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Yucca Mountain Site Characterization Project

Geotechnical Characterization for the Main Drift of the Exploratory Studies Facility

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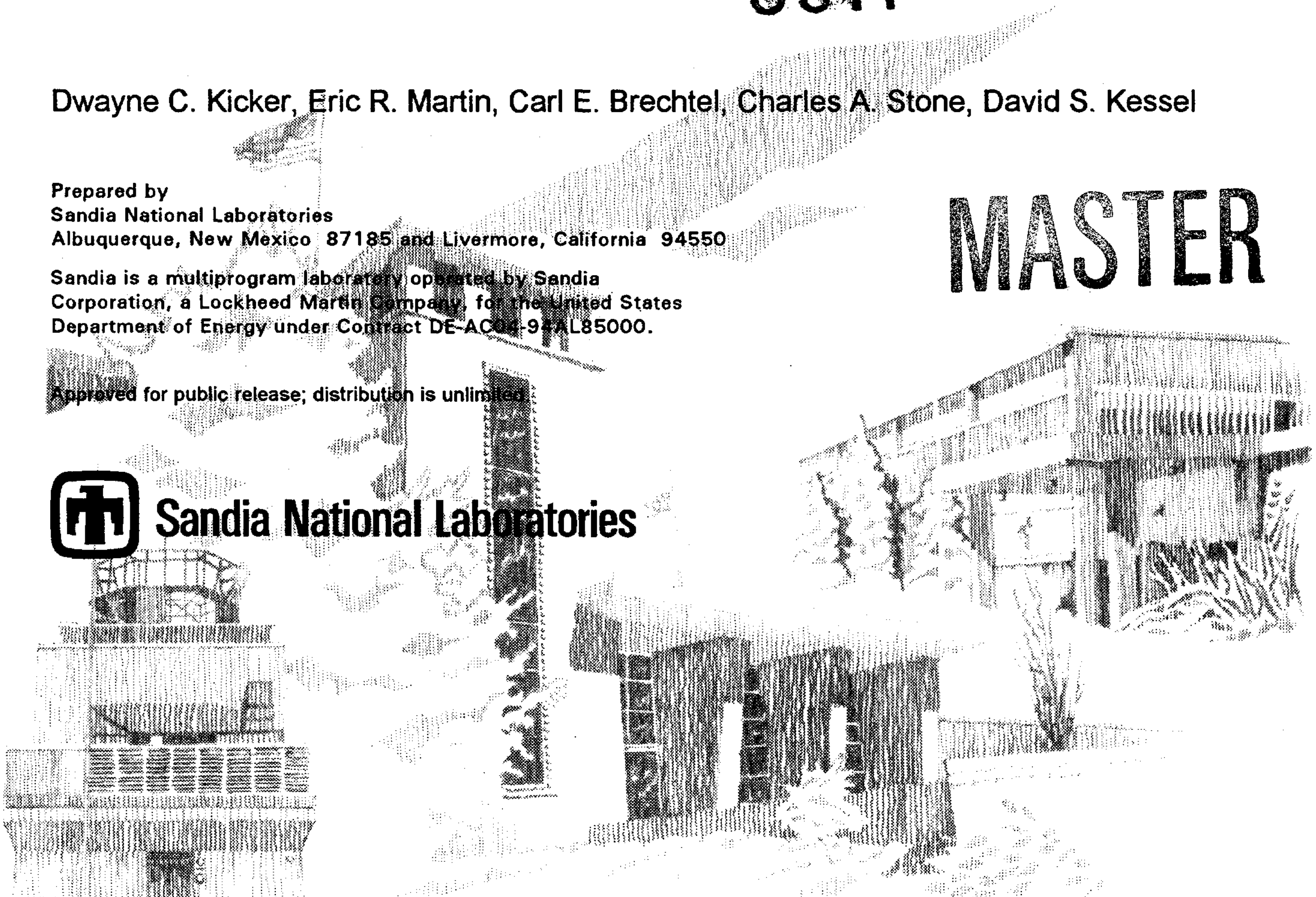

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Geotechnical Characterization for the Main Drift of the Exploratory Studies Facility

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Abstract

Geotechnical Characterization of the Main Drift of the Exploratory Studies Facility was based on borehole data collected in site characterization drilling and on scanline rock mass quality data collected during the excavation of the North Ramp. The Main Drift is the planned 3,131-m (10,273-ft) near-horizontal tunnel to be excavated at the potential repository horizon for the Yucca Mountain Site Characterization Project. Main Drift borehole data consisted of three holes — USW SD-7, SD-9, and SD-12— drilled along the tunnel alignment. In addition, boreholes USW UZ-14, NRG-6, and NRG-7/7A were used to supplement the database on subsurface rock conditions. Specific data summarized and presented included lithologic and rock structure core logs, rock mechanics laboratory testing, and rock mass quality indices. Cross sections with stratigraphic and thermal-mechanical units were also presented. Topics discussed in the report include geologic setting, geologic features of engineering and construction significance, anticipated ground conditions, and the range of required ground support.

Rock structural and rock mass quality data have been developed for each 3-m (10-ft) interval of core in the middle nonlithophysal stratigraphic zone of the Topopah Spring Tuff Formation. The distribution of the rock mass quality data in all boreholes used to characterize the Main Drift was assumed to be representative of the variability of the rock mass conditions to be encountered in the Main Drift. Observations in the North Ramp tunnel have been used to project conditions in the lower lithophysal zone and in fault zones.

This work was supported by the United States Department of Energy under Contract DE-AC04-94AL85000 and was prepared under the Yucca Mountain Site Characterization Project WBS numbers 1.2.3.2.6.2.1, 1.2.3.2.6.2.2, and 1.2.3.2.6.2.3, QA Grading Report #1.2.3.2.6.2.1, Revision 0. The planning document that guided this work activity was Work Agreement #071, Revision 00. The information and data documented in this report were collected under a fully qualified QA Program, except as noted in the report.

This report supports work defined in the Site Characterization Plan Section 8.3.1.14.2 and is discussed in Study Plan SP-8.3.1.14.2, Revision 0, Sections 2.3.1.3 and 2.3.2.3.

ACKNOWLEDGMENTS

The authors would like to acknowledge the support and contributions of the various organizations involved in conduct of the surface-based site characterization activities. Timothy J. Sullivan, Department of Energy (DOE), supported the work as WBS Element Manager responsible for the Soil and Rock Properties studies. Dale Engstrom of Spectra provided lithology logs for USW SD-7, SD-9, SD-12, and UZ-14 boreholes. David C. Buesch, U.S. Geological Survey (USGS), provided review of logs for USW SD-7 and UZ-14. Gerald Nieder-Westermann, TRW/Morrison Knudsen, assisted in the development of the Main Drift cross section. Geologists of the Drilling Support Division, Drilling Support Sample Management Department, T&MSS, were responsible for development of the field rock structural logs.

Coordination and direction of the field support activities was performed by Kenneth Skipper, Drew Coleman, and Leroy Heath of the DOE.

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1.0 Introduction

1.1 Purpose

The purpose of this report is to provide a geological and geotechnical characterization along the path of the Exploratory Studies Facility (ESF) Main Drift to support the geotechnical design. The ESF is being constructed by the U.S. Department of Energy (DOE) and is part of the Yucca Mountain Site Characterization Project (YMP). The purpose of the site characterization activities is to evaluate the feasibility of locating a high-level nuclear waste repository at the Yucca Mountain site. This report was prepared as part of the Soil and Rock Properties studies, W.B.S. 1.2.3.2.6.2 in accordance with Study Plan 8.3.1.14.2, *Soil and Rock Properties of Potential Locations of Surface and Subsurface Access Facilities* (DOE).[1]

1.2 Background

The Main Drift is the planned horizontal tunnel that will be excavated at the potential repository horizon over a length of 3,131 m (10,273 ft) between the North and South Ramps of the YMP ESF. Each of these tunnels will be excavated using a 7.62-m (25-ft) diameter tunnel boring machine (TBM). In the first phase of ESF construction, the North Ramp portal and surface pad were constructed in 1994. The second phase of construction includes the excavation of the North Ramp currently in progress. The North Ramp[2] extends 2804 m (9,200 ft) from the surface portal to the potential repository horizon. The Main Drift will then be constructed followed by the 1,921-m (6,302-ft) South Ramp[3] to connect to the surface. A map showing the locations of the North Ramp, Main Drift, and South Ramp is shown in Figure 1-1.

Three systematic drilling (SD) exploratory boreholes (USW SD-7, SD-9, and SD-12) were drilled to characterize the geological and geotechnical rock properties along the Main Drift alignment and to support the design and construction of the Main Drift. North Ramp Geologic (NRG) holes, NRG-6 and -7/7A, and hole UZ-14 were also used to increase the available database at the Main Drift horizon. Nonqualified rock quality data from borehole USW G-4 was reported (Lin et al. 1993a), however, these data were not included in this study. Stratigraphic contacts from USW G-4 were included in the three-dimensional geologic model of the YMP site that was the basis for the development of the Main Drift cross section. The three SD holes were

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[1] Department of Energy (1991). Yucca Mountain Site Characterization Project, Study Plan No. 8.3.1.14.2, *Studies to Provide Soil and Rock Properties of Potential Locations of Surface and Subsurface Access Facilities*, U.S. Geological Survey, Las Vegas, NV, November.

[2] ESF Layout Calculation—BABEAD000-01717-0200-00003, Rev. 02.

[3] Ibid.

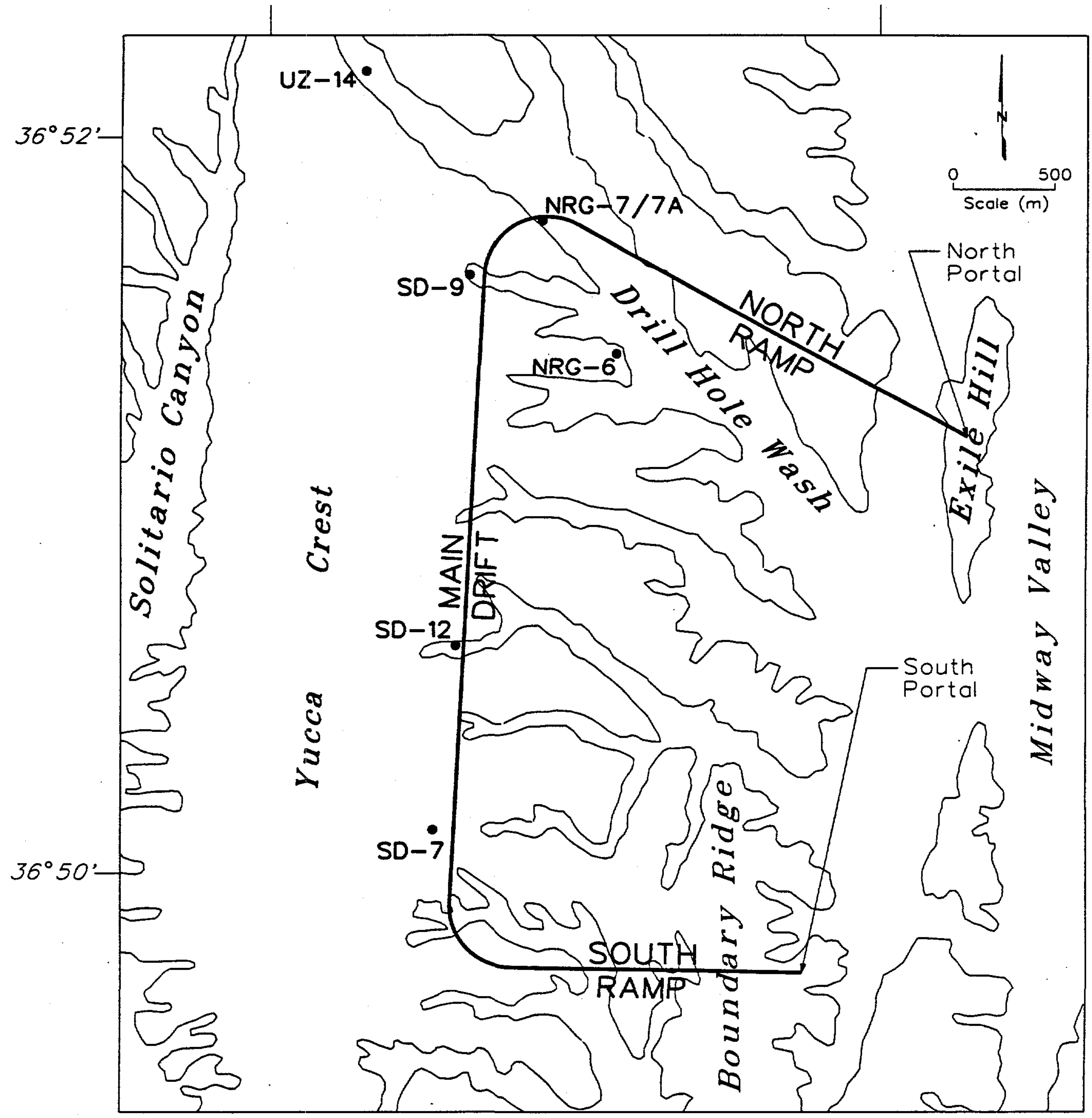

Figure 1-1. Plan map of conceptual repository, locations of the North Ramp, Main Drift, and South Ramp, and locations of the boreholes used to characterize the Main Drift.

located next to the planned tunnel alignment but were required to be a minimum of 15 m (49.2 ft) from the tunnel centerline as per the ESF design requirements (DOE 1994). The approximate location of these boreholes is shown in Figure 1-1.

A geologic cross section shown in Figure 3-1, Section 3.0, includes the stratigraphic units, the location of the SD boreholes, and the proposed Main Drift alignment. The Main Drift differs from the North Ramp in that the entire length of tunnel is contained in one thermal-mechanical unit—the second Topopah Spring welded unit (TSw2), which is a moderately to densely welded, devitrified ash flow of the Topopah Spring Tuff that contains less than approximately 10% by volume lithophysal cavities. The Main Drift is almost entirely within the Topopah Spring crystal-poor middle nonlithophysal stratigraphic zone (Tptpmn). Geologic, geotechnical, and geophysical logs were developed for each hole. No additional rock mechanics testing data, beyond that developed in the NRG holes was available at the time of preparation of this report. The geologic logging consisted of detailed lithologic descriptions and stratigraphic identifications. The geotechnical log recorded rock structural features such as type, fracture characteristics, rock quality designation (RQD), core recovery, weathering, hardness, and lithophysae and other void content. Physical property test data from rock mechanics testing of core included density, porosity, unconfined compressive strength, triaxial compressive strength, and Brazilian indirect tensile strength. Borehole televiewer logs also were generated for each hole.

Estimates of rock mass quality were determined using both the Q (Barton et al. 1974) and the rock mass rating (RMR) (Bieniawski 1979) systems for classifying rock masses. The geotechnical core logging data was used as input for both classification systems using the approach described by Brechtel et al. (1995).

The rock mass quality data and rock mechanics testing data were used to derive estimates of rock mass mechanical properties required for design analysis using the methodology proposed by Hardy and Bauer (1991).

Tunneling experience from the construction of the North Ramp was considered in the characterization of the Topopah Spring middle nonlithophysal zone (Tptpmn). Rock mass quality data were collected along scanlines in the Tiva Canyon Tuff (Tpc) of the North Ramp and compared to the North Ramp core-based rock quality assessments. Data from the Tiva Canyon welded tuff, excluding the high lithophysal portion, were assumed to have characteristics similar to the Tptpmn. Based on this comparison, adjustments were made to the rock quality parameters not directly derived from the core to attempt to incorporate the observed field conditions.

1.3 Scope

This report provides a geological and geotechnical characterization of the ESF Main Drift. The primary focus of this characterization is to assess the variability of rock mass quality of the Tptpmn for input to the design and the construction of the Main Drift. A geologic cross section along the Main Drift is presented to provide the stratigraphic context of the rock properties data. Geologic description is limited to the middle nonlithophysal zone.

No new surface mapping was conducted as part of this study. Description of the faults in the vicinity of the Main Drift is based primarily on surface mapping by Scott and Bonk (1984) and recently reported results of the ongoing studies of faults by the USGS reported by Spengler et al. (1994).

Rock mass quality data in the immediate area of the Main Drift alignment was produced in three of the SD program holes, USW SD-7, SD-9, and SD-12, for direct input to this study. Since the spacing of these holes was large (>920 m; 3,018 ft), the data set from the Tptpmn was augmented by using all other available rock structure logging data (boreholes NRG-6, NRG-7/7A, and UZ-14). Because of the limited data, spatial correlation of the rock mass quality trends was not performed, and the variability of rock mass quality was therefore examined by stratigraphic depth in the unit.

The soil and rock study plan includes site characterization studies and activities required for siting and designing the ESF, including both surface structures and subsurface access structures. Table 1-1 lists the individual studies within the study plan, their objectives, and the activities included in each study. The investigation activities conducted during the Main Drift geotechnical characterization supported all three of the studies in Table 1-1.

Table 1-1. Studies, Objectives, and Activities of the Soil and Rock Properties Study Plan (8.3.1.14.2) — *Studies to Provide Soil and Rock Properties of Potential Locations of Surface and Subsurface Access Facilities**

SCP Activity No.	Study	Objectives	Activities
8.3.1.14.2.1	Exploration Program	Characterize soil and rock conditions that influence ESF construction.	Site Reconnaissance Preliminary and Detailed Exploration
8.3.1.14.2.2	Laboratory Tests and Material Property Measurements	Conduct laboratory tests and material property measurements on representative samples of soil and rock.	Physical Properties and Index Laboratory Tests Mechanical and Dynamic Laboratory Property Tests
8.3.1.14.2.3	Field Tests and Characterization Measurements Study	Conduct field tests and characterization measurements to determine in situ physical, mechanical, and dynamic properties of soil and rock.	Physical Property Field Tests and Characterization Measurements Mechanical Property Field Tests Geophysical Field Measurements

*DOE, 1991.

Table 1-2 correlates study activities with specific investigations conducted during geotechnical characterization for the Main Drift. The objectives of each study are also summarized in the table.

Table 1-2. Correlation of Study Areas and Activities with Specific Investigations Conducted in the Main Drift

Study	Activity	Investigation	Objective
Exploration Program	Preliminary and Detailed Exploration	Drill SD-7, SD-9, SD-12, UZ-14, NRG-6, and NRG-7/7A.	Determine depth, thickness, and continuity of strata and thermal-mechanical (thermal-mechanical) units intersected by North Ramp cross section.
		Perform down-hole video logs.	Provide visual estimate of rock quality, fracturing density, detect free water.
		Perform geophysical logging.	Stratigraphic correlations in new holes.
Laboratory Tests and Materials Property Measurements	Physical Property and Index Laboratory Tests	Laboratory Measurements of Physical Properties— density, porosity, grain density.	Characterize bulk properties of rock for engineering designs of materials handling facilities; verify geophysical tool functions.
	Mechanical and Dynamic Laboratory Property Tests	Laboratory Mechanical Property tests—uniaxial compressive strength, triaxial strength, elastic modulus, Poisson's ratio, Brazilian tensile strength.	Measure intact rock properties to provide basis for rock mass quality assessment and rock mass mechanical properties.
Field Tests and Characterization of Measurements	Physical Property Field Tests and Characterization Measurements	Rock Structural Logging	Describe rock structural features to support development of rock mass quality indices.
		Generate Rock Mass Classification—Q and RMR	Provide basis for empirical design of tunnel support, provide basis for developing rock mass mechanical properties.
	Mechanical Property Field Tests	Generate Rock Mass Mechanical Property Estimates—Strength and Modulus	Provide design parameters for numerical analysis of thermal and seismic loading.

1.4 Quality Assurance

All core logging and rock testing data utilized in this study were generated under quality assurance (QA) procedures governing the various technical organizations involved in the activities. Data collection and collation, supporting preparation of this report, were documented in scientific notebooks and analysis files in accordance with SNL Quality Assurance Implementing Procedures (QAIPs) 20-2 and 2-4. These notebooks will be entered into the SNL participant data archive. All data presented in this report were generated under QA procedures unless otherwise noted.

Nonqualified existing data and preliminary data have been utilized in this report where qualified data do not exist or are not currently available. Table 1-3 has been developed to document these occurrences and to meet requirements of the DOE's Quality Assurance Requirements and Description for maintenance of traceability. Throughout the text, some footnotes have been utilized to refer to information relevant to the Main Drift which is in

Table 1-3. Nonqualified and Preliminary Data and Assumptions

Data or Assumptions	Data Status	Application	Data Reference	Effects
Geologic Cross Section along Main Drift	N*	Presentation of lithostratigraphic units along Main Drift, Figure 3-1	Basis of development is nonqualified 3-D geologic model of YMP site, Version YMP.R2.0	Projection of geologic contacts between SD holes, fault displacements, Table 3-3
Thermal-Mechanical Units Cross Section Figure 3-2	N*	Presentation of thermal-mechanical units along North Ramp	Basis for development is Figure 3-1	Figure 3-2

*N = Nonqualified existing data.

preparation and represents preliminary data. Other footnotes refer to qualified data submitted to the project by Technical Data Information Form (TDIF), but not assigned accession numbers required for listing in the references. These TDIF references are presented in Appendix A.

1.5 Report Organization

Following this introduction, Section 2.0 of the report presents the summary of the geotechnical characterization of the Main Drift. A description of the geology along the Main Drift is provided in Section 3.0. The geotechnical data, including rock structure data and rock mechanics laboratory test data, are presented in Section 4.0. The rock mass quality based on the geotechnical data in Section 4.0 is presented in Section 5.0. Section 6.0 presents an assessment of the rock mass mechanical properties. References are presented in Section 7.0.

Appendix A includes a list of TDIF references used in this report. Appendix B contains a rank-ordered table of rock mass quality estimates for the Tptpmn. Individual data and logs for boreholes USW SD-7, SD-9, SD-12 and UZ-14 are presented in Appendix C including:

- Geology and Rock Structure Log,
- Core Hole Structural Data Summary, and
- Estimated Rock Mass Quality Indices Based on Core Log Data.

Appendix D contains a key block stability analysis comparison of the North Ramp and Main Drift orientations.

2.0 Summary and Conclusions

2.1 Introduction

This section summarizes the subsurface rock conditions anticipated in the Main Drift and the impact these conditions may have on construction. Since the method of excavation and tunnel alignment have been previously chosen, this report focuses on the prediction of the rock mass characteristics and properties, and the identification of the required range of ground support. The Main Drift will be excavated between the North and South Ramps at the potential repository horizon for a distance of 3,131 m (10,273 ft) using a 7.62-m (25-ft) diameter TBM. Portal and starter tunnel facilities were completed in mid-1994 and the excavation of the North Ramp had reached 960 m at the time of preparation of this report.

The Main Drift is projected to be excavated almost entirely within the Tptpmn with only the last 237 m excavated in the Topopah Spring lower lithophysal zone (Tptpll). The geotechnical data in this report are limited to these two zones and are derived from the ESF boreholes USW NRG-6, NRG-7/7A, UZ-14, SD-7, SD-9, and SD-12. The data evaluated included lithologic and stratigraphic identifications, rock structural logs, and rock mechanics tests. Rock mass quality was then projected using core data. Geotechnical data collected during construction of the North Ramp were also used to improve the interpretation of the core hole data.

The data collection and analysis methodology used throughout are described by Brechtel et al. (1995). However, rock mass quality assessments from the North Ramp tunnel in the Tiva Canyon formation were compared to the rock mass quality predicted from the North Ramp core data to check the performance of the core-based rock quality assessment. Some parameter ranges used to estimate rock quality for the Main Drift were changed on the basis of the North Ramp experience. In addition, rock mass quality from the high lithophysae portion of the Tiva Canyon and from the "imbricate" faults intersected by the North Ramp were used to project conditions in the Tptpll and fault zones, respectively.

2.2 Geotechnical Summary

2.2.1 Geology and Major Structural Features Along the Main Drift

The Main Drift will be constructed in the Tptpmn for approximately 2,894 m (9,495 ft), and for 237 m (776 ft) in the Tptpll, both of which are zones of the Topopah Springs Tuff (Tpt), a welded volcanic ash-flow tuff of the Miocene Paintbrush group. There are two known major structural geologic features with potential engineering and construction significance that are projected to be intersected by the Main Drift:

- the Sundance Fault Zone and
- the Abandoned Wash Fault.

Projected intersections with the Main Drift are shown in Section 3.0, Figure 3-1. No data is available on these faults at depth; however, tunneling experience in the North Ramp indicates low values of rock mass quality ($Q \leq 0.04$) can occur in the localized zone of shear movement within faults. Observed structural instability in faults has included rock fallout and instability in the crown with very low stand-up times for the newly excavated unsupported roof. In one fault zone within the North Ramp, the TBM was unable to set the gripper pads in areas of extreme rock fallout.

The Abandoned Wash Fault is a north-northeast trending fault that appears to terminate against the Ghost Dance Fault (Scott and Bonk 1984) and is considered a possible splay off the major fault. It has an approximate 74°W dip and 21 m (70 ft) of projected dip-slip displacement where it is projected to intersect the Main Drift at station 57+10 m. A parallel fault is shown on surface mapping (Section 3.0, Figure 3-4) to cross the Main Drift to the north of the Abandoned Wash Fault at approximately 54+96 m. These faults are projected to cut the tunnel at angles as low as approximately 14° which will result in the persistence of the fault zone along the tunnel for some distance. A fault in the North Ramp with a similar low angle of incidence caused construction delays.

The Sundance Fault System is a northwest trending feature with an apparent right-lateral offset of the Ghost Dance Fault of at least 52 m (Spengler et al. 1994) (Section 3.0, Figure 3-4). On the surface, this fault system consists of a zone of near vertically dipping faults at least 274 m (900 ft) wide with the dominant feature, the Sundance Fault, located at the center of the zone. The Sundance Fault is projected to cross the Main Drift alignment at station 36+40 m. Observations of the structural influence of the "imbricate" faults in the North Ramp (500–750 m) indicate that the brittle, densely welded tuff rocks exhibit a larger area of fault influence than in moderately or nonwelded tuffs. Rock damage adjacent to faults was more extensive in the densely welded tuffs. On this basis, the Sundance Fault zone is projected to have rock qualities similar to the lower 25% of the Tptpmn, with Q values projected to be between 0.04 and 0.3 through the 274-m (900-ft) area around the fault.

2.2.2 Joint Structure

The anticipated fracture patterns in the Tpt have been based on the general agreement of fracture data from both the Tpc and Tpt. Fracture data sources included oriented core data from both the Tpt and Tpc (Lin et al. 1993b),[4] observations from the North Ramp Starter Tunnel, mapping of the Tpc in the North Ramp Tunnel, and mapping of the Tpt at Fran Ridge.[5] The Tpc

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[4] Existing data, not qualified.

[5] Preliminary data.

and Tpt , very similar in terms of rock properties, were deposited within a relatively short period of geologic time and have been subjected to the same post-emplacement tectonic stresses. The various fracture orientation data indicate similar trends in the two tuff units and it has, therefore, been assumed that the predominant joint sets observed in the Tpc of the North Ramp tunnel will be present in the Tpt of the Main Drift. Three steeply dipping joint sets are projected to occur oriented at 353°/84°, 132°/82°, and 262°/78° (dip direction/dip). The most frequently occurring joint set (353°/84°) strikes generally parallel to the Main Drift. This set is also generally parallel to the Ghost Dance Fault, which runs parallel to the Main Drift, approximately 170 m (558 ft) to the east. The joint set is projected to have an adverse impact on stability because of its generally parallel orientation. An analysis of the potential to form blocks that can fall from the tunnel crown (key blocks), based on these three predominant sets, indicates the maximum size key block may be approximately three times larger than in the North Ramp.

2.2.3 Hydrology

The Main Drift drilling indicated generally dry conditions along the Main Drift alignment and tunnel excavation is therefore anticipated to be in unsaturated conditions. Review of the borehole video logs from USW SD-7, SD-9, and SD-12 did not indicate any water inflow of significance to construction activities. However, perched water does occur at the YMP site, and it is possible that drilling has not sampled existing perched water along the Main Drift.

2.2.4 Rock Structure Data from the Main Drift Core

Analysis of the condition of the core from the Tptpmn was performed to project the rock mass quality. Combining the data from each of the boreholes, the amount of lost core for the Tptpmn was 15% of the total core length. Rubble zones accounted for 20% of the total length. The Tptpll to be intersected by the Main Drift was characterized by consistently higher core losses and rubble. For example, in the 24 m below the base of the Tptpmn, NRG-6 averaged 47% lost core and rubble, while NRG-7/7A averaged 77% lost core and rubble.

RQD (Deere 1968) determined for the Tptpmn is summarized in Section 4.1.2, Table 4-2, and averaged 23%. An *enhanced-RQD* was also calculated by filtering the effects of fractures judged to be coring induced and averaged 38%. The relative rock quality (Deere 1968) based on the mean RQD is very poor. The *enhanced-RQD* ranges from 1.5 to 2.6 times greater than the RQD suggesting poor rather than very poor rock quality.

A cross-hole comparison of RQD was developed for the six available holes to evaluate the potential for stratigraphically based variation of rock quality. This comparison (illustrated by Figure 4-4 in Section 4.1.2) suggested that three zones of low RQD occur at the top and middle of the Tptpmn and in the upper portion of the Tptpll. The lower part of the Tptpmn was a correlatable zone of higher RQD with a vertical thickness of approximately 20 m. The portion of the Tptpll to be intersected by the Main Drift was an interval with consistent high core loss and rubble (47% from NRG-6 and 77% from NRG-7/7A), very low RQD (<8%), and irregular hole condition. Approximate Main Drift stations for these zones are listed in Section 4.1.2.

The weathering of the rock that constitutes the fracture surfaces (Section 4.1.3) has been described as either fresh or slightly weathered, with rock hardness primarily described as hard.

After correcting for sampling bias induced by the vertical holes using Terzaghi's (1965) correction procedure, it was found that fractures (Section 4.1.5) in the 80° to 90° dip range were the most dominant with a frequency of occurrence of 66.9%. The fracture surfaces in the Tptpmn were primarily clean. The most predominant infill materials included white crystalline (8%), white non-crystalline (10%), and black dendritic (17%). Clay infill in this zone were very scarce. The fractures were predominantly planar (66%) with a significant occurrence of irregular surfaces (21%). The small-scale roughness of the fractures was described as either moderately rough (50%) or smooth (39%).

The majority of the fractures identified in the core were judged to be coring-induced (type C) by the core loggers and represented almost half of the total fractures. These fractures were predominantly near horizontal and were not considered in assessing fracture characteristics.

2.2.5 Intact Rock Mechanical Properties

Rock mechanical properties tests were conducted on core from USW NRG-6 and NRG-7/7A in the Tptpmn. The rock mechanics laboratory test data are summarized in Table 2-1 and indicate that the rock was generally high strength, densely welded tuff. The porosities were relatively low, averaging 11%. Uniaxial compressive strength varied between 112.1 MPa (16,255 psi) and 261.9 MPa (37,975 psi) with a standard deviation equal to 29.2% of the mean

Table 2-1. Summary of Mean Values for Rock Mechanics Laboratory Test Data

Rock Property	Number of Tests	Mean Value	Standard Deviation
Uniaxial compressive strength (MPa)	13	179.80	52.50
Elastic modulus (GPa)	27	32.90	3.80
Cohesion (MPa)	13	42.50	—
Angle of internal friction (degrees)	13	49.60	—
Poisson's ratio	27	0.21	0.03
Indirect tensile strength (MPa)	7	11.40	3.20
Dry bulk density (g/cc)	36	2.25	0.08
Porosity (%)	38	11.00	3.20
Average grain density (g/cc)	18	2.53	0.01

strength of 179.8 MPa (26,070 psi). The intact elastic modulus averaged 32.9 GPa (4.77×10^6 psi) with an average Poisson's ratio of 0.21.

Confined testing was performed on small samples at confining pressures of 0, 5 and 10 MPa. Analysis of the data indicated a Mohr-Coulomb cohesion of 42.5 MPa (6,160 psi) and an angle of internal friction of 49.6°. Data are presented in Section 4.2.

2.2.6 Rock Mass Quality Indices

Rock mass quality indices, Q and RMR, were estimated for each 3-m (10-ft) interval of the Main Drift borehole data (boreholes USW SD-7, SD-9, SD-12, UZ-14, NRG-6, and NRG-7/7A) based on the described condition of the core and the rock mechanics laboratory test data. Values for two of the Q parameters, Jn and SRF, were generated using Monte Carlo simulation of distributions determined from rock quality assessments from within the North Ramp Tunnel in the Tpc. Fault zones were not specifically represented in the borehole rock quality estimates because none of the holes penetrated the fault zones. Fault conditions were therefore estimated separately based on observations in the North Ramp.

2.2.6.1 RMR and Q Data. The distribution of RMR and Q data was summarized by generating values for the Tptpmn corresponding to rock mass quality at levels of 5%, 20%, 40%, 70%, and 90% cumulative frequency of occurrence and are listed in Table 2-2. These levels of occurrence are used to generate a range of estimated rock mass mechanical properties. The values of Q or RMR at other cumulative frequency of occurrence can be read from the table in Appendix B.

Table 2-2. RMR and Q Values at Five Levels of Cumulative Frequency of Occurrence

Cumulative Frequency of Occurrence (%)	RMR	Q	Relative Rating		
			Rock Mass Quality	RMR	Q
5	50	0.14	Very Good	81–100	40–100
20	55	0.29	Good	61–80	10–40
40	58	0.42	Fair	41–60	4–10
70	63	1.39	Poor	21–40	1–4
90	67	10.56	Very Poor	<20	0.1–1

The range of RMR values for the Tptpmn is fairly small, with all intervals indicating either a fair or a good rock mass quality. The Q values range from a very poor to a good rock mass quality, with a majority of the intervals (69%) indicating a poor to very poor quality rock mass.

The core-based projections of Q from the North Ramp core data (Brechtel et al. 1995) were compared to Q values assessed from the North Ramp Tunnel excavation to verify the methodology for determining Q and RMR from core data. The distribution of Q values was similar for both the core-based and North Ramp excavation assessments in the Tpc with the actual rock quality in the tunnel being lower than predicted. The support requirements based on the YMP Ground Support Guidelines[6] have also been compared for both core-based and tunnel Q assessments. The distribution of support categories in both assessments was nearly identical which demonstrated that the core-based rock quality assessment had provided a realistic pre-excavation assessment of the rock mass quality that was generally well matched with field conditions observed in the Tpc.

The core rock structure data were not assembled for the portion of the Tptpll because of the high proportion of lost core and rubble. Based on the rubblized nature of the core and the presence of large lithophysae in the downhole video, the conditions are projected to be similar to the upper lithophysal zone of the Tpc. Q values ranged between 0.04 and 2.68 with a median value of 0.64 in the scanline rock mass quality descriptions of the North Ramp in the Tiva Canyon upper lithophysal zone.

2.2.6.2 Projected Range of Ground Support. The distribution of Q values and associated Q parameters (RQD/Jn and Jr /Jn) were used to identify the types of ground support indicated by the YMP Ground Support Guidelines and the relative lengths of the Main Drift that will require the indicated support. Actual ground support will be controlled by the specific capabilities of the TBM and the constructor's assessment of specific requirements for personnel safety. The distribution of the anticipated ground support for the Tptpmn in the Main Drift is shown in Figure 2-1 (ground support categories are defined in Section 5.4, Table 5-3). According to this analysis and the YMP support guidelines, 46% of the tunnel length will require rockbolts and shotcrete (category 3b) and 36% of the tunnel will require steel sets with partial lagging (category 4). Ground support requirements in the Tptpll in the Main Drift are projected to be category 4—steel sets and partial lagging—based on the consistently low RQD.

2.2.7 Rock Mass Mechanical Properties Estimates

Rock mass mechanical properties are required for input into the numerical analyses that support the geotechnical design of the Main Drift. Rock mass mechanical properties have been estimated for the Tptpmn based on the methodology proposed by Hardy and Bauer (1991) using published empirical correlations with RMR. Estimated rock mass strength for each of the five cumulative frequencies of occurrence (5%, 20%, 40%, 70%, and 90%) of RMR data is compared to intact rock strength in Table 2-3. The estimated rock mass strength represents a substantial reduction from the laboratory measurements of intact rock compressive strength that is based on empirical correlation with RMR. The method of estimating rock mass strength has not been validated and requires future ESF testing for validation.

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[6] BABEAB000-01717-2100-40151-01, *Exploratory Studies Facility Package 2C, TS North Ramp Ground Support Master Elevations and Sections*, July 27, 1994.

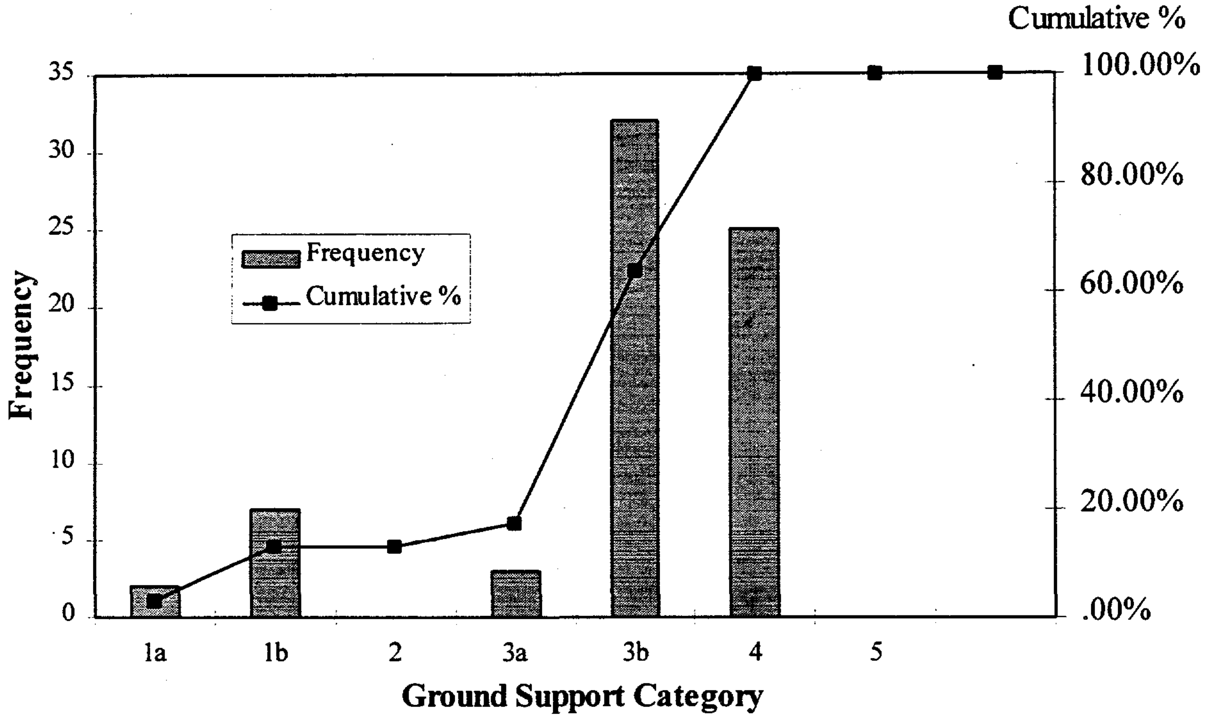

Figure 2-1. Projected distribution of ESF ground support category for the Tptpmn—Main Drift boreholes.

Table 2-3. Comparison of Intact Rock Values to Estimated Rock Mass Property Values for Each of the Five Rock Mass Classes

Rock Mass Property	Intact Rock Values	Estimated Rock Mass Values for Cumulative Frequency of Occurrence of RMR				
		5%	20%	40%	70%	90%
Rock strength (MPa)	179.8	3.7	5.19	6.28	10.17	20.19
Cohesion, C (MPa)	42.5	1.1	1.4	1.6	2.2	4.1
Internal fiction angle, ϕ (degrees)	49.6	49	49	50	50	50
Dilation angle (degrees)	25	25	25	25	25	25
Elastic modulus (GPa)	32.90	5.07	7.01	8.40	13.23	25.03
Poisson's ratio	0.21			0.21		

Rock mass strength parameters based on the Mohr-Coulomb failure criteria were determined for each of the five frequencies of occurrence as listed in Table 2-3 for the Tptpmn. Rock mass elastic modulus and the recommended value of Poisson's ratio are also listed in Table 2-3.

2.3 Conclusions

The major conclusions developed from this assessment are:

- The available subsurface data on rock structural features and rock quality appears adequate to characterize the range of conditions that will be encountered excluding the known fault zones. Cross-hole evaluation of RQD suggests some correlatable intervals of higher and lower RQD based on the distance from the top of the Tptpmn.

- There is no data on the rock characteristics in and around the two known fault zones to be intersected by the Main Drift. The width of the poor rock quality zones within the faults and the rock quality in the fault zone is unknown. The angle of incidence of the Abandoned Wash structure is low and adverse conditions associated with the fault zone could persist for some distance.

- The tuff rocks to be encountered by the Main Drift are highly fractured and have generally low rock mass quality. Rock conditions are projected to be similar to those encountered in the densely welded portions of the Tpc in the North Ramp.

- The predominant joint sets projected to occur in the Main Drift have the potential to produce unstable blocks in the roof that are approximately three times larger than in the North Ramp. This potential, coupled with the fact that the Main Drift is oriented parallel to the joint set that is the most frequently occurring, suggests that stability conditions may be more adverse in the Main Drift than in the North Ramp.

- Fault zones have not been directly characterized by the Main Drift subsurface investigations. Two major faults are identified by surface mapping, but other unmapped faults may also be present as was the case in the North Ramp.

3.0 Geology of the Main Drift

3.1 Introduction

This section provides the geologic and stratigraphic framework for the rocks encountered along the ESF Main Drift alignment. Geologic investigation of the alignment included lithologic description of core from boreholes USW SD-7, SD-9, and SD-12; analysis of geologic mapping done by Scott and Bonk (1984); and fault mapping studies by Spengler et al. (1994).

The objective of the geologic investigation of the Main Drift alignment, using the Main Drift boreholes and existing surface mapping data, was to:

- develop stratigraphic and thermal-mechanical cross sections along the drift alignment;
- locate and describe any significant faults that may cross the alignment; and
- correlate rock structure data, rock mass quality data, and rock mass properties data with the stratigraphic unit containing the Main Drift.

3.2 Stratigraphy

The ESF Main Drift alignment is planned to be excavated within the middle nonlithophysal zone of the Tpt of the Paintbrush Group. Drilling of the three SD boreholes along the drift alignment penetrated the Miocene age volcanic rocks of the Paintbrush Group, Calico Hills Formation, Prow Pass, and Bullfrog Members of the Crater Flat Tuff. The stratigraphic units found along the alignment are part of a thick sequence of bedded and ash-flow tuffs which originated in eruptions of the Timber Mountain-Oasis Valley Caldera Complex to the north of Yucca Mountain between 11 and 14 million years ago (Byers et al. 1976). The Tptpmn of the Paintbrush Group is the host rock for the majority of the Main Drift excavation. Lithostratigraphic units have been described by Moyer et al. (1995).[7]

This report uses the recently developed stratigraphic nomenclature of the U.S. Geological Survey.[8] Recent work by the USGS has modified the stratigraphy by raising the Paintbrush and Timber Mountain Tuffs to group status (Sawyer et al. 1994). The detailed nomenclature for the

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[7] Moyer, T.C., J.K. Geslin, and D.C. Buesch (1995). *Summary of Lithologic Logging of New and Existing Boreholes at Yucca Mountain, Nevada, July 1994 to November 1994,* U.S. Geological Survey Open-File Report 95-102, U.S. Department of the Interior, Denver, Colorado.

[8] Ibid.

Tpt, based on compositional and lithologic distinctions identified in core and less on outcrop data, has been developed by the USGS[9] and is presented in Table 3-1.

Table 3-1. Lithostratigraphic Nomenclature of the Tpt at Yucca Mountain, Nevada*

Topopah Spring Tuff	**Tpt-**	
crystal-rich member (quartz latite)	Tptr	
vitric zone	Tptrv	
non- to partially welded subzone	Tptrv3	
moderately welded subzone	Tptrv2	
vitrophyre subzone	Tptrv1	
nonlithophysal zone	Tptrn	
lithophysal zone	Tptrl	
crystal-rich lithophysal subzone	Tptrl2	
crystal transition subzone	Tptrl1	
crystal-poor member (high-silica rhyolite)	Tptp	
upper lithophysal zone	Tptpul	
cavernous lithophysae subzone	Tptpul2	
small lithophysae subzone	Tptpul1	
middle nonlithophysal zone	Tptpmn	
upper subzone	Tptpmn3	Main Drift Horizon
lithophysae bearing subzone	Tptpmn2	
lower subzone	Tptpmn1	
lower lithophysal zone	Tptpll	
lower nonlithophysal zone	Tptpln	
vitric zone	Tptpv	
vitrophyre subzone	Tptpv3	
moderately welded subzone	Tptpv2	
non- to partially welded subzone	Tptpv1	

NOTE: The lithostratigraphic nomenclature above and below the Topopah Spring Tuff is listed in Table 4-1 of Brechtel et al. (1995) *The Geotechnical Characterization of the North Ramp of the Exploratory Studies Facility*, SAND95-0488, Volume 1, Sandia National Laboratories, Albuquerque, NM.

* Moyer et al.

This scheme uses both primary compositional differences and secondary cooling and alteration features to define the stratigraphy. It is important to note that secondary features such as lithophysae and vapor-phase alteration are dependent more on cooling history of the rock mass and can crosscut the primary features such as boundary between crystal-rich and crystal-poor

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[9] Ibid.

zones. Furthermore, these secondary features commonly exhibit significant lateral variation, dependent on variations in cooling history.

Boreholes USW SD-9 and SD-12 have been logged by both the USGS[10] and SNL.[11] Stratigraphic contacts are gradational and subject to interpretation and result in minor differences in contact identification. Additionally, minor differences in nomenclature are noted as well. Borehole USW SD-7 has been logged by SNL.[12] Lithology logs produced by SNL are incorporated directly into the Geology and Rock Structure Logs developed in this study. Geologic and thermal-mechanical cross sections in this report are derived from the USGS three-dimensional Lynx model version YMP.R2.0[13] which uses the contact elevations defined by USGS personnel.

Stratigraphic and thermal-mechanical units that were sampled within the Main Drift boreholes are summarized in Table 3-2, which lists the unit thicknesses penetrated by drilling. All of these boreholes penetrate the entire thickness of the Tpt. Description of the stratigraphic units is restricted to the Tpt for this report.

The Tpt is a multiple-flow, compound cooling unit, ash-flow tuff consisting of three eruptive pulses (Lipman et al. 1966). This unit has been divided into a lower crystal-poor unit (high-silica rhyolite) and an upper crystal-rich unit (quartz latite).[14] The unit is characterized by thin zones at the top and bottom where the nonwelded tuffs grade into moderately to densely welded vitrophyre zones. The thick middle portion of the flow is moderately to densely welded, devitrified, and commonly altered by vapor-phase mineralization.

Lithophysal cavities vary throughout and break the unit into a number of distinct zones which help define both the lithostratigraphic and thermal-mechanical units. The vitric zones on the top and bottom of the flow are both nonlithophysal. The thick, devitrified middle portion of the flow, however, contains an alternating sequence of nonlithophysal and lithophysal zones, as listed in Table 3-1. While the term nonlithophysal is applied to many of the zones, it should be pointed out that minor amounts of lithophysae occur throughout the devitrified portion of the flow. These can sometimes be used to define distinct subzones, such as the lithophysal bearing subzone in the Tptpmn.

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[10] Ibid.

