tuff	¶ Tctlv Tctbt	Tramuc Trammd Tramlc Tramlv Trambt	0-370 0-21 111-249	Tram Tuff Pre-Tram Tuff bedded tuff Dacitic lava and flow breccia (Only found in northern and western Yucca Mountain)	Pyroclastic flow deposits and bedded tuffs Pyroclastic flow and fallout deposits Dacitic lavas and flow breccia; bedded tuff at base	Tram 1	Tuff (not differentiated) Units older than Tram Tuff not included	# BF2 (zeolitic)	entiated	"Not Available" "Not Available" Older units not included	[#] tr3		"Not Available" "Not Available" Older units not included	[#] tr3	"Not Available" "Not Available" Older units not included	Older units not inc	uded		# Sequence 4 (Layer 4) Tctuc - Tctlc Sequence 3 (Layer 3) Tctlv - Tctbt	(lithic-poor unit, variable welding, altered pumice § Tctuc/Tctmd/ Tctlc/Tctlv (lithic-rich unit; 10–60% altered lithic clasts) § Tctbt (pre-Tct bedded tuffs; altered pyroclastic fallout deposits) § T/// (dacitic flow breccia with interbedded thin lava flows) § T///bt (bedded tuff deposit;
15.2–14			(bedded tuff deposit; reworked, altered pumice fragments)	*** Lithic Ridge Tuff *** Bedded tuff *** Lava and flow breccia (informal *** Bedded tuff *** Lava and flow breccia (informal *** Lava and flow breccia (informal	Tr # TIrbt # TII2 # TIIbt	Tund	185–304	western Yucca Mountain)	Pyroclastic flow deposits			Units older than the Tram T not included	ūff		# tr2 nd units below)	[#] tr2		[#] tr2					Sequence 2 (Layer 2) Tund	Image: second
15.1 Not given ** 65.5 ** >251.0			tiows/bedded tufts, transition from quartz-rich to quartz-poor)	*** Bedded tuff *** Older Tuffs (informal) *** Unit a (informal) *** Unit b (informal) *** Unit c (informal) *** Unit c (informal) *** Sedimentary rocks and calcified *** Tuff of Yucca Flat (informal) Not present in model or area Pre-Tertiary sedimentary roc Lone Mountain Dolomite Roberts Mountain Formation	# TII3bt # Tt # Tta # Tta # Ttb # Ttc tuff # Tca # Ty # SIm # SIm # Srm	Mesozoic Paleozoic	45–350+	Pre-Lithic Ridge Tuff volcanic rocks Older units not included	Pyroclastic flow deposits and bedded tuffs Older units not included														Not present (Layer 1) Paleozoic (lower bounding surface)	transition from quartz-ric to quartz-poor)

SYMBOL REFERENCES

Yucca Mountain Site Description 2000, (CRWMS M&O, 2000a) has the same unit abbreviation for the Tiva Canyon nonwelded subzone and the nonwelded interval for that subzone of the crystal-rich vitric member.

- Table 4.5-2 of the Yucca Mountain Site Description 2000, (CRWMS M&O, 2000a) has a lower case "L" where a "1" is used in all other Tables included here.
- Buesch, et al., (1996), Open-File Report 94-469, Table 2 repeats the Lithic-rich zone, subzone and interval abbreviations (Tptf, Tptrf, Tptrfl and Tptrfn) for the zone, subzone, and interval within the crystal-poor member (Tptp). Tptf defines a lithic-rich zone. The contact between the overlying crystal-rich member and the underlying crystal-poor member is within the interior of the lithic-rich zone. The correct symbols should be Tptf, Tptpf, Tptpfl, and Tptpfn; per Yucca Mountain Site Description 2000 (CRWMS M&O, 2000a), Table 4.5-2.
- Unit description from Table 4.5-1 and Table 4.5-2 (CRWMS M&O, 2000a); source of lithostratigaphic units and descriptions given as Moyer and Geslin (1995) for the Prow Pass Tuff; Spengler, et al., (1981) pp. 83–84 and Spengler and Chormack (1984) pp. 25–26 for the Bullfrog Tuff; and Carr, et al., (1986), Spengler, et al., (1981), Maldonado and Koether (1983), and Scott and Castellanos (1984) pp. 34, 36–37 for the Tram Tuff. Unit symbol given in Table 4.8-1 (CRWMS M&O, 2000a); source of lithostratigraphic description given as Geologic Framework Model 3.1 (CRWMS M&O 2000b). Direct correlation of the Bullfrog Tuff and the Tram Tuff between Table 4.5-1 and 4.8-1 (CRWMS M&O, 2000a), is not possible with this information.
- Unit description from Table 4.5-1(CRWMS M&O, 2000a); source of lithostratigaphic units and descriptions given as study of borehole G-1 (Spengler, et al., 1981, p. 36–39) Unit symbol given in Table 4.8-1 (CRWMS M&O, 2000a); source of lithostratigraphic description given as DTN: MO9510RIB00002.004 [YMP Reference Information Base Item: Stratigraphic Characteristics; Geologic/Lithologic Stratigraphy (1996)] (CRWMS M&O, 1997a). Descriptions given do not permit unit correlation.
- Geologic Framework Model 2000 (Bechtel SAIC Company, LLC, 2004c) and Geologic Framework Model 3.1 (CRWMS M&O, 2000b) (Geologic Framework Model 3.1 not included in the Yucca Mountain Stratigraphic and Model Unit Correlation Chart), references subdivision of the Crater Flat Group into six zones to accommodate needs of Geologic Framework Model users as given in Buesch and Spengler (1999, p. 62–64); only a direct correlation of Prow Pass Tuff properties is represented in the publication.
- Not able to directly correlate to stratigraphic units.
- Age added from Geologic Time Scale (Gradstein and Ogg, 2004)
- †† Table 6-2 of Geologic Framework Model 2000 (Bechtel SAIC Company, LLC, 2004c) labels this unit a subzone—should be zone.
- See page 3-32, 2004 Yucca Mountain Site Description (Bechtel SAIC Company, LLC, 2004e) for explanation.
- §§ Units do not correlate to Scott and Bonk (1984).

Discrete unit divisions not given.

- ¶¶ Unit symbol from Table 4.8-1 (CRWMS M&O, 2000a); source given as DTN: MO9510RIB00002.004 [YMP Reference Information Base Item: Stratigraphic Characteristics; Geologic/Lithologic Stratigraphy (1969)] (CRWMS M&O, 1997a).
- ## Model stratigraphic units [e.g., Table 6-2 (Bechtel SAIC Company, LLC, 2004c) and Table 4.8-1 (CRWMS M&O, 2000a)] correlates the Tuff unit "X" (Tpki) to the rhyolite of Comb Peak per Table 2 of Buesch, et al., 1996; however, Table 2 (Buesch, et al., 1996) describes the rhyolite lava flows and related tephra of the Rhyolite of Comb Peak as Tpk and the older pyroclastic flows tentatively correlated with the rhyolite of Comb Peak as Tuff unit "X" (Tpki). It is unclear if the Post-tuff unit "X" bedded tuff (Tpbt6) is equivalent to the Pre-Rainier Mesa Tuff bedded tuff (Tmbt1). MO9510RIB00002.004 (CRWMS M&O, 1997a), source indicated for multiple tables, lists Tpbt6 in the Yucca Mountain Stratigraphic Nomenclature table but not the Tmbt1 bedded tuff; it does describe the Tmbt1 unit but not the Tpbt6 bedded tuff.
- *** These hierarchical stratigraphic relationships do not coincide with Section 3.3.4.5, page 3-15 of the 2004 Yucca Mountain Site Description (Bechtel SAIC Company, LLC, 2004e).

CHART REFERENCES

Bechtel SAIC Company, LLC. (BSC) "Geologic Framework Model (GFM2000)." MDL–NBS–GS–000002. Rev. 02. Table 6-2. Las Vegas, Nevada: Bechtel SAIC Company, LLC. pp. 6-12 through 6-15. 2004a.
 Table 6-2:
 Correlation Chart for Model Stratigraphy
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