[11] Geologic Core Log for SD-9, TDIF No. 303743 DTN: SNF02052794001.001 and TDIF No. 304282 DTN: SNF02052794001.002; and Geologic Core Log for SD-12, TDIF No. 303744 DTN: SNF02012894001.001.

[12] Geologic core logic for SD-7, DTN: SNT02110894001.001.

[13] Buesch, D.C., J.E. Nelson, R.P. Dickerson, R.M. Drke, and C.A. San Juan. (1996). *Distribution of Lithostratigraphic Units Within the Central Block of Yucca Mountain, Nevada: A Three-Dimensional Computer-Based Model, Version YMP.R2.0*, Open-File Report 95-124, U.S. Geological Survey, Denver, CO.

[14] Moyer et al.

Table 3-2. Thickness of Stratigraphic Units in Main Drift Boreholes

Stratigraphic Unit	Symbol	Thermal-Mechanical Units	Thickness (m)		
			SD-7	SD-9	SD-12
Paintbrush Group:					
Tiva Canyon Tuff	**Tpc-**				
welded zones, undivided	Tpcu	**TCw**	93.1*	17.4*	72.9*
cystal-poor vitric zone	Tpcpv	**PTn**	6.2	10.7	7.4
Pre-Tiva Canyon Tuff Bedded Tuff	**Tpbt4**		#	1.1	1.4
Yucca Mountain Tuff	**Tpy**		#	13.7	NP
Pre-Yucca Mountain Tuff Bedded Tuff	**Tpbt3**		#	4.8	3.0
Pah Canyon Tuff	**Tpp**		#	21.4	3.9
Pre-Pah Canyon Tuff Bedded Tuff	**Tpbt2**		#	8.8	7.0
Topopah Spring Tuff	**Tpt-**				
crystal-rich member (quartz latite)	Tptr-				
vitric zone, moderately & non- to partially welded	Tptrv 3 & 2		7.5	3.9	3.2
vitric zone, vitrophyre subzone	Tptrv1	**TSw1**	0.3	1.1	1.9
nonlithophysal zone	Tptrn		30.3	50.9	32.2
lithophysal zone	Tptrl		NP	13.7	12.2
crystal-poor member (rhyolite)	Tptp-				
upper lithophysal zone	Tptpul		59.3	77.0	57.1
middle nonlithophysal zone	Tptpmn	**TSw2**	36.8	33.2	38.1
lower lithophysal zone	Tptpll		66.1	103.6	76.9
lower nonlithophysal zone	Tptpln		52.2	54.6	72.3
vitric zone, vitrophyre subzone	Tptpv 3	**TSw3**	25.3	16.3	9.1
vitric zone, moderately & non- to partially welded	Tptpv 2 & 1	**CHn**	#	13.9	30.5
Pre-Topopah Spring Tuff Bedded Tuff	**Tpbt1**		#	4.8	1.1
Calico Hills Formation:	**Tac**				7.3*
Prow Pass Tuff:	**Tcp**		61.0*	103.9	
Bullfrog Tuff:	**Tcb**			122.6*	

*Denotes thickness of unit where both contacts not present.

NP = Unit not Present

= Unit thickness not calculated due to very limited or no recovery.

The Tptpmn is the horizon in which the Main Drift will be excavated. The thickness ranges from 33.2 m (109 ft) at SD-9, 38.1 m (125 ft) at SD-12, and 36.8 m (120.8 ft) at SD-7. This unit is rhyolitic in composition, devitrified, and moderately to densely welded. Phenocrysts form 1% to 2% of the rock and are dominated by feldspars with rare oxidized biotite. Pumice clasts and lithic clasts are present and each comprise 1% to 2% of the rock. Vapor-phase alteration is present in 5% to 20% of the rock as wisps, diffuse spots, and rims around lithophysae where present. Matrix colors typically range from light brown (2.5YR6/3) to grayish red-purple (5RP4/2) to moderate brown (5YR5/4).

Lithophysae are rare but not entirely absent. The USGS[15] recognizes three subzones based largely on lithophysal content as follows:

- the lower nonlithophysal subzone in which lithophysae are absent or less than 1%,
- the middle lithophysae bearing subzone characterized by 1–3% of spherical lithophysae typically less than 30 mm in size, and
- the upper nonlithophysal subzone where lithophysae are once again absent to less than 1%.

Within the SD boreholes in this report, the middle lithophysae bearing subzone is not recognized in SD-12 and SD-7, but is seen in SD-9 and in the supplemental holes NRG-6, NRG-7/7A, and UZ-14. This suggests that this subzone will be found at the north end of the Main Drift alignment, but dies out to the south.

The cross section shown in Figure 3-1 shows the north end of the Main Drift to be just below the upper contact of the Tptpmn. As the Main Drift proceeds to the south, it will gradually penetrate deeper to near the base of this zone as it approaches the Abandoned Wash Fault. South of the Abandoned Wash Fault, the Main Drift will be below the lower contact of the Tptpmn in the Tptpll based on the thickness of this unit observed in SD-12 and SD-7 (contact not defined on cross section).

The Tptpll is characterized by extensive zones of lost core and rubble in the boreholes along the Main Drift. The thickness ranges from 104 m (340 ft) at SD-9, 77 m (252 ft) at SD-12, and 66 m (217 ft) at SD-7. This zone is densely welded and devitrified, with vapor-phase minerals lining the lithophysal cavities and extensive haloes of vapor-phase alteration (5–30% of rock volume). Matrix colors are typically light brown to moderate red, and phenocrysts of feldspar and rare oxidized biotite comprise 1–2% of the rock. Pumice and lithic clasts are present at percentages ranging from 1 to 7%.

Intact pieces of core typically show from less than 1% to several percent of lithophysal cavities. Actual percentages, however, are hard to estimate from the limited recovery and are likely much higher, on the order of 20% or more as estimated from downhole videotapes. The cavities are typically elongate, from 2 to 10 cm, but occasionally as large as 20 cm or more.

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[15] Ibid.

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BOREHOLE PROJECTIONS

(projected perpendicular to section)

Borehole	Projected to Section along Azimuth	Ground Elevation (m)	Distance to Section (m)
USW SD-7*	97°	1382.5	102.6
USW SD-9	95°	1302.3	71.0
USW SD-12*	97°	1323.8	39.4

* Based on preliminary survey data

BOREHOLE CONTACT PROJECTIONS

(projected down dip)

Borehole	Projected to Section along Azimuth	Dip	Distance to Section (m)
USW SD-7*	86.9°	7.4°	103.2
USW SD-9	93.5°	5.9°	71.1
USW SD-12*	88.2°	7.1°	38.5

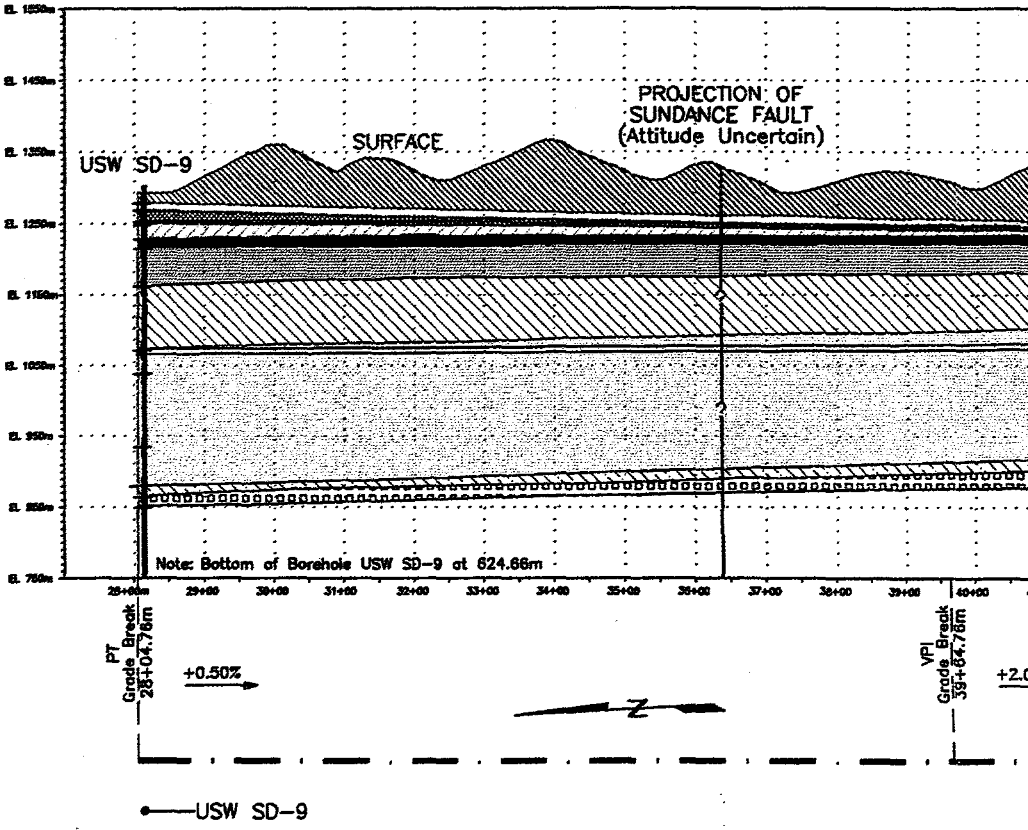
* Based on preliminary survey data

Note: Cross Section based on USGS LYNX Model YMP.R2.0: Not qualified data. Projections of stratigraphic contacts from USW SD-7, USW SD-9 and USW SD-12 are along dip direction as derived from Model YMP.R2.0 for each borehole locality.

PRELIMINARY TS MAIN DRIFT DATA

Station (m)	Grade	Invert Elevation (m)
28+04.76 (PT)	+0.50%	1065.00
39+64.76 (VPI)	+2.00%	1070.80
54+64.76 (VPI)	+2.47%	1100.80
59+36.89 (PC)		*1112.46

*Calculated.



STRATIGRAPHY[1]

		LITHO-STRATIGRAPHIC UNITS	SYMBOL	THERMAL-MECHANICAL UNITS
PAINTBRUSH GROUP	TIVA CANYON	▨ Tiva Canyon Tuff; undifferentiated, devitrified	Tpcun	TCw
		☐ Tiva Canyon Tuff; crystal-poor, vitric, nonwelded to moderately welded	Tpcpv1 & 2	PTn
		▩ Pre-Tiva Canyon Tuff Bedded Tuff	Tpbt4	
	YUCCA MTN.	Yucca Mountain Tuff	Tpy	
		▩ Pre-Yucca Mountain Tuff Bedded Tuff	Tpbt3	
	PAH CANYON	▨ Pah Canyon Tuff	Tpp	
		Pre-Pah Canyon Tuff Bedded Tuff	Tpbt2	
	TOPOPAH SPRING	■ Topopah Spring Tuff; crystal-rich, vitric, nonwelded to moderately welded	Tptrv2 & 3	
		▤ Topopah Spring Tuff; crystal-rich, devitrified, *nonlithophysal (includes vitrophyre)*	Tptrn	TSw1
		▧ Topopah Spring Tuff; crystal-poor, upper lithophysal (includes crystal-rich lithophysal)	Tptpul	
		☐ Topopah Spring Tuff; crystal-poor, middle *nonlithophysal*	Tptpmn	TSw2
		Topopah Spring Tuff; crystal-poor, lower lithophysal	Tptpll	
		Topopah Spring Tuff; crystal-poor, lower nonlithophysal	Tptpln	
		▧ Topopah Spring Tuff; crystal-poor, vitrophyre subzone	Tptpv3	TSw3
		▢ Topopah Spring Tuff; crystal-poor, vitric, non-welded to moderately welded	Tptpv1&2	CHn

LEGEN

+ BOREHOLE CONTACTS BA
BOREHOLES USW SD-9
ALONG DIP; QUALIFIED D

+ BOREHOLE CONTACTS BA
BOREHOLE USW SD-7 A
PRELIMINARY DATA, LOGG
BY USGS.

COMPARISON OF CONTA PROJECTED FROM BOR CONTACT ELEVATIONS FROM LYNX M

Units	SD-9			SD-12	
	Borehole Contact Elev (m)	Lynx Contact Elev (m)	Difference (m)	Borehole Contact Elev (m)	Lynx Contact Elev (m)
Tpcun	1278.0	1278.5	0.5	1245.9	1245.6
Tpcpv	1267.3	1267.3	0.0	1238.5	1237.1
Tpy	1252.5	1253.8	1.3	1237.0	1235.9
Tpbt3	1247.7	1248.5	0.8	1234.0	1233.3
Tpp	1226.4	1227.7	1.3	1230.1	1230.5
Tptrv	1213.6	1215.3	1.7	1219.9	1219.9
Tptrn	1181.6	1180.9	−0.7	1185.8	1185.1
Tptpul	1070.8	1072.5	1.7	1118.5	1116.4
Tptpmn	1037.6	NA	NA	1079.0	NA
Tptpll	934.0	NA	NA	1001.5	NA
Tptpln	879.4	879.2	−0.2	929.3	930.4
Tptpv3	863.1	864.4	1.3	920.1	920.4
Tptpv1&2	849.2	851.1	1.9	889.8	890.3

NA: Unit not recognized in core recovered or unit is

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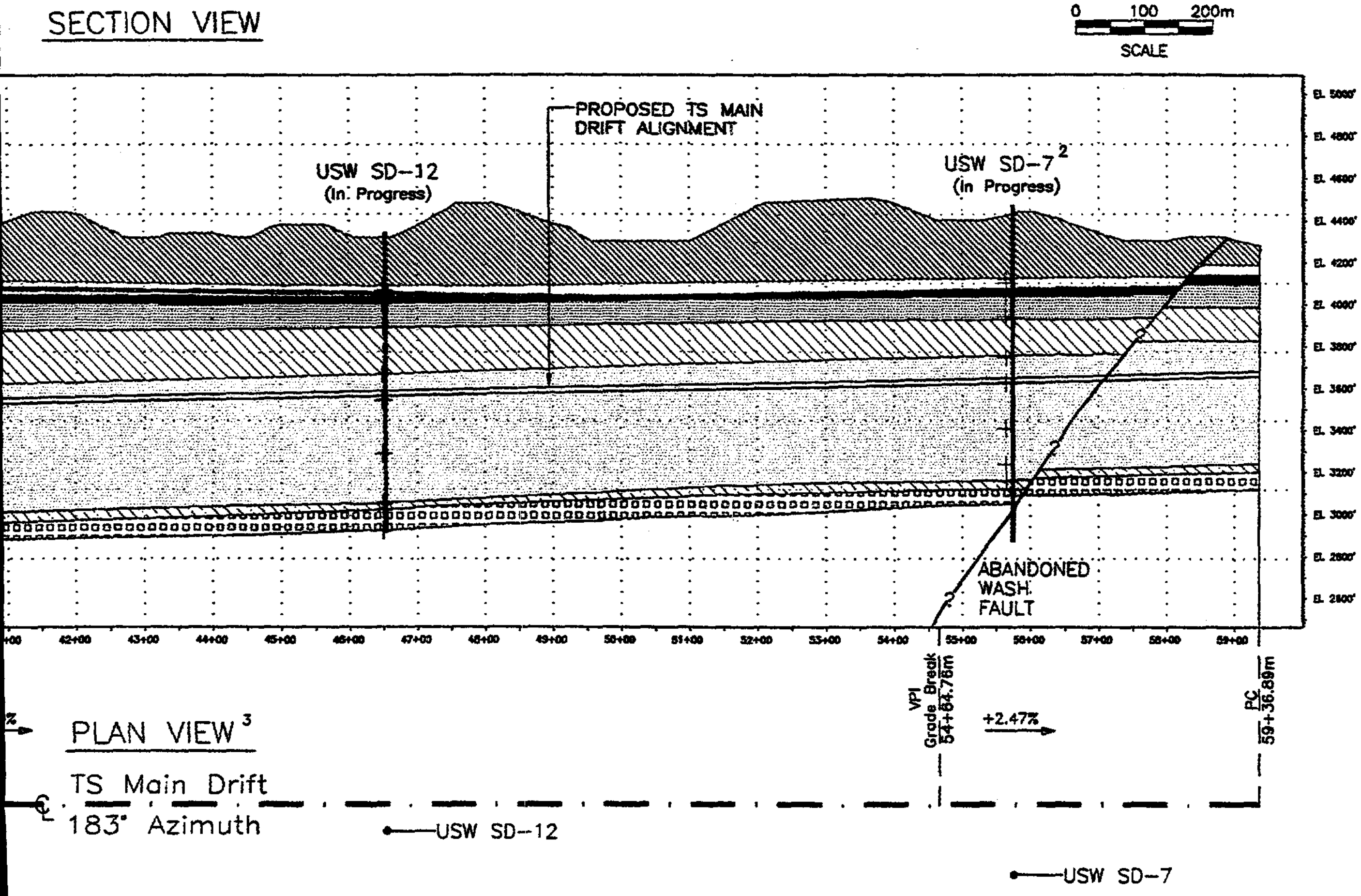
[1] Stratigraphic and thermal-mechanical units as defined by Buesch, et al., USGS Open File Report 94—469, 1996. "Revised stratigraphic nomenclature and macroscopic identification of lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain, Nevada".

[2] All contacts for USW SD-7 are preliminary, contacts for Tptpln and Tptpv3 are estimated. Recovery of nonwelded units within Ptn very poor, Yucca Mountain Tuff not recognized, Pah Canyon Tuff not found but may be present in unrecovered intervals.

[3] Plan View data from North Ramp Layout Calculation, document no. BABAED000—01717—0200—00003.



ED ON PROJECTING
ND USW SD-12
A, USGS OFR95-102.

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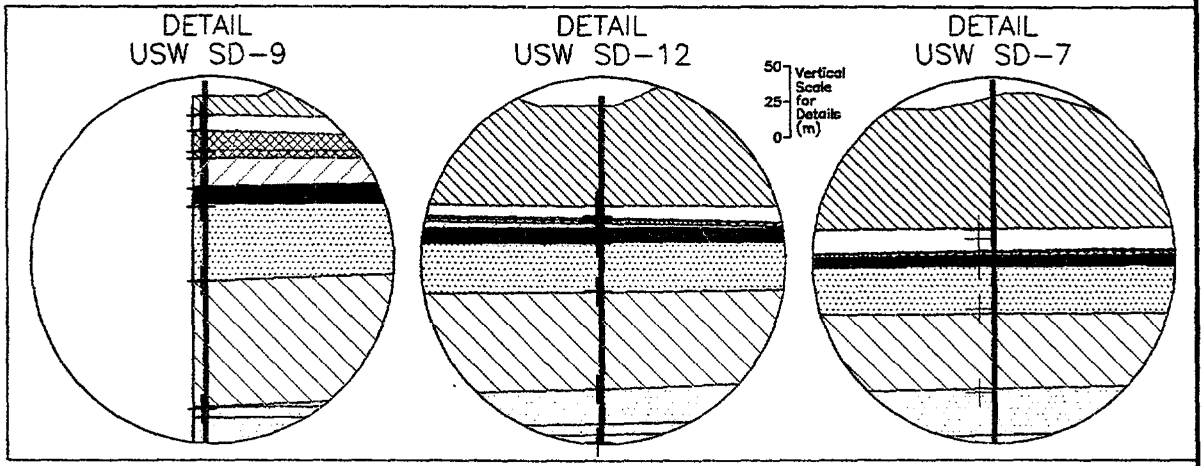

CT ELEVATIONS
EHOLES AND
MEASURED
DEL

	SD-7		
rence (m)	Borehole Contact Elev (m)	Lynx Contact Elev (m)	Difference (m)
-0.1	1255.9	1256.8	0.9
-1.4	1249.8	1241.2	-8.6
-1.1	NA	NA	NA
-0.7	NA	NA	NA
0.4	NA	NA	NA
0.0	1231.0	1230.4	-0.6
-0.7	1200.4	1196.7	-3.7
-0.1	1141.0	1143.5	2.5
NA	1104.2	NA	NA
NA	1038.2	NA	NA
1.1	985.9	951.9	-24.0
0.3	960.6	949.4	-11.2
0.7	NA	NA	NA

ifferentiated in Lynx model.

Figure 3-1. Stratigraphic cross section along the ESF Main Drift.

3.3 Geologic Cross Sections

The geologic cross section shown in Figure 3-1, was developed to project the stratigraphic units along the Main Drift alignment, and to serve as a basis for a thermal-mechanical units cross section presented in Section 3.4. The cross section uses contact elevations and geologic structures taken directly from the digital, three-dimensional lithostratigraphic computer model of Yucca Mountain, version YMP.R2.0, developed by the Rock Characteristics Section of the USGS.[16] Model version YMP.R2.0 includes boreholes USW SD-7, SD-9 and SD-12 as well as USW G-4 and, therefore, is based on the best available stratigraphic data close to the Main Drift alignment. The lithostratigraphic units have been grouped in a way that allows exact correspondence to the defined thermal-mechanical stratigraphy, but introduces some irregularities in the hierarchy of lithostratigraphic divisions.

Contact elevation data from the Main Drift SD boreholes were projected onto the section to verify the elevations of the contacts from the computer model against the existing qualified data. Solid black lines representing the boreholes are projected at actual elevation along the shortest distance (perpendicular) into the section. Stratigraphic contact elevations are shown by blue crosses adjacent to the boreholes. These contacts were projected down the average stratigraphic dip from the borehole into the plane of the cross section. The average dip of the lithostratigraphic units was used because the available dip of the top of the Tptpmn is anomalously high where compared to units above and below. The local attitudes of this contact were derived from structure contour maps of the surfaces included in the documentation of the Lynx version YMP.R2.0 model.[17]

3.4 Thermal-Mechanical Stratigraphy

The volcanic rocks at Yucca Mountain display a relatively narrow variance in chemical composition, but a wide range in features dependent on temperature of emplacement and cooling history. The aspects which most affect the physical and mechanical properties are the degree to which the individual particles in the deposits have been fused together or "welded" by post-emplacement heat and pressure, measured by the degree of flattening of the pumice clasts, and the resulting porosity of the rock. Repository design efforts are based on thermal-mechanical units that are defined by similarities in rock mass thermal and mechanical properties, which are largely a function of the degree of welding and porosity.

The Main Drift boreholes penetrate six previously defined thermal-mechanical units (Ortiz et al. 1985). A chart correlating Yucca Mountain stratigraphy with the thermal-mechanical units is included in Figure 3-2, and a version of the Main Drift cross section showing only thermal-mechanical units is presented in Figure 3-3. The important contact between the Tsw1 and Tsw2 has been presented here as equivalent to the base of the crystal-poor upper lithophysal

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[16] Ibid.

[17] Buesch et al.

Geologic Stratigraphy		Thermal Mech. Unit	Lithologic Description	Stratigraphic Units[1]
	Alluvium	UO	Alluvium, nonwelded ashflows and bedded tuffs	QTac, Tmr, Tmbt1, Tpki, Tpbt5, Tpcrv3, Tpcrv2
Timber Mtn. Group	Rainier Mesa Tuff			
Paintbrush Group	Tuff Unit "X"			
	Tiva Canyon Tuff	TCw	Nonlithophysal subzone	Tpcrv1, Tpcrn
			Lithophysae–bearing subzone	Tpcrl, Tpcpul, Tpcpmn, Tpcpll
			Nonlithophysal subzone	Tpcpln, Tpcpv3
	Yucca Mtn. Tuff	PTn	Vitric nonwelded	Tpcpv2, Tpcpv1 Tpbt4, Tpy, Tpbt3, Tpp, Tpbt2, Tptrv3, Tptrv2
	Pah Canyon Tuff			
	Topopah Spring Tuff	TSw1[2]	Nonlithophysal subzone welded devitrified tuff lithophysae poor	Tptrv1, Tptrn
			Lithophysae bearing subzone welded devitrified tuff up to 25% lithophysal cavities by volume	Tptrl, Tptpul *Contact based on 10% lithophysal content*
		TSw2	"Nonlithophysal" (contains sparse lithophysae); potential subzone repository horizon	*Contact based on stratigraphic break* Tptpmn, Tptpll, Tptpln
		TSw3	Virtophyre	Tptpv3
Calico Hills Formation		CHn1	Ashflows and bedded units, may be vitric or zeolitized	Tptpv2, Tptpv1 Tpbt1, Tac

[1] New USGS nomenclature, Thomas C. Moyer, et al 1995, ibid.

[2] TSw1 basal contact is variously described as the base of the Tptpul stratigraphic unit, or as the point near the base of the Tptpul where lithophysal content drops from greater than 10% to less than 10%. See Elayer (1995) for discussion.

Figure 3-2. Correlation of stratigraphic and thermal-mechanical units along the ESF Main Drift alignment (modified by Ortiz et al. 1985).

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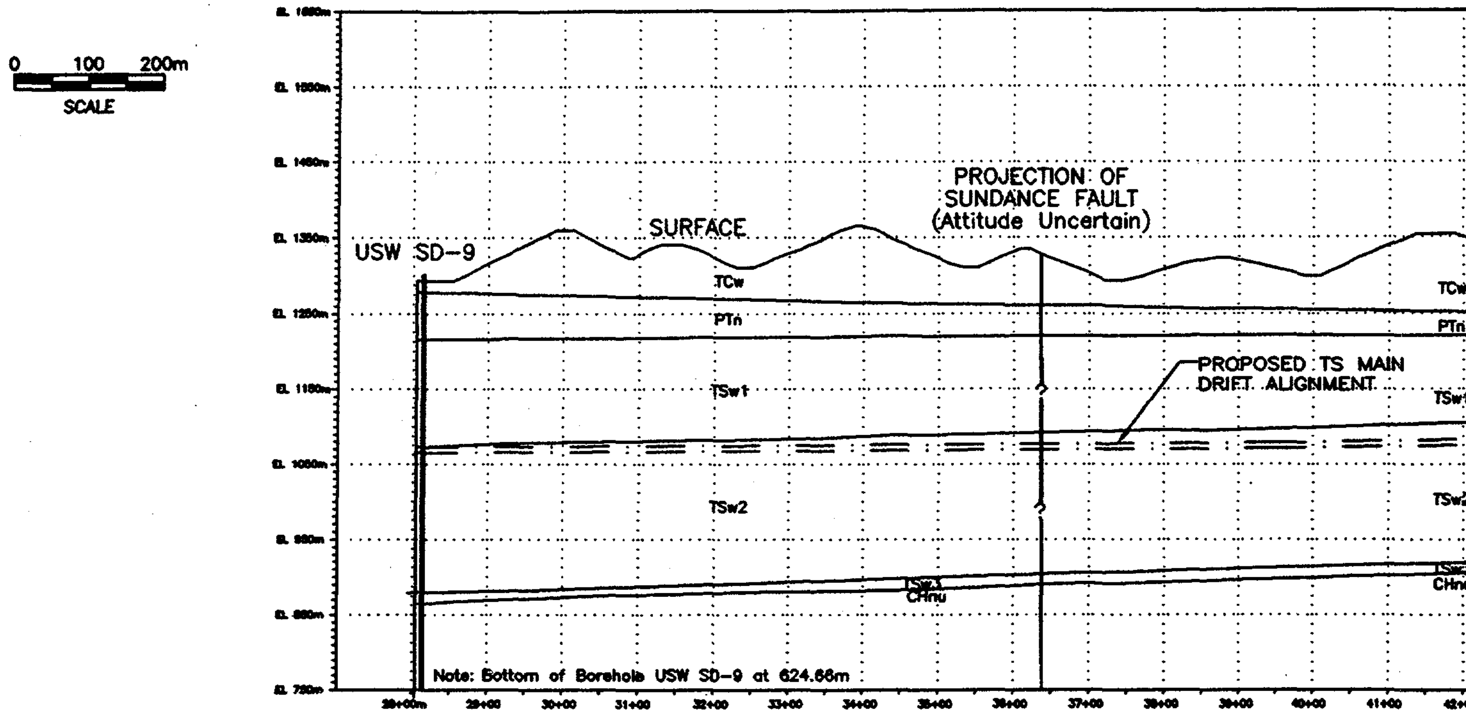
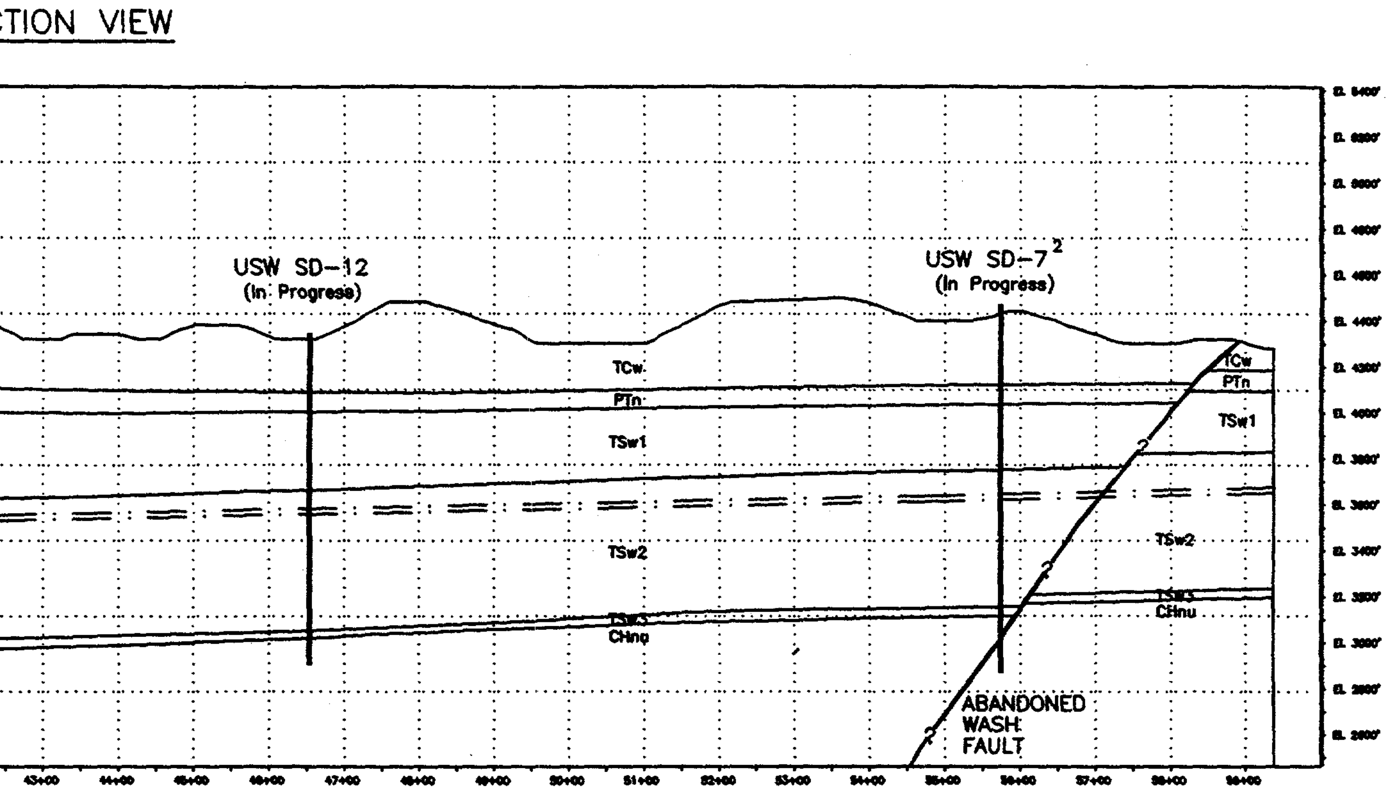


Reference Stratigraphy Unit Name (Designation)	Description
Tiva Canyon welded unit (TCw)	Moderately to densely welded, devitrified ash-flow tuff of t Canyon Tuff of the Paintbrush Group. Contains lithophysal nonlithophysal subunits.
Upper Paintbrush nonwelded unit (PTn)	Partially welded to nonwelded, vitric and occasionally devitri the lower Tiva Canyon, Yucca Mountain, Pah Canyon, and Spring Tuffs of the Paintbrush Group.
Topopah Spring welded unit, lithophysae-rich (TSw1)	Moderately to densely welded, devitrified ash flows of the Spring Tuff of the Paintbrush Group that locally contains n approximately 10% by volume lithophysal cavities.
Topopah Spring welded unit, lithophysae-poor (TSw2)	Moderately to densely welded, devitrified ash flows of the Spring Tuff of the Paintbrush Group that contains less tha approximately 10% by volume lithophysal cavities. This is repository host rock.
Topopah Spring welded unit, vitrophyre (TSw3)	Vitrophyre near the base of the Topopah Spring Tuff of th Group.
Calico Hills nonwelded unit, undifferentiated (CHnu)	Nonwelded ashflows and bedded tuffs of Calico Hills Forma basal Topopah Spring Tuff.



	Thermal-Mechanical Unit
Tiva d	TCw
tuffs of pah	PTn
pah than	TSw1
pah proposed	TSw2
intbrush	TSw3
and	CHnu

Figure 3-3. Thermal-mechanical unit cross section along the Main Drift.

unit.[18] Recent work by Elayer[19] suggests that the contact location should be revised to locate it as per the original definition based on approximately 10% lithophysal content. This potential change is noted in Figure 3-3.

The thermal-mechanical units are based primarily on welded versus nonwelded rocks and on the porosity and presence of lithophysal cavities. The degree of welding present within the rocks of the Paintbrush Group ranges from nonwelded bedded tuffs that can be crumbled by hand to densely welded ash-flow tuffs. As the degree of welding may vary both vertically and laterally within an ash-flow unit, the thermal-mechanical unit boundaries reflect the boundaries between welded and nonwelded zones. Thermal-mechanical unit boundaries may vary with stratigraphic units.

Of note to ESF Main Drift design is the distinction between the upper two Tpt welded units, TSw1 and TSw2. These units are both within the densely welded, devitrified portions of the Tpt, but are reported to differ in that TSw1 contains zones where void space from lithophysal cavities commonly exceeds 10% by volume. TSw2, which contains the Main Drift horizon, also contains lithophysae bearing units, but to a lesser extent. The Tptpmn, in which the majority of the Main Drift is to be excavated, is the uppermost of the three lithostratigraphic units which comprise the TSw2.

3.5 Major Structural Features

3.5.1 Yucca Mountain Structural Framework

Yucca Mountain consists of a number of north trending structural blocks that have been tilted gently eastward by major west dipping, high-angle normal faults (Scott and Bonk 1984). The structural block containing the ESF is 3–4 km wide and is shown in Figure 3-4[20] to be bounded on the west and east by the Solitario Canyon and Bow Ridge Faults, respectively. Estimated displacement on the Solitario Canyon Fault ranges from 400 m (1312 ft) (Carr 1984) to 500 m (1640 ft) (USGS 1984). Displacement on the Bow Ridge Fault is variously described as 120 m (400 ft) (Carr 1984) to 220 m (725 ft) (USGS 1984) and is reported as 125 m ±9 m (410 ft ±30 ft) along the North Ramp alignment by Buesch et al. (1994).

Faults along the west sides of the major structural blocks at Yucca Mountain typically show highly brecciated zones as wide as 500 m, while the east margins of the blocks are characterized by abundant subparallel, west dipping normal faults described by some authors as

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[18] Peck, J.M., U.S. Clanton, C.A. Rautman, R.W. Spengler, and D. Vaniman (1991). Science Application International Corp. (SAIC), Las Vegas, Nevada, to D.C. Dobson and J.R. Dyer, Department of Energy, YMP, Nevada, May 15 letter.

[19] Elayer, R.W. (1995). Definition of the Potential Repository Block, Document No. BC0000000-01717-5705-00009, Revision 00, CRWMS/M&O, TRW Environmental Safety Systems, Inc., Las Vegas, Nevada.

[20] Buesch et al.

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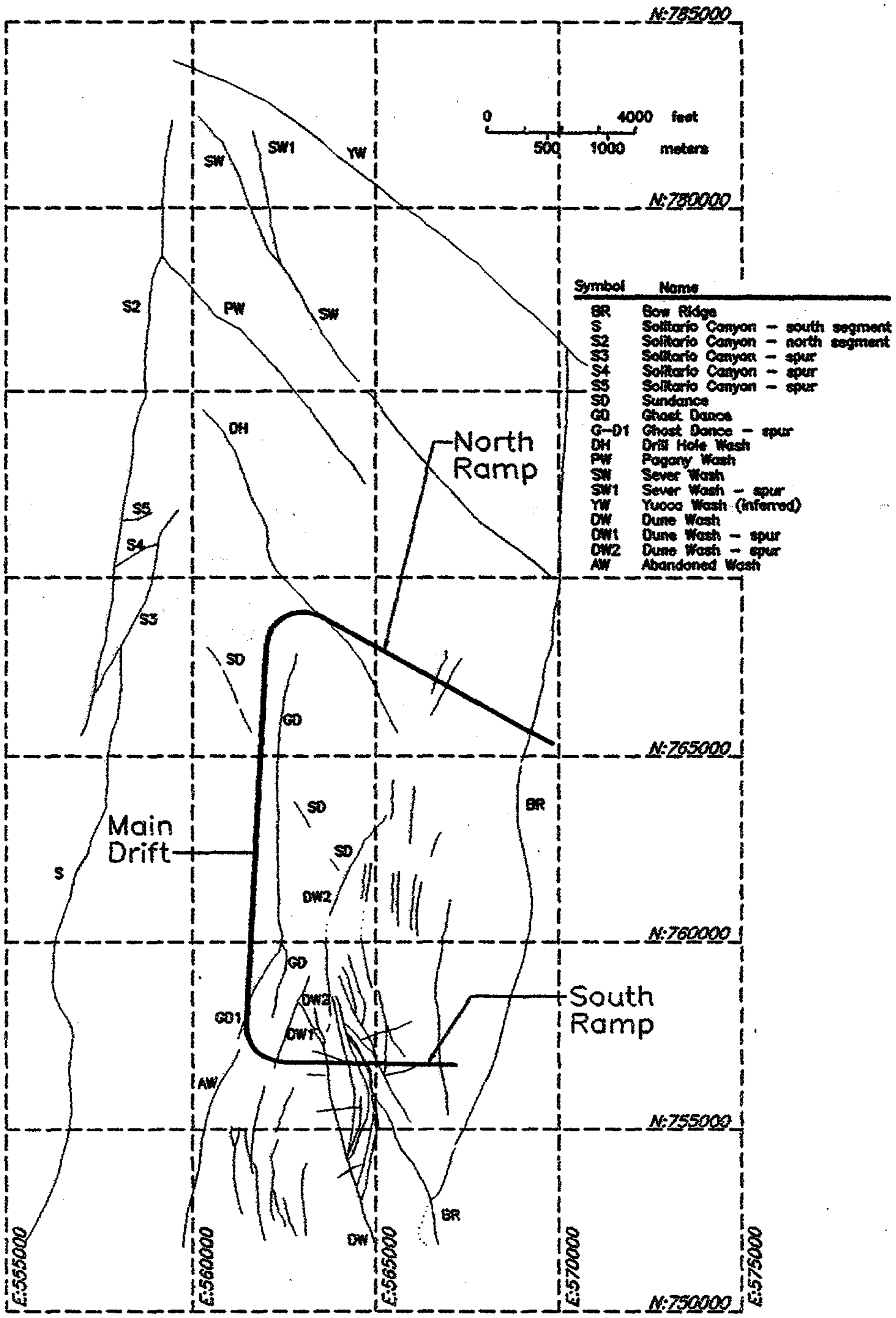

5,000 foot grid based on Nevada State Coordinate System

Figure 3-4. Map of ESF area showing surface location of identified faults (adapted from USGS OFR 95-124).*

*Ibid.

imbricate normal fault zones (Scott and Rosenbaum 1986). Individual faults within these zones typically displace strata by only a few meters and the dip of strata between the faults progressively steepens eastward toward the margins of the broken zones. These fault zones increase in width toward the southern end of Yucca Mountain, which paleomagnetic and field mapping evidence shows to have rotated about 30° in a clockwise direction relative to the north end of the mountain (Spengler and Fox 1989). A number of northwest trending, right-lateral, strike-slip faults exist in the northern portions of Yucca Mountain, but the amount of displacement is probably minor as inferred from little or no offset of stratigraphic units (Carr 1984).

3.5.2 Faults Recognized Along the Main Drift Alignment

The potential repository has been sited in the area of the central block of Yucca Mountain that is the least disrupted by faulting. Most faults within this area are north trending, down-to-the-west structures with 5 m or less offset and do not cross the Main Drift alignment, as shown in Figure 3-4, and Figure 3-5[21] shows surface faults identified by Scott and Bonk (1984). Exceptions to this are the Ghost Dance Fault and Sundance Fault Zone. The Main Drift is located approximately 160 m (525 ft) west of the surface trace of the Ghost Dance Fault for most of its length, but crosses a possible splay of this fault system, referred to as the Abandoned Wash Fault and a small parallel structure near the south end. The only additional structures noted by Scott and Bonk (1984) that are found on the alignment are several high-angle fracture sets with no apparent offset on the crest of Live Yucca Ridge above ESF station 36+00 m.

The known and suspected faults to be encountered by the Main Drift and the projected points of intersection based on the three-dimensional geologic model and Figure 3-5 are summarized in Table 3-3. Attitudes are derived from surface mapping or geophysics and the ramp station intersections are, therefore, approximate.

Table 3-3. Known Faults Projected to Encounter the Main Drift and Approximate Ramp Station

Ramp Station (m)*	Strike	Dip	Fault Type	Projected Dip-Slip Displacement	Name
36+40	N40°W	90°	strike-slip	0 m	Sundance Fault Zone
54+96†	N25° E	__‡	normal	__‡	Unnamed Fault
57+10	N25° E	74°	normal	21 m (70 ft)	Abandoned Wash Fault

* USGS OFR-95-124[13] and Figure 3-5.
? Intersection with ramp alignment on surface.
? No dip or displacement available in Scott and Bonk (1984) or USGS OFR 95-124.[13]

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[21] Geology of the Exploratory Studies Facility TS Loop, CRWMS M&O, Document No. BAB000000-01717-0200-00002, Rev. 00, TRW Environmental Safety Systems, Las Vegas, Nevada.

Title: GEOLOGY OF THE EXPLORATORY
STUDIES FACILITY TS LOOP

DOCUMENT IDENTIFIER: BAB000000-01717-0200-00002 Rev 00 Page 13 OF 35

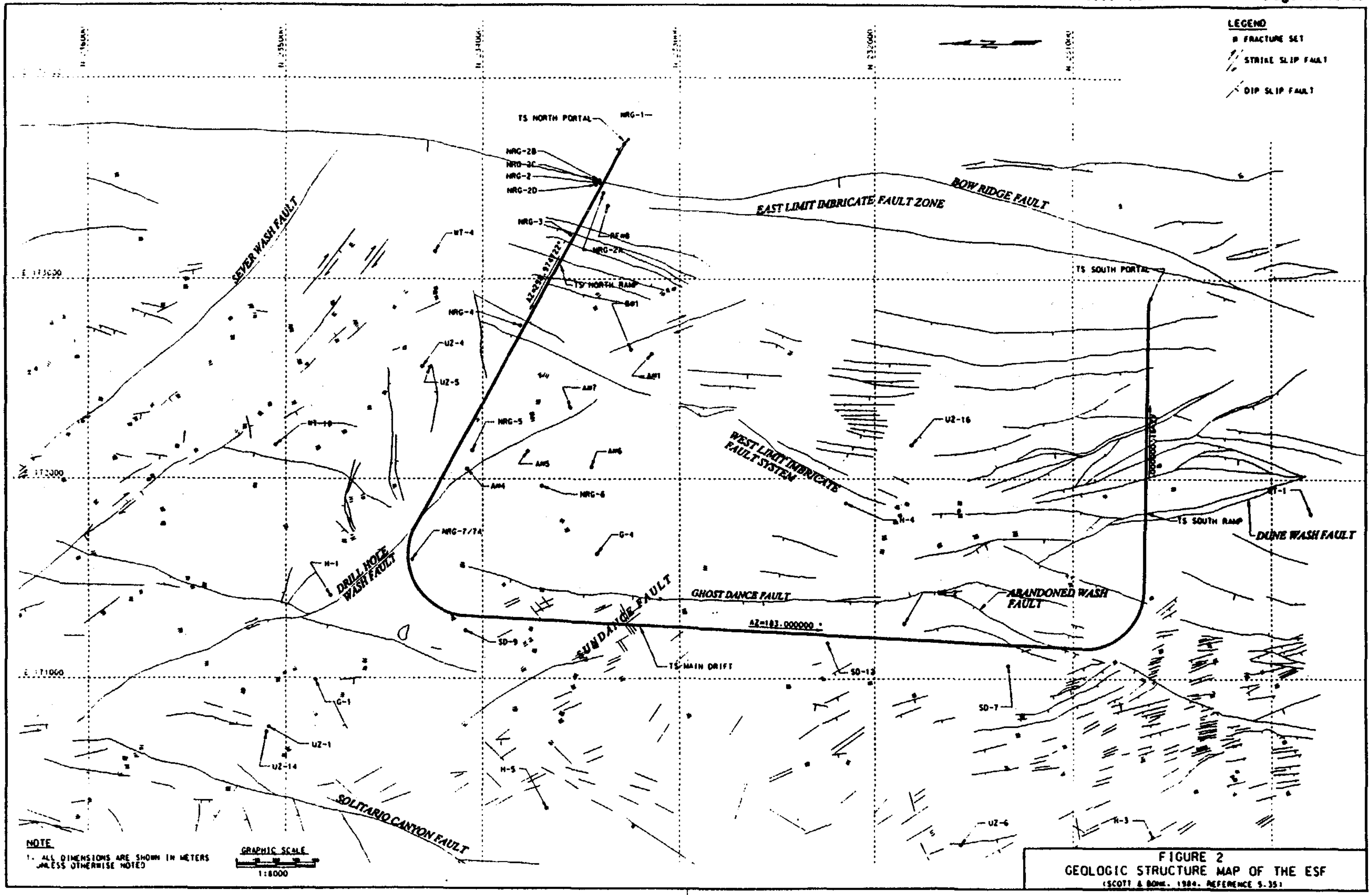

Figure 3-5. Surface locations of faults mapped by Scott and Bonk (1984)*

*Ibid.

The Ghost Dance Fault is reported to have 38 m of offset at the southern boundary of the proposed repository outline. However, displacement decreases to the north and is not detectable in Drill Hole Wash (Spengler et al. 1993). The Sundance Fault System is a northwest trending feature with apparent right-lateral offset of the Ghost Dance Fault of at least 52 m (Spengler et al. 1994). This structure is described as a zone of near-vertical N30°–N40°W trending faults at least 274 m (900 ft) wide, with the dominant feature at the center of the zone termed the Sundance Fault. The Sundance Fault is projected to cross the drift alignment at ramp station 36+40 m.

The fault labeled as the Abandoned Wash Fault in Figure 3-2 is a north-northeast trending fault mapped by Scott and Bonk (1984) that continues the trend of the main segment of the Abandoned Wash Fault to the south and appears to terminate against the Ghost Dance Fault. This fault is assigned a 74°W dip in the USGS[22] three-dimensional model, and has approximately 21 m (70 ft) of down-to-the-west dip separation. A parallel fault crosses the Main Drift alignment on the surface at station 54+96 m, however, no data on dip or displacement is available.

3.6 Joint Structure

The welded portions of the Tpc have been recognized by Barton et al. (1989) to contain two types of fractures: post-emplacement cooling joints and later tectonic joints. The cooling joints are observed to have low roughness coefficients and a lesser dispersion of orientations. Tectonic joints generally exhibit higher roughness coefficients, a greater dispersion of orientations, and a higher number of terminations against earlier joints.

Ongoing studies by the USGS[23] recognize that jointing characteristics vary significantly, depending on the degree of welding. In general, densely welded horizons show the greatest fracture frequencies. Nonwelded tuffs, on the other hand, show very few or no joints. This is due, at least in part, to the accommodation of stress by intergranular slip within the nonwelded units.

Mapping of the fracture network at Pavement P2001 at Fran Ridge by the USGS[24] illustrates some of the differences in jointing style between stratigraphic horizons. At this location, the Tptpmn is observed to contain large, continuous, and well-connected fractures similar to those recognized previously in the Tpc, while the overlying upper lithophysal zone of the Tpt exhibits shorter fractures with a greater number of blind terminations and a less-connected fracture network.

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[22] Buesh et al.

[23] Sweetkind, D.S., E.R. Verbeek, F.R. Singer, F.M. Byers, Jr., and L.G. Martin (to be published in 1995). *Surface Fracture Network at Fran Ridge Pavement P20001, near Yucca Mountain, Nye County, Nevada*, U.S. Geological Survey Administrative Report to the Department of Energy, Yucca Mountain Project Office.

[24] Ibid.

The U.S. Bureau of Reclamation[25] (USBR) has identified five structural feature trends in the North Ramp based on preliminary tunnel mapping data in the Tpc:

- joint set #1: dip = 84°, dip direction = 353°
- joint set #2: dip = 82°, dip direction = 132°
- joint set #3: dip = 78°, dip direction = 262°
- joint set #4: dip = 68°, dip direction = 174°
- joint set #5: dip = 16°, dip direction = 107°

The USBR set #5 is a subhorizontal parting characterized by thin anastomosing veins of vapor-phase alteration parallel to foliation. These features are most prominent in the middle *nonli*thophysal zone of the Tiva and may occur in other zones. Observations in the North Ramp indicate this structural feature is only a discontinuous separation a small percentage of the time. However, this feature represents a potential discontinuity or weakness, but has been considered a joint set as per Barton et al. (1974). Based on tunnel observations, the USBR joint set #4 rarely coexists with joint set #1; therefore, joint set #4 is considered to be a subset of joint set #1 because of the similar strike.

Based on these observations from the North Ramp Tunnel, three predominant joint sets can be identified and are listed in Table 3-4. These data are similar to the analysis of fracture patterns in existing oriented-core data (Lin et al. 1993b). Because there is general agreement between data sets on fracture orientation, it was assumed that the fracture sets to be encountered in the Tpt during excavation of the Main Drift will be similar to the North Ramp and Fran Ridge data. The Tpc and Tpt are very similar in terms of rock properties, were deposited within a relatively short period of geologic time, and have been subjected to the same post emplacement tectonic stresses.

Table 3-4. Orientation of Joint Sets Assumed to be Present in Tpt

Joint Set	Dip (degrees)	Dip Direction (degrees)
1.00	84.00	353.00
2.00	82.00	132.00
3.00	78.00	262.00

3.7 Hydrology

The Main Drift will be excavated in the unsaturated portion of the YMP stratigraphy. No evidence of water inflow of construction significance was observed in video logs of SD-7, SD-9 or SD-12 in the middle nonlithophysal or lower lithophysal zones to be cut in the Main Drift. Fault zones along the ramp were not directly sampled by any of the boreholes and conditions at the faults which will be penetrated by the Main Drift are not known. Perched water has been observed at the YMP site.

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[25] U.S. Bureau of Reclamation (1995). *Geotechnical Report for Station 0+6 to 4+00 m, North Ramp of the ESF*, Report, DTN: GS950508314224.003.

4.0 Borehole Geotechnical Data

4.1 Rock Structure Data

This section of the report presents a summary of the rock structural data from boreholes USW NRG-6, NRG-7/7A, SD-7, SD-9, SD-12, and UZ-14 as the basis of characterization of rock characteristics along the Main Drift. The majority of the Main Drift (stations 28+05 to 57+00 m) cuts across the Tptpmn, and the structural data for this entire zone has been summarized for presentation. Near station 57+00 m, the Abandoned Wash Fault is projected to intersect the Main Drift and causes an up to the south displacement of approximately 15 m. Beyond this fault, the Main Drift is projected to be excavated approximately 15–20 m below the Tptpmn/Tptpll contact. The structural character of this portion of the Tptpll is compared to the Tptpmn for the interval 57+00 to 59+37 m.

The rock structure data are discussed under the following headings:

- lost core and rubble zones,
- Rock Quality Designation (RQD),
- rock weathering and hardness,
- fracture type,
- mineral infill and thickness,
- fracture surface roughness and planarity, and
- fracture frequency.

Appendix A lists TDIF numbers and data tracking numbers (DTN) of the individual core hole logs. The core log data for USW SD-7, SD-9, SD-12 and UZ-14 are presented in Appendix C. A detailed description of the structural core logging process along with core log data for USW NRG-6 and NRG-7/7A have been previously reported by Brechtel et al. (1995).

4.1.1 Core Recovery

The amount of lost core and rubble were logged for every 3-m (10-ft) interval of core throughout each borehole. The quantity of intact core and core rubble recovered and the quantity of lost core are general indicators of both the quality of the rock and the drilling technique. Lost core is defined as gaps in the core record where the rock sample has been ground up during drilling or where an empty void/cavity exists. A rubble zone includes sections of core where the rock is fragmented to the point where logging individual fractures is not feasible. The effect of the drilling technique on the proportion of lost core and rubble has been assessed by Brechtel et al. (1995) and it was suggested that it is the fractured nature of the welded tuffs and the presence of lithophysae voids that produce the amount of lost and rubblized core and not the coring method.

The core recovery data are summarized in Table 4-1 for the Tptpmn. This table lists the percentages of intact core, rubble zones, and lost core (normalized to the total core length within the middle nonlithophysal zone) which are compared graphically in Figure 4-1. The amount of lost core from each hole ranged from 8.8% to 34.2% of the total core interval within the stratigraphic zone. Rubble zones ranged from 11.9% to 31.4%. Overall, 65% of the total core was recovered intact and logged, 15% was lost and 20% was rubblized. This is consistent with the core recovery in other welded units considered in the analysis of the North Ramp (NRG) borehole data.

Table 4-1. Summary of Core Recovery Data for the Tptpmn—Main Drift Boreholes

Borehole	Total Logged (m)	Whole Core Recovered (m)	% of Total	Lost Core (m)	% of Total	Rubble Zones (m)	% of Total	Lost Core & Rubble (m)	% of Total
SD-7	36.6	21.2	57.9	3.9	10.7	11.5	31.4	15.4	42.1
SD-9	33.5	23.4	69.9	4.8	14.3	5.3	15.8	10.1	30.1
SD-12	39.6	27.4	69.2	3.5	8.8	8.7	22.0	12.2	30.8
NRG-6	30.5	21.8	71.5	2.7	8.9	6.0	19.7	8.7	28.5
NRG-7/7A	36.6	17.3	47.2	12.5	34.2	6.8	18.6	19.3	52.8
UZ-14	33.5	26.3	78.5	3.2	9.5	4.0	11.9	7.2	21.5
TOTAL	210.3	137.4	65.3	30.6	14.5	42.3	20.1	72.9	34.7

The upper portion of the lower lithophysal zone is characterized by very high proportions of lost core and rubble. For example, NRG-7/7A averages 62% lost core and 15% rubble in the first 24 m below the base of the Tptpmn.

4.1.2 RQD Data

RQD (Deere 1963) is a core recovery percentage that considers only those pieces of core which are 100 mm (4 in) or greater in length. This index has been widely used as a general indicator of rock mass quality and is an input for the RMR and Q systems. The RQD percentage is determined as follows:

$$\text{RQD}(\%) = \frac{\sum \text{Piece lengths} \geq 100\,\text{mm (4 inches)}}{\text{Interval length}} \times 100 \qquad (4\text{-}1)$$

where all discontinuity features observed in the core were considered. Lost core and rubble zones do not contribute any piece lengths, but are considered in the interval length. RQD was determined for both the core run interval and on even 3-m (10-ft) intervals.

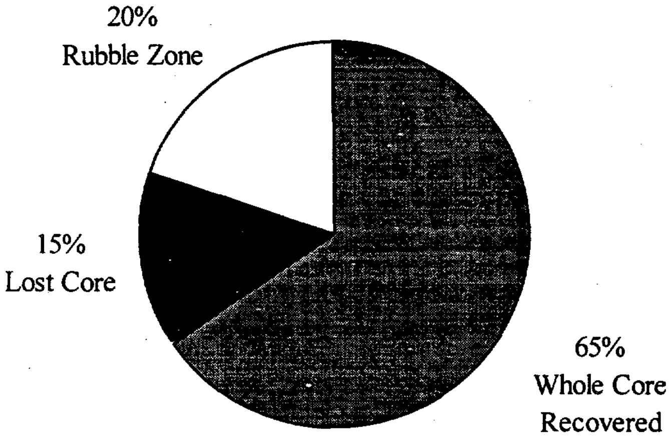


Figure 4-1. Pie chart showing core recovery, lost core and rubble zones as a percentage of total core in the Tptpmn—Main Drift boreholes.

The RQD used for geotechnical design purposes considered all fractures identified in the core, including those identified by the core loggers as natural, indeterminate, and drilling induced. A parameter, *enhanced-RQD*, was also calculated in which the drilling-induced fractures were not considered resulting in greater piece length determinations. The resulting core RQD and *enhanced-RQD* are compared in Table 4-2 for the Tptpmn for each of the Main Drift boreholes. Frequency histograms and the cumulative percent occurrence for RQD and *enhanced-RQD* are shown in Figures 4-2 and 4-3, respectively.

Table 4-2. Comparison of RQD and *Enhanced-RQD* Data for the Tptpmn—Main Drift Boreholes

		SD-7	SD-9	SD-12	NRG-6	NRG-7/7A	UZ-14	All Holes	Relative Rating	
RQD	Mean	15	33	24	11	15	37	23	**RQD (%)**	**Rating**
	Median	12	19	25	8	11	29	16	91-100	Excellent
	Std. Dev.	15	28	16	12	14	31	22	76-90	Good
Enhanced-RQD	Mean	29	49	39	28	28	55	38	51-75	Fair
	Median	26	50	38	29	28	51	33	26-50	Poor
	Std. Dev.	23	28	24	18	21	33	26	1-25	Very Poor
Enhanced-RQD/RQD	Mean	1.9	1.5	1.6	2.6	1.8	1.5	1.7	0-1	Extremely Poor
	Median	2.2	2.6	1.5	3.6	2.5	1.8	2.1		

The relative rock quality according to the RQD system (Deere 1968) is shown in Table 4-2 to compare to the Main Drift RQD values. The relative rock quality based on average

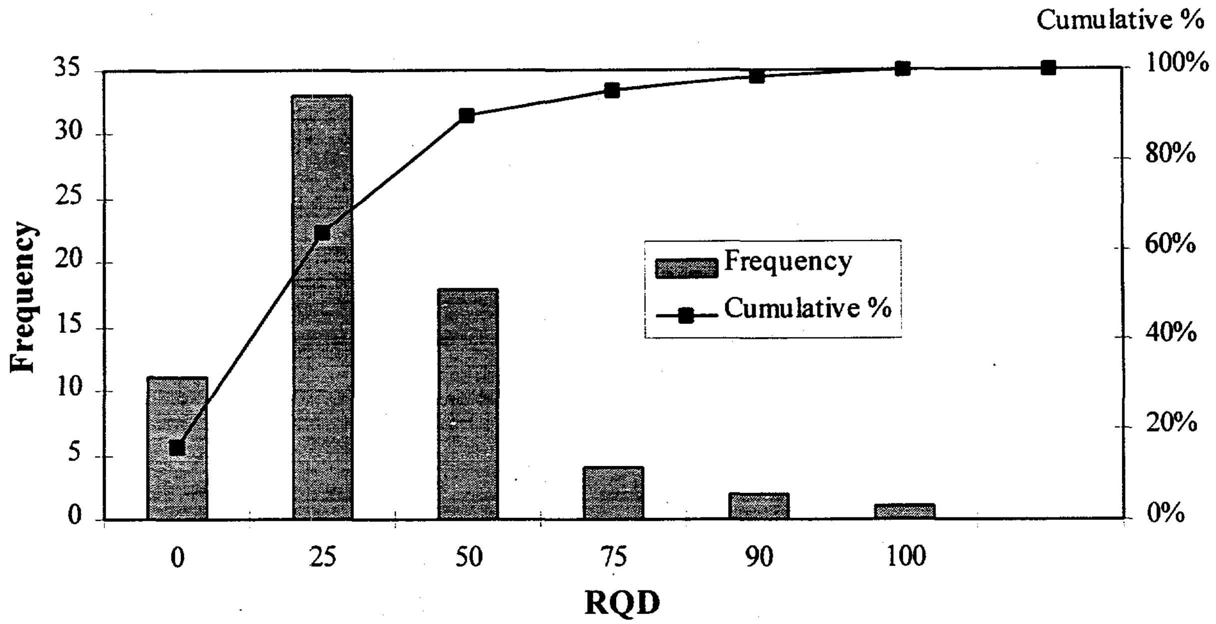


Figure 4-2. Histogram showing RQD frequency in the Tptpmn—Main Drift boreholes.

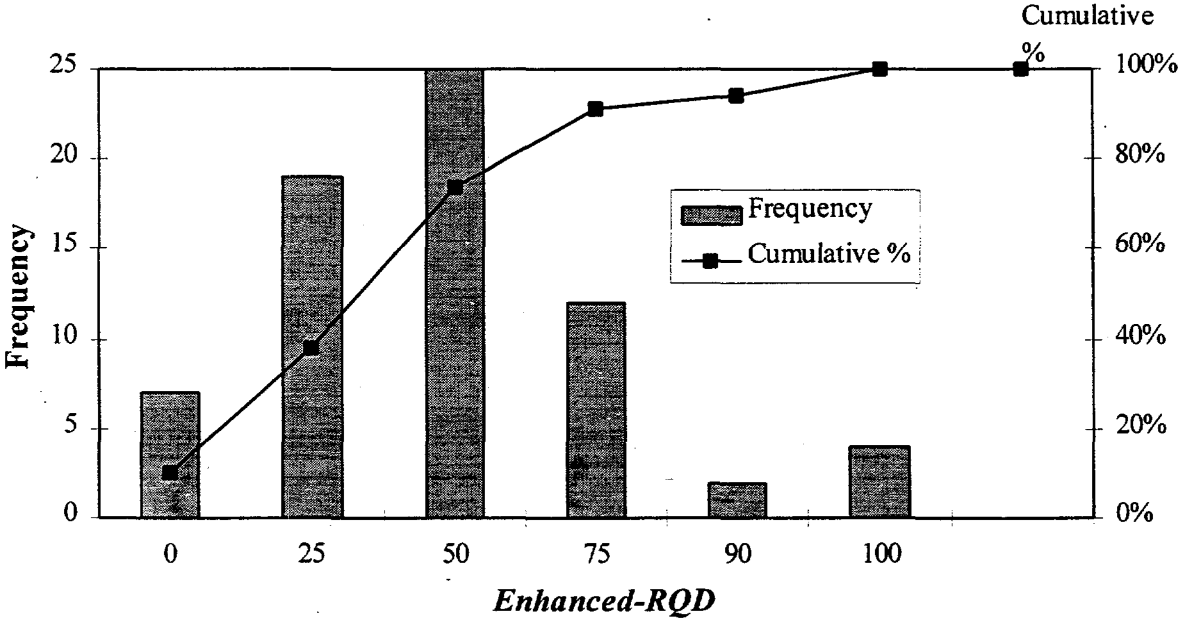


Figure 4-3. Histogram showing *enhanced-RQD* frequency in the Tptpmn—Main Drift boreholes.

RQD in the Tptpmn ranges from poor to very poor among the various holes. Table 4-2 also shows the ratio of *enhanced-RQD* to RQD for both mean and median values. Using average values from each borehole, the *enhanced-RQD* ranges from 1.5 to 2.6 times greater than the core RQD, suggesting poor to fair rather than very poor to poor rock quality.

RQD does not provide a complete assessment of rock structural quality; however, it provides a basis for cross-hole comparison to assess the potential of variation along the Main Drift as it cuts across the strata units. This comparison is shown in Figure 4-4 which lists the 3-m (10-ft) RQD values with increasing depth from the top of the Tptpmn. The approximate ramp station is listed on the left side of the figure for 10-m vertical increments of the stratigraphy. The comparison is generalized using the mean RQD for 3-m (10-ft) intervals which are compared to stratigraphy at the right side of the table and suggests the presence of two zones of generally higher RQD. Areas of lower RQD occur above, in between, and below, with the middle area associated with the lithophysal subzone in the Tptpmn. Below the Tptpmn, the portion of the Tptpll projected to be cut by the Main Drift is characterized by very low RQD, with the low values very consistent from hole to hole.

4.1.3 Rock Weathering and Hardness

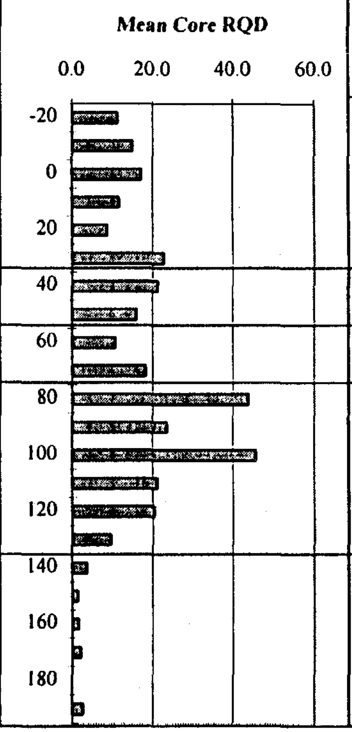
Weathering is a parameter that describes the condition of the rock that constitutes the core surface. Rock weathering is determined for each 3-m (10-ft) interval of core using the qualitative descriptors listed in Table 4-3 which are based on recommendations by the International Society of Rock Mechanics (ISRM 1981). The distribution of the rock weathering is presented graphically in Figure 4-5 for the Tptpmn. Rock for this zone is either fresh or slightly weathered (51% and 49%, respectively, of the whole core recovered).

Rock hardness is a general descriptor of the strength of the rock material. Hardness is typically determined by scratching the rock surface or by striking the rock with a hammer and observing the response of the material. However, to satisfy the technical requirements for the core samples recovered in YMP drilling, the rock hardness was subjectively estimated by visual inspection. The hardness classification descriptors are listed in Table 4-4. The distribution of rock hardness is presented graphically in Figure 4-6. The rock in the Tptpmn has been generally classified as hard (80%) and very hard (15%).

4.1.4 Lithophysae Content

The lithophysae content includes the surface area percentage of lithophysal and other voids observed in the rock and is estimated for each 3-m (10-ft) interval of core using standard charts for estimating mineral content in thin sections. The distribution of the estimated lithophysal content is shown in Figure 4-7 for the Tptpmn. Percent lithophysae is low, with an average value of 0.3%, median of 0.0%, and a standard deviation of 0.8%. Lithophysal contents of the core recovered from the Tptpll ranged from 0 to 3% (from NRG-7/7A) using the core-based descriptive method reported by Brechtel et al. (1995). However, borehole video suggests that a substantially higher volume of lithophysal cavities may be present.

Approximate Main Drift Station (m)	Distance From Base of Interval* (ft)	Nominal Metric Distance (m)	Core RQD									Areas of Higher Rock Quality	Stratagraphic Zone	Thermal-mechanical Unit
			▭ = *middle nonlithophysal zone*						Mean	Standard Deviation	Coefficient of Variation			
			NRG-7	SD-9	NRG-6	UZ-14	SD-12	SD-7						
-	-20	-6	0	16	11	-	5	25	11.4	9.7	0.9		T.S. C.P. U. Lithophysal Zone	TSw1
-	-10	-3	5	41	8	36	0	0	15.0	18.5	1.2			
-	0	0	9	28	9	10	40	8	17.3	13.5	0.8			
28+05	10	3	8	7	0	15	41	0	11.8	15.4	1.3		**T.S. C.P. M. Non-lithophysal Zone**	TSw2
-	20	6	4	12	11	15	11	0	8.8	5.6	0.6			
30+00	30	9	0	62	5	29	28	13	22.8	22.5	1.0			
-	40	12	10	64	16	6	25	7	21.3	22.1	1.0	Area 1		
-	50	15	48	0	0	0	20	28	16.0	19.8	1.2			
-	60	18	18	8	0	26	0	13	10.8	10.3	0.9		**Lithophysal Subzone**	
34+00	70	21	12	19	30	40	4	5	18.3	14.3	0.8			
-	80	24	25	52	32	65	41	48	43.8	14.4	0.3	Area 2		
-	90	27	2	48	0	32	24	36	23.7	19.2	0.8			
42+00	100	30	29	78	14	94	42	17	45.7	33.2	0.7			
-	110	34	17	18	4	82	0	6	21.2	30.7	1.4			
-	120	37	10	16	0	54	33	10	20.5	19.7	1.0			
55+00	130	40	8	0	0	0	46	4	9.7	18.1	1.9			
57+00	140	43	0	5	6	-	8	0	3.8	3.6	1.0		T.S. C.P. L. Lithophysal Zone	
	150	46	0	0	0	-	8	0	1.6	3.6	0.0			
Fault	160	49	0	3	0	-	4	-	1.8	2.1	0.0			
	170	52	0	4	0	-	5	-	2.3	2.6	1.2			
57+00	180	55	0	0	0	-	0	-	0.0	0.0	0.0			
-	190	58	0	1	5	-	5	-	2.8	2.6	1.0			



*0 ft = Approximate top of Topopah Spring Tuff middle nonlithophysal zone

Figure 4-4. Cross-hole comparison of RQD in the Tptpmn and portions of the Tptpll.

Table 4-3. Explanation of Weathering Descriptions and Log Abbreviations

Weathering Class	Log Abbreviation	Further Explanation
Fresh	F	Rock and fractures not oxidized or discolored, no separation of grains, change of texture or solutioning.
Slightly weathered	S	Oxidized or discolored fractures and nearby rock, some dull feldspars, no separation of grains, minor leaching.
Moderately weathered	M	Fractures and most of the rock oxidized or discolored, partial separation of grains, rusty or cloudy crystals, moderate leaching of soluble minerals.
Intensely weathered	I	Fractures and rock totally oxidized or discolored, extensive clay alteration, leaching complete, extensive grain separation, rock is friable.
Decomposed	D	Grain separation and clay alteration complete.

F=Fresh, S=Slightly Weathered, M=Moderately Weathered,
I=Intensely Weathered, D=Decomposed

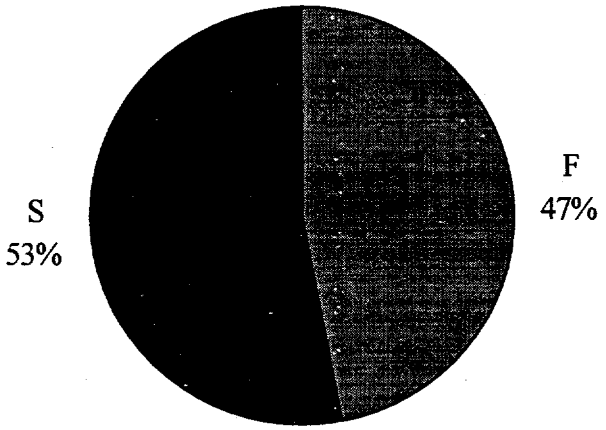


Figure 4-5. Distribution of rock weathering parameters for the Tptpmn—Main Drift boreholes.

Table 4-4. Explanation of Estimated Hardness and Log Abbreviations

Hardness Class	Log Abbreviation	Further Explanation
Extremely hard	1	Cannot be scratched, chipped only with repeated heavy hammer blows.
Very hard	2	Cannot be scratched, broken only with repeated heavy hammer blows.
Hard	3	Scratched with heavy pressure, breaks with heavy hammer blow.
Moderately hard	4	Scratched with light–moderate pressure, breaks with moderate hammer blow.
Moderately soft	5	Grooved (16th inch) with moderate heavy pressure, breaks with light hammer blow.
Soft	6	Grooved easily with light pressure, scratched with fingernail, breaks with light–moderate manual pressure.
Very soft	7	Readily gouged with fingernail, breaks with light pressure.
Soil-like	8	cohesive
Soil-like	9	non-cohesive

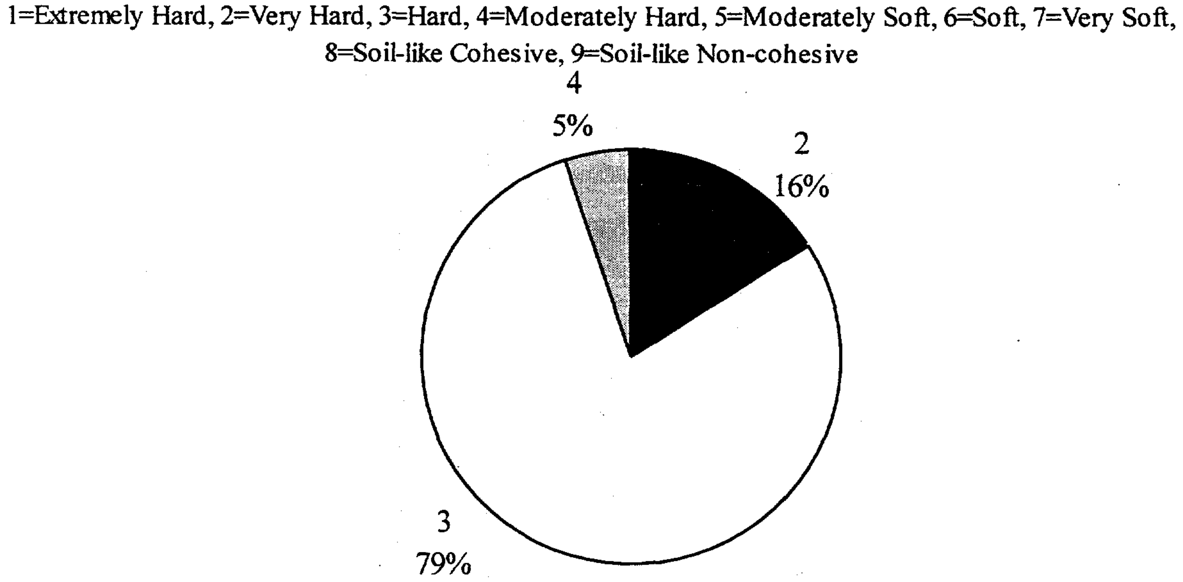


Figure 4-6. Distribution of the estimated hardness rating as a percentage of the total drilling in the Tptpmn—Main Drift boreholes.

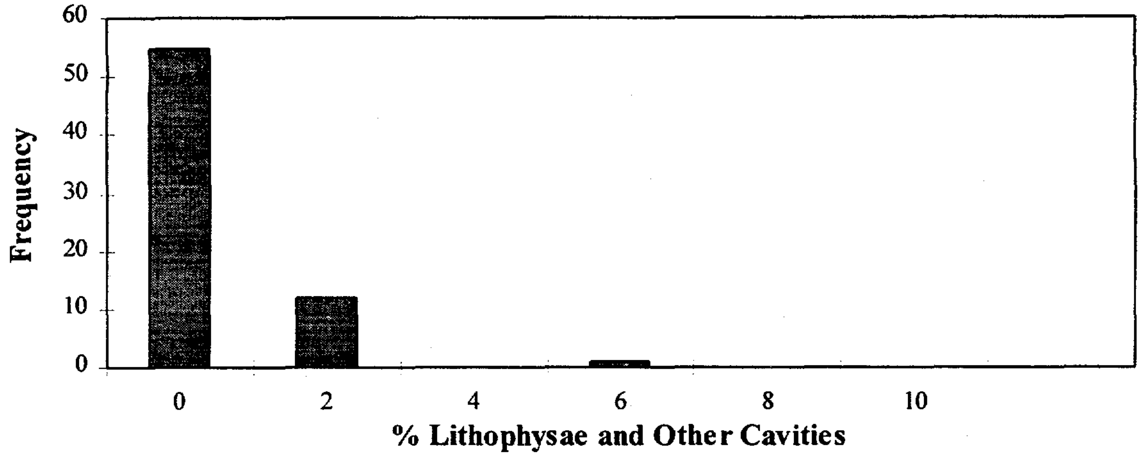


Figure 4-7. Histogram of the distribution of the percent lithophysae and other cavities in the Tptpmn—Main Drift boreholes.

4.1.5 Fracture Data

Extensive fracture data has been collected in the core logging process for the boreholes. The information for each individual fracture can include the following:

- structural feature type,
- fracture inclination,
- fracture mineral infilling,
- fracture infilling thickness,
- fracture planarity, and
- fracture roughness.

Detailed instructions for the geotechnical logging process, including the description of these fracture characteristics, are provided by Brechtel et al. (1995). The distribution of each fracture characteristic for the Tptpmn unit is described in the following subsections. No detailed processing of fracture characteristics was performed due to the large quantity of lost core and rubble in the lower lithophysal zone.

4.1.5.1 Feature Type. There are four categories of structural features that are identified during the logging of the core:

- N—natural fractures,
- I—indeterminate (uncertain origin) fractures,
- C—coring-induced fractures, and
- V—vug or void larger than core.

Natural fractures are indicated by mineral coatings, evidence of weathering, slickensides, and lack of rematch/fit between the discontinuity surfaces across the core. The fractures judged to be coring-induced are generally perpendicular to the axis of the core and are typically clean, fresh, and fit tightly back together. Fractures identified as indeterminate (I) often have been shaped by drilling rotation and cannot clearly be identified as natural (N) or coring induced (C). Voids or vugs that are larger than the core have also been identified during the logging process.

The total occurrence of each of type of feature is listed in Table 4-5, and distribution of these structural features is shown in Figure 4-8. Coring-induced (C) fractures have the largest proportion of occurrence in the Tptpmn. Only natural (N) and indeterminate (I) fractures have been considered in assessing the other fracture characteristics which include fracture inclination, mineral infilling and thickness, fracture planarity and roughness, and fracture frequency. For the Tptpmn, N and I feature types constitute 48.5% of the total fractures.

4.1.5.2 Fracture Inclination. Fracture inclination is the angle between the plane normal to the core axis and the fracture plane. The boreholes considered in the Main Drift are vertical, and fracture inclination is the dip angle of the fracture. The frequency of occurrence of dip angles grouped in 10° increments is shown in Figure 4-9. With no correction for sampling bias applied, low-angle fractures (less than or equal to 10°) occur most frequently. Sampling fracture inclination from core hole data introduces a bias in favor of fractures that are oriented perpendicular to the core axis. This sampling bias has been corrected using Terzaghi's (1965) procedure to provide a more representative distribution of fracture inclination, which is also illustrated in Figure 4-9. The application of Terzaghi's correction to borehole data for the ESF has been described by Lin et al. (1993b) and Brechtel et al. (1995). The corrected data shows that fractures with dips in the 80° to 90° range are the most dominant with a frequency of occurrence of 66.9%. The corrected fracture frequency for fracture dips between 70° and 90° is 22.0 m^{-1}.

Table 4-5. Total Number of Core Structural Features in the Tptpmn—Main Drift Boreholes

Borehole	Total Features	Natural N	Indeterminate I	Coring Induced C	Voids V
NRG-6	330	91	35	204	0
NRG-7/7A	319	59	71	189	0
UZ-14	315	104	74	137	0
SD-7	297	98	62	137	0
SD-9	250	68	38	140	4
SD-12	363	95	114	154	0
TOTAL	1874	515	394	961	4
% of occurrence	—	27.5	21	51.3	0.2

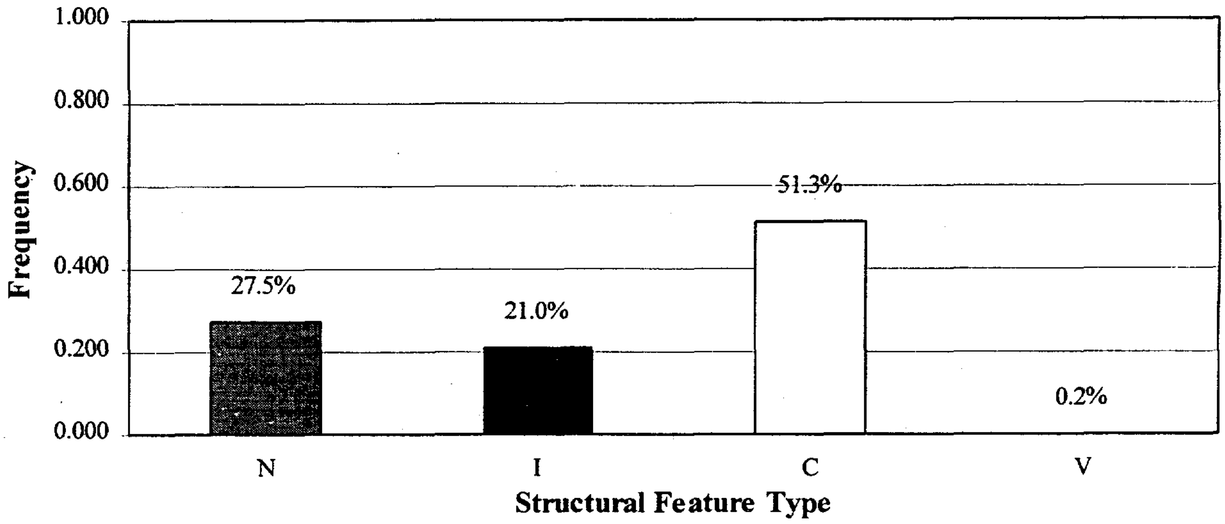


Figure 4-8. Distribution of the structural features in the Tptpmn—Main Drift boreholes.

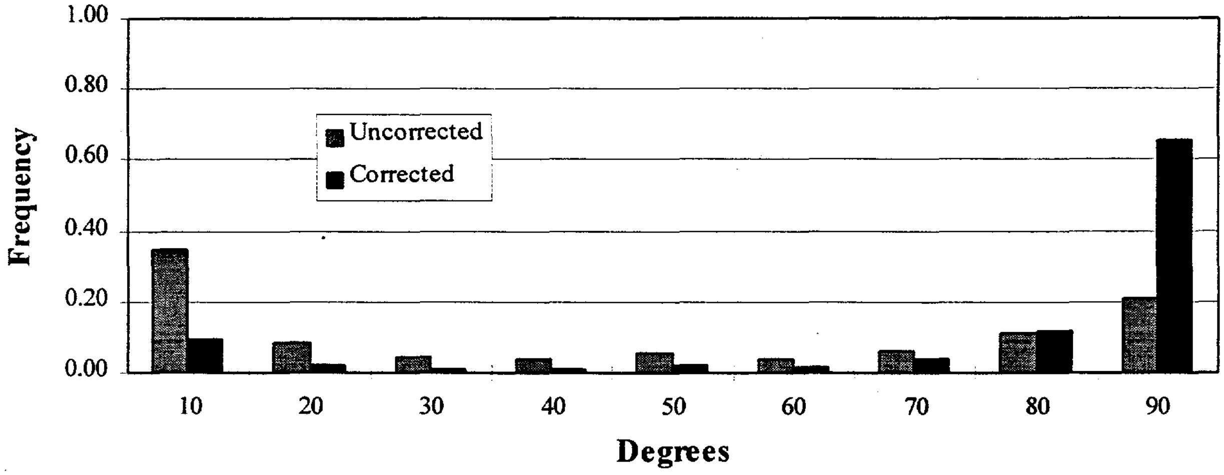


Figure 4-9. Distribution of fracture inclinations for both uncorrected and corrected (using Terzaghi's correction) data in the Tptpmn—Main Drift boreholes.

4.1.5.3 Fracture Infill Mineralization and Thickness. The amount and type of infill mineralization within the discontinuity effects the shear strength of the discontinuity surface and relates directly to the quality of the rock mass. The number of fractures with infill mineralization was logged using the following categories to describe the infill type:

- C—clean,
- WC—white crystalline,

- WN—white noncrystalline,
- BC—black crystalline,
- BD—black dendritic,
- TD—brown dendritic,
- TC—tan crystalline,
- SI—silica,
- MN—manganese,
- CA—calcite,
- CL—clay
- TN—tan noncrystalline,
- FE—iron, and
- BN—brown noncrystalline.

The thickness of the infill was described using the following categories:

- C—clean, no filling;
- S—very thin, surface sheen;
- T—thin (up to 0.1 inch);
- M—moderately thick (0.1-0.4 inch);
- V—very thick (0.4-1.0 inch); and
- E—extremely thick (>1.0 inch).

The distribution of infill mineralization and thickness data is illustrated in Figures 4-10 and 4-11, respectively, for the Tptpmn. The fracture surfaces in the core are primarily clean (56% of the occurrence of "N" and "I" type fractures). The predominant infill materials include white crystalline (WC, 8% occurrence), white non-crystalline (WN, 10% occurrence), and black dendritic (BD, 17% occurrence). Clay infill in this zone is very scarce (0.1% occurrence in the Main Drift boreholes). Fractures exposed in the North Ramp tend to have thicker infillings than projected from core analysis. This may be due to the tendency of softer infills to be eroded by the compressed-air coring technique.

4.1.5.4 Fracture Planarity and Roughness. Fracture planarity and roughness also contribute to the shear strength of the discontinuity surface and directly affect the quality of the rock mass. Planarity describes the overall shape of the fracture and is subdivided into the following categories:

- P—planar,
- C—curved,
- S—stepped, and
- I—irregular.

Roughness describes the local or small-scale relief of the discontinuity surface and is categorized as follows:

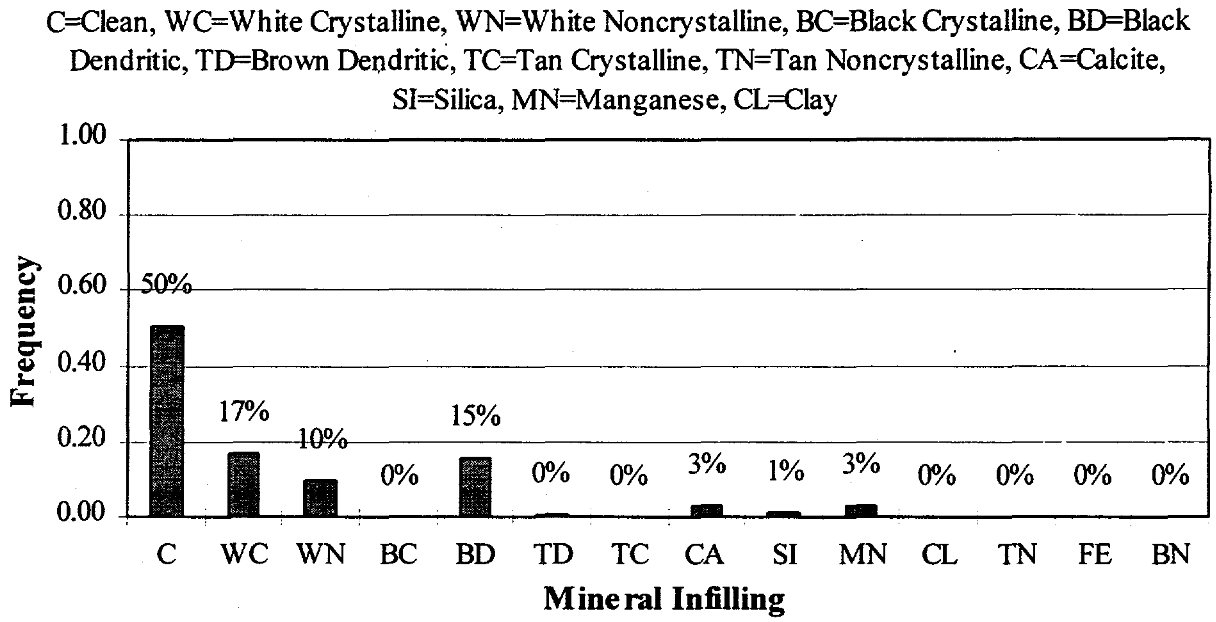


Figure 4-10. Distribution of fracture mineral infillings in the Tptpmn—Main Drift boreholes.

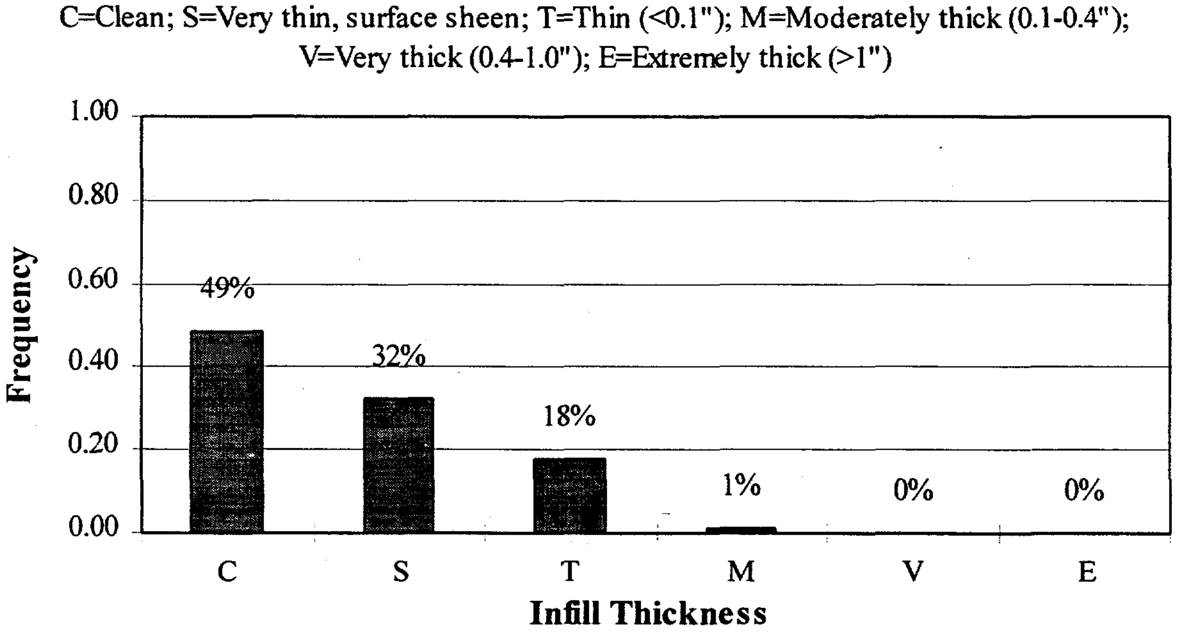


Figure 4-11. Distribution of fracture infill thickness in the Tptpmn—Main Drift boreholes.

- V—very rough,
- R—rough,
- M—moderately rough,
- S—smooth, and
- P—polished.

The distributions of the frequency of occurrence of types of fracture planarity and roughness are shown in Figures 4-12 and 4-13, respectively. The fractures in the Tptpmn are predominately planar (66 % of the total occurrence) with a significant occurrence of irregular surfaces (21%). The small-scale roughness of the fractures is primarily described as either moderately rough (50%) or smooth (39%).

4.2 Rock Mechanics Laboratory Test Data

The available rock mechanics laboratory test data for the Tptpmn at the time of initial preparation of this report were from core holes NRG-6 and -7/7A. Limited additional data was subsequently produced in holes USW SD-9 and SD-12. These data, summarized in Table 4-6, include the following rock properties:

- unconfined compressive strength;
- elastic modulus and Poisson's ratio;
- dry bulk density, porosity, average grain density;
- indirect tensile strength; and
- confined compressive strength.

The data have been combined in Table 4-6 to provide the range of values, mean, standard deviation, and number of tests for each rock property determined. The table is subdivided into two groups of summary statistics (USW NRG-6 and -7/7A versus all data) to evaluate any changes resulting from the inclusion of the SD-9 and SD-12 data.

The confined compressive strengths for intact rock were obtained in triaxial tests on 25.4-mm (1.0-in) diameter samples with confining pressures of 0, 5, and 10 MPa. The results are compared in Figure 4-14a as compressive strength versus confining pressure for NRG-7/7A samples from 262.65- and 263.78-m depths in Table 4-6, and in Figure 4-14b which includes supplemental data from boreholes SD-9 and SD-12. Least-square linear fits of the data sets were performed and plotted on these figures in the form:

$$\sigma_1 = N\sigma_3 + \sigma_c \qquad (4\text{-}2)$$

where

σ_1 = the strength of the rock at failure,
σ_3 = the confining stress,
σ_c = the unconfined compressive strength, and
N = a confinement factor.

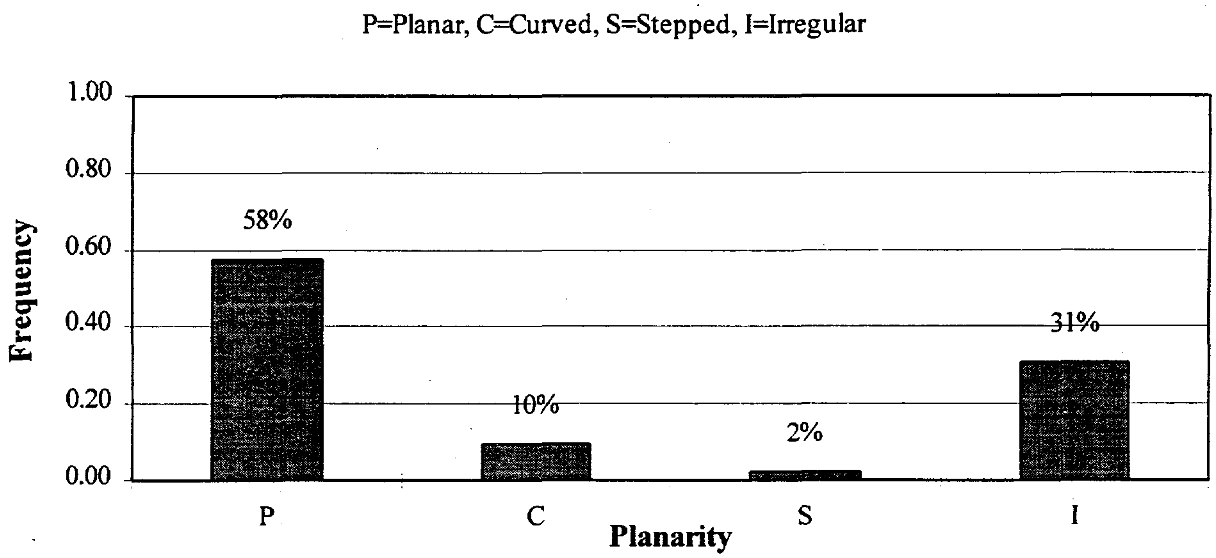


Figure 4-12. Distribution of fracture planarity for the Tptpmn—Main Drift boreholes.

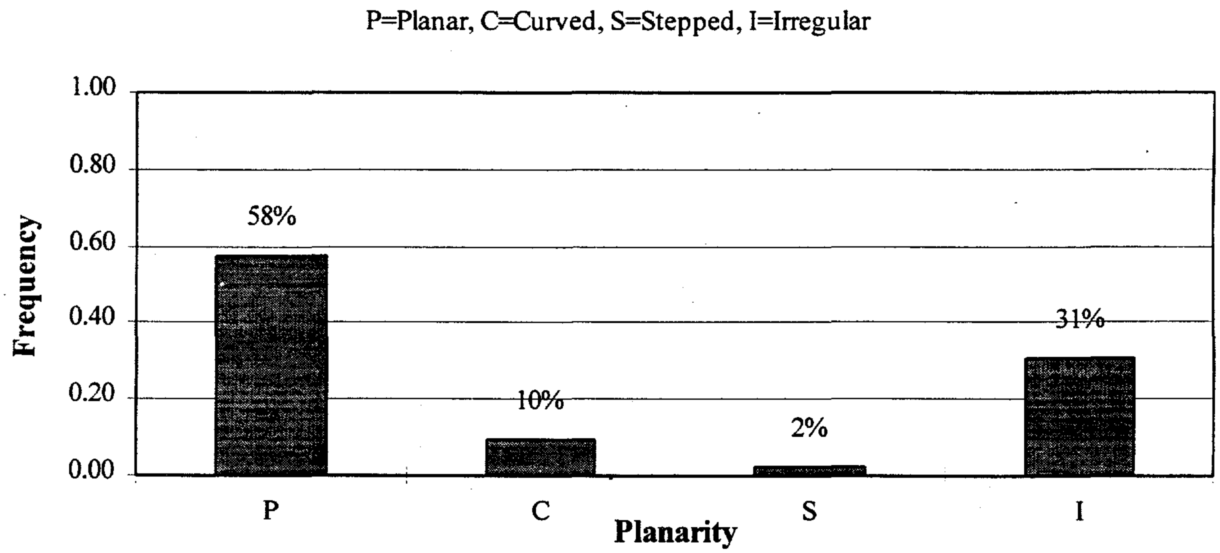


Figure 4-13. Distribution of the fracture roughness for the Tptpmn—Main Drift boreholes.

Table 4-6. Summary of Rock Mechanics Laboratory Test Data for Tptpmn—Main Drift Boreholes

Core Hole	Depth		UCS[1]	Porosity	Young's Modulus	Poisson's Ratio	Dry Bulk Density	Confined Compressive Test (MPa)[2]		Indirect Tensile Strength	Average Grain Density
	(m)	(ft)	(MPa)	(%)	(GPa)		(g/cc)	Confined Pressure	Axial Stress	(MPa)	(g/cc)
NRG-6	219.67	720.7-A	235.5	8.5	37.1	0.19	2.29				
	219.67	720.7-B									2.50
	226.26	742.3-A	162.3	11.0	30.6	0.20	2.25			14.50	
	226.26	742.3-B		9.7			2.28				
	226.26	742.3-C									2.53
	226.44	742.9-A	212.8	10.0	32.4	0.22	2.28			13.00	
	226.44	742.9-B		10.3			2.27				
	226.44	742.9-C									2.53
	232.53	762.9-A	112.1	9.5	29.2	0.18	2.31				
	232.53	762.9-B									2.55
	235.77	773.5-A	117.4	10.3	36.2	0.23	2.26			7.90	
	235.77	773.5-B		11.9			2.22				
	235.77	773.5-C									2.52
	236.89	777.2-A		8.0							
	236.89	777.2-B									2.50
	239.21	784.8-A	223.0	9.6	29.7	0.17	2.27				
	239.21	784.8-B		9.6			2.27			12.50	
	239.21	784.8-C									2.51
	239.45	785.6-A	218.6	9.3	30.1	0.16	2.27				
	239.45	785.6-B		9.3			2.27			14.10	
	239.45	785.6-C									2.51
	241.28	791.6-A		11.4							
	241.28	791.6-B									2.52
	245.92	806.8-A	261.9	8.0	31.7	0.16	2.31				
	245.92	806.8-B									2.51
NRG-7/7A	236.71	776.6-B									2.54
	236.83	777.0-A	143.8	10.6	32.9	0.22	2.27				
	243.90	800.2-A	179.2	10.3			2.27				
	245.55	805.6-A		12.6	21.4	0.27	2.21	10.00	147.10		
	245.55	805.6-B									2.53
	245.76	806.3-A	225.4	10.1	36.7	0.19	2.28				
	246.16	807.6-B									2.53
	246.37	808.3-B									2.53
	249.48	818.5-A	126.3	10.2	33.1	0.20	2.27				
	252.19	827.4-A		14.6	23.4	0.33	2.18	10.00	135.30		
	252.19	827.4-B									2.55
	252.50	828.4-A		15.9			2.16			6.10	
	259.05	849.9-A		27.7			1.84				
	260.61	855.0-A		11.0			2.25			11.60	
	261.64	858.4-B									2.53
	261.89	859.2-A	118.8	11.3	38.8	0.20	2.28				
	262.65	861.7-A		9.6	33.9	0.21	2.28	5.00	250.80		
	262.65	861.7-B									2.53
	263.78	865.4-A		10.3	32.3	0.19	2.27	10.00	325.20		
	263.78	865.4-B		10.4	34.0	0.21	2.27	10.00	354.00		
	263.78	865.4-D		11.7	32.0	0.25	2.23	10.00	235.50		
	263.78	865.4-E		10.0	34.1	0.22	2.28	10.00	316.70		
	263.78	865.4-C		10.4	35.0	0.20	2.27	5.00	259.80		
	263.78	865.4-F		10.4	34.5	0.21	2.27	5.00	322.30		
	263.78	865.4-G		11.1	34.0	0.18	2.25	5.00	255.10		
	263.78	865.4-H		11.1	36.8	0.21	2.25	5.00	231.60		

Table 4-6. Summary of Rock Mechanics Laboratory Test Data for Tptpmn—Main Drift Boreholes

Core Hole	Depth (m)	Depth (ft)	UCS[1] (MPa)	Porosity (%)	Young's Modulus (GPa)	Poisson's Ratio	Dry Bulk Density (g/cc)	Confined Compressive Test (MPa)[2] Confined Pressure	Confined Compressive Test (MPa)[2] Axial Stress	Indirect Tensile Strength (MPa)	Average Grain Density (g/cc)
NRG-7/7A	263.78	865.4-I		10.7	34.3	0.20	2.26	0.00	215.80		
	263.78	865.4-J		10.4	33.5	0.19	2.27	0.00	232.00		
	263.78	865.4-K		10.3	34.9	0.22	2.27	0.00	239.10		
	263.78	865.4-L		10.6	35.7	0.21	2.26	0.00	248.50		
	263.78	865.4-M									2.53
Summary	Minimum		112.1	8.0	21.4	0.16	1.84	-	-	6.10	2.50
Statistics	Maximum		261.9	27.7	38.8	0.33	2.31	-	-	14.50	2.55
for NRG-6	Mean		179.8	11.0	32.9	0.21	2.25	-	-	11.39	2.53
and NRG-7/7A	Standard Deviation		52.5	3.2	3.8	0.03	0.08	-	-	3.19	0.01
only[3]	Number of Samples		13.0	38.0	27.0	27	36.00	-	-	7.00	18.00
SD-9	232.11	761.5-A			33.9	0.21		0.00	231.50		
	234.30	768.7-A			36.9	0.20		0.00	254.50		
	235.21	771.7-A			34.8	0.19		0.00	160.80		
	236.10	774.6-B			16.8	0.19		0.00	60.10		
	251.98	826.7-A			31.9	0.21		0.00	224.90		
	253.84	832.8-C			29.8	0.19		0.00	183.30		
	256.67	842.1-E-1			36.3	0.20		0.00	208.90		
SD-12	223.94	734.7-B			31.9	0.18		0.00	193.30		
	227.26	745.6-B			34.5	0.20		5.00	330.70		
	232.44	762.6-B			34.1	0.20		10.00	272.80		
	238.08	781.1-B			36.7	0.21		0.00	198.20		
Summary	Minimum		112.1	8.0	16.8	0.16	1.84	-	-	6.10	2.50
Statistics	Maximum		261.9	27.7	38.8	0.33	2.31	-	-	14.50	2.55
for All	Mean		179.8	11.0	32.8	0.21	2.25	-	-	11.39	2.53
Boreholes	Standard Deviation		52.5	3.2	4.4	0.03	0.08	-	-	3.19	0.01
	Number of Samples		13.0	38.0	38.0	38	36.00	-	-	7.00	18.00

[1] Uniaxial compressive tests conducted on 50.8-mm (2.0-in) diameter samples.

[2] Triaxial (confined) compressive tests conducted on 25.4-mm (1.0-in) diameter samples.

[3] Used for development of rock mass mechanical properties estimates in Section 6.2.

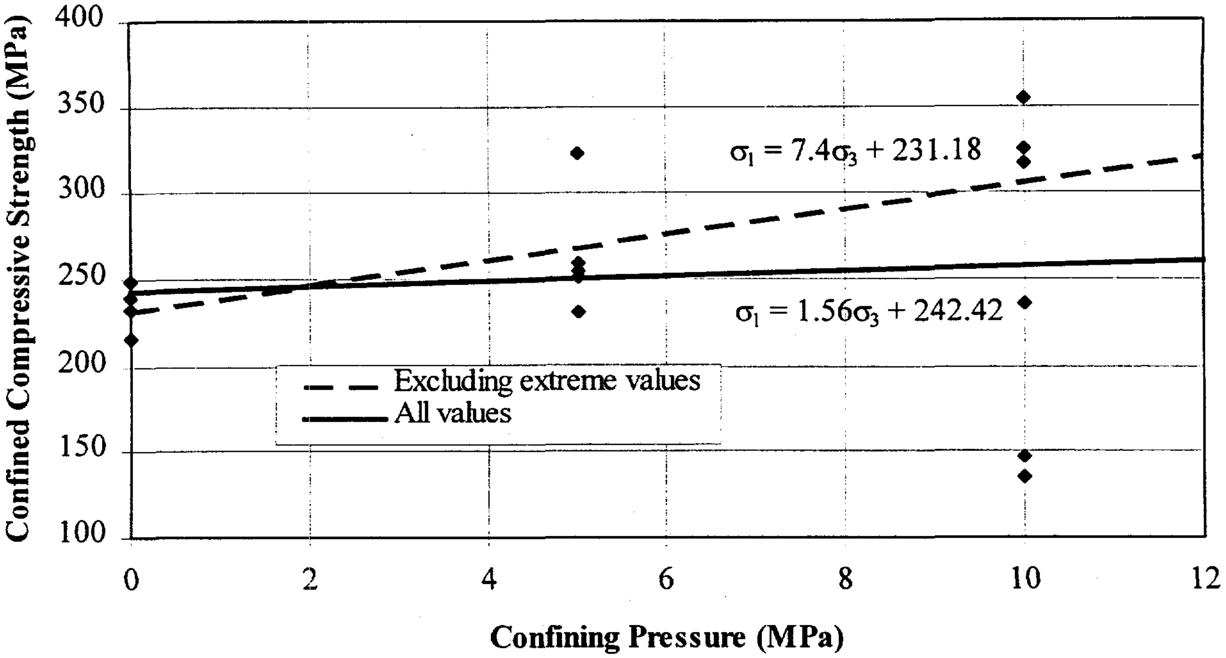


Figure 4-14a. Confined compressive strength results for the Tptpmn—NRG-6 and NRG-7/7A boreholes.

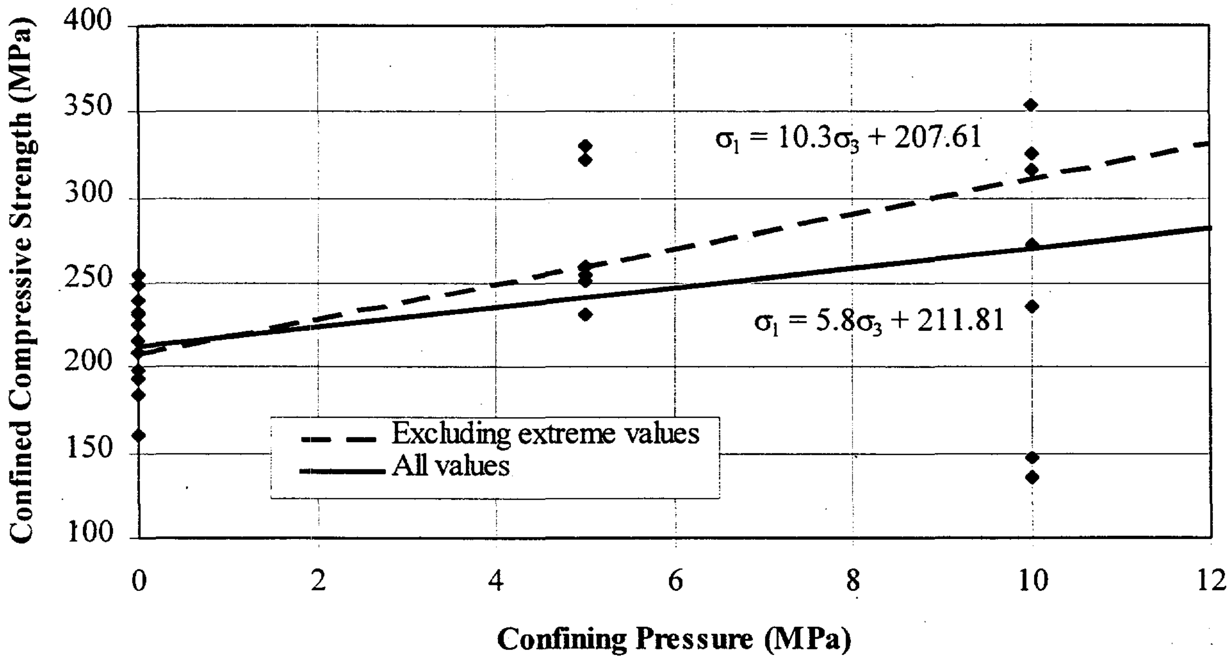


Figure 4-14b. Confined compressive strength results for the Tptpmn—NRG-6, NRG-7/7A, SD-9 and SD-12 boreholes.

The relationship between the linear equation above and the Mohr-Coulomb parameters, cohesion (C) and internal friction angle (ϕ), is given by the following:

$$\tau = C + \sigma_n \tan\phi \, , \tag{4-3}$$

where

t = shear stress,
$C = \text{cohesion} = \sigma_c / 2\sqrt{N}$,
σ_n = normal stress, and
$\phi = \text{angle of internal friction} = 2\left(\tan^{-1}\sqrt{N} - 45^\circ\right)$.

The least-square fits of the triaxial test data were performed to develop intact rock failure criteria using Equations 4-2 and 4-3. The results are listed in Table 4-7. Fits of all the NRG data produced unreasonably low values of confinement effect (N) and friction angle (ϕ). If the two extreme values were removed, a more typical friction angle of 49.6° would result. Inclusions of the SD-9 and SD-12 data produced changes in the linear equation coefficients of 39% for the slope (N) and 10% for the intercept (σ_c). These changes were considered within the existing variability.

Table 4-7. Intact Rock Failure Criteria — Tptpmn

Boreholes	**Data**	$\sigma_1 = N\sigma_3 + \sigma_c$		**Standard Deviation**	$C = \tau + \sigma \tan\phi$	
		N	**σ_c (MPa)**	**(MPa)†**	**C (MPa)**	**ϕ**
NRG-6,	All values	1.6	242.4	69.2	97.1	12.6
NRG-7/7A	Excluding extreme values*	7.4	231.2	33.1	42.5	49.6
NRG-6,	All values	5.8	211.8	61.3	43.9	44.9
NRG-7/7A, SD-9, SD-12	Excluding extreme values*	10.3	207.6	46.8	32.4	55.4

* $\sigma_1 < 150$ MPa @ $\sigma_3 = 10$ MPa

† standard deviation of data from least-square equation

The mean uniaxial compressive strength for the 25.4-mm (1.0-in) diameter samples from NRG data only was 233.8 MPa. The 25.4-mm diameter mean was higher than for the 50.8-mm (2.0-in) diameter UCS tests listed in Table 4-6, which had a mean strength of 179.8 MPa and a standard deviation of 52.5 MPa. With the inclusion of the SD data, the mean unconfined strength of the 25.4-mm diameter samples was 203.9 MPa. These differences were considered to be within the existing variability of the data, and no size effects due to the sample diameters were observed.

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5.0 Rock Mass Quality Assessment

5.1 Introduction

Rock mass quality has been assessed using both the RMR and Q rock mass classification systems. Each of these classification systems assigns a numerical rating to a series of parameters that affect the quality of the rock mass. The parameters are related to the degree of jointing, interaction of joint orientations to form blocks, joint frictional strength, rock strength versus active stress, and hydrologic conditions. The individual parameter ratings are combined using empirical relationships to determine an overall rock quality index (Bieniawski 1979; Barton et al. 1974).

A methodology for estimating the rock mass quality parameters, Q and RMR, was developed for core rock structural data from the NRG holes, reported by Brechtel et al. (1995). This methodology has been extended to the Main Drift borehole geotechnical data with modifications that take advantage of recent rock mass description data produced in the ongoing excavation of the North Ramp. The available data on rock structural conditions in the Tptpmn is limited to the six boreholes (USW SD-7, SD-9, SD-12, NRG-6, NRG-7/7A, and UZ-14) utilized in this study. Comparison of the outcrop mapping data from Fran Ridge and structural mapping data from Tpc in the North Ramp, discussed in Section 3.6, suggests joint structures are similar. The North Ramp data[26] have, therefore, been used to improve the rock mass quality estimates for the Main Drift in three areas:

- The distribution of the SRF and Jn parameters in the Tpc, excluding the high lithophysae interval, have been used to modify the core-based methodology to estimate Q in the Tptpmn.
- The range of Q values from the Tpc upper lithophysal zone in the North Ramp was assumed to be representative of the portion of the Main Drift to be excavated in the Tptpll.
- The Q values developed for fault zones encountered during excavation of the North Ramp in the Tpc are projected as the basis for conditions in the faults to be encountered along the Main Drift.

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[26] Interim Data Transmittal, Yucca Mountain Site Characterization Project, Rock Mass Quality Data for NRST Stations 60 to 475 m, 475 to 530 m, and 530 to 600 m, TDIF No. 304267 DTN: SNF32120393001.001, TDIF No. 304283 DTN: SNF32120393001.002, and TDIF No. 304351 DTN: SNF32120393001.003.

5.2 Rock Mass Quality Projections for the Tptpmn

The RMR and Q indices have been estimated for the Tptpmn using the 3-m (10-ft) intervals from the core log data for USW SD-7, SD-9, SD-12, NRG-6, NRG-7/7A, and UZ-14. The rock mass quality indices are presented in log form in Appendix C. Q values in NRG-6 and NRG-7/7A have been resimulated using Jn and SRF distributions from the North Ramp data.[27] The resulting rock mass quality was projected to represent the expected variation that will occur as the Main Drift cuts across the zone. No spatial correlation of specific values was assumed due to the limited data; however, cross correlation of RQD data in Section 4.2.1 does suggest rock quality will vary with stratigraphic location.

5.2.1 Rock Mass Quality Indices for the RMR System—Tptpmn

The calculation of RMR as defined by Bieniawski (1979) includes the summation of the ratings of five parameters as shown in the following equation:

$$\mathrm{RMR} = \mathrm{C} + \mathrm{RQD\text{-}I} + \mathrm{JS} + \mathrm{JC} + \mathrm{JW} \tag{5-1}$$

where

RMR = a dimensionless number between 0 and 100,
C = rock strength parameter,
RQD-I = Rock Quality Designation (RQD) parameter,
JS = joint spacing parameter,
JC = joint condition parameter, and
JW = joint water parameter.

RMR includes an additional adjustment to account for the strike and dip orientations of the joints relative to the direction of mining. In this report, the application of RMR is limited to the estimation of rock mass mechanical properties which does not require joint orientation adjustment.

The distribution of each parameter (except JW) for the Tptpmn is shown in Figure 5-1. The groundwater conditions at the repository level of the Yucca Mountain site are projected to be dry. Therefore, according to the RMR guidelines, the groundwater rating (JW) was set at 15. Details of the determination of each parameter are provided by Brechtel et al. (1995). In this study, the rock strength parameter (C) was determined by Monte Carlo simulation of the rock mechanics testing data from NRG boreholes.

The RMR values for each 3-m (10-ft) interval are calculated according to Equation 5-1 by summing the individual parameter values for that interval. The distribution of RMR values for the Tptpmn is shown in Figure 5-2. The RMR data were rank ordered to determine the cumulative frequencies of occurrence and values are presented for 5%, 20%, 40%, 70% and 90% as listed in Table 5-1. These frequencies of occurrence were proposed by Hardy and Bauer

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[27] Ibid.

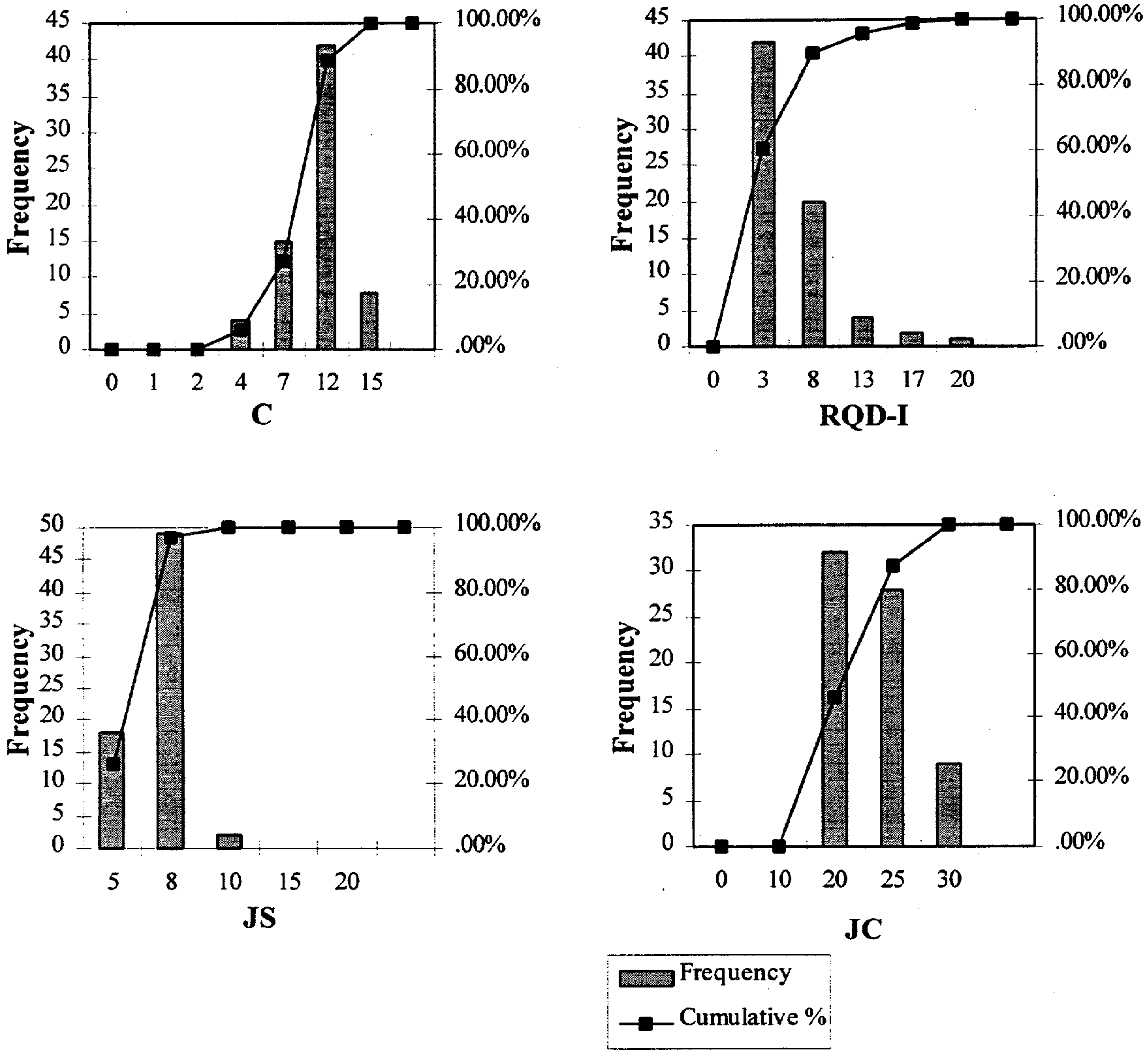

Figure 5-1. Histograms showing the distribution of the RMR system parameters for the Tptpmn—Main Drift boreholes.

Table 5-1. RMR Values at Five Levels of Cumulative Frequency of Occurrence

Cumulative Frequency of Occurrence (%)	RMR	Relative Rating	
5	50	very good	81-100
20	55	good	61-80
40	58	fair	41-60
70	63	poor	21-40
90	67	very poor	<20

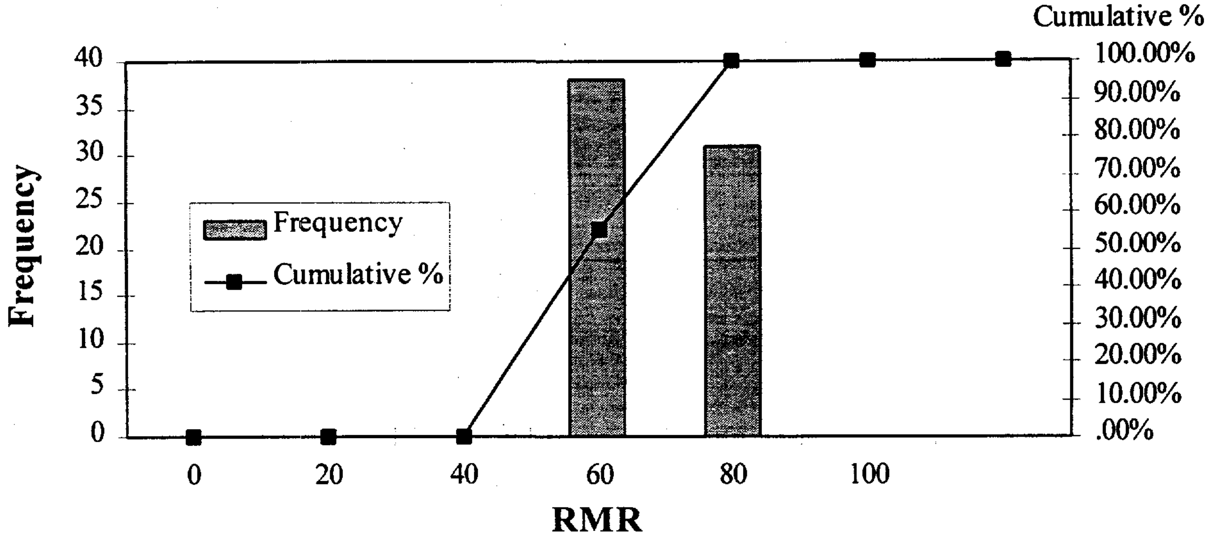

Figure 5-2. Distribution of the RMR in the Tptpmn—Main Drift boreholes.

(1991) to develop rock mass mechanical properties that represent the range of variability. The rank-ordered data are presented in Appendix B and indicate that the RMR ranges from a fair to a good rock mass quality according to the RMR relative ratings listed in Table 5-1.

5.2.2 Rock Mass Quality Indices for the Q System—Tptpmn

The Q System uses six parameters that are combined using the following relationship to determine a numerical rating of the rock mass (Barton et al. 1974):

$$Q = \frac{RQD}{Jn} \times \frac{Jr}{Ja} \times \frac{JW}{SRF} \qquad (5\text{-}2)$$

where

RQD = Rock Quality Designation (%),
Jn = joint set number,
Jr = joint roughness number,
Ja = joint alteration number,
JW = joint water factor, and
SRF = stress reduction factor.

The first pair of parameters (RQD/Jn) is an approximate description of the block size. The next pair of parameters (Jr/Ja) is a measure of the interblock shear strength, and the final pair of parameters (JW/SRF) is a description of active stress.

The methodology for determining each of these parameters from core structural data has been described by Brechtel et al. (1995). The joint set number (Jn) and the stress reduction factor (SRF) cannot be readily determined from core data. Brechtel et al. (1995) assumed a uniform distribution of Jn between 4 and 9 based on available mapping data from the NRST, and a similar methodology for determining SRF values was assumed based on the distribution conditions of the NRST. These original assumptions have been compared to parameter assessments from recent data from the Tpc[28] in the North Ramp. The upper lithophysal zone of the Tpc from the North Ramp data was not included because it was not considered representative of the Tptpmn. The frequencies of occurrence of both the assumed and the North Ramp values of Jn and SRF for the Tpc are shown in Figure 5-3.

The field data distribution represents the North Ramp assessments[29] and is similar to the original assumed distribution, but indicates conditions more adverse to stability. Jn values of 12 appear in the field data, but were not anticipated in the assumed distribution. An SRF value of 5 is more prominent in the North Ramp data primarily due to the existence of open joints. To adjust for these variances, data distributions for the Jn and SRF parameters were modified to match the distributions determined from the North Ramp field mapping in an attempt to maintain a conservative assessment of conditions in view of the data limitations.

The distribution of each Q system parameter for the Tptpmn is shown in Figure 5-4. As in the RMR system, the groundwater parameter (JW) is not shown because it is anticipated that all excavations at the ESF will be "dry" corresponding to a JW value of 1.

The Q values for each 3-m (10-ft) interval are calculated according to Equation 5-2 based on the individual parameter values for that interval. The distribution of Q values for the Tptpmn is shown in Figure 5-5. The Q data were rank ordered to determine the values at cumulative frequencies of occurrence of 5%, 20%, 40%, 70%, and 90% as listed in Table 5-2. Rank-ordered values are presented in Appendix B. It can be seen that Q ranges from a very poor to a good rock mass quality according to Q guidelines, with a majority of the intervals (64%) indicating a very poor rock mass quality.

5.3 Evaluation of Projected RMR and Q Results—Tptpmn

The Q and RMR values determined from the Main Drift borehole data (USW NRG-6, NRG-7/7A, SD-7, SD-9, SD-12, and UZ-14) have been evaluated by comparing the correlation of Q and RMR results to a case-history correlation reported by Bieniawski (1976). This provides a means to check the rock quality assessments by the core logging procedure against previously published rock quality data. The core-based Main Drift Q and RMR calculation procedure uses the methodology presented by Brechtel et al. (1995), except that adjusted data distributions for the Jn and SRF parameters were used in the Monte Carlo simulation. The effectiveness of the core-based methodology was also evaluated by comparing the core-based North Ramp data for the Tpc to the Q and RMR data determined from scanline descriptions developed during construction of the North Ramp.[30] This evaluation was performed to verify that the core-based

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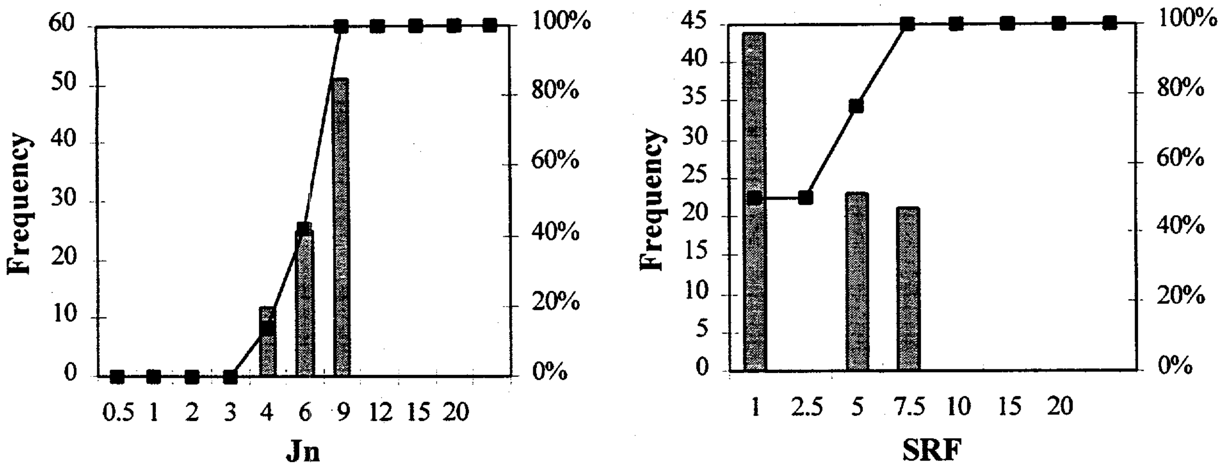
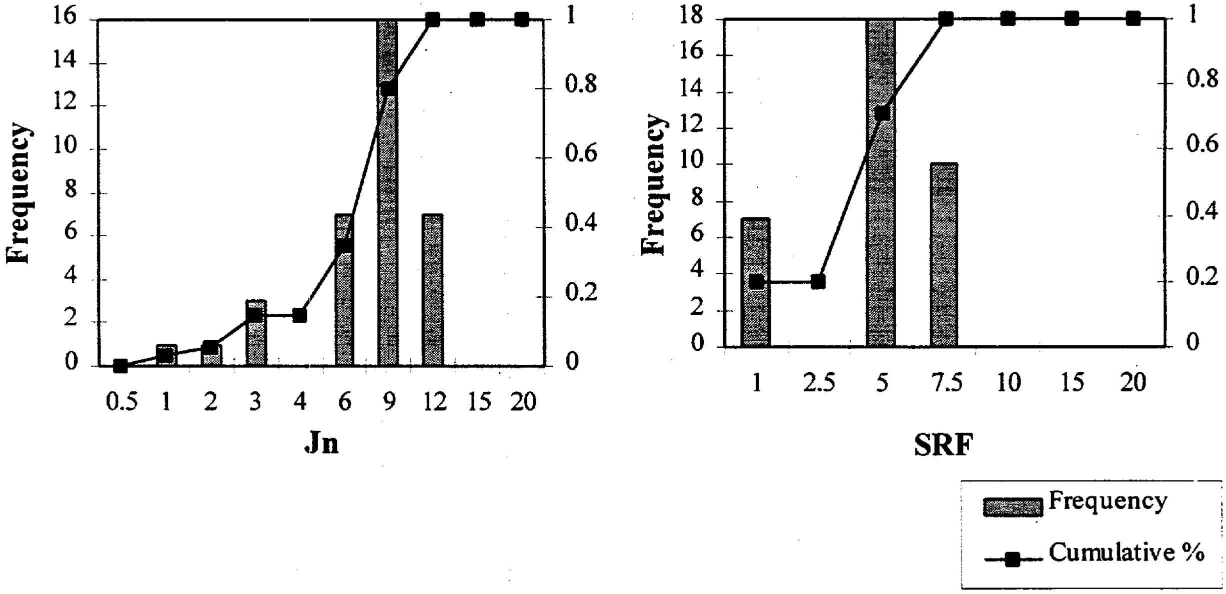
[28] Ibid.

[29] Ibid.

[30] Ibid.



a. Assumed distribution of Jn and SRF



b. Distribution of North Ramp field-assessed values of Jn and SRF

Figure 5-3. Distribution of the previously assumed values (Brechtel et al. 1995) and the field-assessed values (North Ramp Tiva Canyon Member) of Jn and SRF.

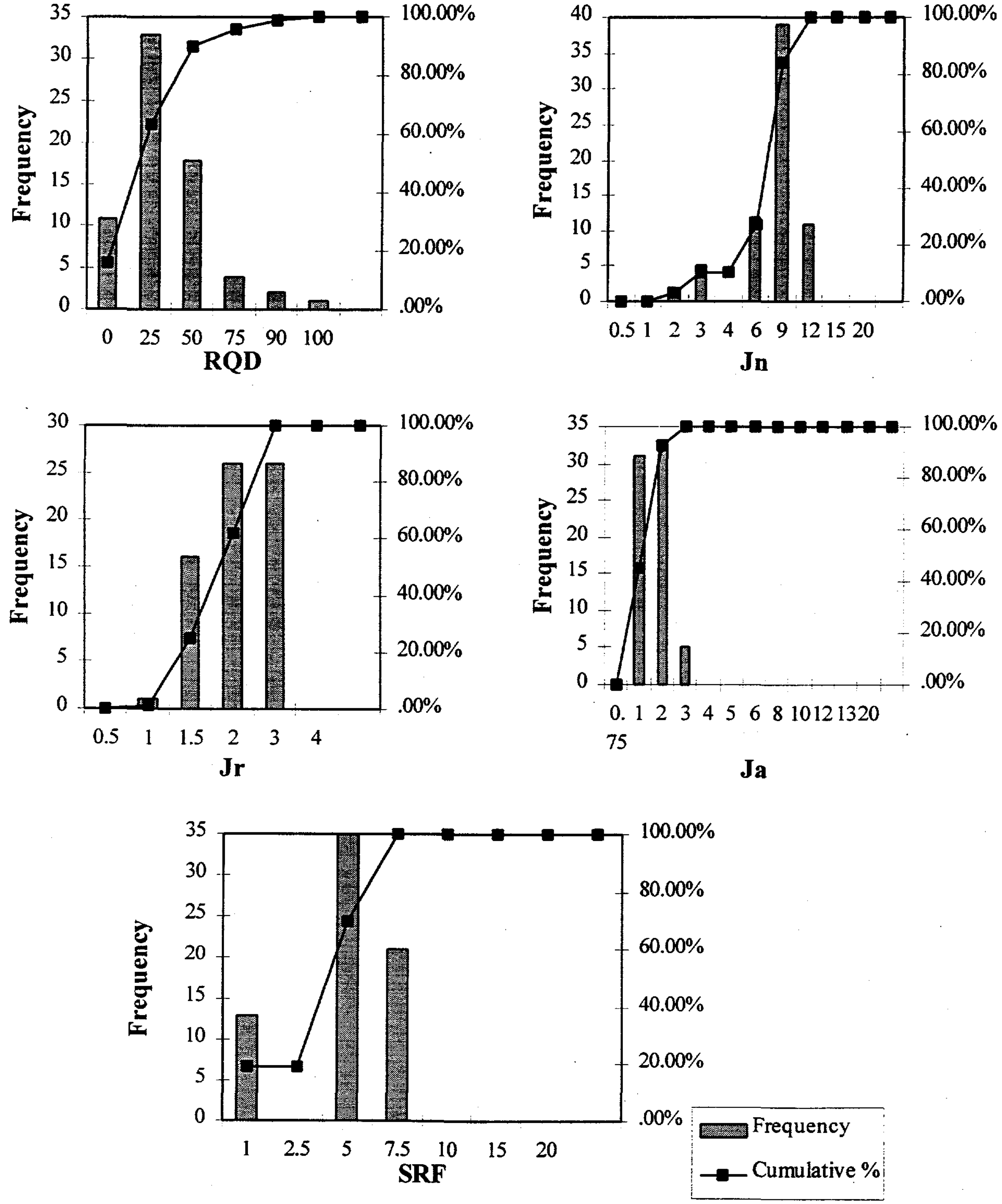


Figure 5-4. Histograms showing the distribution of the Q system parameters for the Tptpmn—Main Drift boreholes.

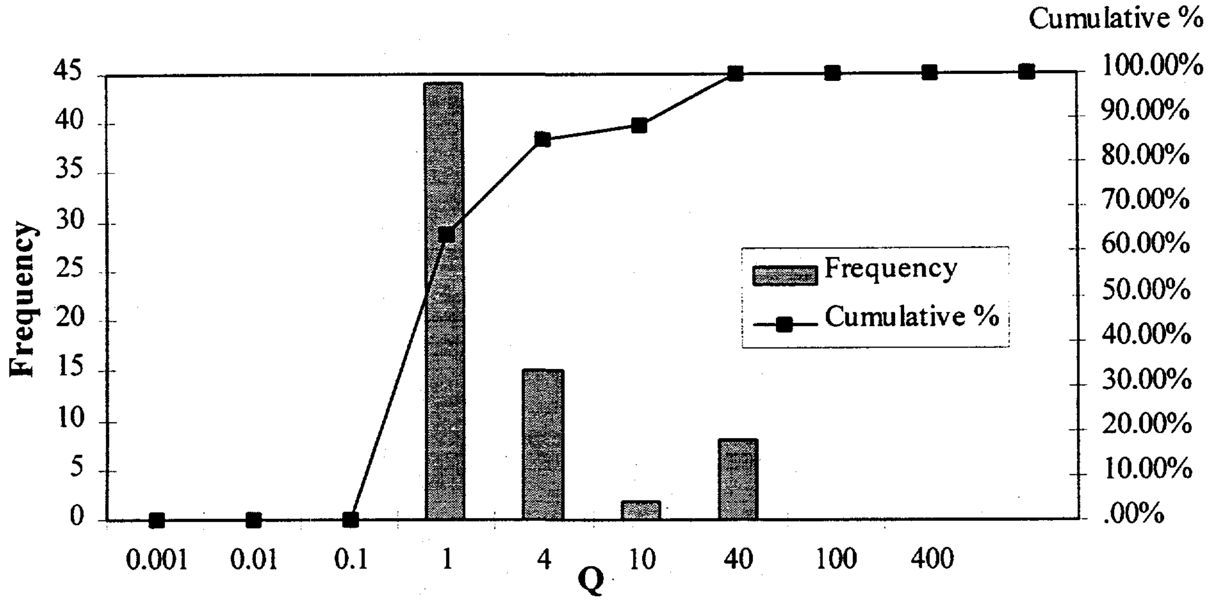


Figure 5-5. Distribution of the estimated Q in the Tptpmn—Main Drift boreholes.

Table 5-2. Q Values at Five Levels of Cumulative Frequency of Occurrence

Cumulative Frequency of Occurrence (%)	Q	Relative Rating	
5	0.14	exceptionally good	400–1000
20	0.29	extremely good	100–400
40	0.42	very good	40–100
70	1.39	good	10–40
90	10.56	fair	4–10
		poor	1–4
		very poor	0.1–1
		extremely poor	0.01–0.1
		exceptionally poor	0.001–0.01

rock quality assessments were reasonable when compared to field assessments made in the North Ramp tunnel.

5.3.1 Correlation of Q and RMR Results

Bieniawski (1976) developed the following correlation between Q and RMR values based on 111 case histories:

$$RMR = 9\ln(Q) + 44 \,. \qquad (5\text{-}3)$$

The case history data were also used to develop a 90% confidence interval bounding the relationship. Equation 5-3, including the confidence intervals, is shown in Figure 5-6 with correlated Q and RMR data from the Main Drift boreholes. For Q values greater than 1, the Main Drift data is generally consistent with Bieniawski's relationship of Q and RMR. However, for Q values less than 1, the Main Drift data often exceed the upper 90% confidence limit. Hardy and Bauer (1991) attributed this effect to the fact that the stress/strength term (SRF) in the Q system accounts for structural effects similar to the RQD, while the strength index in the RMR system remains fairly constant for a particular rock type. The procedure for calculating RMR for the ESF tunnels is less sensitive to joint conditions when compared to the Q system. Also, because RMR is used to determine rock mass mechanical properties in this work, it has not been adjusted for joint orientation.

5.3.2 Comparison of Q Values from Field- and Core-Based Assessments

The core-based results for Tpc are compared to actual field data from rock quality assessments in the North Ramp to assess the performance of the core-based projections. The North Ramp has not currently reached the Tptpmn and, therefore, no field data for this zone is available for comparison.

Prior to construction of the North Ramp, the rock mass quality of the North Ramp was projected using the data from the North Ramp borehole (NRG series) rock structure logs and the same core-based rock quality assessment methodology described in this section (Brechtel et al. 1995). As the North Ramp is being excavated, rock mass quality is being collected from scanline descriptions, and Q and RMR are being assessed for every 5-m interval along the tunnel length.[31] These data have been compiled for the portion of the Tpc stratigraphic unit (North Ramp tunnel stations 0+60 to 1+88 m and 3+50 to 5+30 m) for each 5-m interval in the tunnel. The two data sets are compared in Figure 5-7 by showing the cumulative frequency of occurrence of Q values. The distributions are very similar, however, the actual rock quality in the tunnel is lower than predicted by the core.

The projected ground support requirements indicated by the two data sets in Figure 5-7 have been determined according to the YMP Ground Support Guidelines.[32] The support

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[31] Ibid.

[32] BABEAB000-01717-2100-40151-01, Exploratory Studies Facility Package 2C, Topopah Springs North Ramp Ground Support Master Elevations and Sections, July 27, 1994.

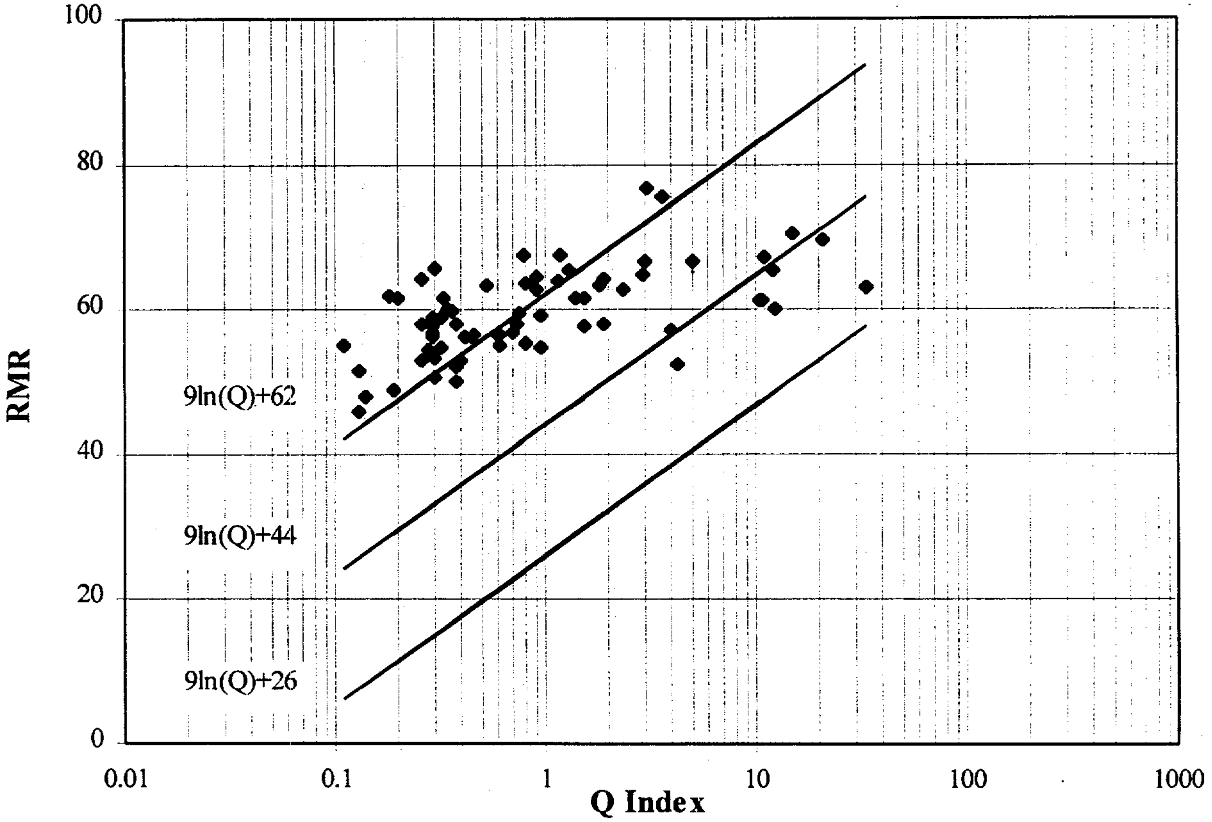

Figure 5-6. Correlation of Q and RMR results for the Tptpmn—Main Drift boreholes.

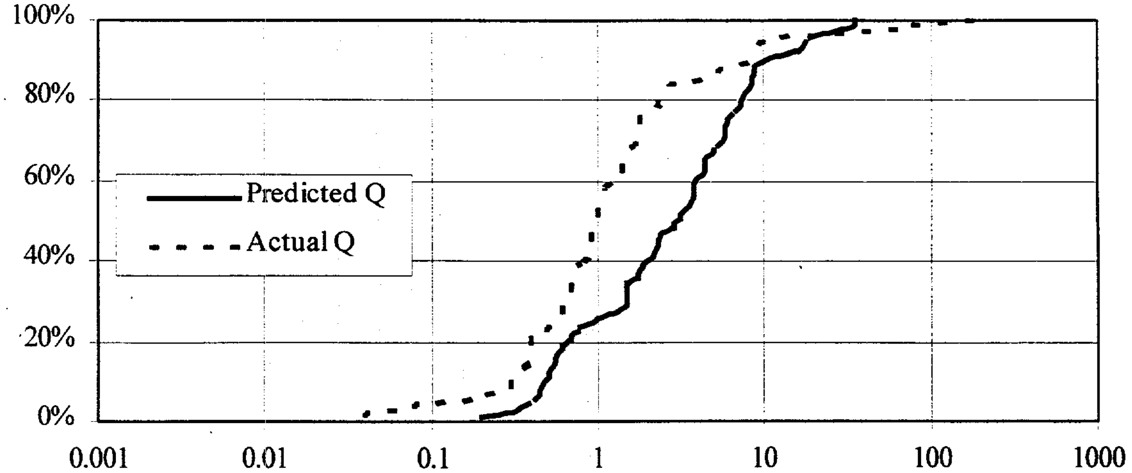

Figure 5-7. Comparison of cumulative frequency of occurrence of Q for both core-based (predicted) and field-assessed (actual) values for the Tpc stratigraphic unit.

guidelines for each 3-m (10-ft) borehole interval of the Tpc unit (using all NRG series boreholes) were determined based on the Q parameters, and the frequency of occurrence of each support category is shown in Figure 5-8. Support categories used in this comparison are defined in Table 5-3 based on the YMP Ground Support Guidelines. The core-based data for the Tpc unit projects that the majority of the tunnel will require Category 3b support which includes a pattern of 15 rockbolts across the crown with 50–75 mm of shotcrete fully covering the tunnel wall from the crown to the invert.

Ground support requirements based on the field-assessed Q parameters and the YMP Ground Support Guidelines are presented in Figure 5-9 as frequency of occurrence. The distribution of ground support is very similar to the ground support requirements determined from borehole data indicating that the empirical approach is robust and that the core-based projections are realistic. Although differences were observed in the predicted and actual Q values, the predicted ground support distribution according to the YMP support guideline (which is based on the Q parameters) was nearly identical to the field-assessed ground support requirements.

5.4 Indicated Ground Conditions and Support Requirements—Tptpmn

Although the joint structure exposed in the North Ramp excavations is similar to jointing in the surface pavements mapped at Fran Ridge, the difference in orientation of the North Ramp and Main Drift is projected to result in more adverse ground conditions in the Main Drift. This difference is illustrated by key block analyses based on North Ramp joint orientations and comparative analysis of the two tunnel alignments, and supports the assessment of ground support requirements using the YMP Ground Support Guidelines and the projected rock quality (Q) in the Tptpmn.

5.4.1 Key Block Stability Analysis—Tptpmn

A key block stability analysis using the three joint sets in Table 5-4 has been performed comparing the North Ramp, with a tunnel azimuth of 299°, to the Main Drift which will have a tunnel azimuth of 183°. A key block is a critical block or wedge in the tunnel wall that is finite, removable, and potentially unstable (Goodman and Shi 1985). The UNWEDGE Version 2.2[33] key block stability analysis program has been used in this analysis. The program uses an ubiquitous, non-probabilistic approach to key block analysis which emphasizes the prediction of the formation of the maximum potential key block size given a particular joint set, tunnel

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[33] Carvalho, J., E. Hoek, and B. Li (1992). *UNWEDGE—Program to Analyze the Geometry and Stability of Underground Wedges*, Rock Engineering Group, University of Toronto, Toronto, Canada.

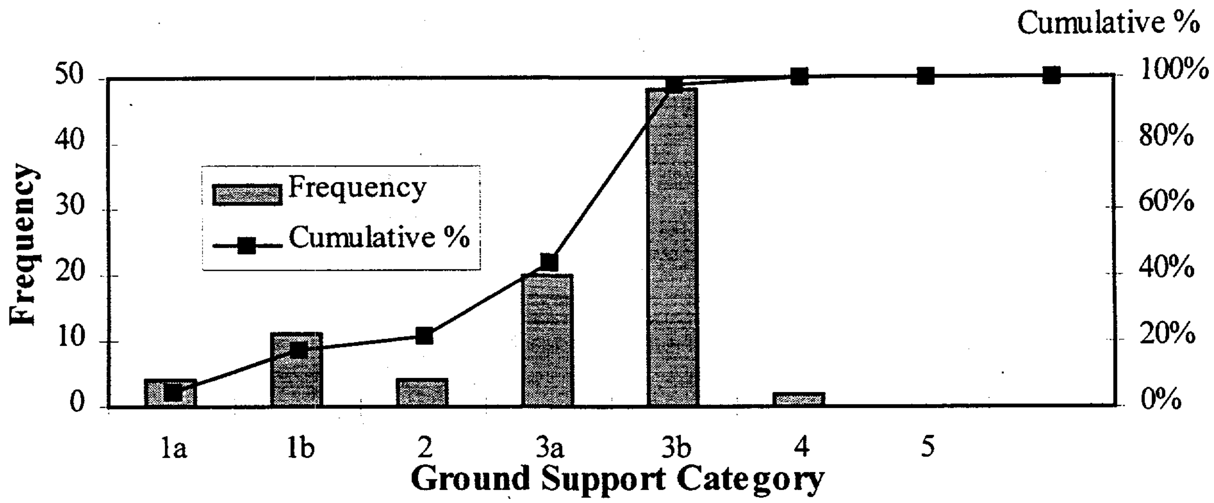

Figure 5-8. Distribution of ground support category from NRG borehole data for the Tpc stratigraphic unit of the Tiva Canyon Formation.

Table 5-3. YMP Ground Support Categories

YMP Ground Support Category	Description of Ground Support
1a	An array of 8 rockbolts with welded wire mesh; bolt density = 8 bolts/1.5 m
1b	An array of 8 rockbolts with welded wire mesh; bolt density = 8 bolts/1.5 m; supplement with spot bolting
2	An array of 15 rockbolts with welded wire mesh; bolt density = 15 bolts/1.5 m
3a	An array of 8 rockbolts; bolt density = 8 bolts/1.5 m; supplement with spot bolting; apply 50–75 mm shotcrete
3b	An array of 15 rockbolts; bolt density = 15 bolts/1.5 m apply 50–75 mm shotcrete
4	Steel sets at 1.2 m spacing with partial lagging
5	Steel sets at 0.6–1.2 m spacing with full lagging

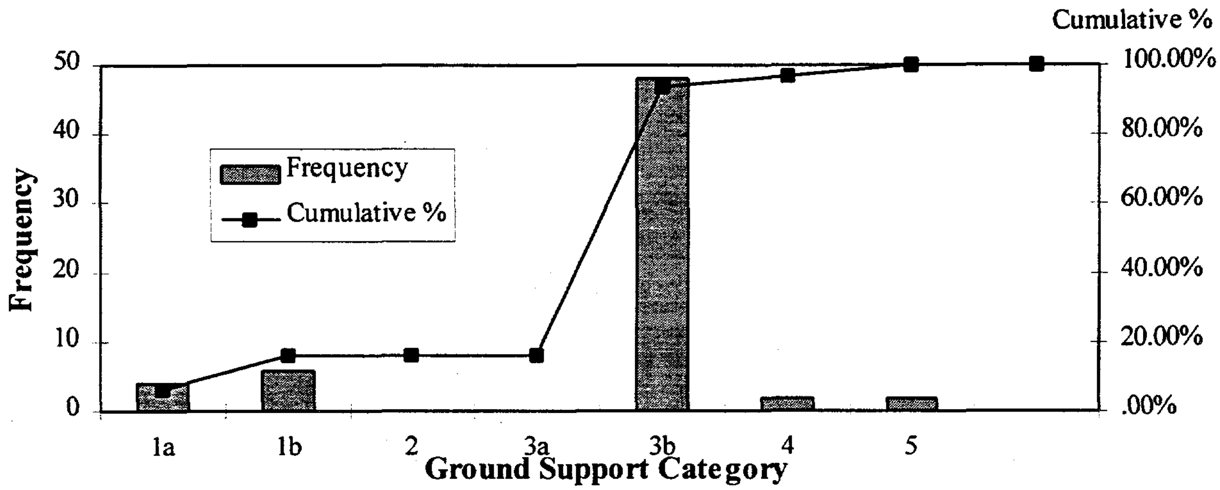

Figure 5-9. Distribution of ground support category from North Ramp tunnel data for the Tpc unit of the Tiva Canyon Formation.

Table 5-4. Comparison of Key Block Analysis Results for the North Ramp and Main Drift

	North Ramp				Main Drift			
Wedge #	Volume (m^3)	Apex Height (m)	Tonnes	Safety Factor	Volume (m^3)	Apex Height (m)	Tonnes	Safety Factor
1	21.6807	7.8	59	0	58.75	10.8	159	0
2	0.0007	0.3	<1	0.06		not formed		
3	0.0009	0.4	<1	0.55	0.01	0.4	<1	0.55
4	21.6807	7.8	59	infinite	58.75	10.8	159	infinite
5	0.0007	0.3	<1	0.53		not formed		
6	0.0009	0.4	<1	0.12	0.01	0.4	<1	0.12

orientation, and tunnel cross section. The results of the analysis are provided in Appendix D and are described below.

This analysis of the joint structure, based on the assumption of similar joint orientations in both the North Ramp and Main Drift, suggests that given similar rock mass conditions, the Main Drift will experience an increase in the frequency of ground stability problems in the crown (formation of key blocks) due to the orientation of joints relative to the tunnel alignment. A comparison of the maximum potential key block volume, apex height, block tonnage, and safety factor are shown in Table 5-4. The volume and tonnage of the maximum potential key block formed in the crown (wedge #1 in Table 5-4) is estimated to be three times greater in the Main

Drift than in the North Ramp. Although not directly resulting from the analysis, it is inferred that the Main Drift tunnel crown has the potential for more key blocks which will result in poorer ground conditions compared to the North Ramp because the most predominant joint set is generally parallel to the tunnel axis.

The effect on block formation in the tunnel walls (wedges #2, #3, #5 and #6 in Table 5-4) is mixed. The North Ramp alignment allows the potential formation of four wedge types whereas the Main Drift alignment allows only two. The analysis indicates that the relative size of the maximum potential key blocks in the tunnel wall increases in the Main Drift compared to the North Ramp, however, the block sizes are negligible with respect to ground control.

5.4.2 Indicated Ground Support—Tptpmn

The distribution of the projected rock mass quality (Q), illustrated in Figure 5-5, and the YMP Ground Support Guidelines have been used to determine support requirements using the associated Q parameters. The relative lengths of the Main Drift that will require the indicated support can be derived from the distribution of projected ground support shown in Figure 5-10. The ground support categories are described in Table 5-3. This analysis suggests that within the Tptpmn, 46% of the tunnel length will require category 3b support (rockbolts with shotcrete) and 36% of the tunnel length will require category 4 support (steel sets with partial lagging).

5.5 Rock Mass Quality—Tptpll

Specific rock mass quality assessments were not performed on the portion of the Tptpll containing the Main Drift between stations 57+00 m to 59+37 m. Recovery of core in this part of the Main Drift boreholes was very low, and the resulting RQD listed in Figure 4-4, Section 4.0, gives an average RQD of <10%. Review of downhole video records indicates that the upper portion of the Tptpll contains lithophysal cavities larger than the diameter of the core (60 mm) and that the condition of the borehole is uniformly irregular, type C3, according to the descriptive nomenclature used by Brechtel et al. (1995).

Rock mass conditions based on the core data may be similar to the upper lithophysal zone of the Tpc in the North Ramp. Rank-ordered Q data from the North Ramp in this zone of cavernous lithophysae indicated a range of Q values from 0.04 to 2.68 with a median value of 0.64. Based upon comparison of RQD, Table 4-4, Section 4.0, it is projected that ground support requirements in the portions of the Main Drift will be category 4.

5.6 Rock Mass Quality—Fault Zones

Fault zones along the Main Drift have not been sampled by the boreholes, and no direct data on the character or extent of the fault zones is available at depth. Observations in the North Ramp excavations through the Tpc indicate that rock mass quality in the densely welded tuffs is generally lower than in the nonwelded tuffs. The presence of faults in the welded tuffs adversely

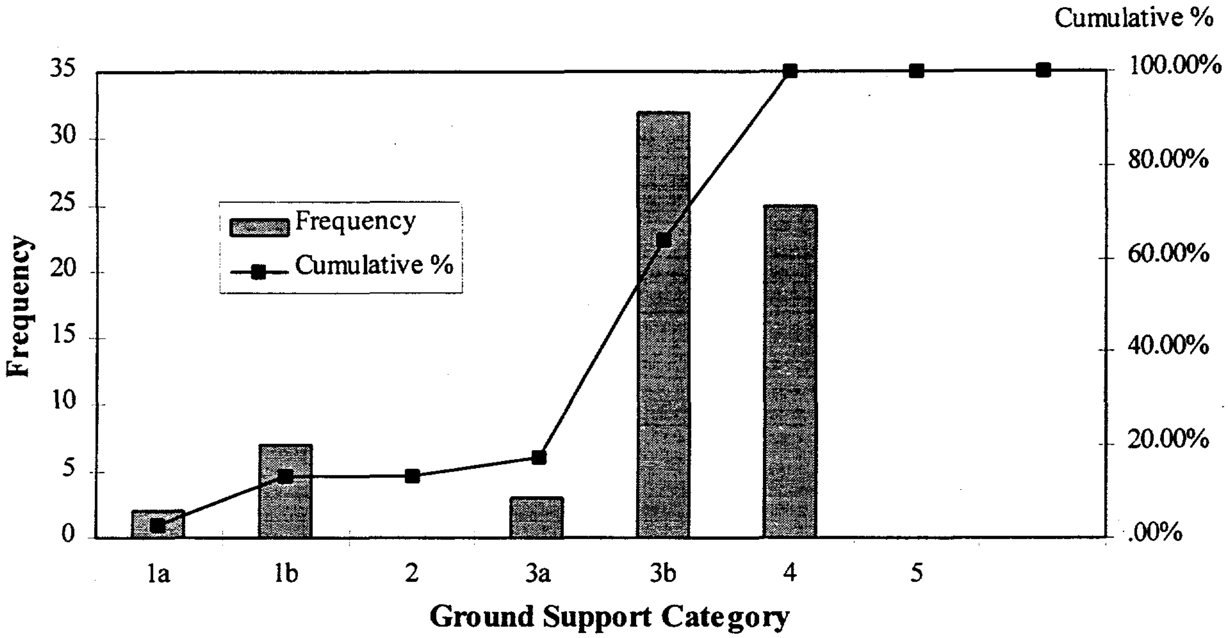

Figure 5-10. Projected distribution of ESF ground support category for the Tptpmn—Main Drift boreholes.

affects rock quality in the area of the faults, as opposed to the nonwelded tuffs where the fault-related effects are more localized.

Examination of the variation of Q from the North Ramp in the area affected by the "imbricate" faults suggests a median Q of 0.44 which corresponds to roughly the lower 25% of the Tpc data. On this basis, rock quality near the points of intersection of the Main Drift with the Sundance Fault zone and the Abandoned Wash Fault are expected to be similar to the range of Q values associated with a cumulative frequency of occurrence of 25% in the Tptpmn data in Section 5.2. This would suggest Q values of 0.3 or less. In the Sundance Fault zone, these values of Q could be characteristic of the rock roughly 185 m before and after the central zone which is projected to occur at station 36+40 m. Note that this location is based on the projection of the fault zone as vertical and that there is no subsurface information. Data from discrete 5-m intervals intersected by normal faults in the North Ramp indicate Q values as low as 0.04.

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6.0 Assessment of Rock Mass Mechanical Properties

6.1 Introduction

Rock mass mechanical properties are required for input into the numerical analyses that support the geotechnical design of the Main Drift. Mechanical properties at the rock mass scale are known to vary significantly from mechanical rock properties determined from laboratory specimens. These differences are the result of the inherent complexities of rock as an engineering material and are primarily attributed to the jointed nature of the rock. The rock mass mechanical properties of interest included rock mass strength, the elastic modulus, and the Poisson's ratio.

Hardy and Bauer (1991) have recommended rock mass strength criteria and mechanical models for representing the rock mass response of the tuff at Yucca Mountain. Empirical methods are used with RMR data and the laboratory rock mechanical properties to estimate the rock mass mechanical properties. These empirical methods will require validation by future ESF testing.

6.2 Rock Mass Strengths

A site-specific rock mass strength criteria has been developed following the procedure of Hardy and Bauer (1991) using both the Hoek and Brown (1988) and Yudhbir et al. (1983) strength criteria. The data needed for using this approach include the rock mass quality index RMR, intact rock uniaxial compressive strength, and triaxial compressive strength data.

Both Hoek and Brown (1988) and Yudhbir et al. (1983) use the 1974 version of RMR (RMR_{74}, Bieniawski 1974a) in their rock mass strength determination. However, the site characterization of the tunnels of the ESF have adopted the most recent version of RMR (RMR_{79}, Bieniawski 1979) which uses a slightly modified method of assessing the individual parameters of the RMR system. Brechtel et al. (1995) have assessed the use of both RMR_{74} and RMR_{79} and found that the resulting difference in the RMR_D (design RMR determined from both the RMR and Q systems) is small and does not significantly affect the rock mass strength determination.

RMR_D is calculated by converting Q to RMR and averaging both the converted Q and the RMR. The value of Q is converted to RMR by using a correlation developed by Bieniawski (1976):

$$RMR_{CAL} = 9 \times \ln(Q) + 44 . \tag{6-1}$$

The design RMR is then determined as:

$$RMR_D = \frac{RMR_{79} + RMR_{CAL}}{2} . \tag{6-2}$$

The rock mass strengths are generated for five classes of rock mass quality based on the cumulative frequencies of occurrence of 5%, 20%, 40%, 70%, and 90% as presented in Section 5.0. The values of Q, RMR_{CAL}, RMR_{79}, and RMR_D are listed in Table 6-1 for the Tptpmn. The use of the RMR_D values in the rock mass strength determination is described in the following sections.

Table 6-1. Tabulation of Q, RMR_{79}, and Design RMR_D Values for the Five Classes of Rock Mass Quality in the Tptpmn

	Rock Mass Quality Class				
	1	**2**	**3**	**4**	**5**
Q	0.14	0.29	0.42	1.39	10.56
RMR_{CAL}	26	33	36	47	65
RMR_{79}	50	55	58	63	67
RMR_D	38	44	47	55	66

6.2.1 Yudhbir Criterion

Yudhbir et al. (1983) selected a strength criterion proposed by Bieniawski (1974b) for rock materials:

$$\sigma_1 = A\sigma_c + B\sigma_c\left(\frac{\sigma_3}{\sigma_c}\right)^{\alpha} , \tag{6-3}$$

where

σ_c = intact rock uniaxial compressive strength,
σ_1 = the strength of the rock mass,
σ_3 = the confining stress,
A = 1.0 for intact rock or f(RMR) for rock mass, and
α, B = rock material constants dependent on the rock type.

Yudhbir et al. (1983) developed an expression for A that makes the above strength criterion applicable to rock masses:

$$A = e^{0.0765\,(RMR) - 7.65} . \tag{6-4}$$

6.2.2 Hoek and Brown Criterion

Hoek and Brown (1988) have developed the following rock mass strength criterion:

$$\sigma_1 \;=\; \sigma_3 + \sqrt{m \sigma_c \sigma_3 + s \sigma_c^2}\ , \tag{6-5}$$

where σ_1, σ_3 and $s\sigma_c$ are defined above, and m and s are constants which are a function of both the rock properties and the extent to which the rock has been fractured. For undisturbed rock masses (e.g., machine-excavated rock), m and s have been related to RMR as follows:

$$m \;=\; m_i \, e^{(RMR - 100)/28} \text{ and} \tag{6-6}$$

$$s \;=\; e^{(RMR - 100)/9}\ . \tag{6-7}$$

The parameter m_i is the value of m for intact rock and is found by fitting Equation 6-5 to triaxial test data from laboratory specimens where the value of s is set equal to one.

6.2.3 Failure Criteria Parameters for Intact Strength Results

Triaxial testing data, developed for 25.4-mm (1.0-in) diameter samples of the Tptpmn, were presented in Section 4.2, Table 4-6. Failure criteria based on the NRG data in Table 4-6 were used to estimate rock mass strength. The subsequent addition of test results from SD-9 and SD-12 to the database was not judged to change the intact failure criteria enough to warrant revising the analysis. Scatter in the NRG data was large and attempts to fit the nonlinear failure criteria presented in Sections 6.2.1 and 6.2.2 resulted in convex-shaped curves if extreme values were removed, or unrealistically low confining pressure effects if all data values were used. Curve parameters for Equations 6-3 and 6-5 were previously derived by Lin et al. (1993a) who analyzed a set of existing, unqualified rock mechanics testing data from the TSw2 unit. These curve parameters were tested against the qualified Tptpmn data by inspection and by error analysis, and were found to fit the NRG intact strength with the same degree of error as the linear least-square failure criteria. Figure 6-1 compares the Yudhbir and Hoek-Brown curves to the confined testing data from Table 4-6. The standard deviations of the NRG data from the curves were 34.3 and 36.6 MPa (Yudhbir and Hoek-Brown, respectively). The goodness of fit was acceptable when compared to the NRG least-square criteria (excluding extreme values) which had a standard deviation of 34.6 MPa.

The parameters B and α for the Yudhbir et al. criteria and m_i for the Hoek and Brown criteria are listed in Table 6-2. These parameters describe the effect of confining pressure and were used with the mean value of the uniaxial compressive strength tests (179.8 MPa) for the 50.8-mm (2.0-in) diameter samples listed in Table 4-6 to define the intact failure criteria.

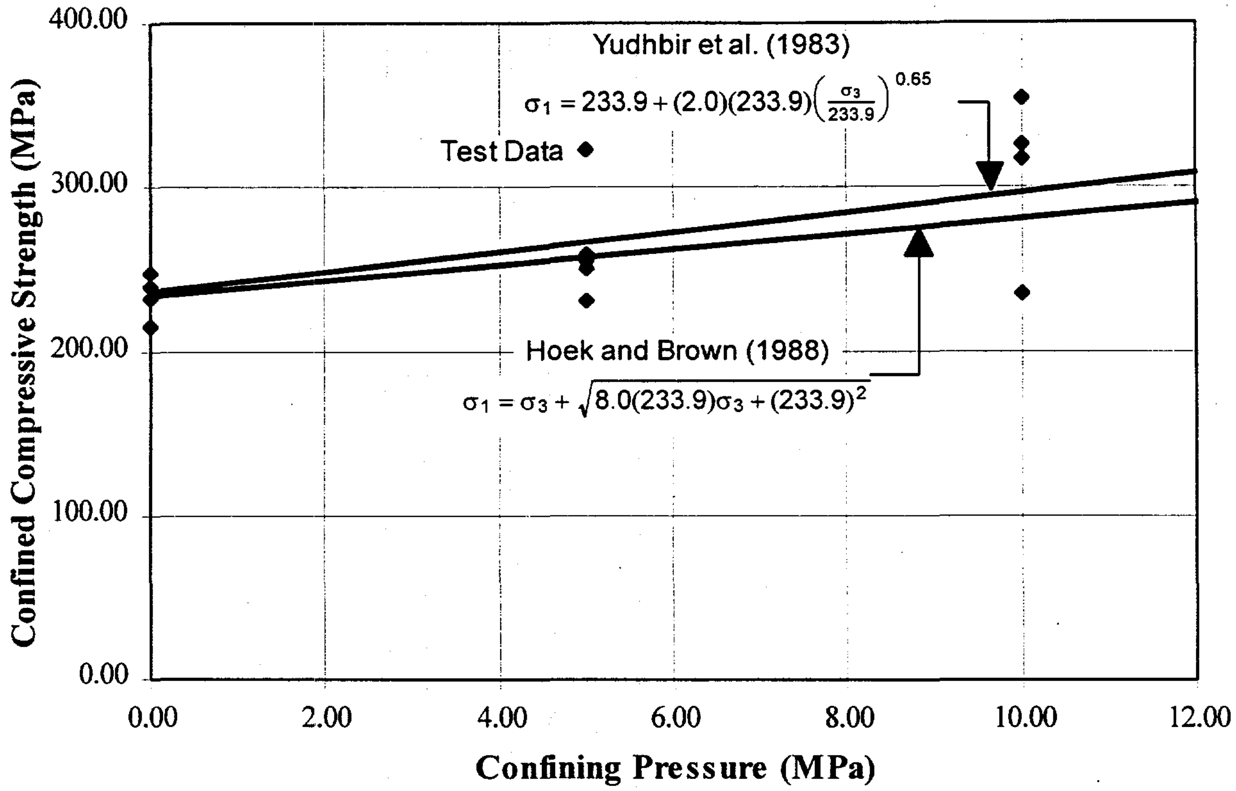

Figure 6-1. Comparison of Tptpmn testing data to intact rock mass strength criteria.

Table 6-2. Constants for the Rock Mass Strength Criteria in MPa

		Cumulative Frequency of Occurrence of RMR				
	Parameter	5%	20%	40%	70%	90%
Yudhbir Criterion	A	0.009	0.014	0.017	0.032	0.074
	B			2.00		
	α			0.65		
	σ_c			179.8		
Hoek & Brown Criterion	m	0.88	1.08	1.20	1.60	2.37
	s	0.0010	0.0019	0.0028	0.0066	0.0227
	m_i			8.00		
	σ_c			179.8		
Design Rock Mass Strength (MPa)	a	3.70	5.19	6.28	10.17	20.19
	b	10.59	10.60	10.58	10.45	10.12
	c	0.69	0.71	0.71	0.73	0.75

6.2.4 Design Rock Mass Strengths

Rock mass failure criteria were calculated using the parameters in Table 6-2 for intact rock with adjustment for RMR value at cumulative frequencies of occurrence of 5%, 20%, 40%, 70%, and 90%. Parameter A in the Yudhbir criteria and both m and s in the Hoek and Brown criteria are functions of RMR.

The rock mass strengths determined from both the Yudhbir et al. (1983) and Hoek and Brown (1988) criteria were then averaged to determine a site-specific rock mass strength criterion. The relationship between rock mass strength and confining stress was expressed in the form:

$$\sigma_1 = a + b\sigma_3^c , \tag{6-8}$$

where parameters a, b, and c were determined for RMR value class using a curve fit of data pins between 0 and 3 MPa confining pressure. The parameter values are presented in Table 6-2, and the rock mass strength curves are shown in Figure 6-2. The mean intact uniaxial rock strength is also plotted on Figure 6-2 to illustrate the magnitude of the reduction from intact rock strength to rock mass strength.

6.2.5 Rock Mass Mohr-Coulomb Strength Parameters and Dilation Angles

The Mohr-Coulomb strength parameters, including cohesion (C) and angle of internal friction (ϕ), and the dilation angle are commonly used to describe the rock mass strength in numerical analysis. The strength parameters were developed from a linear fit of strength data pairs (σ_1, σ_3) used to produce the strength envelopes in Figure 6-1. The linear relationship was expressed in the form of Equation 4-1. Parameters σ_c and N were used to generate a rock mass Mohr-Coulomb failure criterion relating shear (τ) and normal stress (σ_n) according to Equation 4-2. The resulting values of C and ϕ for each rock mass class are listed in Table 6-3. The non-associated flow rule suggested by Michelis and Brown (1986), which uses a dilation angle equal to half the internal friction angle, was considered suitable for the tuff rocks of the ESF (Hardy and Bauer 1991) and the resulting values for dilation angles are also listed in Table 6-3. The intact Mohr-Coulomb strength parameters (Section 4.2) are listed in Table 6-3 for comparison to the rock mass values.

6.3 Rock Mass Elastic Moduli

The following correlation between rock mass elastic modulus and RMR has been developed by Serafim and Pereira (1983) and was recommended for use by Hardy and Bauer (1991) for preliminary assessment:

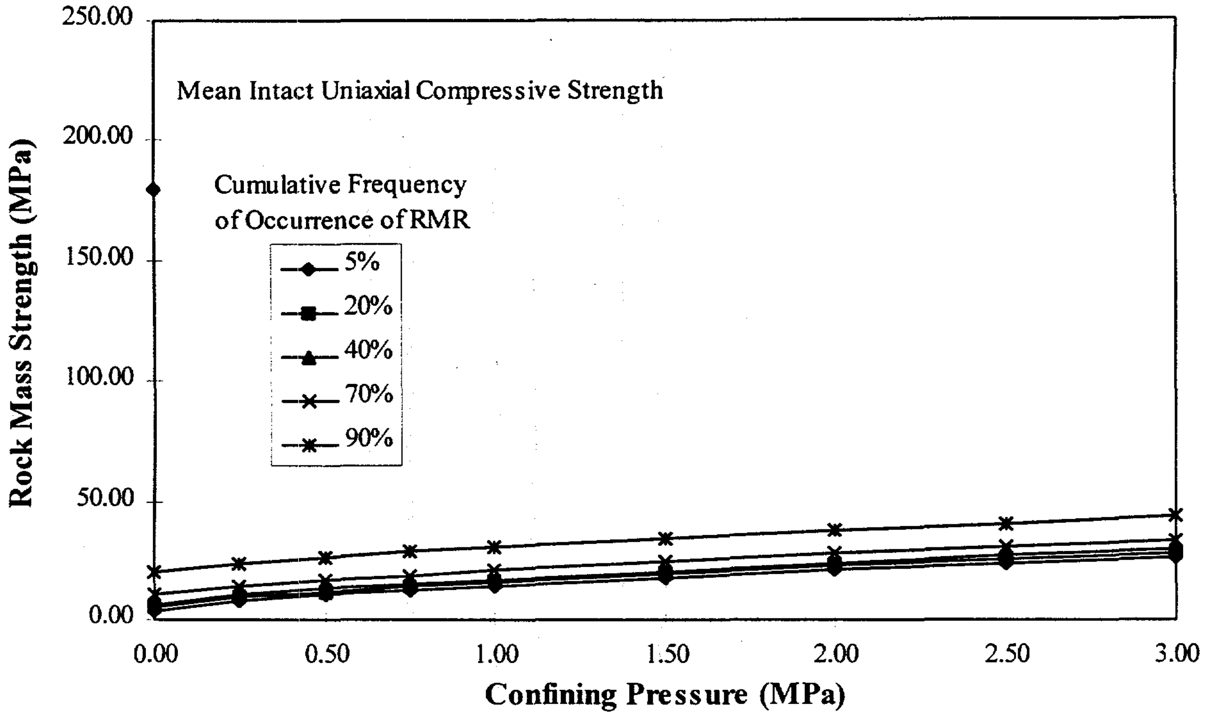

Figure 6-2. Design rock mass strength envelopes for the Tptpmn—Main Drift boreholes.

Table 6-3. Range of Strength Parameters and Dilation Angles for the Mohr-Coulomb Failure Criterion in the Tptpmn

	Intact Rock[1] Values	Cumulative Frequency of Occurrence of RMR				
		5%	20%	40%	70%	90%
Confinement factor, N	7.4	7.2	7.3	7.4	7.4	7.4
Uniaxial compressive strength, σ_c (MPa)	179.8	6.1	7.6	8.5	12.2	22.1
Cohesion, C (MPa)	33.0[2]	1.1	1.4	1.6	2.2	4.1
Internal friction angle, ϕ (degrees)	49.6[2]	49	49	50	50	50
Dilation angle (degrees)	25	25	25	25	25	25

[1] NRG data in Table 4-6

[2] Calculated using equation 4-3, σ_c = 179.8 and N = 7.4

$$E = 10^{(RMR - 10)/40}, \qquad (6\text{-}9)$$

where E is expressed in GPa and E ≤ average intact sample modulus = 32.9 MPa. Values of rock mass moduli have been calculated for the five rock mass quality classes (using RMR_{79} as shown in Table 6-1) and are listed in Table 6-4.

Table 6-4. Range of Estimated Rock Mass Modulus (GPa) for the Tptpmn

Cumulative Frequency of Occurrence of RMR				
5%	**20%**	**40%**	**70%**	**90%**
5.07	7.01	8.40	13.23	25.03

6.4 Rock Mass Poisson's Ratio

Empirical relationships to estimate Poisson's ratio from rock mass quality are not available. The mean value of Poisson's ratio from laboratory tests (Section 4.2) were adopted as the rock mass Poisson's ratio. The rock mass Poisson's ratio for the Tptpmn is 0.21. No adjustments for rock class are recommended.

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7.0 References

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Appendix A

Interim Data Transmittal References

1. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Fracture Data Sheets — Six Groups of Detailed Line Survey Data for the Exploratory Studies Facility, North Ramp Starter Tunnel: Pilot Bore, Bench Cuts, Test Alcove #1, Slash Cuts, Drainage Cuts, and Portal Cuts," U.S. Geological Survey, U.S. Bureau of Reclamation, DTN:GS950308314224.001.

2. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Detailed Line Survey from the North Ramp of the Exploratory Studies Facility, Stations 0+60 to 4+00," U.S. Geological Survey, U.S. Bureau of Reclamation, DTN:GS950508314224.002.

3. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Geotechnical Report for Stations 0+60 to 4+00, North Ramp of the ESF," U.S. Geological Survey, U.S. Bureau of Reclamation, DTN:GS950508314224.003.

4. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Mechanical Properties Data for Drill Hole NRG-6 Samples from Depths of 462.3 ft to 1085.0 ft," Sandia National Laboratories, TDIF No. 301785, DTN:SNL02030193001.004.

5. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Mechanical Properties Data for Drill Hole NRG-6 Samples from Depths of 5.7 ft to 1092.3 ft," Sandia National Laboratories, TDIF No. 304135, DTN:SNL02030193001.022.

6. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Mechanical Properties Data for Drill Hole NRG-7/7A Samples from Depths of 507.4 ft to 881.0 ft," Sandia National Laboratories, TDIF No. 303340, DTN:SNL02030193001.019.

7. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Mechanical Properties Data for Drill Hole NRG-7/7A Samples from Depths of 345.0 ft to 1408.6 ft," Sandia National Laboratories, TDIF No. 304095, DTN:SNL02030193001.021.

8. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Rock Mass Quality for the NRT Stations 60 to 475 m," Sandia National Laboratories, TDIF No. 304267, DTN:SNF32120393001.001.

9. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Rock Mass Quality Data for NRT Stations 475 to 530 m," Sandia National Laboratories, TDIF No. 304283, DTN:SNF32120393001.002.

10. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Rock Mass Quality for NRT Stations 530 to 600 m," Sandia National Laboratories, TDIF No. 304351, DTN:SNF32120393001.003.

11. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Geologic Core Log for Hole USW SD-7," Sandia National Laboratories, DTN:SNT02110894001.001.

12. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Geologic Core Log for SD-9," Sandia National Laboratories, TDIF No. 303743 DTN:SNT02052794001.001 and TDIF No. 304282 DTN:SNT02052794001.002.

13. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Geologic Core Log for SD-12," Sandia National Laboratories, TDIF No. 303744 DTN:SNT02012894001.001.

14. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Geology and Rock Structure Log for Hole USW SD-7, 675–825 ft," Revision 0, Sandia National Laboratories, DTN:SNF29041993002.066. Superseded by .075.

15. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Geology and Rock Structure Log for Hole USW SD-9, 700–850 ft," Revision 0, Sandia National Laboratories, DTN:SNF29041993002.051. Superseded by .076.

16. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Geology and Rock Structure Log for Hole USW SD-12, 650–800 ft," Revision 0, Sandia National Laboratories, DTN:SNF29041993002.054.

17. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Geology and Rock Structure Log for Hole USW UZ-14, 700–850 ft," Revision 0, Sandia National Laboratories, DTN:SNF29041993002.079.

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22. Interim Data Transmittal, Yucca Mountain Site Characterization Project, "Estimated Rock Mass Quality Indices Based on Core Log Data for Hole USW NRG-6, 710–1100 ft, TSw2 Unit," Revision 4, Sandia National Laboratories, DTN:SNF29041993002.074.

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25. Interim Data Transmittal, Yucca Mountain Site Characterization Project, “Estimated Rock Mass Quality Indices Based on Core Log Data for Hole USW SD-9, 700–850 ft, TS Middle Nonlithophysal Zone,” Revision 1, Sandia National Laboratories, DTN:SNF29041993002.070.

26. Interim Data Transmittal, Yucca Mountain Site Characterization Project, “Estimated Rock Mass Quality Indices Based on Core Log Data for Hole USW SD-12, 650–800 ft, Middle Nonlithophysal Zone,” Revision 1, Sandia National Laboratories, DTN:SNF29041993002.072.

27. Interim Data Transmittal, Yucca Mountain Site Characterization Project, “Estimated Rock Mass Quality Indices Based on Core Log Data for Hole USW UZ-14, 700–850 ft, TS Middle Nonlithophysal Zone,” Revision 0, Sandia National Laboratories, DTN:SNF29041993002.065.

28. Interim Data Transmittal, Yucca Mountain Site Characterization Project, “Rock Mass Mechanical Properties Estimates for Topopah Spring Middle Nonlithophysal Zone (NRG-6, NRG-7/7A, SD-7, SD-9, SD-12 and UZ-14),” Revision 1, Sandia National Laboratories, DTN:SNF29041993002.082.

29. Interim Data Transmittal, Yucca Mountain Site Characterization Project, “Rank-Ordered Rock Mass Quality Indices Q and RQD for Boreholes NRG-6, NRG-7/7A, SD-7, SD-9, SD-12 and UZ-14,” Revision 1, Sandia National Laboratories, DTN:SNF29041993002.081.

30. Interim Data Transmittal, Yucca Mountain Site Characterization Project, “TS Main Drift Cross Section Version QA3,” Sandia National Laboratories, DTN:SNF29041993002.078.

Appendix B

Rank-Ordered Rock Mass Quality Estimates for the Tptpmn

Table B-1. Rank-Ordered Rock Mass Quality Data for Tptpmn

Count	Cumulative Frequency of Occurrence	Q	RMR	RQD
1	1%	0.11	45.98	0
2	3%	0.13	47.93	0
3	4%	0.13	48.69	0
4	6%	0.14	50.10	0
5	7%	0.18	50.50	0
6	9%	0.19	51.50	0
7	10%	0.20	52.20	0
8	12%	0.26	52.40	0
9	13%	0.26	53.00	0
10	14%	0.26	53.07	0
11	16%	0.28	53.19	0
12	17%	0.29	54.31	2
13	19%	0.29	54.72	4
14	20%	0.29	54.81	4
15	22%	0.29	55.12	5
16	23%	0.30	55.17	5
17	25%	0.30	55.20	6
18	26%	0.30	56.07	6
19	28%	0.32	56.16	7
20	29%	0.32	56.24	7
21	30%	0.33	56.50	8
22	32%	0.34	56.60	8
23	33%	0.36	56.60	10
24	35%	0.38	56.75	10
25	36%	0.38	56.95	10
26	38%	0.38	57.00	11
27	39%	0.40	57.58	11
28	41%	0.42	57.77	12
29	42%	0.45	57.95	12
30	43%	0.46	58.07	13
31	45%	0.53	58.07	13
32	46%	0.59	58.10	14
33	48%	0.61	58.73	15
34	49%	0.61	58.83	15
35	51%	0.70	59.17	16

Table B-1. *continued*

Count	Cumulative Frequency of Occurrence	Q	RMR	RQD
36	52%	0.74	59.34	17
37	54%	0.75	59.73	17
38	55%	0.78	60.00	18
39	57%	0.80	60.07	18
40	58%	0.80	61.23	19
41	59%	0.91	61.33	20
42	61%	0.92	61.43	24
43	62%	0.95	61.51	25
44	64%	0.96	61.52	25
45	65%	1.15	61.61	26
46	67%	1.18	61.70	28
47	68%	1.31	62.71	28
48	70%	1.39	62.76	29
49	71%	1.52	63.13	29
50	72%	1.55	63.33	30
51	74%	1.81	63.40	32
52	75%	1.91	63.70	32
53	77%	1.91	63.76	33
54	78%	2.37	64.07	36
55	80%	2.89	64.07	40
56	81%	2.97	64.39	41
57	83%	3.05	64.75	41
58	84%	3.64	65.44	42
59	86%	4.00	65.50	46
60	87%	4.23	65.62	48
61	88%	5.00	66.50	48
62	90%	10.56	66.66	48
63	91%	10.79	67.09	52
64	93%	11.05	67.50	62
65	94%	12.00	67.54	64
66	96%	12.38	69.50	65
67	97%	14.93	70.45	78
68	99%	21.00	75.50	82
69	100%	33.33	76.72	94

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Appendix C

USW SD-7, SD-9, SD-12 and UZ-14 Core Logs and Data

Geology and Rock Structure Log

Core Hole Rock Structural Data Summary

Estimated Rock Mass Quality Indices Based on Core Log Data

USW SD-7 CORE LOGS AND DATA

Geology and Rock Structure Log

Core Hole Rock Structural Data Summary

Estimated Rock Mass Quality Indices Based on Core Log Data

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
GEOLOGY AND ROCK STRUCTURE LOG
Hole USW SD-7, 675-825 ft

Sandia National Laboratories
Print Date: 7/3/95
WBS 1.2.3.2.6.2
QA:L
Revision 0

BOREHOLE ID: USW SD-7
STUDY PLAN NO: 8.3.1.2.2.1
CORE SIZE: PQ
DRILL DATES: 1/25/95-1/27/95
GROUND ELEV: 4470.0 ft
COORDINATES: N758949.76
E561240.29

TOTAL DEPTH: 675-825 ft
ANGLE FROM VERT: 0°
AZIMUTH: NA

Field Rock Structure

Logged by:

A. Mendenhall
D. Switzer
C. Henson
S. Hopkins
P. Ringgenberg
M. Wagner
R. Wilcoxon
R. Morris
M. Pitterle
J. Kirkwood
C. Hermes
D. Hattler

Drilling Support Division, Drilling Support and Sample Management Department, T&MSS

Relogged by:

Eric R. Martin Agapito Associates, Inc.

Lithology and Stratigraphy

Logged by:

D. Engstrom Sandia National Laboratories

Checked by:

Eric R. Martin Agapito Associates, Inc.

Log prepared by Agapito Associates, Inc. for Sandia National Laboratories

EXPLANATION
GEOLOGY AND ROCK STRUCTURE

FRACTURE TYPE OR FEATURE

N Natural fractures are indicated by mineral coatings, evidence of weathering, slickensides, lack of rematch/fit between sides or by surfaces that form an ellipse in the core.
C Coring-induced fractures are generally normal to the axis of the core or indicate some torquing of the core. They are typically clean, fresh and fit tightly back together.
I Indeterminate fractures are those not clearly described as "N" or "C." This includes fracture surfaces that have been shaped by drilling rotation.
H Handling-induced fractures are formed in the core by removal from the core barrel or placement in the core box. These fractures are witnessed and, according to BTP-SMF-008, are by the SMF personnel by lines parallel to the fracture on both sides of the core. "H" fractures are typically not recorded in the log unless there is a specific reason.
V Vug or large void.
P Foliation plane due to gravity flattening upon deposition, not a fracture.

LOST CORE AND RUBBLE

☒ LOST CORE

|×.20 ×| RUBBLE ZONE
(with average maximum diameter of rubble pieces to nearest 0.01 ft;
NM = not measured)

HARDNESS (Subjective estimate, YMP procedures do not allow core to be broken or scratched etc.)

1 Extremely Hard—Cannot be scratched, chipped only with repeated heavy hammer blows.
2 Very Hard—Cannot be scratched, broken only with repeated heavy hammer blows.
3 Hard—Scratched with heavy pressure, breaks with heavy hammer blow.
4 Moderately Hard—Scratched with light-moderate pressure, breaks with moderate hammer blow.
5 Moderately Soft—Grooved (16th in.) with moderate heavy pressure, breaks with light hammer blow.
6 Soft—Grooved easily with light pressure, scratched with fingernail, breaks with light-moderate manual pressure.
7 Very Soft—Readily gouged with fingernail, breaks with light manual pressure.
8 Soil Like—Cohesive
9 Soil Like—Non-cohesive

WEATHERING

F Fresh—Rock and fractures not oxidized or discolored, no separation of grains, change of texture or solutioning.
S Slightly Weathered—Oxidized or discolored fractures and nearby rock, some dull feldspars, no separation of grains, minor leaching.
M Moderately Weathered—Fractures and most of rock oxidized or discolored, partial separation of grains, crystals rusty or cloudy, moderate leaching of soluble minerals.
I Intensely Weathered—Fractures and rock totally oxidized or discolored, extensive clay alteration, leaching complete, grain separation extensive, rock is friable.
D Decomposed—Grain separation and clay alteration complete.

PLANARITY

P Planar
C Curved
S Stepped
I Irregular

ROUGHNESS

V Very rough, stepped, near-normal steps and ridges occur.
R Rough, large angular asperities can be seen.
M Moderately rough, asperities clearly visible, surface has an abrasive feel; to slightly rough, small asperities are visible and can be felt.
S Smooth, no asperities, smooth to the touch.
P Polished, slickensided, extremely smooth and shiny.

INFILLING THICKNESS AND MINERALIZATION

C Clean, no filling.
S Very thin, surface sheen
T Thin (up to 0.1 inches)
M Moderately thick (0.1 - 0.4 inches)
V Very thick (0.4 - 1.0 inches)
E Extremely thick, greater than 1.0 inches)

C Clean
WC White, crystalline
WN White, non-crystalline
TD Brown dendritic
TC Tan crystalline
TN Tan, non-crystalline

CA Calcite
SI Silica
MN Manganese
CL Clay
BC Black crystalline
BD Black dendritic

EXPLANATION (concluded)
GEOLOGY AND ROCK STRUCTURE

CORE RQD

Core RQD is calculated using piece lengths that are defined by all fractures (type N, I, and C) that exist in the core when it is removed from the core barrel. Only handling-induced breaks are discounted in piece length determination. RQD is calculated as:

$$RQD = \frac{\sum \textit{Piece lengths} \geq 0.33\,ft}{\textit{Interval length}} \times 100.$$

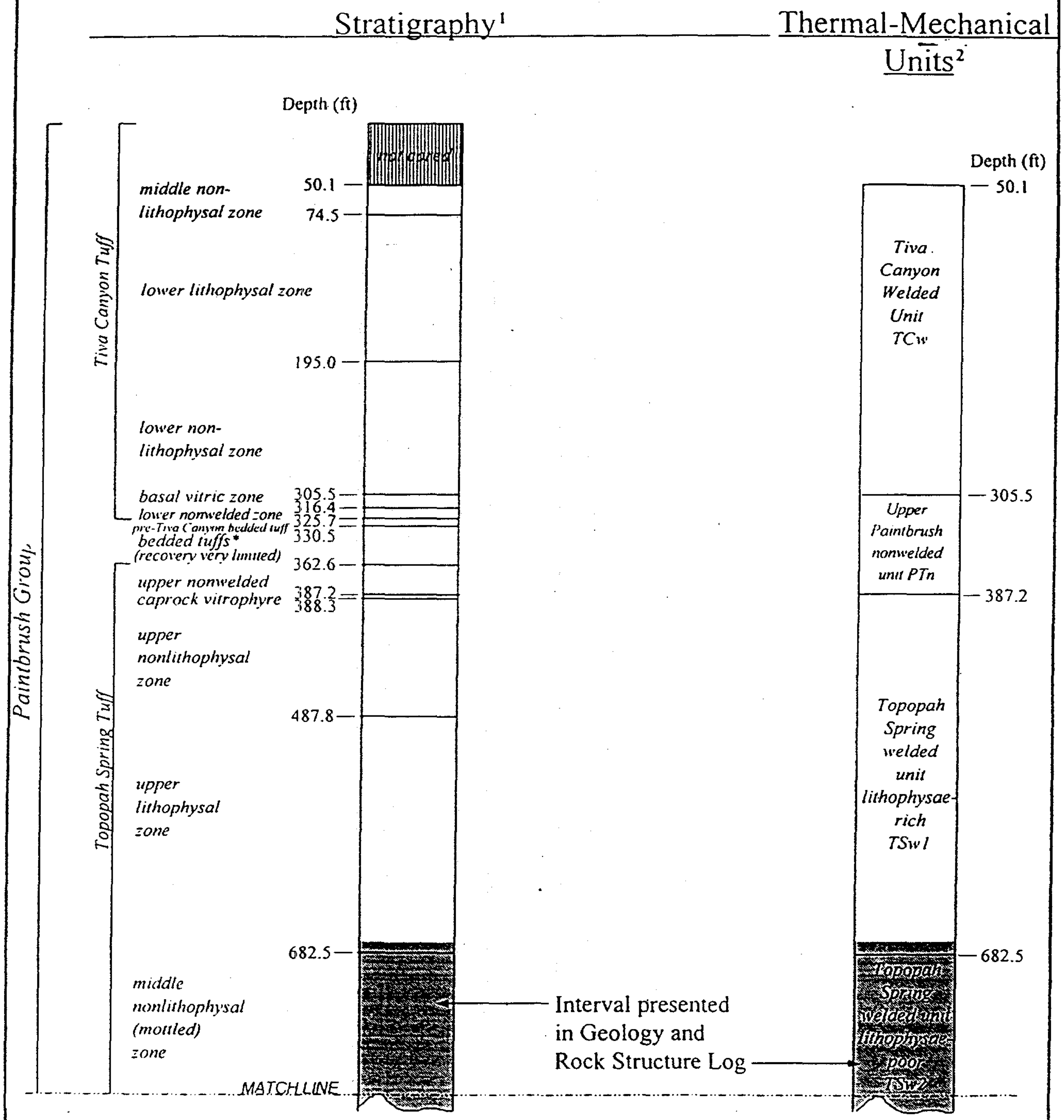
RQD is calculated for both the core run interval (run RQD) and even 10-ft intervals. If a piece length $\geq$ 0.33 ft crosses over a 10-ft interval boundary, the portion of the piece length that occurs in the 10-ft interval is included in the summation.

ESTIMATED PERCENTAGE LITHOPHYSAE & OTHER CAVITIES

The percentage of lithophysal voids and other cavities is estimated for each core run interval where sufficient whole core is available. Excessive lost core and rubble zones may prevent the estimate on specific core runs. The estimate is based on comparison of the core with charts designed for estimating the proportions of various rock or mineral components. Estimates are then spot checked using a quantitative graphical summation technique to calculate the percent area occupied by lithophysal cavities in core photographs or video tape.

The estimated percent cavities volume for core runs is used to calculate a run length, weighted average for even 10-ft intervals. (Runs for which percent cavities cannot be determined are assumed to have the average percentage for the 10-ft interval; intervals for which the percent cavities were not estimated are labeled "Not Measured;" zones containing vapor-phase alteration and very small or no lithophysal cavities are labeled as <1%).

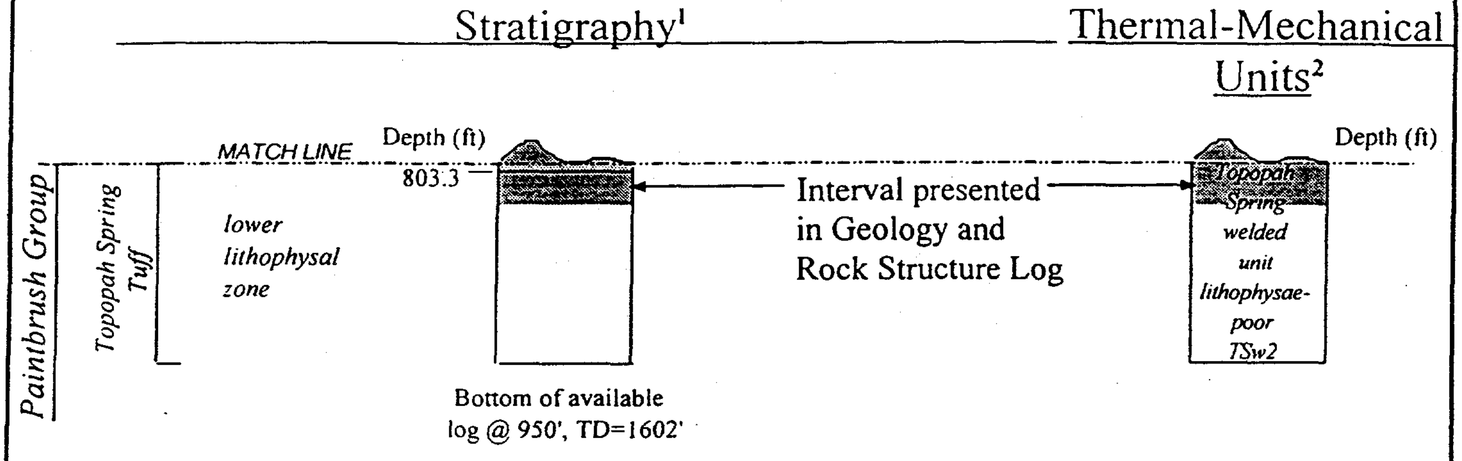
USW SD-7 (1 of 2)
Stratigraphic and Thermal-Mechanical Units Summary
0 - 800 ft



*interval from 330.5 to 362.6 contains very limited recovery of bedded tuffs Yucca Mountain Tuff is not recognized in this interval. Pah Canyon Tuff was not found but may exist in unrecovered interval from 342.0 to 362.6.

Date: 7/5/95

USW SD-7 (2 of 2)
Stratigraphic and Thermal-Mechanical Units Summary
800 - 950 ft



Date: 7/7/95

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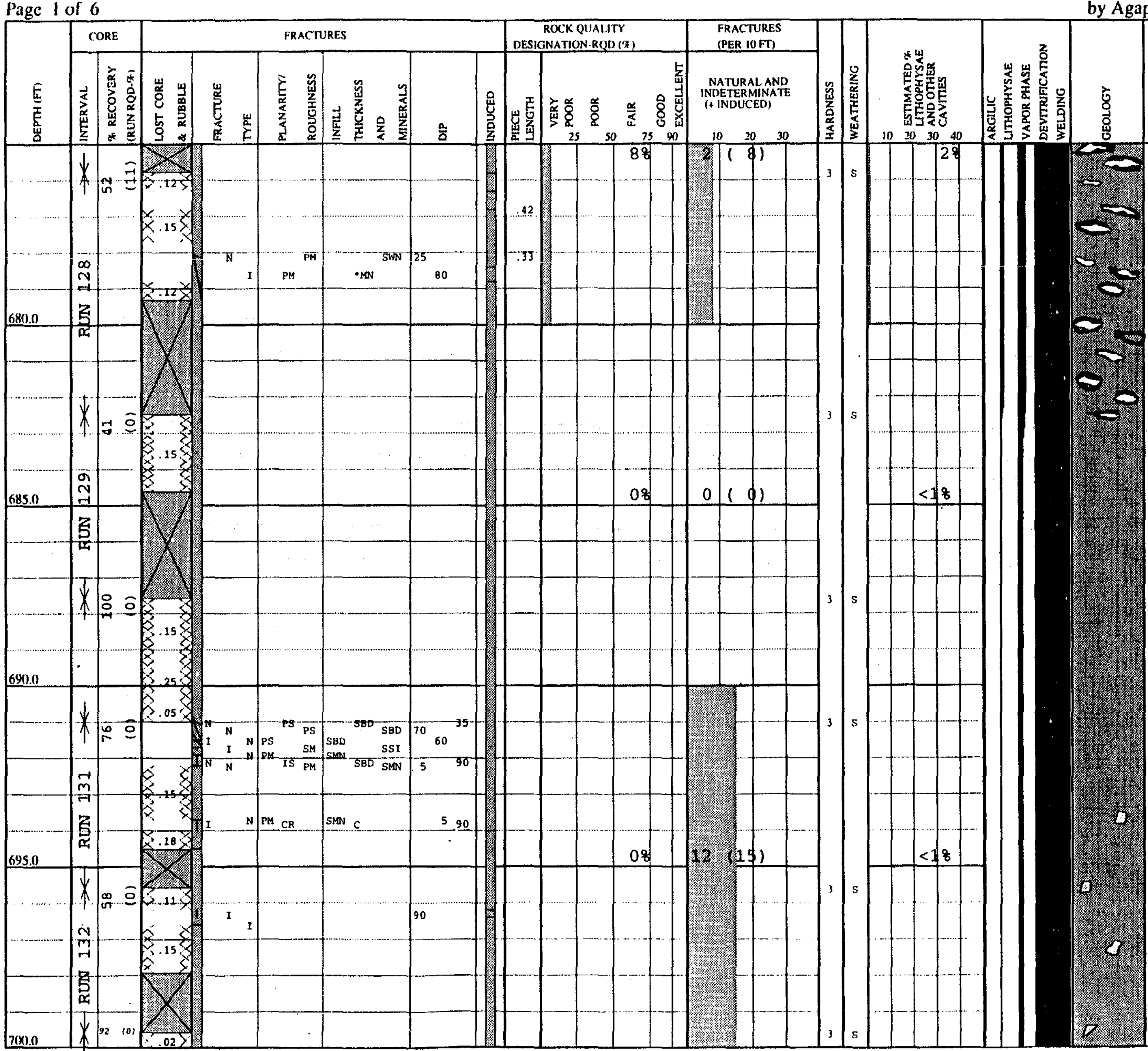
[1] Lithologic log of Borehole USW SD-7. Dale Engstrom, unpublished data.

[2] Thermal-mechanical units as defined by Buesch, et al., USGS Open File Report 94-469, 1996. "Proposed stratigraphic nomenclature and macroscopic identification of lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain, Nevada."

Yucca Mountain, Drillhole USW SD-7
Page 1 of 6

GEOLOGY AND ROCK STRUCTURE LOG

Sandia National Laboratories
by Agapito Associates, Inc.



487.8-682.5 ft. TOPOPAH SPRING UPPER LITHOPHYSAL ZONE cont'd. Pale red-brown (2.5R7/4), close-spaced small irregular-shaped lithophysae, coated with vapor phase mins, 2-4mm light pink-gray alteration halo makes 15-20% of rock volume, 5-6% is 1-3mm blue alteration border and mm-size blue alteration streaks through groundmass, 75% is unaltered, 2-3% quartz latite soft lithics up to 50mm, 2-3% feldspar phenocrysts, trace biotite, poorly developed foliation.
671.6-675.8 ft. Unrecovered.
676.7-677.8 ft. Broken.
678.9-679.3 ft. Rubble.
679-682.5 ft. Unrecovered.
682.5-803.3 ft. TOPOPAH SPRING MIDDLE NONLITHOPHYSAL ZONE. Pale orange-gray (5YR7/2) densely welded, devitrified, with very weakly lithophysal cognate pumice, wavy sub-horizontal lines of alteration may be replacement of flattened nonlithophysal pumice, 5-7% 3-5mm long streaks of alteration apparently nucleated by small pumice, rare small 5mm white subangular lithics especially at 694.1-714.7 ft., 2-3% feldspar phenocrysts, trace biotite.
682.5-684.3 ft. Rubble.
684.3-684.6 ft. Unrecovered.

694.5-695.6 ft. Unrecovered.
695.6-697.6 ft. Broken.

697.6-699.6 ft. Unrecovered.

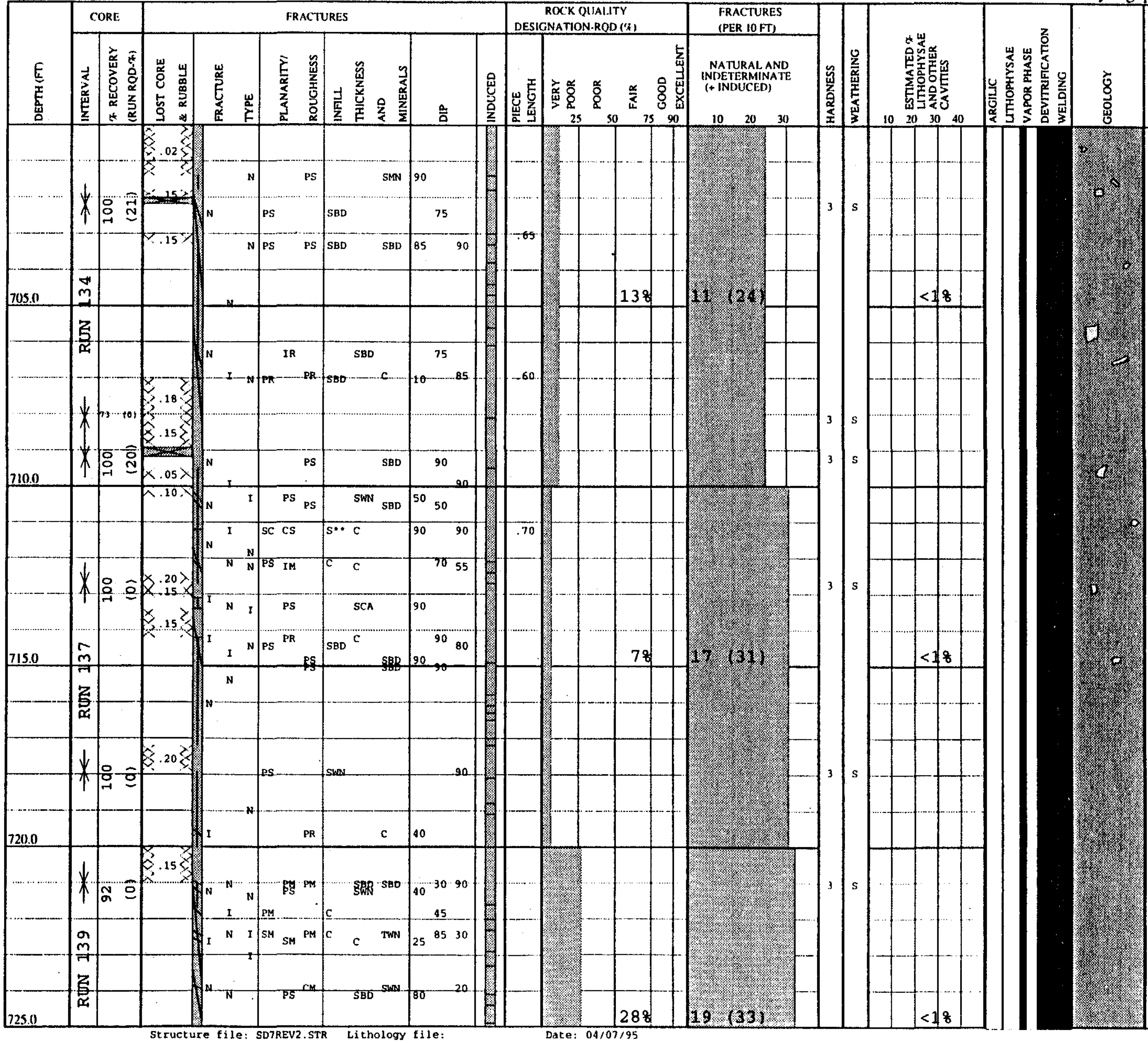
Structure file: SD7REV2.STR Lithology file: Date: 04/07/95

WPlog v 5.00

Yucca Mountain, Drillhole USW SD-7
Page 2 of 6

GEOLOGY AND ROCK STRUCTURE LOG

Sandia National Laboratories
by Agapito Associates, Inc.



682.5-803.3 ft. TOPOPAH SPRING MIDDLE NONLITHOPHYSAL ZONE cont'd. Pale orange-gray (7.5R7/2) densely welded, devitrified, 10-15% pumice that is close to indistinguishable from matrix, light blue-gray alteration around nonlithophysal pumice sites, grainy devitrified groundmass, 10% light blue-gray alteration streaks, 1-2% feldspar phenocrysts, <1% biotite, joint orientation dominantly 30° to core axis or horizontal.
707.0-709.2 ft. Broken.

725.7-726.1 ft. Unrecovered.

Structure file: SD7REV2.STR Lithology file:

Date: 04/07/95

WPlog v 5.00

Yucca Mountain, Drillhole USW SD-7
Page 3 of 6

GEOLOGY AND ROCK STRUCTURE LOG

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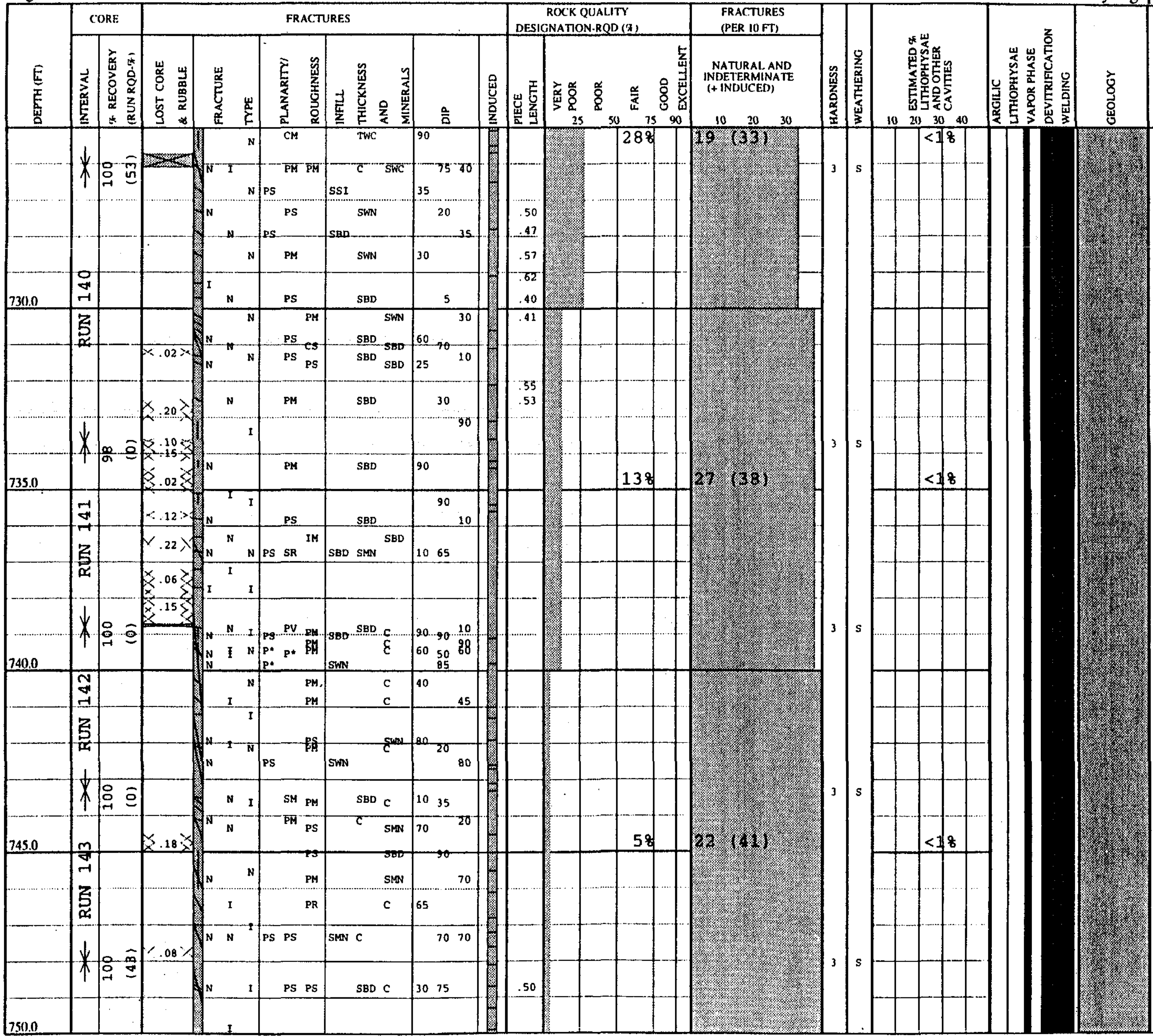

682.5-803.3 ft. TOPOPAH SPRING MIDDLE NONLITHOPHYSAL ZONE cont'd. Pale orange-gray (7.5R7/2) densely welded, devitrified, 10-15% pumice that is close to indistinguishable from matrix, light blue-gray alteration around nonlithophysal pumice sites, grainy devitrified groundmass, 10% light blue-gray alteration streaks, 1-2% feldspar phenocrysts, <1% biotite, joint orientation dominantly 30° to core axis or horizontal.

725.7-726.1 ft. Unrecovered.

733.6-734.9 ft. Broken.

737.6-738.7 ft. Broken.

Structure file: SD7REV2.STR Lithology file:

Date: 04/07/95

WPlog v 5.00

Yucca Mountain, Drillhole USW SD-7
Page 4 of 6

GEOLOGY AND ROCK STRUCTURE LOG

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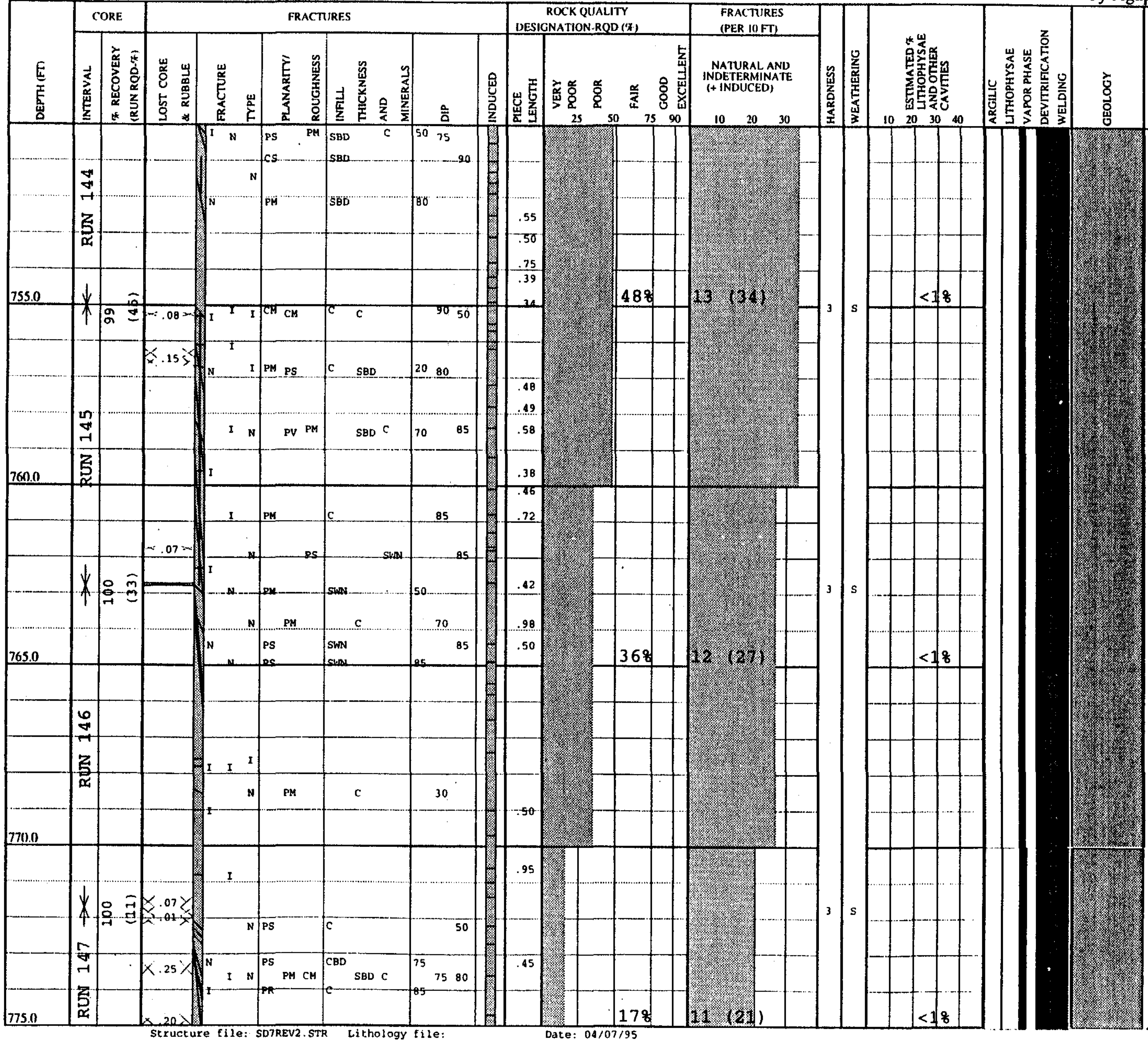


LITHOLOGIC DESCRIPTION AND STRATIGRAPHY

682.5-803.3 ft. TOPOPAH SPRING MIDDLE NONLITHOPHYSAL ZONE cont'd. Pale orange-gray (7.5R7/2) densely welded, devitrified, 10-15% pumice that is close to indistinguishable from matrix, light blue-gray alteration around nonlithophysal pumice sites, grainy devitrified groundmass, 10% light blue-gray alteration streaks, 1-2% feldspar phenocrysts, <1% biotite, joint orientation dominantly 30° to core axis or horizontal.

765.4-767.4 ft. Broken.

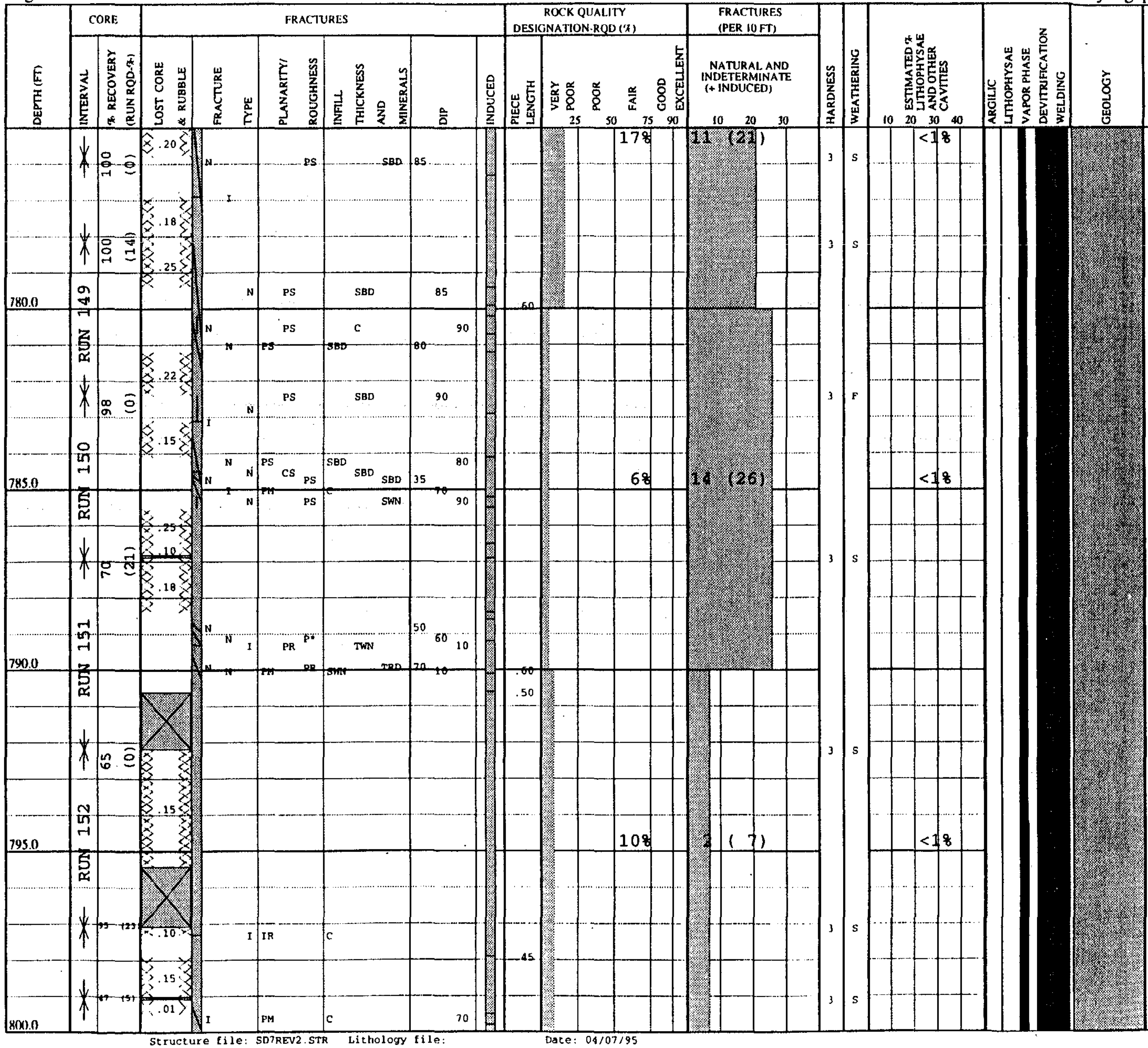
771.4-772.8 ft. Broken.

Structure file: SD7REV2.STR Lithology file: Date: 04/07/95 WPlog v 5.00

Yucca Mountain, Drillhole USW SD-7
Page 5 of 6

GEOLOGY AND ROCK STRUCTURE LOG

Sandia National Laboratories
by Agapito Associates, Inc.



682.5-803.3 ft. TOPOPAH SPRING MIDDLE NONLITHOPHYSAL ZONE cont'd. Pale orange-gray (7.5YR7/3) densely welded although shard remnants can still be distinguished under the binocular microscope, devitrified, 15-20% cognate pumice nearly indistinguishable from matrix, most of groundmass contains poorly defined 5x10mm light pink alteration spots, 2-4% elongated to subangular crystal-rich soft lithics up to 30mm length, 2-3% small rounded mixed composition hard lithics, mostly dense red-gray or altered light gray, 3-5% feldspar phenocrysts, no biotite seen, mostly low-angle fracture weakly coated by Fe-MnOx dendrites.

775.2-775.8 ft. Broken.
777.1-779.3 ft. Broken.
781.1-782.4 ft. Broken.
783.4-784.1 ft. Broken.
786.5-788.4 ft. Broken.

790.6-792.2 ft. Unrecovered.

795.4-797.1 ft. Unrecovered.

798.7-799.5 ft. Broken

Structure file: SD7REV2.STR Lithology file: Date: 04/07/95

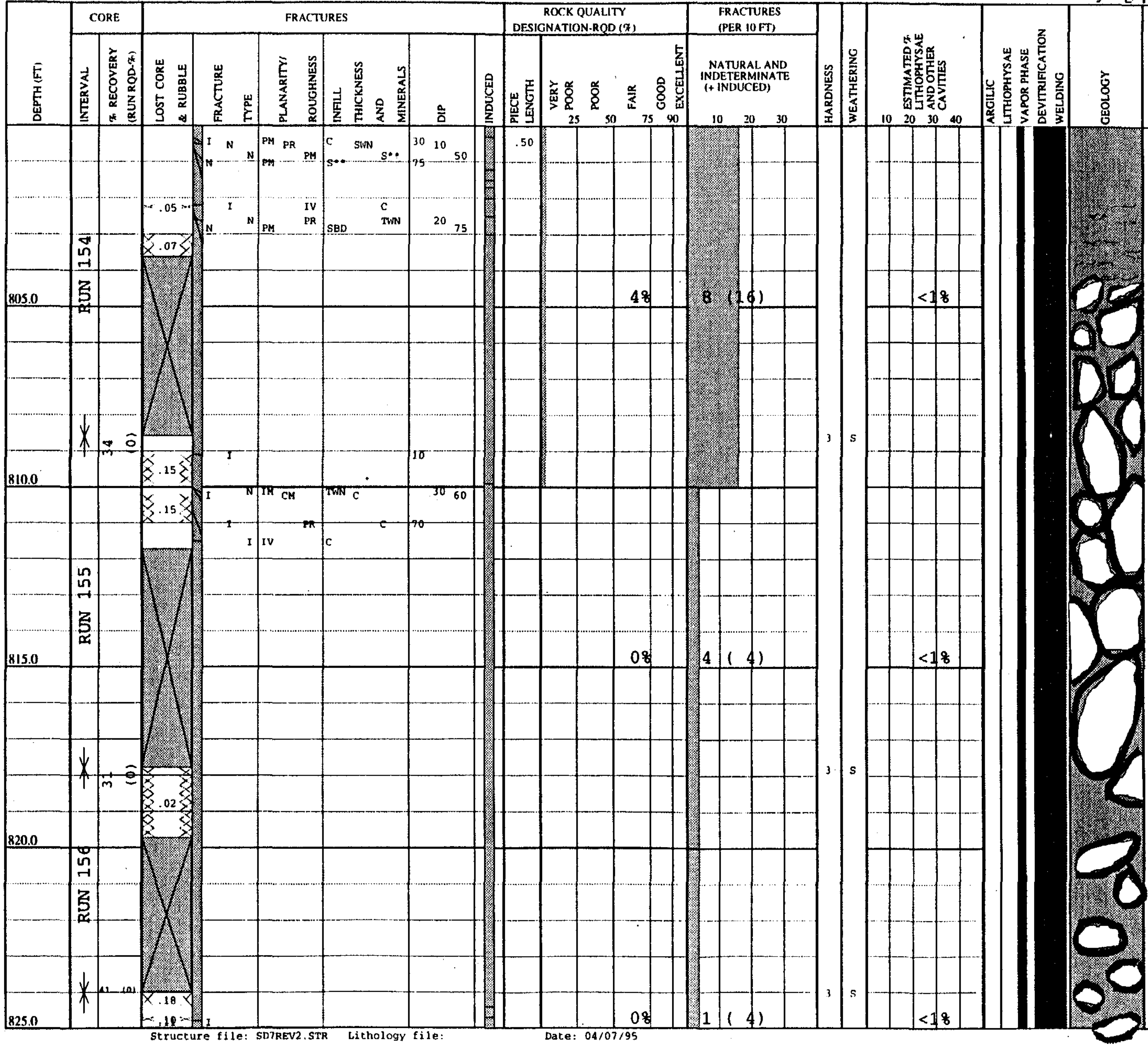
WPlog v 5.00

Yucca Mountain, Drillhole USW SD-7

Page 6 of 6

GEOLOGY AND ROCK STRUCTURE LOG

Sandia National Laboratories
by Agapito Associates, Inc.



682.5-803.3 ft. TOPOPAH SPRING MIDDLE NONLITHOPHYSAL ZONE cont'd. Pale orange-gray (7.5YR7/3) densely welded although shard remnants can still be distinguished under the binocular microscope, devitrified, 15-20% cognate pumice nearly indistinguishable from matrix, most of groundmass contains poorly defined 5x10mm light pink alteration spots, 2-4% elongated to subangular crystal-rich soft lithics up to 30mm length, 2-3% small rounded mixed composition hard lithics, mostly dense red-gray or altered light gray, 3-5% feldspar phenocrysts, no biotite seen, mostly low-angle fracture weakly coated by Fe-MnOx dendrites.

801.6 ft. Increase in patchy blue alteration, intensity increasing downward.

802.0 ft. Increase of light pink-gray alteration (10%) rimming weakly lithophysal pumice sites, blue alteration borders also increasing downward (to 40%).

803.0-811.1 ft. Broken.

803.3-1020.0 ft. TOPOPAH SPRING LOWER LITHOPHYSAL ZONE. Pale red-gray (7.5R7/2) densely welded, devitrified, majority of lithophysae are unseen, however, severely broken or rubblized core fragments often coated by thin white crystalline vapor-phase minerals with alteration halo, unseen lithophysae appear to be medium-sized moderately spaced, 10-15% light pink alteration as halo, up to 50-55% blue alteration, 3-4% round feldspar phenocrysts, biotite not seen.

803.6-808.6 ft. Unrecovered.

811.7-817.8 ft. Unrecovered.

Structure file: SD7REV2.STR Lithology file: Date: 04/07/95 WPlog v 5.00

CODING EXPLANATION

STRATIGRAPHIC ABBREVIATIONS

T.C.	Tiva Canyon Tuff	C.P. M. Nonlith.	Crystal-Poor Middle Nonlithophysal Zone
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone
	Bedded Tuff		
Y.M.	Yucca Mountain Tuff		
	Bedded Tuff		
P.C.	Pah Canyon Tuff		
	Bedded Tuff		
T.S.	Topopah Spring Tuff	C.R. Vitric	Crystal-Rich Vitric Zone
		C.R. Nonlith.	Crystal-Rich Nonlithophysal Zone
		C.R. Lith.	Crystal-Rich Lithophysal Zone
		C.P. U. Lith.	Crystal-Poor Upper Lithophysal Zone
		C.P. M. Nonlith.	Crystal-Poor Middle Nonlith.
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone Vitrophyre
		C.P. Vitric NW	Crystal-Poor Vitric Zone Non- to Partially Welded and Moderately Welded
	Bedded Tuff		
C.H.	Calico Hills Formation		

THERMOMECHANICAL UNITS

UO—Undifferentiated Overburden
TCw—Tiva Canyon Welded Unit
PTn—Upper Paintbrush Nonwelded Unit
TSw1—Topopah Spring Welded Unit—Lithophysae Rich
TSw2—Topopah Spring Welded Unit—Lithophysae Poor
TSw3—Topopah Spring Welded Unit—Vitrophyre
CHn1—Calico Hills and Lower Paintbrush Nonwelded Unit

COLUMN INFORMATION (Page 3)

RQD (%)	$RQD\ (\%) = \frac{\sum \text{Piece lengths} \geq 0.33\ ft}{\text{Interval length}} \times 100.$
CORE RQD	Core RQD based on piece lengths defined by all types of fractures (C, I, N and V).
ENHANCED RQD	Effect of fractures identified as coring induced (Type C) are filtered from the piece lengths.
LITHOPHYSAL (and other cavities)	Percent void due to lithophysae and other cavities, estimated visually by counting the number of cavities, estimating the average diameter, calculating the void volume assuming spherical cavities, and normalizing to the core volume. NM—Not Measured
WEATHERING	Subjective evaluation of rock degradation by mechanical/chemical agents: F: Fresh S: Slightly weathered M: Moderately weathered I: Intensely weathered D: Decomposed

HARDNESS

Subjective evaluation of resistance to breakage:
1: Extremely hard
2: Very hard
3: Hard
4: Moderately hard
5: Moderately soft
6: Soft
7: Very soft
8: Soil-like, cohesive
9: Soil-like, non-cohesive

COLUMN INFORMATION (Page 4)

FEATURE TYPE

Following codes indicate origin of feature:
N: Natural—indicated by mineral coating or evidence of weathering, slickensides, lack of fit between sides.
I: Indeterminate—origin questionable, rotated so that coatings possibly removed.
C: Coring induced—fresh, clean, tightly fitting breaks.
V: Vug or large void.

INCLINATION (degrees)

Angle between plane normal to core axis and plane of fracture (Type N and I only).

MINERAL INFILLING

Describes the infilling on fracture surfaces (Type N and I only):
C: Clean
WC: White crystalline
WN: White noncrystalline
BC: Black crystalline
BD: Black dendritic
TD: Brown dendritic
TC: Tan crystalline
CA: Calcite
SI: Silica
MN: Manganese
CL: Clay
TN: Tan noncrystalline
FE: Iron oxide
BN: Brown noncrystalline

INFILL THICKNESS

Describes the thickness of mineral infillings on the fracture surface (Type N and I only):
S: Very thin, surface sheen
T: Thin (up to 0.1 inches)
M: Moderately thick (0.1-0.4 inches)
V: Very thick (0.4 - 1.0 inches)
E: Extremely thick, greater than 1.0 inches

PLANARITY

Describes the overall shape of the feature (Type N and I only):
P: Planar
C: Curved
S: Stepped
I: Irregular

ROUGHNESS

Describes the local relief of the surface (Type N and I only):
V: Very rough—stepped, near-normal steps and ridges occur.
R: Rough—large angular asperities can be seen.
M: Moderately rough—asperities clearly visible, surface has abrasive feel.
S: Smooth—no asperities, smooth to the touch.
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		C.P. Vitric	Crystal-Poor Vitric Zone
	Bedded Tuff		
Y.M.	Yucca Mountain Tuff		
	Bedded Tuff		
P.C.	Pah Canyon Tuff		
	Bedded Tuff		
T.S.	Topopah Spring Tuff	C.R. Vitric	Crystal-Rich Vitric Zone
		C.R. Nonlith.	Crystal-Rich Nonlithophysal Zone
		C.R. Lith.	Crystal-Rich Lithophysal Zone
		C.P. U. Lith.	Crystal-Poor Upper Lithophysal Zone
		C.P. M. Nonlith.	Crystal-Poor Middle Nonlithophysal Zone
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
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		C.P. Vitric	Crystal-Poor Vitric Zone Vitrophyre
		C.P. Vitric NW	Crystal-Poor Vitric Zone Non- to Partially Welded and Moderately Welded
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TSw3—Topopah Spring Welded Unit—Vitrophyre
CHn1—Calico Hills and Lower Paintbrush Nonwelded Unit

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

Core Hole Structural Data Summary

Hole USW SD-7

Interval — 670-830 ft, Middle Nonlithophysal Zone

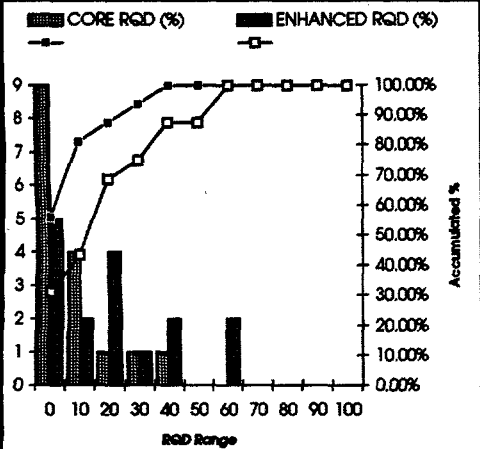
BASE OF 10-FT INTERVAL	STRATI-GRAPHY ZONE	THERMO-MECHANICAL UNIT	CORE RQD* %	ENHANCED RQD** %	ESTIMATED % CAVITIES	LOST CORE (ft)	RUBBLE ZONE (ft)	WEATHERING (ft in 10-ft interval)***					HARDNESS (ft in 10-ft interval)***								
													ROCK							SOIL	
								F	S	M	I	D	1	2	3	4	5	6	7	8	9
680	T.S. U. Lith.	TSw1	8	14	2	4.9	3.4		10.0						10.0						
690	T.S. M. Nonlith.	TSw2	0	0	<1	5.5	4.5		10.0						10.0						
700	T.S. M. Nonlith.	TSw2	0	0	<1	2.8	5.3		10.0						10.0						
710	T.S. M. Nonlith.	TSw2	13	32	<1	0.5	4.1		10.0						10.0						
720	T.S. M. Nonlith.	TSw2	7	7	<1	0.0	2.5		10.0						10.0						
730	T.S. M. Nonlith.	TSw2	28	64	<1	0.4	1.0		10.0						10.0						
740	T.S. M. Nonlith.	TSw2	13	22	<1	0.1	4.2		10.0						10.0						
750	T.S. M. Nonlith.	TSw2	5	44	<1	0.0	0.8		10.0						10.0						
760	T.S. M. Nonlith.	TSw2	48	69	<1	0.0	0.6		10.0						10.0						
770	T.S. M. Nonlith.	TSw2	36	46	<1	0.1	0.1		10.0						10.0						
780	T.S. M. Nonlith.	TSw2	17	29	<1	0.0	4.8		10.0						10.0						
790	T.S. M. Nonlith.	TSw2	6	20	<1	0.1	5.0	4.5	5.5						10.0						
800	T.S. M. Nonlith.	TSw2	10	16	<1	3.4	4.9		10.0						10.0						
810	T.S. L. Lith.	TSw2	4	21	<1	5.0	1.5		10.0						10.0						
820	T.S. L. Lith.	TSw2	0	5	<1	6.4	2.7		10.0						10.0						
830	T.S. L. Lith.	TSw2	0	0	<1	7.6	1.9		10.0					1.9	8.1						

Me
Me
Mo
Sta
Var
Ran
Mini
Max
Sum
Cou

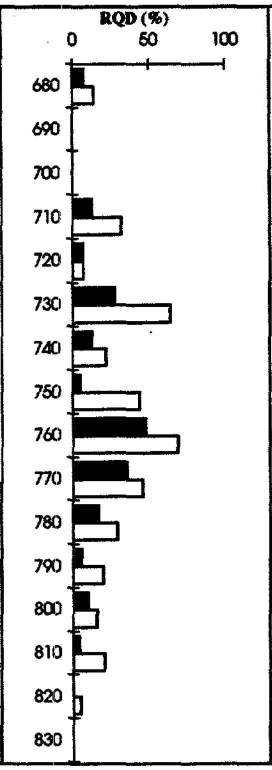
* CORE RQD—Determined from piece lengths formed by all types of fractures (C, I, N and V).

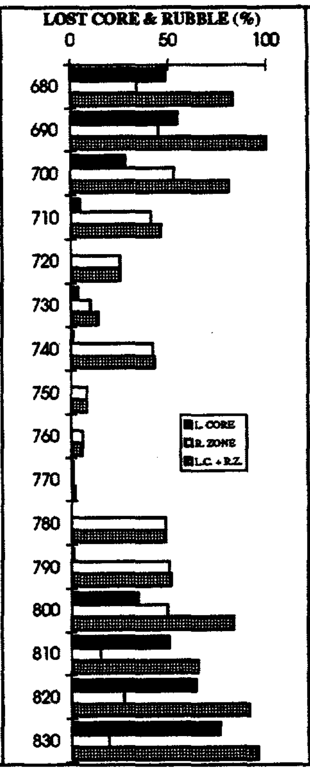
** ENHANCED RQD—Determined by filtering the effects of fractures identified as coring induced (Type C) from the piece lengths.

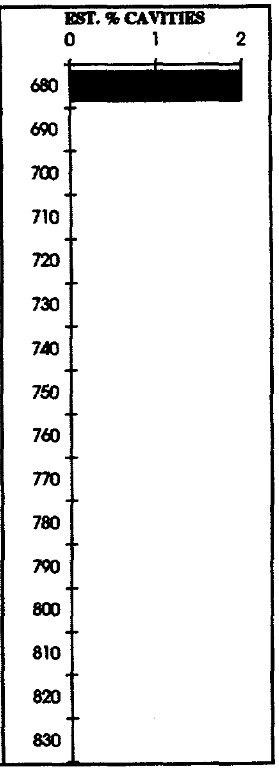
*** Footage in interval may not equal 10 ft because of lost core, rubble, or ommission during logging.



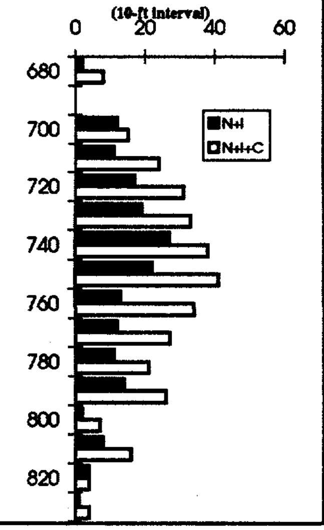
CORE RQD Summary		ENHANCED RQD Summary	
n	12.19	Mean	24.31
an	7.5	Median	20.5
e	0	Mode	0
dard Deviation	14.0	Standard Deviation	21.9
nce	195.0	Variance	477.8
e	48	Range	69
num	0	Minimum	0
num	48	Maximum	69
	195	Sum	389
nt	16	Count	16







YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
Core Hole Structural Data Summary
Hole USW SD-7
Interval — 670-830 ft, Middle Nonlithophysal Zone

BASE OF 10-FT INTERVAL	STRATIGRAPHY ZONE	THERMO-MECHANICAL UNIT	FEATURE TYPE				FRACTURE FREQUENCY (10-ft interval)	NO. OF FRACTURES W/INCLINATION (degrees)								
			N	I	C	V		10	20	30	40	50	60	70	80	90
680	T.S. U. Lith.	TSw1	1	1	6					1					1	
690	T.S. M. Nonlith.	TSw2														
700	T.S. M. Nonlith.	TSw2	7	5	3			6			1		1	1		3
710	T.S. M. Nonlith.	TSw2	9	2	13			1							2	8
720	T.S. M. Nonlith.	TSw2	10	7	14			4			1	2	1	1	1	7
730	T.S. M. Nonlith.	TSw2	13	6	14			3	2	4	4	1			2	3
740	T.S. M. Nonlith.	TSw2	18	9	11			9		5		1	3	2		7
750	T.S. M. Nonlith.	TSw2	12	10	19			5	2	2	3	1		5	3	1
760	T.S. M. Nonlith.	TSw2	5	8	21			3	1			2		1	3	3
770	T.S. M. Nonlith.	TSw2	6	6	15			5		1		1		1		4
780	T.S. M. Nonlith.	TSw2	7	4	10			2				3			3	3
790	T.S. M. Nonlith.	TSw2	11	3	12			4			1	1	1	2	2	3
800	T.S. M. Nonlith.	TSw2		2	5			1						1		
810	T.S. L. Lith.	TSw2	5	3	8			3	1	1		1			2	
820	T.S. L. Lith.	TSw2	1	3				1		1			1	1		
830	T.S. L. Lith.	TSw2		1	3			1								
TOTAL			105	70	154	0		48	6	15	10	13	7	15	19	42
PERCENT OF OCCURRENCE			32	21	47	0		27	3.4	8.6	5.7	7.4	4	8.6	11	24

NO. OF FRACTURES W/MINERAL INFILLING TYPE														NO. OF FRACTURES W/ INFILL THICKNESS CODE					NO. OF FRACTURES W/PLANARITY CODE				NO. OF FRACTURES W/ROUGHNESS CODE				
C	WC	WN	BC	BD	TD	TC	CA	SI	MN	CL	TN	FE	BN	S	T	M	V	E	P	C	S	I	V	R	M	S	P
		1							1					1					2						2		
4				4				1	3					8					6	1	1	1		1	4	4	
2				6					3					9					9			1		3		7	
0		2		4			1							8					10	1	1	1		2	1	9	
6	2	5		5				1						11	2				13	2	2				11	6	
1		4		11					1					16					18	1	1	1	1	1	9	7	
4		2		3					3					8					17		1			1	8	9	
3				5										5					7	3			1		6	3	
3		4												4					7						4	3	
7				4										3					8	1				1	2	6	
5		3		5										7	2				11	1				2	2	7	
2																			1			1		1	1		
5		2		1										4	1				6			1	1	2	4		
		1													1				1	1		2	1	1	2		
6	2	24	0	48	0	0	1	2	11	0	0	0	0	84	6	0	0	0	116	11	6	8	4	15	56	61	0
9	1.1	14	0	28	0	0	0.6	1.1	6.3	0	0	0	0	93	6.7	0	0	0	82	7.8	4.3	5.7	2.9	11	41	45	0

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
Estimated Rock Mass Quality Indices Based on Core Log Data
Hole USW SD-7
Interval — 670–830 ft, Middle Nonlithophysal Zone

END DEPTH	STRATIGRAPHY ZONE	THERMO-MECHANICAL UNIT	Q CLASSIFICATION SYSTEM [1] Barton et al. (1974)							RMR CLASSIFICATION SYSTEM [2] Bieniawski (1979)					
			RQD** (%)	Jn*	Jr	Ja	Jw	SRF*	Q*	C	RQD-I	JS	JC	JW	RMR
680	T.S. U. Lith.	TSw1	8	9.00	2.10	1.22	1.00	5.00	0.38	12	3	8	23.1	15	61.1
690	T.S. M. Nonlith.	TSw2	0	9.00	2.10	1.22	1.00	5.00	0.38	4	3	5	23.1	15	50.1
700	T.S. M. Nonlith.	TSw2	0	9.00	2.10	1.22	1.00	5.00	0.38	12	3	5	23.1	15	58.1
710	T.S. M. Nonlith.	TSw2	13	6.00	1.40	1.00	1.00	5.00	0.61	12	3	8	18.6	15	56.6
720	T.S. M. Nonlith.	TSw2	7	6.00	1.42	1.24	1.00	5.00	0.38	7	3	8	19.2	15	52.2
730	T.S. M. Nonlith.	TSw2	28	3.00	1.76	1.53	1.00	1.00	10.79	12	8	8	18.2	15	61.2
740	T.S. M. Nonlith.	TSw2	13	12.00	1.72	1.30	1.00	7.50	0.19	7	3	5	18.7	15	48.7
750	T.S. M. Nonlith.	TSw2	5	9.00	1.56	1.18	1.00	5.00	0.29	12	3	8	18.2	15	56.2
760	T.S. M. Nonlith.	TSw2	48	9.00	1.70	1.00	1.00	5.00	1.81	12	8	8	20.4	15	63.4
770	T.S. M. Nonlith.	TSw2	36	9.00	1.57	1.67	1.00	5.00	0.75	12	8	8	16.3	15	59.3
780	T.S. M. Nonlith.	TSw2	17	9.00	1.33	1.00	1.00	7.50	0.34	15	3	8	19.0	15	60.0
790	T.S. M. Nonlith.	TSw2	6	12.00	1.36	1.43	1.00	7.50	0.11	12	3	8	17.2	15	55.2
800	T.S. M. Nonlith.	TSw2	10	9.00	2.10	1.22	1.00	7.50	0.26	15	3	8	23.1	15	64.1
810	T.S. L. Lith.	TSw2	4	3.00	2.14	1.50	1.00	1.00	4.76	12	3	8	18.7	15	56.7
820	T.S. L. Lith.	TSw2	0	9.00	2.10	1.22	1.00	5.00	0.38	12	3	8	23.1	15	61.1
830	T.S. L. Lith.	TSw2	0	9.00	2.10	1.22	1.00	5.00	0.38	7	3	5	23.1	15	53.1

Jn*, SRF* = interval values generated by Monte Carlo simulation; to calculate Q*.

RQD**: If RQD is less than 10, the value 10 is used in the calculation of Q* as per Barton et al. (1974).

[1] Barton , N., R. Lien, and J. Lunde, "Engineering Classification of Rock Masses for the Design of Tunnel Support," Rock Mechanics, 6:189-236 (Springer Verlag, 1974).

[2] Bieniawski, Z.T., "The Geomechanics Classification in Rock Engineering Applications," Proceedings, 4th International Congress on Rock Mechanics, Montreaux, Switzerland, 2:41-48 (A. A. Balkema, 1979).

Q

Jn — Joint Set Number
Jr — Joint Roughness Number
Ja — Joint Alteration Number
Jw — Joint Water Reduction Factor
SRF — Stress Reduction Factor

Q = (RQD/Jn)(Jr/Ja)(Jw/SRF)

RMR

C— Strength Index
RQD-I— RQD Index
JS— Joint Spacing Index
JC— Discontinuity Condition Index
JW— Groundwater Index

RMR = C + RQD-I + JS + JC +JW

EXPLANATION OF CALCULATION

Rock mass quality indices, Q (Barton et al., 1974) and RMR (Bieniawski, 1979), have been estimated for 10-ft intervals using Rock Structural Data Summaries developed from structural logging of the core, observations of rock conditions in the North Ramp Starter Tunnel, North Ramp tunnel, and laboratory testing data.

- Q is developed to evaluate the distribution of rock mass quality as a basis for developing the range of credible rock mass quality to establish the ground support requirements within rock units and to derive rock mass mechanical properties according to the methodology proposed by Hardy and Bauer (1991). Procedures used in the calculation were:

$$Q = \frac{RQD^{**}}{Jn^{*}} \bullet \frac{Jr}{Ja} \bullet \frac{Jw}{SRF^{*}}$$

Note: Any spatial correlation may be masked by Monte Carlo simulation of Jn and SRF.

where RQD** = Core RQD where all fractures types [natural (N), indeterminate (I), coring induced (C) and vugs (V)] have been considered in determination of RQD. If the RQD is less than 10%, the value used is set to 10 as per Barton et al. (1974). By definition, soil-like materials are considered to have zero RQD.

Jn* = Joint Set Numbers: Cannot be determined from the core log data and are generated by Monte-Carlo simulation assuming a uniform distribution of values between 1 and 12 derived from mapping of the North Ramp tunnel.

Jr = Joint Roughness Number: A weighted average value derived based on the N and I type fractures in the 10-ft interval.

Ja = Joint Alteration Number: A weighted average value derived from the description of N and I type fractures in the interval.

Jw = Joint Water Factor: Set equal to 1.0 assuming dry conditions.

SRF* = Stress Reduction Factor: For nonwelded units, SRF is determined from the ratio of UCS/σ_1 (UCS = unconfined compressive strength, σ_1 = overburden stress). If unconfined compressive strength data is not available for the 10-ft interval, a compressive strength is generated by Monte-Carlo simulation using laboratory test data for the thermomechanical units. For welded tuff units, SRF cannot be determined from core log data and is generated by Monte Carlo simulation assuming a distribution derived from mapping of the North Ramp tunnel.

- The use of the Core RQD is conservative since it includes the effect of coring induced breaks. Filtering the effects of coring induced breaks from the RQD calculation ("Enhanced RQD") produced an increase in the mean RQD. The mean values for thermomechanical units in USW SD-7, 670-830 ft, Middle Nonlithophysal Zone are:

	Core RQD	Enhanced RQD
TSw2, Middle Nonlithophysal Zone	12.2%	24.3%

- RMR is estimated based on the Rock Structural Summary log data, and rock strength data. Procedures used in the calculation were:

$$RMR = C + RQD\text{-}I + JS + JC + JW$$

where C = Rock Strength Index: Derived from compressive strength estimated by unconfined compressive strength laboratory test data for the 10-ft interval. If data is not available for the 10-ft interval, a compressive strength is generated by Monte-Carlo simulation using laboratory test data for the thermomechanical unit.

RQD-I = RQD Index: Derived using the Core RQD value for the 10-ft interval.

JS = Joint Spacing Index: Derived from the rock structural data for the 10-ft interval, excludes coring induced features.

JC = Discontinuity Condition Index: Derived from the description of fractures in the 10-ft interval.

JW = Groundwater Index: Assumed dry conditions

- Q and RMR data are presented in log format to associate parameters with depth intervals in the core log; however, any spatial correlation may be masked by Monte-Carlo simulation.

STRATIGRAPHIC ABBREVIATIONS

T.C.	Tiva Canyon Tuff	C.P. M. Nonlith.	Crystal-Poor Middle Nonlithophysal Zone
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone
	Bedded Tuff		
Y.M.	Yucca Mountain Tuff		
	Bedded Tuff		
P.C.	Pah Canyon Tuff		
	Bedded Tuff		
T.S.	Topopah Spring Tuff	C.R. Vitric	Crystal-Rich Vitric Zone
		C.R. Nonlith.	Crystal-Rich Nonlithophysal Zone
		C.R. Lith.	Crystal-Rich Lithophysal Zone
		C.P. U. Lith.	Crystal-Poor Upper Lithophysal Zone
		C.P. M. Nonlith.	Crystal-Poor Middle Nonlithophysal Zone
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone Vitrophyre
		C.P. Vitric NW	Crystal-Poor Vitric Zone Non- to Partially Welded and Moderately Welded
	Bedded Tuff		
C.H.	Calico Hills Formation		

THERMOMECHANICAL UNITS

UO—Undifferentiated Overburden
TCw—Tiva Canyon Welded Unit
PTn—Upper Paintbrush Nonwelded Unit
TSw1—Topopah Spring Welded Unit—Lithophysae Rich
TSw2—Topopah Spring Welded Unit—Lithophysae Poor
TSw3—Topopah Spring Welded Unit—Vitrophyre
CHn1—Calico Hills and Lower Paintbrush Nonwelded Unit

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
Estimated Rock Mass Quality Indices Based on Core Log Data
Hole USW SD-7
Interval — 670–830 ft, Middle Nonlithophysal Zone

END DEPTH	STRATIGRAPHY ZONE	THERMO-MECHANICAL UNIT	Q CLASSIFICATION SYSTEM [1] Barton et al. (1974)							RMR CLASSIFICATION SYSTEM [2] Bieniawski (1979)					
			RQD** (%)	Jn*	Jr	Ja	Jw	SRF*	Q*	C	RQD-I	JS	JC	JW	RMR
680	T.S. U. Lith.	TSw1	8	9.00	2.10	1.22	1.00	5.00	0.38	12	3	8	23.1	15	61.1
690	T.S. M. Nonlith.	TSw2	0	9.00	2.10	1.22	1.00	5.00	0.38	4	3	5	23.1	15	50.1
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720	T.S. M. Nonlith.	TSw2	7	6.00	1.42	1.24	1.00	5.00	0.38	7	3	8	19.2	15	52.2
730	T.S. M. Nonlith.	TSw2	28	3.00	1.76	1.53	1.00	1.00	10.79	12	8	8	18.2	15	61.2
740	T.S. M. Nonlith.	TSw2	13	12.00	1.72	1.30	1.00	7.50	0.19	7	3	5	18.7	15	48.7
750	T.S. M. Nonlith.	TSw2	5	9.00	1.56	1.18	1.00	5.00	0.29	12	3	8	18.2	15	56.2
760	T.S. M. Nonlith.	TSw2	48	9.00	1.70	1.00	1.00	5.00	1.81	12	8	8	20.4	15	63.4
770	T.S. M. Nonlith.	TSw2	36	9.00	1.57	1.67	1.00	5.00	0.75	12	8	8	16.3	15	59.3
780	T.S. M. Nonlith.	TSw2	17	9.00	1.33	1.00	1.00	7.50	0.34	15	3	8	19.0	15	60.0
790	T.S. M. Nonlith.	TSw2	6	12.00	1.36	1.43	1.00	7.50	0.11	12	3	8	17.2	15	55.2
800	T.S. M. Nonlith.	TSw2	10	9.00	2.10	1.22	1.00	7.50	0.26	15	3	8	23.1	15	64.1
810	T.S. L. Lith.	TSw2	4	3.00	2.14	1.50	1.00	1.00	4.76	12	3	8	18.7	15	56.7
820	T.S. L. Lith.	TSw2	0	9.00	2.10	1.22	1.00	5.00	0.38	12	3	8	23.1	15	61.1
830	T.S. L. Lith.	TSw2	0	9.00	2.10	1.22	1.00	5.00	0.38	7	3	5	23.1	15	53.1

Jn*, SRF* = interval values generated by Monte Carlo simulation; to calculate Q*.

RQD**: If RQD is less than 10, the value 10 is used in the calculation of Q* as per Barton et al. (1974).

Q	RMR
Jn — Joint Set Number	C— Strength Index
Jr — Joint Roughness Number	RQD-I— RQD Index
Ja — Joint Alteration Number	JS— Joint Spacing Index
Jw — Joint Water Reduction Factor	JC— Discontinuity Condition Index
SRF — Stress Reduction Factor	JW— Groundwater Index
Q = (RQD/Jn)(Jr/Ja)(Jw/SRF)	RMR = C + RQD-I + JS + JC +JW

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[1] Barton , N., R. Lien, and J. Lunde, "Engineering Classification of Rock Masses for the Design of Tunnel Support," Rock Mechanics, 6:189-236 (Springer Verlag, 1974).

[2] Bieniawski, Z.T., "The Geomechanics Classification in Rock Engineering Applications," Proceedings, 4th International Congress on Rock Mechanics, Montreaux, Switzerland, 2:41-48 (A. A. Balkema, 1979).

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USW SD-9 CORE LOGS AND DATA

Geology and Rock Structure Log

Core Hole Rock Structural Data Summary

Estimated Rock Mass Quality Indices Based on Core Log Data

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
GEOLOGY AND ROCK STRUCTURE LOG
Hole USW SD-9, 700-850 ft

Sandia National Laboratories
Print Date: 3/14/95
WBS 1.2.3.2.6.2.1
QA:L
Revision 0

BOREHOLE ID: USW SD-9
STUDY PLAN NO: 8.3.1.2.2.1
CORE SIZE: HQ
DRILL DATES: 5/94 to 11/94
GROUND ELEV: 4272.5'
COORDINATES: 767,988.6N
561,818.0E

TOTAL DEPTH: 2223.1'
ANGLE FROM VERT: 0°
AZIMUTH: n/a

Field Rock Structure

Logged by:
J. Kirkwood
D. Hattler
A. Mendenhall
R. Wilcoxon
R. Myers
G. Olsen
J. Moyer
D. Switzer
M. Pitterle

Drilling Support Division, Drilling Support and Sample Management Department, T&MSS

Relogged by:
Eric Martin — Agapito Associates, Inc.

Lithology and Stratigraphy

Logged by:
D. Engstrom — Sandia National Laboratories

Checked by:
E. Martin — Agapito Associates, Inc.

Log prepared by Agapito Associates, Inc. for Sandia National Laboratories

EXPLANATION
GEOLOGY AND ROCK STRUCTURE

FRACTURE TYPE OR FEATURE

N Natural fractures are indicated by mineral coatings, evidence of weathering, slickensides, lack of rematch/fit between sides or by surfaces that form an ellipse in the core.

C Coring-induced fractures are generally normal to the axis of the core or indicate some torquing of the core. They are typically clean, fresh and fit tightly back together.

I Indeterminate fractures are those not clearly described as "N" or "C." This includes fracture surfaces that have been shaped by drilling rotation.

H Handling-induced fractures are formed in the core by removal from the core barrel or placement in the core box. These fractures are witnessed and, according to BTP-SMF-008, are marked by the SMF personnel by lines parallel to the fracture on both sides of the core. "H" fractures are typically not recorded in the log unless there is a specific reason.

V Vug or large void.

P Foliation plane due to gravity flattening upon deposition, not a fracture.

LOST CORE AND RUBBLE

☒ LOST CORE

|×.20 ×| RUBBLE ZONE
(with average maximum diameter of rubble pieces to nearest 0.01 ft;
NM = not measured)

HARDNESS (Subjective estimate, YMP procedures do not allow core to be broken or scratched etc.)

1 Extremely Hard—Cannot be scratched, chipped only with repeated heavy hammer blows.
2 Very Hard—Cannot be scratched, broken only with repeated heavy hammer blows.
3 Hard—Scratched with heavy pressure, breaks with heavy hammer blow.
4 Moderately Hard—Scratched with light-moderate pressure, breaks with moderate hammer blow.
5 Moderately Soft—Grooved (16th in.) with moderate heavy pressure, breaks with light hammer blow.
6 Soft—Grooved easily with light pressure, scratched with fingernail, breaks with light-moderate manual pressure.
7 Very Soft—Readily gouged with fingernail, breaks with light manual pressure.
8 Soil Like—Cohesive
9 Soil Like—Non-cohesive

WEATHERING

F Fresh—Rock and fractures not oxidized or discolored, no separation of grains, change of texture or solutioning.
S Slightly Weathered—Oxidized or discolored fractures and nearby rock, some dull feldspars, no separation of grains, minor leaching.
M Moderately Weathered—Fractures and most of rock oxidized or discolored, partial separation of grains, crystals rusty or cloudy, moderate leaching of soluble minerals.
I Intensely Weathered—Fractures and rock totally oxidized or discolored, extensive clay alteration, leaching complete, grain separation extensive, rock is friable.
D Decomposed—Grain separation and clay alteration complete.

PLANARITY

P Planar
C Curved
S Stepped
I Irregular

ROUGHNESS

V Very rough, stepped, near-normal steps and ridges occur.
R Rough, large angular asperities can be seen.
M Moderately rough, asperities clearly visible, surface has an abrasive feel; to slightly rough, small asperities are visible and can be felt.
S Smooth, no asperities, smooth to the touch.
P Polished, slickensided, extremely smooth and shiny.

INFILLING THICKNESS AND MINERALIZATION

C Clean, no filling.
S Very thin, surface sheen
T Thin (up to 0.1 inches)

M Moderately thick (0.1 - 0.4 inches)
V Very thick (0.4 - 1.0 inches)
E Extremely thick, greater than 1.0 inches)

C Clean
WC White, crystalline
WN White, non-crystalline
TD Brown dendritic
TC Tan crystalline
TN Tan, non-crystalline

CA Calcite
SI Silica
MN Manganese
CL Clay
BC Black crystalline
BD Black dendritic

EXPLANATION (concluded)
GEOLOGY AND ROCK STRUCTURE

CORE RQD

Core RQD is calculated using piece lengths that are defined by all fractures (type N, I, and C) that exist in the core when it is removed from the core barrel. Only handling-induced breaks are discounted in piece length determination. RQD is calculated as:

$$RQD = \frac{\sum \text{Piece lengths} \geq 0.33\,ft}{\text{Interval length}} \times 100.$$

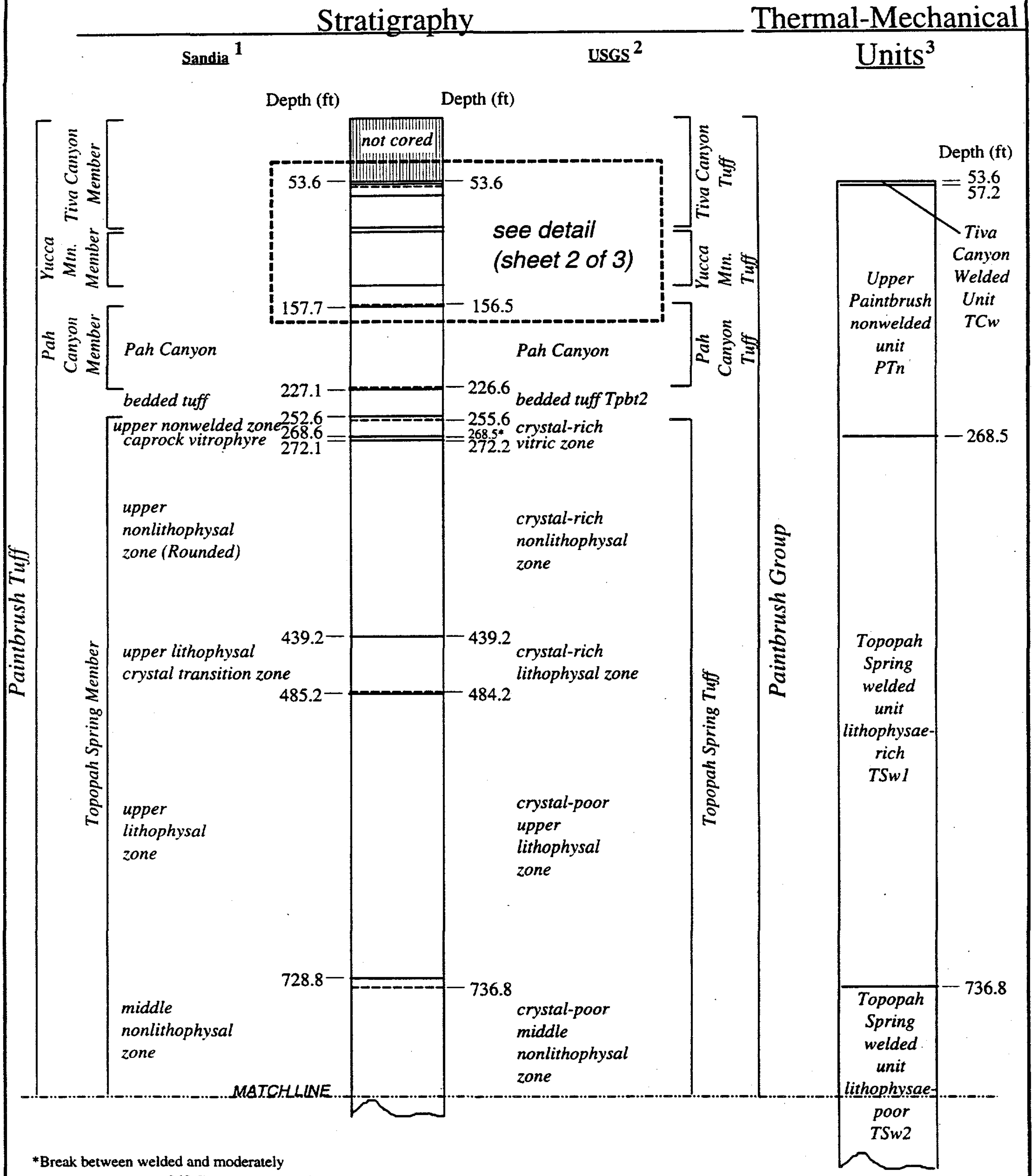
RQD is calculated for both the core run interval (run RQD) and even 10-ft intervals. If a piece length ≥ 0.33 ft crosses over a 10-ft interval boundary, the portion of the piece length that occurs in the 10-ft interval is included in the summation.

ESTIMATED PERCENTAGE LITHOPHYSAE & OTHER CAVITIES

The percentage of lithophysal voids and other cavities is estimated for each core run interval where sufficient whole core is available. Excessive lost core and rubble zones may prevent the estimate on specific core runs. The estimate is based on comparison of the core with charts designed for estimating the proportions of various rock or mineral components. Estimates are then spot checked using a quantitative graphical summation technique to calculate the percent area occupied by lithophysal cavities in core photographs or video tape.

The estimated percent cavities volume for core runs is used to calculate a run length, weighted average for even 10-ft intervals. (Runs for which percent cavities cannot be determined are assumed to have the average percentage for the 10-ft interval; intervals for which the percent cavities was not estimated are labeled "Not Measured;" zones containing vapor-phase alteration and very small or no lithophysal cavities are labeled as <1%).

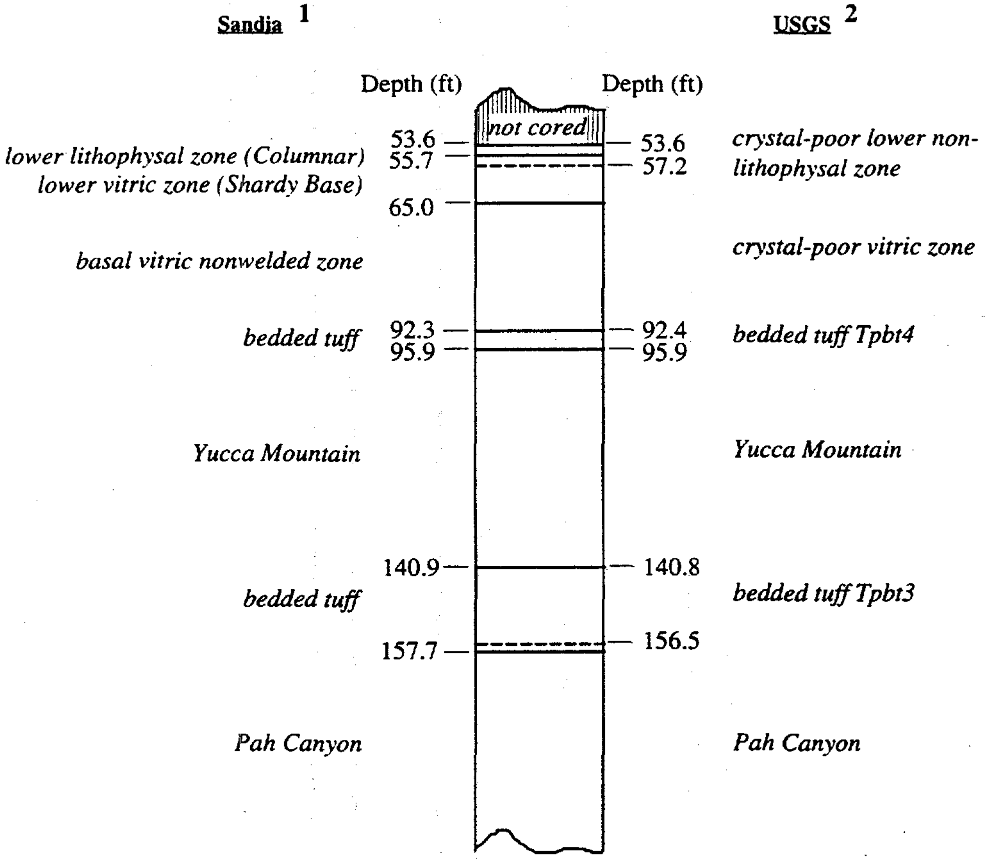
USW SD-9 (1 of 3)
Stratigraphic and Thermal-Mechanical Units Summary
0 - 830 ft



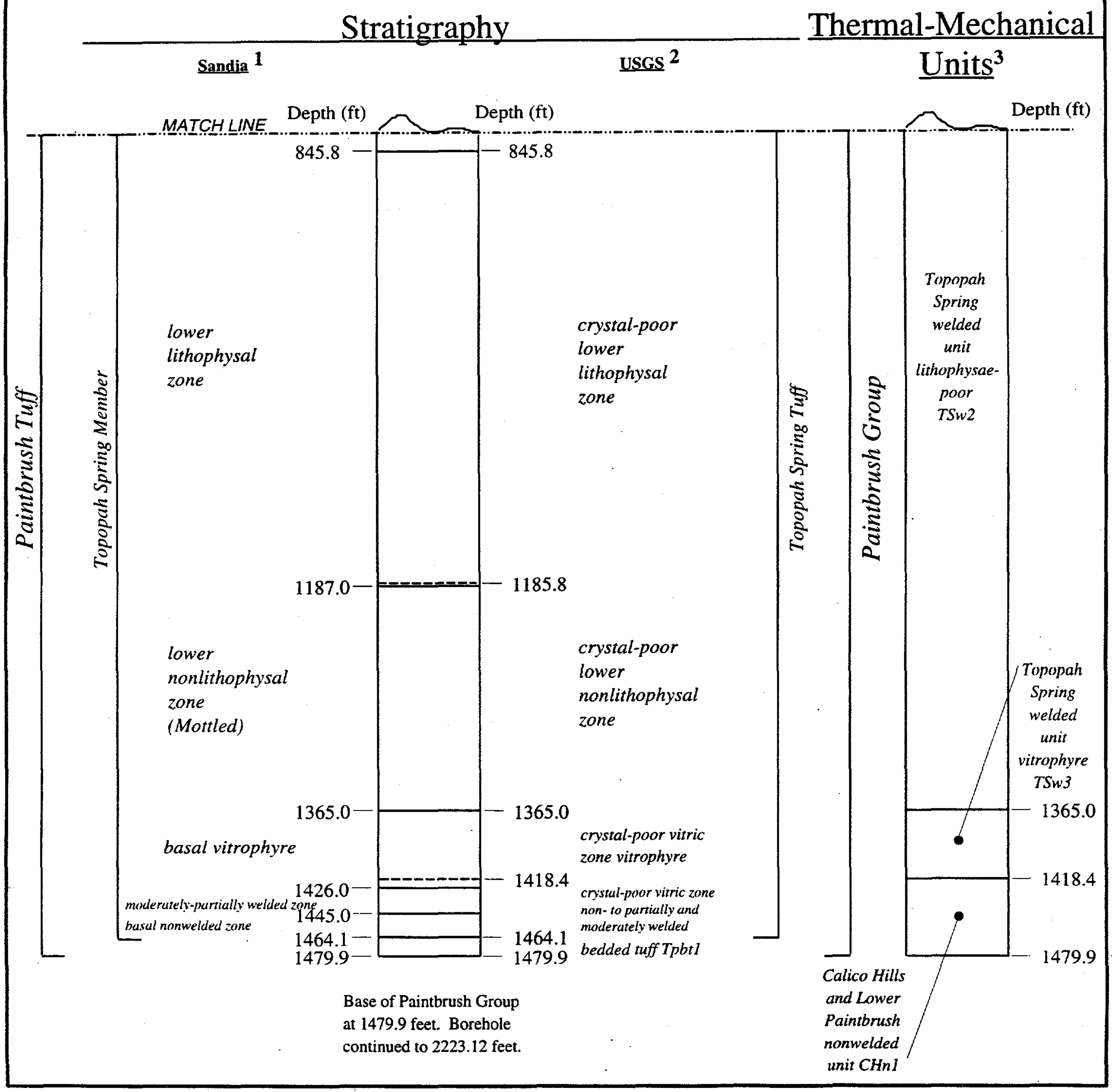
*Break between welded and moderately welded subzones at 268.5'.

USW SD-9 Stratigraphy (2 of 3)
Stratigraphic and Thermal-Mechanical Units Summary
Detail 53.6 - 157.7 ft

Stratigraphy



USW SD-9 (3 of 3)
Stratigraphic and Thermal-Mechanical Units Summary
830 - 1479.9 ft



Date: 2/21/95

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[1] Lithologic log of Borehole USW SD-9. Dale Engstrom, unpublished data.

[2] U.S. Geological Survey - Graphical Lithologic Log of Borehole USW SD-9 from the surface to the base of the Paintbrush Group. T.C. Moyer and G. Mongano DTN: GS940808314211.041

[3] Thermal-mechanical units as defined by Buesch, et al., USGS Open File Report 94-469, 1996. "Revised stratigraphic nomenclature and macroscopic identification of lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain, Nevada."

Yucca Mountain, Drillhole USW SD-9 GEOLOGY AND ROCK STRUCTURE LOG

Page 1 of 6

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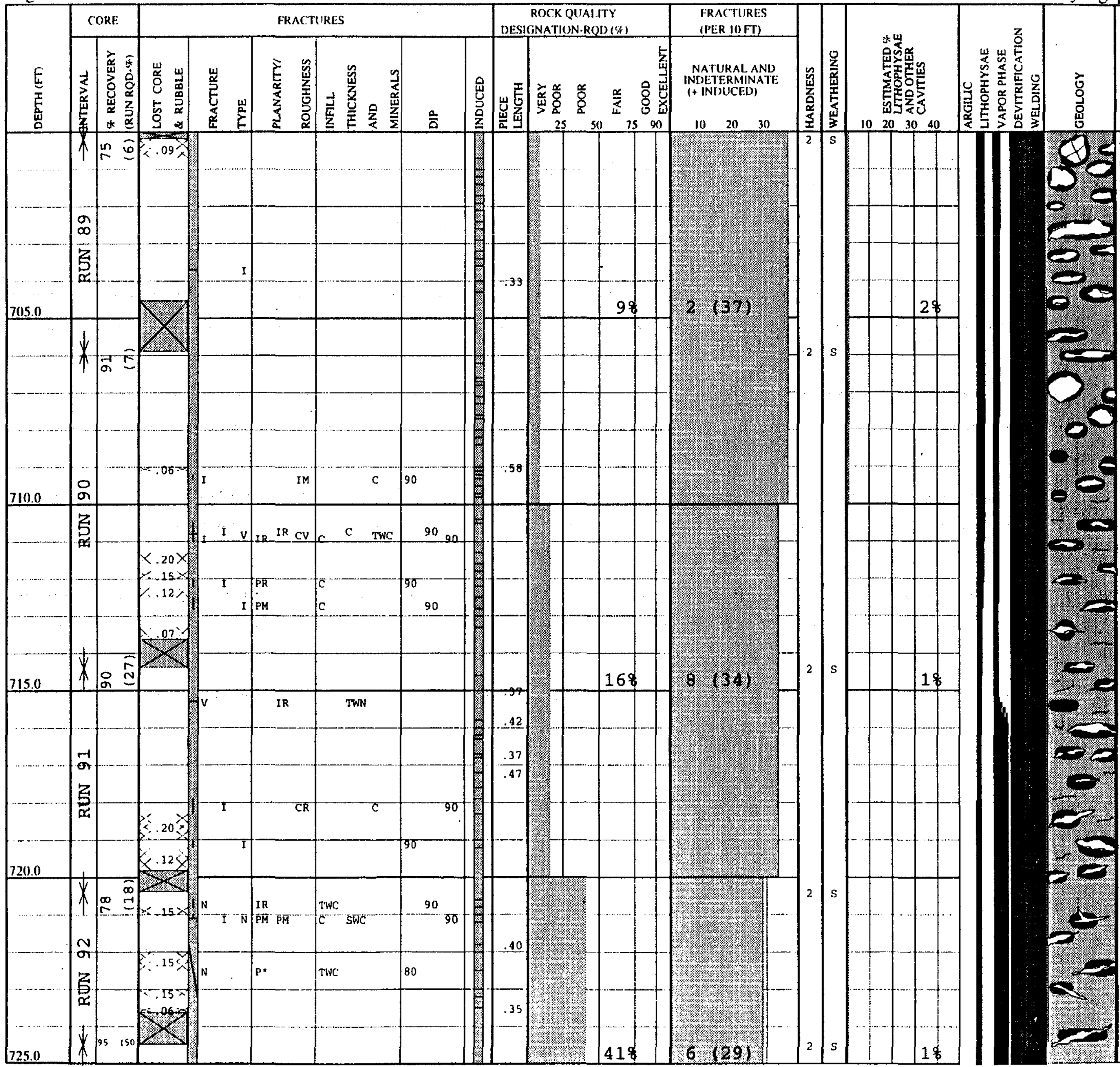

LITHOLOGIC DESCRIPTION AND STRATIGRAPHY

439.2-728.8 TOPOPAH SPRING CRYSTAL-POOR UPPER LITHOPHYSAL ZONE. Medium red-purple (5RP5/2) densely welded, devitrified, 85-90% grainy orange devitrified groundmass, 8-10% light pink-gray vapor-phase alteration spots around lithophysae bordered by 1-2% blue alteration, lithophysae reduced to irregular 1-3mm thick subhorizontal lines of vapor-phase mineralization or barely opened coated vuggy weak lithophysae, crystal-poor with 2-3% white sanidine phenocrysts, 0-.5% biotite flakes, lithophysae oriented along fractures at 705.9 and 714.0.

704.5-705.9 Unrecovered

711.3-713.6 Broken

713.6-714.4 Unrecovered

715.3-728.8 85% blue vapor-phase altered.

718.6-720.4 Broken

723.6-724.5 Unrecovered

Structure file: SD9REV4A.STR Lithology file: Date: 02/20/95 WPlot v 5.0

Yucca Mountain, Drillhole USW SD-9 GEOLOGY AND ROCK STRUCTURE LOG

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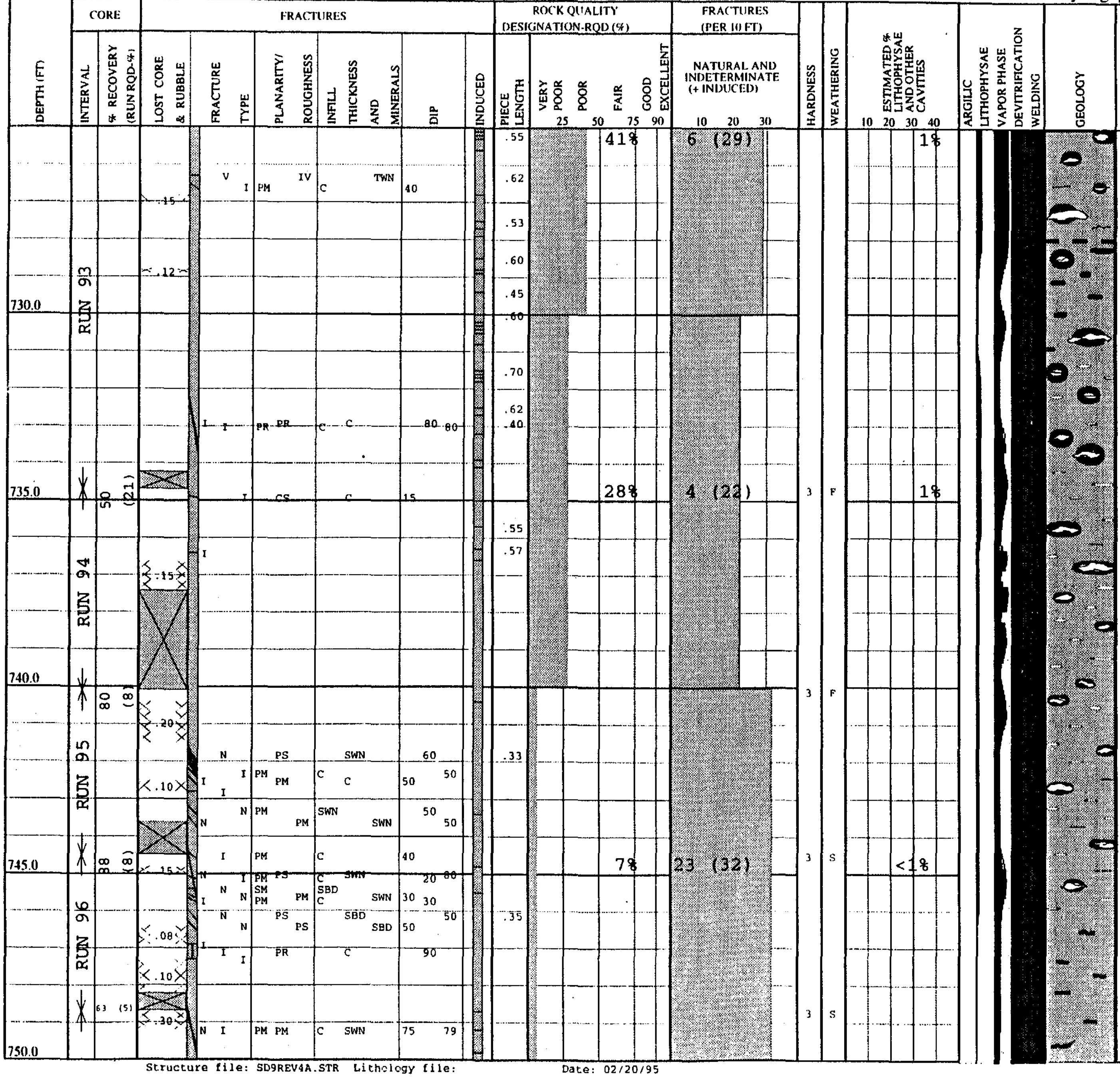

LITHOLOGIC DESCRIPTION AND STRATIGRAPHY

728.8-788.1 TOPOPAH SPRING MIDDLE NONLITHOPHYSAL. Upper Nonlithophysal Subzone, lithophysae lessen to <10%, densely welded, devitrified, groundmass texture finer, more compact, less grainy, mixed alteration zone with strong pervasive blue (5PB6/2) alteration and 17% white fuzzy 15mm vapor-phase streaks around pumice and lithophysae with islands of unaltered groundmass vs. orange-pink zones of unaltered groundmass speckled by 10% white alteration streaks and 7-8mm alteration spots, 17% white irregular hairline flattened pumice with 10mm fuzzy alteration halo, 1-2% feldspar phenocrysts, no biotite seen, most altered zones speckled by specular hematite, specks of dark olive green on post-oxidation surfaces.

736.8-742.2 Broken

737.4-740.1 Unrecovered

743.6-744.5 Unrecovered

746.4-750.1 Broken

Structure file: SD9REV4A.STR Lithology file:

Date: 02/20/95

WPlog v 5.00

Yucca Mountain, Drillhole USW SD-9
Page 3 of 6

GEOLOGY AND ROCK STRUCTURE LOG

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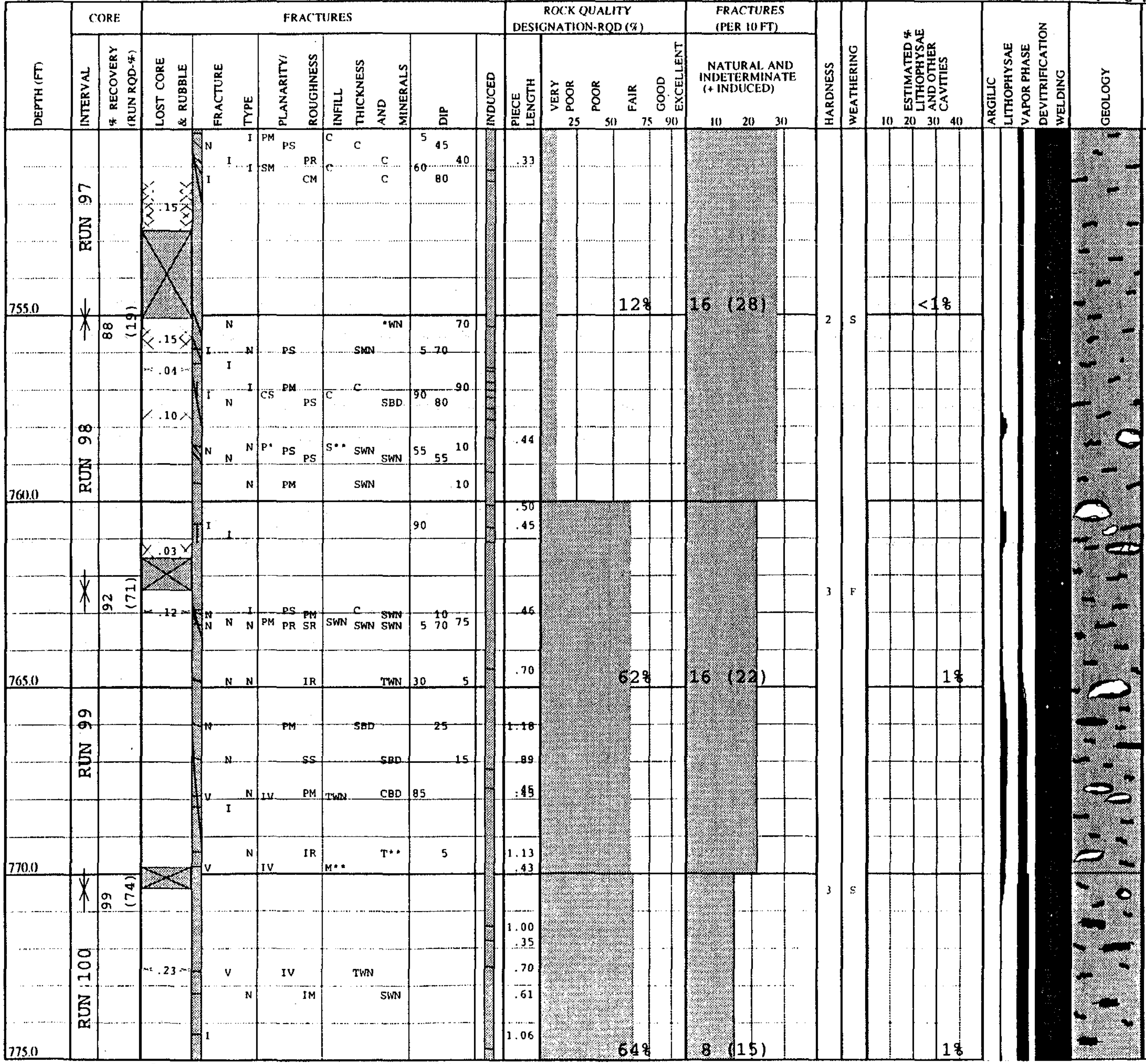

LITHOLOGIC DESCRIPTION AND STRATIGRAPHY

728.8-788.1 TOPOPAH SPRING MIDDLE NONLITHOPHYSAL. Upper Nonlithophysal Subzone, lithophysae lessen to <10%, densely welded, devitrified, groundmass texture finer, more compact, less grainy, mixed alteration zone with strong pervasive blue (5PB6/2) alteration and 17% white fuzzy 15mm vapor-phase streaks around pumice and lithophysae with islands of unaltered groundmass vs. orange-pink zones of unaltered groundmass speckled by 10% white alteration streaks and 7-8mm alteration spots, 17% white irregular hairline flattened pumice with 10mm fuzzy alteration halo, 1-2% feldspar phenocrysts, no biotite seen, most altered zones speckled by specular hematite, specks of dark olive green on post-oxidation surfaces.

751.5-755.1 Broken
752.7-755.1 Unrecovered
757.2-757.9 Broken
757.9-760.6 No Core
760.6-761.3 Broken

765.0 Medium-large lithophysae, 768.2 (borehole video)

769.8-770.4 Unrecovered

Structure file: SD9REV4A.STR Lithology file:
Date: 02/20/95
WPlog v 5.00

Yucca Mountain, Drillhole USW SD-9

GEOLOGY AND ROCK STRUCTURE LOG

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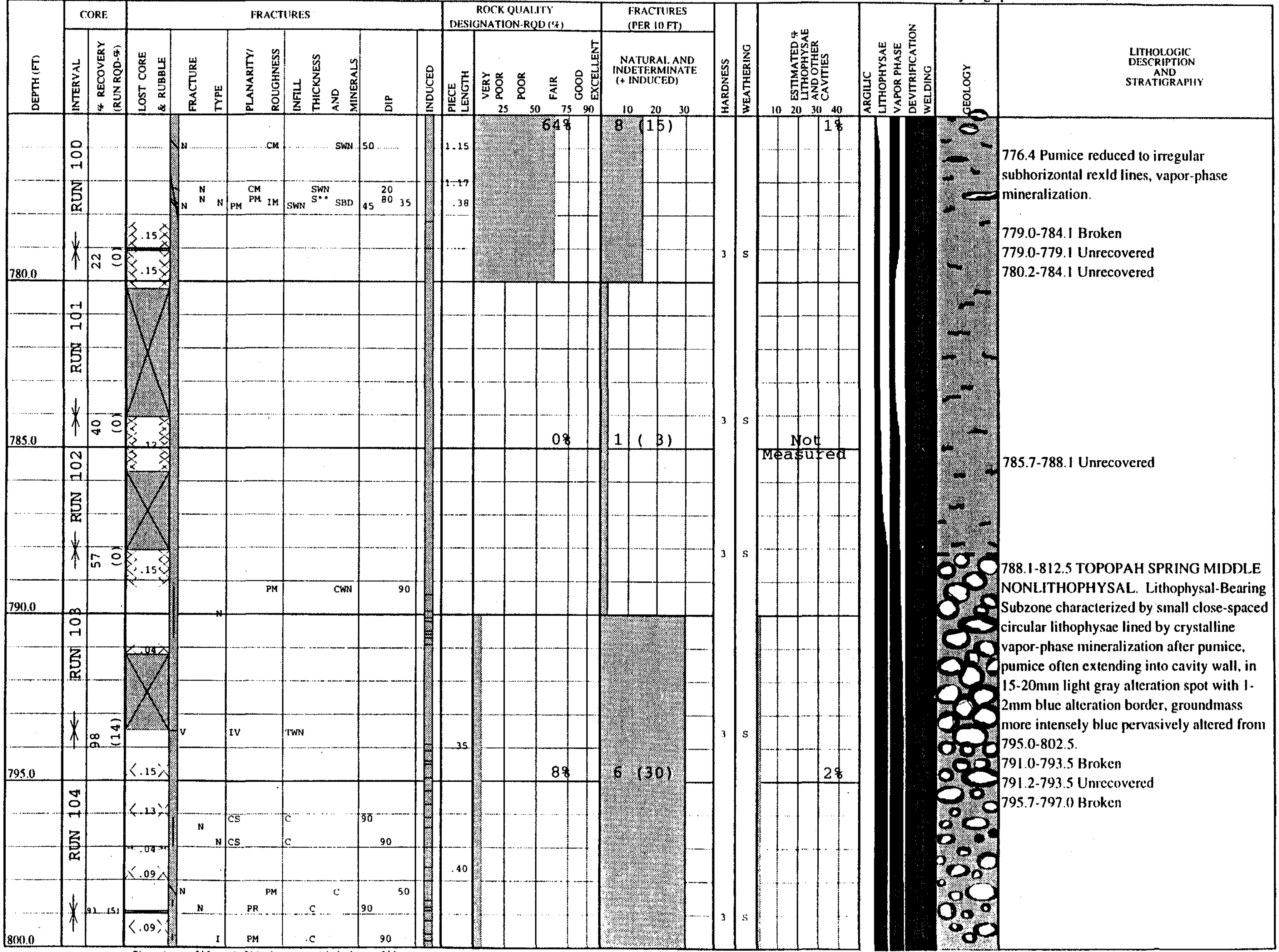

776.4 Pumice reduced to irregular subhorizontal rexld lines, vapor-phase mineralization.

779.0-784.1 Broken
779.0-779.1 Unrecovered
780.2-784.1 Unrecovered

785.7-788.1 Unrecovered

788.1-812.5 TOPOPAH SPRING MIDDLE NONLITHOPHYSAL. Lithophysal-Bearing Subzone characterized by small close-spaced circular lithophysae lined by crystalline vapor-phase mineralization after pumice, pumice often extending into cavity wall, in 15-20mm light gray alteration spot with 1-2mm blue alteration border, groundmass more intensely blue pervasively altered from 795.0-802.5.
791.0-793.5 Broken
791.2-793.5 Unrecovered
795.7-797.0 Broken

Structure file: SD9REV4A.STR Lithology file:

Date: 02/20/95

WPlog v 5.00

GEOLOGY AND ROCK STRUCTURE LOG

Yucca Mountain, Drillhole USW SD-9
Page 5 of 6

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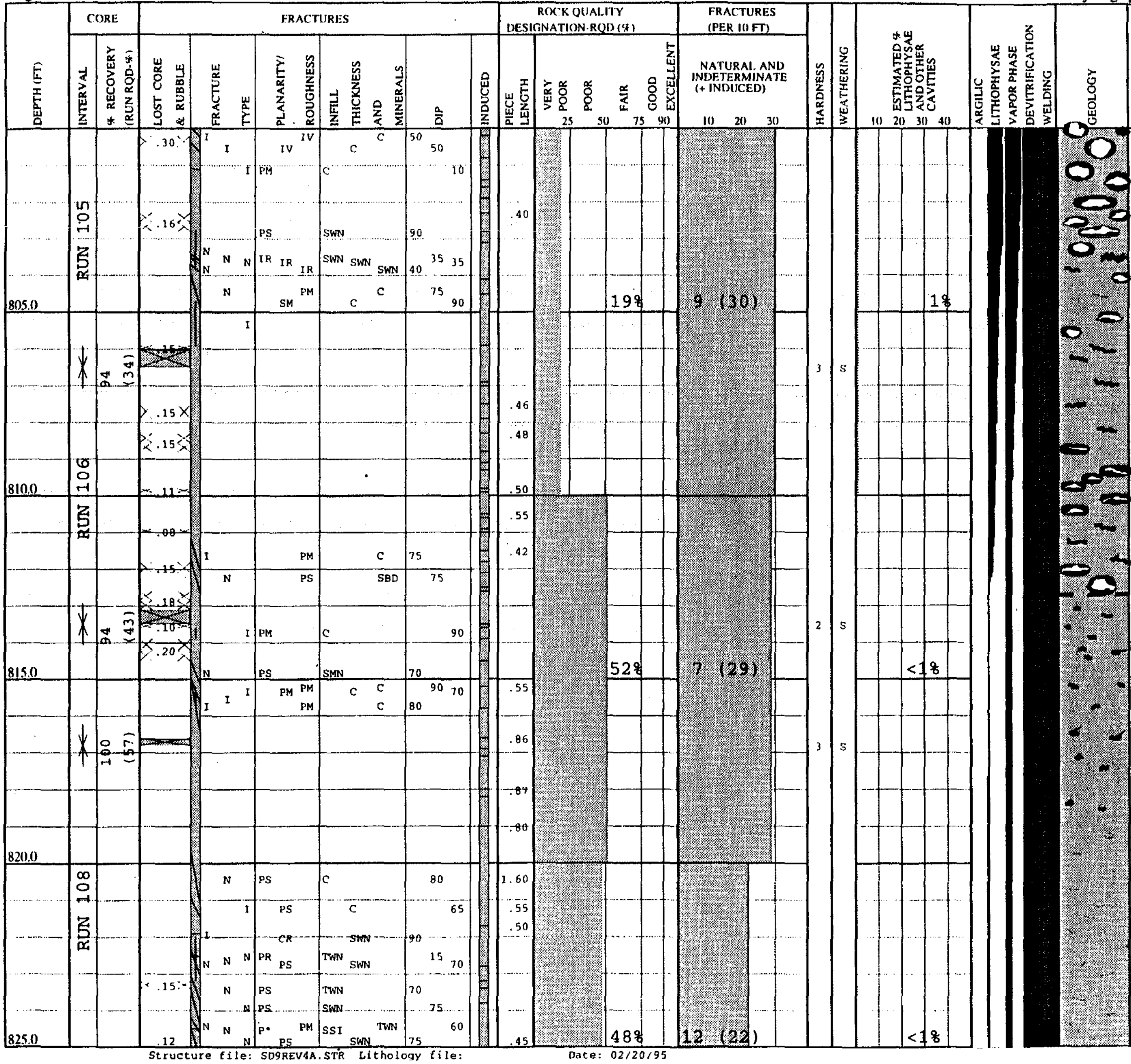

LITHOLOGIC DESCRIPTION AND STRATIGRAPHY

788.1-812.5 TOPOPAH SPRING MIDDLE NONLITHOPHYSAL. Lithophysal-Bearing Subzone characterized by small close-spaced circular lithophysae lined by crystalline vapor-phase mineralization after pumice, *pumice often extending into cavity wall, in* 15-20mm light gray alteration spot with 1-2mm 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.

805.8-806.5 Broken

812.5-845.8, TOPOPAH SPRING MIDDLE NONLITHOPHYSAL. Lower Nonlithophysal Subzone similar to above, dense compact texture, 10% speckled by hazy 5-10mm vapor-phase streaks, some with weak blue border, 1-2% hairline vapor-phase silica veinlets with 20mm blue alteration selvage each 2-3 feet, 2-3% white sanidine phenocrysts, no biotite, 2% rhyolite and quartz latite hard lithics that average 5mm.

813.1-814.3 Broken

Structure file: SD9REV4A.STR Lithology file: Date: 02/20/95 WPlog v 5.00

Yucca Mountain, Drillhole USW SD-9

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GEOLOGY AND ROCK STRUCTURE LOG

Sandia National Laboratories
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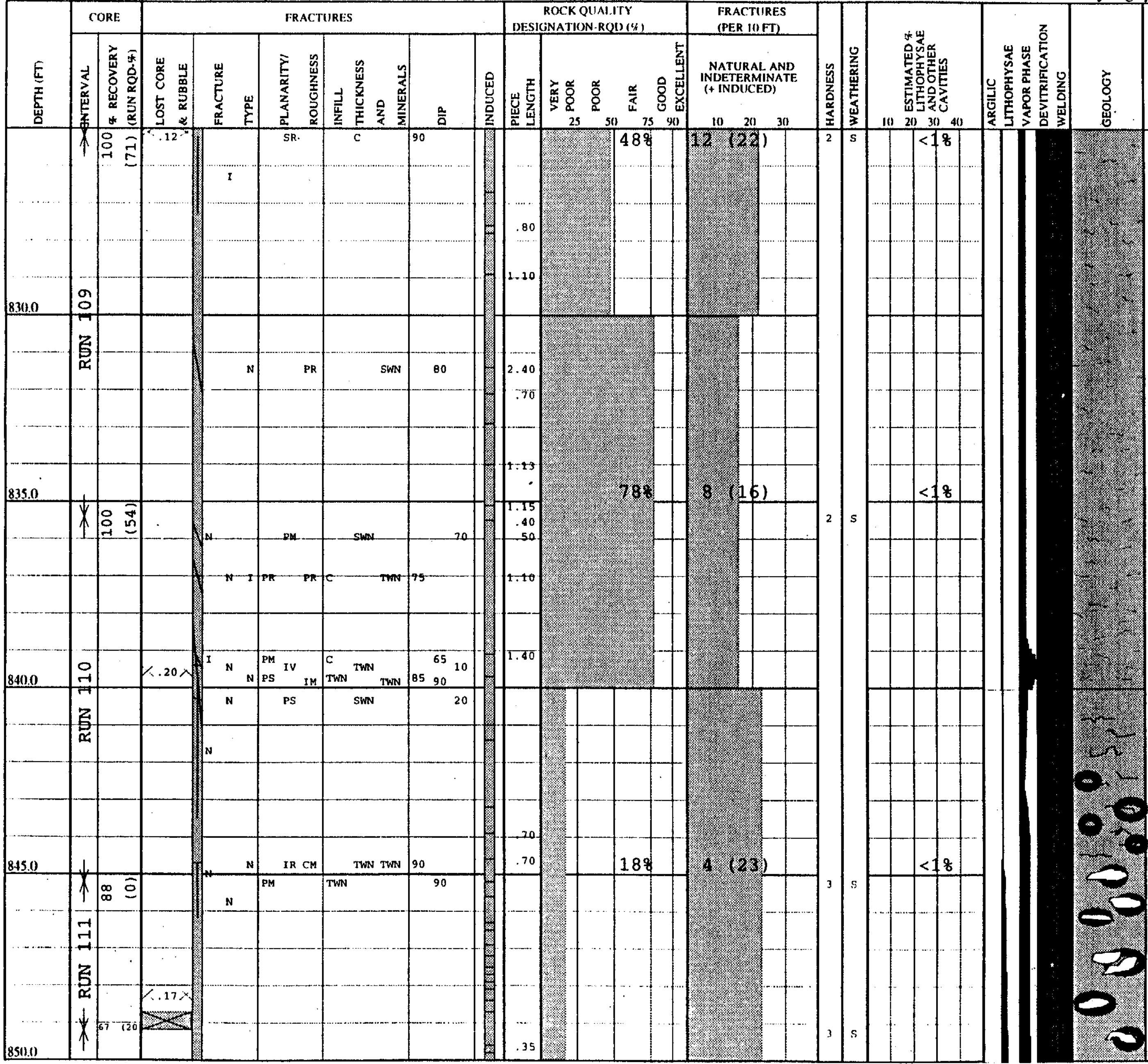

LITHOLOGIC DESCRIPTION AND STRATIGRAPHY

812.5-845.8, TOPOPAH SPRING MIDDLE NONLITHOPHYSAL. Lower Nonlithophysal Subzone, similar to above, dense compact texture, 10% speckled by hazy 5-10mm vapor-phase streaks, some with weak blue border, 1-2% hairline vapor-phase silica veinlets with 20mm blue alteration selvage each 2-3 feet, 2-3% white sanidine phenocrysts, no biotite, 2% rhyolite and quartz latite hard lithics that average 5mm.

838.8-839.8, Strong blue alteration zone.

839.4, Strong vertical joints coated by white vapor-phase silica, 4-6mm pink-gray alteration halo and 1-2mm blue alteration border, below 839.8 15-20% wispy blue alteration selvages around hairline silica veinlets with 1-2mm medium-gray alteration halos, vapor-phase vein mineralization includes SiO2 and carbonate minerals.

841.4, Upper limit of flat recrystallized pumice with blue alteration halo.

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

845.8-1187.0, TOPOPAH SPRING LOWER LITHOPHYSAL ZONE. Medium red-brown (5YR6/3) 5% small pinched oval-shaped lithophysae mostly <20mm, 2-7% light gray pumice less than 35mm with thin brown alteration rims, 1-2% wide variety of lithics majority <25mm, 1-2% sanidine and 0.5% biotite phenocrysts, vertical jointing common.

Structure file: SD9REV4A.STR Lithology file:

Date: 02/20/95

WPlog v 5.00

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
CORE HOLE ROCK STRUCTURAL DATA SUMMARY
Hole USW SD-9, 700–850 ft, Middle Nonlithophysal Zone

Sandia National Laboratories
Print Date: 6/27/95
WBS 1.2.3.2.6.2
QA:L
Revision 1

REVISION HISTORY

Revision 1 Enhanced RQDs were revised upon discovery of an error in WPLLOG's calculations. This revision replaces Revision 0 in its entirety.

CODING EXPLANATION

STRATIGRAPHIC ABBREVIATIONS

T.C.	Tiva Canyon Tuff	C.P. M. Nonlith.	Crystal-Poor Middle Nonlithophysal Zone
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone
	Bedded Tuff		
Y.M.	Yucca Mountain Tuff		
	Bedded Tuff		
P.C.	Pah Canyon Tuff		
	Bedded Tuff		
T.S.	Topopah Spring Tuff	C.R. Vitric	Crystal-Rich Vitric Zone
		C.R. Nonlith.	Crystal-Rich Nonlithophysal Zone
		C.R. Lith.	Crystal-Rich Lithophysal Zone
		C.P. U. Lith.	Crystal-Poor Upper Lithophysal Zone
		C.P. M. Nonlith.	Crystal-Poor Middle Nonlith.
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone Vitrophyre
		C.P. Vitric NW	Crystal-Poor Vitric Zone Non- to Partially Welded and Moderately Welded
	Bedded Tuff		
C.H.	Calico Hills Formation		

THERMOMECHANICAL UNITS

UO—Undifferentiated Overburden
TCw—Tiva Canyon Welded Unit
PTn—Upper Paintbrush Nonwelded Unit
TSw1—Topopah Spring Welded Unit—Lithophysae Rich
TSw2—Topopah Spring Welded Unit—Lithophysae Poor
TSw3—Topopah Spring Welded Unit—Vitrophyre
CHn1—Calico Hills and Lower Paintbrush Nonwelded Unit

COLUMN INFORMATION (Page 3)

RQD (%)	$RQD\ (\%) = \frac{\sum \text{Piece lengths} \geq 0.33\ ft}{\text{Interval length}} \times 100.$
CORE RQD	Core RQD based on piece lengths defined by all types of fractures (C, I, N and V).
ENHANCED RQD	Effect of fractures identified as coring induced (Type C) are filtered from the piece lengths.

LITHOPHYSAL (and other cavities)

Percent void due to lithophysae and other cavities, estimated visually by counting the number of cavities, estimating the average diameter, calculating the void volume assuming spherical cavities, and normalizing to the core volume.
NM—Not Measured

WEATHERING

Subjective evaluation of rock degradation by mechanical/chemical agents:
F: Fresh
S: Slightly weathered
M: Moderately weathered
I: Intensely weathered
D: Decomposed

HARDNESS

Subjective evaluation of resistance to breakage:
1: Extremely hard
2: Very hard
3: Hard
4: Moderately hard
5: Moderately soft
6: Soft
7: Very soft
8: Soil-like, cohesive
9: Soil-like, non-cohesive

COLUMN INFORMATION (Page 4)

FEATURE TYPE

Following codes indicate origin of feature:
N: Natural—indicated by mineral coating or evidence of weathering, slickensides, lack of fit between sides.
I: Indeterminate—origin questionable, rotated so that coatings possibly removed.
C: Coring induced—fresh, clean, tightly fitting breaks.
V: Vug or large void.

INCLINATION (degrees)

Angle between plane normal to core axis and plane of fracture (Type N and I only).

MINERAL INFILLING

Describes the infilling on fracture surfaces (Type N and I only):
C: Clean
WC: White crystalline
WN: White noncrystalline
BC: Black crystalline
BD: Black dendritic
TD: Brown dendritic
TC: Tan crystalline
CA: Calcite
SI: Silica
MN: Manganese
CL: Clay
TN: Tan noncrystalline
FE: Iron oxide
BN: Brown noncrystalline

INFILL THICKNESS

Describes the thickness of mineral infillings on the fracture surface (Type N and I only):
S: Very thin, surface sheen
T: Thin (up to 0.1 inches)
M: Moderately thick (0.1-0.4 inches)
V: Very thick (0.4 - 1.0 inches)
E: Extremely thick, greater than 1.0 inches

PLANARITY

Describes the overall shape of the feature (Type N and I only):
P: Planar
C: Curved
S: Stepped
I: Irregular

ROUGHNESS

Describes the local relief of the surface (Type N and I only):
V: Very rough—stepped, near-normal steps and ridges occur.
R: Rough—large angular asperities can be seen.
M: Moderately rough—asperities clearly visible, surface has abrasive feel.
S: Smooth—no asperities, smooth to the touch.
P: Polished—slickensided, extremely smooth and shiny.

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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

Core Hole Structural Data Summary

Hole USW SD-9

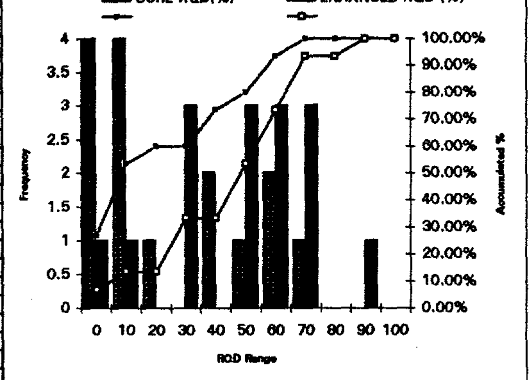
Interval—700–850 ft, Middle Nonlithophysal Zone

BASE OF 10-FT INTERVAL	STRATI-GRAPHY ZONE	THERMO-MECHANICAL UNIT	CORE RQD* %	ENHANCED RQD** %	ESTIMATED % CAVITIES	LOST CORE (ft)	RUBBLE ZONE (ft)	WEATHERING (ft in 10-ft interval)***					HARDNESS (ft in 10-ft interval)***							
													ROCK							S
								F	S	M	I	D	1	2	3	4	5	6	7	8
710	T.S. C.P. U. Lith.	TSw1	9	76	2	1.6	0.6		10.0					9.8	0.2					
720	T.S. C.P. U. Lith.	TSw1	16	54	1	1.0	2.4		10.0					10.0						
730	T.S. C.P. U. Lith.	TSw1	41	60	1	1.3	1.4		10.0					10.0						
740	T.S. C.P. U. Lith.	TSw1	28	56	1	3.1	0.8	5.3	4.7					4.7	5.3					
750	T.S. C.P. M. Nonlith.	TSw2	7	17	<1	1.5	3.5	4.5	5.5						10.0					
760	T.S. C.P. M. Nonlith.	TSw2	12	32	<1	2.4	2.3		10.0					4.9	5.1					
770	T.S. C.P. M. Nonlith.	TSw2	62	72	1	1.1	0.5	7.6	2.4					2.4	7.6					
780	T.S. C.P. M. Nonlith.	TSw2	64	72	1	0.5	1.8	0.4	9.6						10.0					
790	T.S. C.P. M. Nonlith.	TSw2	0	0	NM	6.3	2.9		10.0						10.0					
800	T.S. C.P. M. Nonlith.	TSw2	8	31	2	2.4	2.0		10.0						10.0					
810	T.S. C.P. M. Nonlith.	TSw2	19	50	1	0.5	1.9		10.0						10.0					
820	T.S. C.P. M. Nonlith.	TSw2	52	68	<1	0.6	1.6		10.0					3.3	6.7					
830	T.S. C.P. M. Nonlith.	TSw2	48	65	<1	0.0	0.4		10.0					4.8	5.2					
840	T.S. C.P. M. Nonlith.	TSw2	78	92	<1	0.0	0.3		10.0					10.0						
850	T.S. C.P. M. Nonlith.	TSw2	18	39	<1	0.5	0.3		10.0					5.2	4.8					

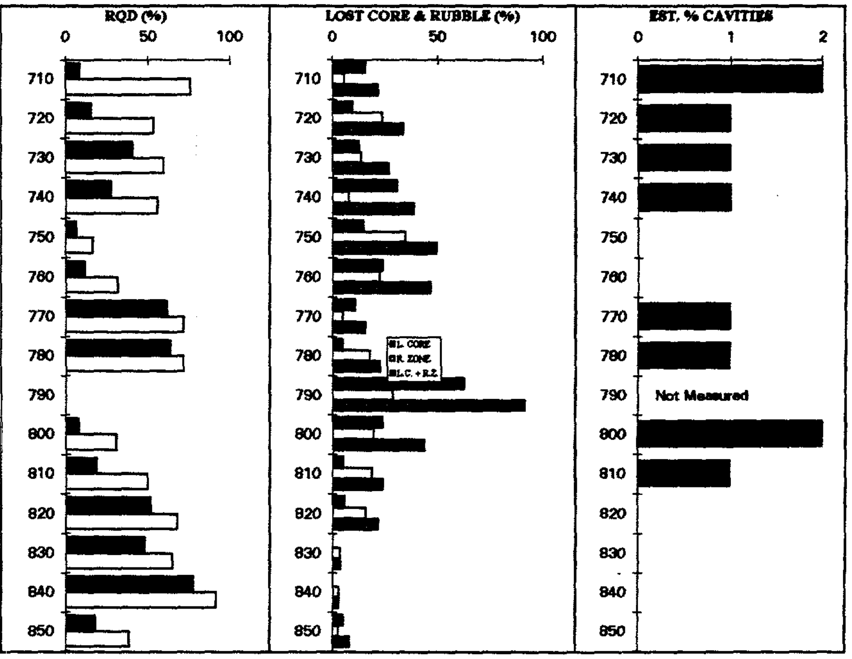
* CORE RQD—Determined from piece lengths formed by all types of fractures (C, I, N and V).

** ENHANCED RQD—Determined by filtering the effects of fractures identified as coring induced (Type C) from the piece lengths.

*** Footage in interval may not equal 10 ft becaues of lost core, rubble, or ommission during logging.

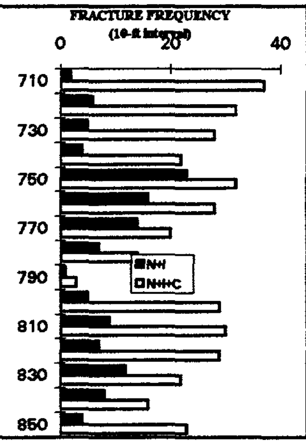


CORE RQD Summary		*ENHANCED RQD Summary*	
Mean	30.80	Mean	52.27
Median	19	Median	56
Mode	#N/A	Mode	72
Standard Deviation	24.7	Standard Deviation	24.5
Variance	610.5	Variance	601.9
Range	78	Range	92
Minimum	0	Minimum	0
Maximum	78	Maximum	92
Sum	462	Sum	784
Count	15	Count	15



YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
Core Hole Structural Data Summary
Hole USW SD-9
Interval—700–850 ft, Middle Nonlithophysal Zone

BASE OF 10-FT INTERVAL	STRATIGRAPHY ZONE	THERMO-MECHANICAL UNIT	FEATURE TYPE				NO. OF FRACTURES W/INCLINATION (degrees)								
			N	I	C	V	10	20	30	40	50	60	70	80	90
710	T.S. C.P. U. Lith.	TSw1		2	35		1								1
720	T.S. C.P. U. Lith.	TSw1		6	26	2									6
730	T.S. C.P. U. Lith.	TSw1	3	2	23	1	1			1				1	2
740	T.S. C.P. U. Lith.	TSw1		4	18		1	1						2	
750	T.S. C.P. M. Nonlith.	TSw2	13	10	9		4	1	2	1	6	5		3	1
760	T.S. C.P. M. Nonlith.	TSw2	8	8	12		5			1	1	3	2	2	2
770	T.S. C.P. M. Nonlith.	TSw2	10	4	6	2	7	1	2				1	1	2
780	T.S. C.P. M. Nonlith.	TSw2	6	1	7	1	2	1		1	2			1	
790	T.S. C.P. M. Nonlith.	TSw2	1		2										1
800	T.S. C.P. M. Nonlith.	TSw2	4	1	24	1					1				4
810	T.S. C.P. M. Nonlith.	TSw2	5	4	21		1			3	2			1	2
820	T.S. C.P. M. Nonlith.	TSw2	2	5	22								2	3	2
830	T.S. C.P. M. Nonlith.	TSw2	9	3	10		2	1				1	3	3	2
840	T.S. C.P. M. Nonlith.	TSw2	6	2	8		2						2	2	2
850	T.S. C.P. M. Nonlith.	TSw2	4		19		1	1							2
TOTAL			71	52	242	7	27	6	4	7	12	9	10	19	29
PERCENT OF OCCURRENCE			19.1	14	65.1	1.88	22	4.88	3.25	5.69	9.76	7.32	8.13	15.4	23.6



	NO. OF FRACTURES W/MINERAL INFILLING TYPE													NO. OF FRACTURES W/INFILL THICKNESS CODE						NO. OF FRACTURES W/PLANARITY CODE				NO. OF FRACTURES W/ROUGHNESS CODE				
	WC	WN	BC	BD	TD	TC	CA	SI	MN	CL	TN	FE	BN	C	S	T	M	V	E	P	C	S	I	V	R	M	S	P
														2									1			1		
														6						2	1		2		4	1		
	3													2	1	2				4			1		1	3		
														4						2	1				2		1	
		10		3										10	13					19		1			1	11	8	
		4		1					1					9	6					10	2	1			1	5	6	
		5		3										6	6	2				6		2	2		4	4	2	
		4		1										1	6					2	2		2			6		
		1												1						1						1		
														5						3	2				1	2	2	
		4												5	4					3		1	5	2	3	3	1	
				1					1					5	2					7						5	2	
		7						1						4	5	3				9	1	1			3	1	6	
		6												2	2	4				6			2	1	3	3	1	
		4													1	3				2	1		1		1	2	1	
	3	45	0	9	0	0	0	1	2	0	0	0	0	62	46	14	0	0	0	76	10	6	16	3	24	48	30	0
2	2.44	36.6	0	7.32	0	0	0	0.81	1.63	0	0	0	0	50.8	37.7	11.5	0	0	0	70.4	9.26	5.56	14.8	2.86	22.9	45.7	28.6	0

REVISION HISTORY

Revision 1 Jn and SRF parameters revised because of additional data from tunnel mapping. Revision 0 is superseded in its entirety.

EXPLANATION OF CALCULATION

Rock mass quality indices, Q (Barton et al., 1974) and RMR (Bieniawski, 1979), have been estimated for 10-ft intervals using Rock Structural Data Summaries developed from structural logging of the core, observations of rock conditions in the North Ramp Starter Tunnel and North Ramp tunnel, and laboratory testing data.

- Q is developed to evaluate the distribution of rock mass quality as a basis for developing the range of credible rock mass quality to establish the ground support requirements within rock units and to derive rock mass mechanical properties according to the methodology proposed by Hardy and Bauer (1991). Procedures used in the calculation were:

$$Q = \frac{RQD^{**}}{Jn^{*}} \bullet \frac{Jr}{Ja} \bullet \frac{Jw}{SRF^{*}}$$

Note: Any spatial correlation may be masked by Monte Carlo simulation of Jn and SRF.

where RQD** = Core RQD where all fractures types [natural (N), indeterminate (I), coring induced (C) and vugs (V)] have been considered in determination of RQD. If the RQD is less than 10%, the value used is set to 10 as per Barton et al. (1974). By definition, soil-like materials are considered to have zero RQD.

Jn* = Joint Set Numbers: Cannot be determined from the core log data and are generated by Monte-Carlo simulation assuming a uniform distribution of values between 1 and 12 derived from mapping of the North Ramp tunnel.

Jr = Joint Roughness Number: A weighted average value derived based on the N and I type fractures in the 10-ft interval.

Ja = Joint Alteration Number: A weighted average value derived from the description of N and I type fractures in the interval.

Jw = Joint Water Factor: Set equal to 1.0 assuming dry conditions.

SRF* = Stress Reduction Factor: For nonwelded units, SRF is determined from the ratio of UCS/σ_1 (UCS = unconfined compressive strength, σ_1 = overburden stress). If unconfined compressive strength data is not available for the 10-ft interval, a compressive strength is generated by Monte Carlo simulation using laboratory test data for the thermomechanical units. For welded tuff units, SRF cannot be determined from core log data and is generated by Monte Carlo simulation assuming a distribution derived from mapping of the North Ramp Tunnel.

- The use of the Core RQD is conservative since it includes the effect of coring induced breaks. Filtering the effects of coring induced breaks from the RQD calculation ("Enhanced RQD") produced an increase in the mean RQD. The mean values for thermomechanical units in USW SD-9 are:

	Core RQD	Enhanced RQD
PTn Unit	48.5%	63.3%
TSw1 Unit	16.4%	43.2%
TSw2 Unit	16.5%	31.6%

- RMR is estimated based on the Rock Structural Summary log data, and rock strength data. Procedures used in the calculation were:

$$RMR = C + RQD\text{-}I + JS + JC + JW$$

where C = Rock Strength Index: Derived from compressive strength estimated by unconfined compressive strength test data for the 10-ft interval. If data is not available for the 10-ft interval, a compressive strength is generated by Monte-Carlo simulation using laboratory test data for the thermomechanical unit.

RQD-I = RQD Index: Derived using the Core RQD value for the 10-ft interval.

JS = Joint Spacing Index: Derived from the rock structural data for the 10-ft interval, excludes coring induced features.

JC = Discontinuity Condition Index: Derived from the description of fractures in the 10-ft interval.

JW = Groundwater Index: Assumed dry conditions

- Q and RMR data are presented in log format to associate parameters with depth intervals in the core log; however, any spatial correlation may be masked by Monte-Carlo simulation.

STRATIGRAPHIC ABBREVIATIONS

T.C.	Tiva Canyon Tuff	C.P. M. Nonlith.	Crystal-Poor Middle Nonlithophysal Zone
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone
	Bedded Tuff		
Y.M.	Yucca Mountain Tuff		
	Bedded Tuff		
P.C.	Pah Canyon Tuff		
	Bedded Tuff		
T.S.	Topopah Spring Tuff	C.R. Vitric	Crystal-Rich Vitric Zone
		C.R. Nonlith.	Crystal-Rich Nonlithophysal Zone
		C.R. Lith.	Crystal-Rich Lithophysal Zone
		C.P. U. Lith.	Crystal-Poor Upper Lithophysal Zone
		C.P. M. Nonlith.	Crystal-Poor Middle Nonlithophysal Zone
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone Vitrophyre
		C.P. Vitric NW	Crystal-Poor Vitric Zone Non- to Partially Welded and Moderately Welded
	Bedded Tuff		
C.H.	Calico Hills Formation		

THERMOMECHANICAL UNITS

UO—Undifferentiated Overburden
TCw—Tiva Canyon Welded Unit
PTn—Upper Paintbrush Nonwelded Unit
TSw1—Topopah Spring Welded Unit—Lithophysae Rich
TSw2—Topopah Spring Welded Unit—Lithophysae Poor
TSw3—Topopah Spring Welded Unit—Vitrophyre
CHn1—Calico Hills and Lower Paintbrush Nonwelded Unit

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
Estimated Rock Mass Quality Indices Based on Core Log Data
Hole USW SD-9
Interval — 700–850 ft, Middle Nonlithophysal Zone

END DEPTH	STRATIGRAPHY ZONE	THERMO-MECHANICAL UNIT	Q CLASSIFICATION SYSTEM [1] Barton et al. (1974)							RMR CLASSIFICATION SYSTEM [2] Bieniawski (1979)					
			RQD** (%	Jn*	Jr	Ja	Jw	SRF*	Q*	C	RQD-I	JS	JC	JW	RMR
710	T.S. C.P. U. Lith.	TSw1	9	12.00	3.00	1.00	1.00	7.50	0.33	2	3	8	28.5	15	56.5
720	T.S. C.P. U. Lith.	TSw1	16	2.00	2.40	1.00	1.00	1.00	19.20	4	3	8	24.0	15	54.0
730	T.S. C.P. U. Lith.	TSw1	41	9.00	2.25	1.00	1.00	5.00	2.05	7	8	8	21.3	15	59.3
740	T.S. C.P. U. Lith.	TSw1	28	12.00	1.67	1.00	1.00	7.50	0.52	7	8	8	20.5	15	58.5
750	T.S. C.P. M. Nonlith.	TSw2	7	9.00	1.65	1.87	1.00	7.50	0.13	7	3	5	16.0	15	46.0
760	T.S. C.P. M. Nonlith.	TSw2	12	12.00	1.58	1.53	1.00	7.50	0.14	4	3	8	17.9	15	47.9
770	T.S. C.P. M. Nonlith.	TSw2	62	9.00	2.20	1.71	1.00	7.50	1.18	12	13	8	19.5	15	67.5
780	T.S. C.P. M. Nonlith.	TSw2	64	9.00	2.33	2.14	1.00	5.00	1.55	7	13	8	18.5	15	61.5
790	T.S. C.P. M. Nonlith.	TSw2	0	9.00	2.10	1.22	1.00	1.00	1.91	15	3	8	23.1	15	64.1
800	T.S. C.P. M. Nonlith.	TSw2	8	12.00	1.60	1.00	1.00	7.50	0.18	15	3	8	20.7	15	61.7
810	T.S. C.P. M. Nonlith.	TSw2	19	12.00	2.56	1.89	1.00	7.50	0.29	12	3	8	20.8	15	58.8
820	T.S. C.P. M. Nonlith.	TSw2	52	6.00	1.71	1.00	1.00	5.00	2.97	12	13	8	18.7	15	66.7
830	T.S. C.P. M. Nonlith.	TSw2	48	9.00	1.50	2.17	1.00	5.00	0.74	12	8	8	15.0	15	58.0
840	T.S. C.P. M. Nonlith.	TSw2	78	6.00	2.13	2.50	1.00	1.00	11.05	12	17	8	15.1	15	67.1
850	T.S. C.P. M. Nonlith.	TSw2	18	12.00	2.00	3.00	1.00	7.50	0.13	12	3	8	13.5	15	51.5

Jn*, SRF* = interval values generated by Monte Carlo simulation; to calculate Q*.

RQD**: If RQD is less than 10, the value 10 is used in the calculation of Q* as per Barton et al. (1974).

Q	RMR
Jn — Joint Set Number	C— Strength Index
Jr — Joint Roughness Number	RQD-I— RQD Index
Ja — Joint Alteration Number	JS— Joint Spacing Index
Jw — Joint Water Reduction Factor	JC— Discontinuity Condition Index
SRF — Stress Reduction Factor	JW— Groundwater Index
Q = (RQD/Jn)(Jr/Ja)(Jw/SRF)	RMR = C + RQD-I + JS + JC +JW

[1] Barton , N., R. Lien, and J. Lunde, "Engineering Classification of Rock Masses for the Design of Tunnel Support," Rock Mechanics, 6:189-236 (Springer Verlag, 1974).

[2] Bieniawski, Z.T., "The Geomechanics Classification in Rock Engineering Applications," Proceedings, 4th International Congress on Rock Mechanics, Montreaux, Switzerland, 2:41-48 (A. A. Balkema, 1979).

USW SD-12 CORE LOGS AND DATA

Geology and Rock Structure Log

Core Hole Rock Structural Data Summary

Estimated Rock Mass Quality Indices Based on Core Log Data

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
GEOLOGY AND ROCK STRUCTURE LOG
Hole USW SD-12, 650-800 ft

Sandia National Laboratories
Print Date: 3/14/95
WBS 1.2.3.2.6.2.1
QA:L
Revision 0

BOREHOLE ID:	USW SD-12	TOTAL DEPTH:	1435.3'
STUDY PLAN NO:	8.3.1.2.2.1	ANGLE FROM VERT:	0°
CORE SIZE:	HQ	AZIMUTH:	n/a
DRILL DATES:	5/94 to 8/94		
GROUND ELEV:	4330.0'		
COORDINATES:	761,957N 561,606E		

Field Rock Structure

Logged by:

R. Henson	
D. Hattler	
M.Wagner	Drilling Support Division, Drilling
C. Hermes	Support and Sample Management
D. Switzer	Department, T&MSS
M. Pitterle	

Relogged by:

Eric Martin	Agapito Associates, Inc.

Lithology and Stratigraphy

Logged by:

D. Engstrom	Sandia National Laboratories

Checked by:

Eric Martin	Agapito Associates, Inc.

Log prepared by Agapito Associates, Inc. for Sandia National Laboratories

EXPLANATION
GEOLOGY AND ROCK STRUCTURE

FRACTURE TYPE OR FEATURE

N Natural fractures are indicated by mineral coatings, evidence of weathering, slickensides, lack of rematch/fit between sides or by surfaces that form an ellipse in the core.

C Coring-induced fractures are generally normal to the axis of the core or indicate some torquing of the core. They are typically clean, fresh and fit tightly back together.

I Indeterminate fractures are those not clearly described as "N" or "C." This includes fracture surfaces that have been shaped by drilling rotation.

H Handling-induced fractures are formed in the core by removal from the core barrel or placement in the core box. These fractures are witnessed and, according to BTP-SMF-008, are marked by the SMF personnel by lines parallel to the fracture on both sides of the core. "H" fractures are typically not recorded in the log unless there is a specific reason.

V Vug or large void.

P Foliation plane due to gravity flattening upon deposition, not a fracture.

LOST CORE AND RUBBLE

☒ LOST CORE

|×.20 ×| RUBBLE ZONE (with average maximum diameter of rubble pieces to nearest 0.01 ft; NM = not measured)

HARDNESS (Subjective estimate, YMP procedures do not allow core to be broken or scratched etc.)

1 Extremely Hard—Cannot be scratched, chipped only with repeated heavy hammer blows.
2 Very Hard—Cannot be scratched, broken only with repeated heavy hammer blows.
3 Hard—Scratched with heavy pressure, breaks with heavy hammer blow.
4 Moderately Hard—Scratched with light-moderate pressure, breaks with moderate hammer blow.
5 Moderately Soft—Grooved (16th in.) with moderate heavy pressure, breaks with light hammer blow.
6 Soft—Grooved easily with light pressure, scratched with fingernail, breaks with light-moderate manual pressure.
7 Very Soft—Readily gouged with fingernail, breaks with light manual pressure.
8 Soil Like—Cohesive
9 Soil Like—Non-cohesive

WEATHERING

F Fresh—Rock and fractures not oxidized or discolored, no separation of grains, change of texture or solutioning.
S Slightly Weathered—Oxidized or discolored fractures and nearby rock, some dull feldspars, no separation of grains, minor leaching.
M Moderately Weathered—Fractures and most of rock oxidized or discolored, partial separation of grains, crystals rusty or cloudy, moderate leaching of soluble minerals.
I Intensely Weathered—Fractures and rock totally oxidized or discolored, extensive clay alteration, leaching complete, grain separation extensive, rock is friable.
D Decomposed—Grain separation and clay alteration complete.

PLANARITY

P Planar
C Curved
S Stepped
I Irregular

ROUGHNESS

V Very rough, stepped, near-normal steps and ridges occur.
R Rough, large angular asperities can be seen.
M Moderately rough, asperities clearly visible, surface has an abrasive feel; to slightly rough, small asperities are visible and can be felt.
S Smooth, no asperities, smooth to the touch.
P Polished, slickensided, extremely smooth and shiny.

INFILLING THICKNESS AND MINERALIZATION

C Clean, no filling.
S Very thin, surface sheen
T Thin (up to 0.1 inches)
M Moderately thick (0.1 - 0.4 inches)
V Very thick (0.4 - 1.0 inches)
E Extremely thick, greater than 1.0 inches)

C Clean
WC White, crystalline
WN White, non-crystalline
TD Brown dendritic
TC Tan crystalline
TN Tan, non-crystalline

CA Calcite
SI Silica
MN Manganese
CL Clay
BC Black crystalline
BD Black dendritic

EXPLANATION (concluded)
GEOLOGY AND ROCK STRUCTURE

CORE RQD

Core RQD is calculated using piece lengths that are defined by all fractures (type N, I, and C) that exist in the core when it is removed from the core barrel. Only handling-induced breaks are discounted in piece length determination. RQD is calculated as:

$$RQD = \frac{\sum \mathit{Piece\ lengths} \geq 0.33\,ft}{\mathit{Interval\ length}} \times 100.$$

RQD is calculated for both the core run interval (run RQD) and even 10-ft intervals. If a piece length ≥ 0.33 ft crosses over a 10-ft interval boundary, the portion of the piece length that occurs in the 10-ft interval is included in the summation.

ESTIMATED PERCENTAGE LITHOPHYSAE & OTHER CAVITIES

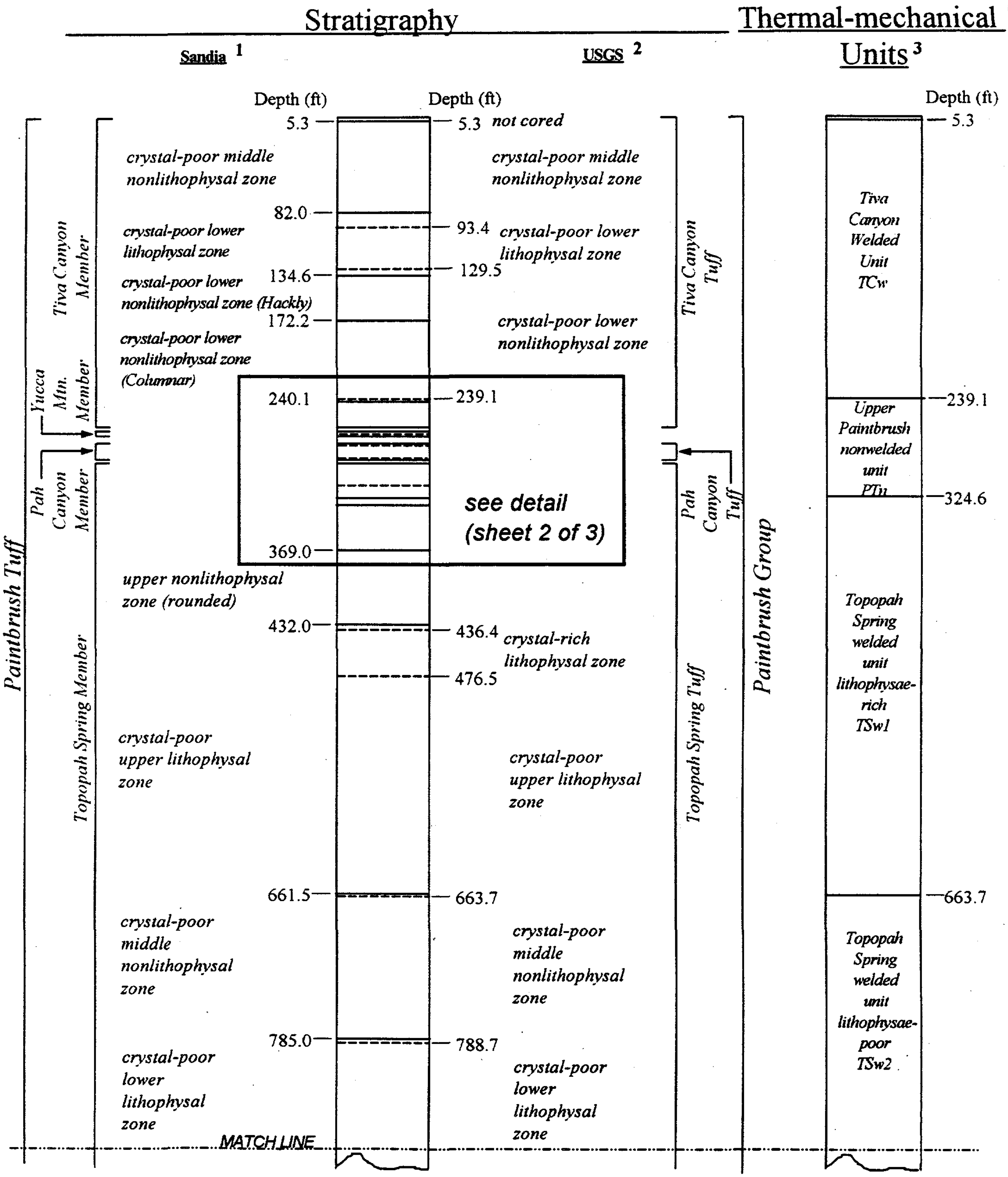
The percentage of lithophysal voids and other cavities is estimated for each core run interval where sufficient whole core is available. Excessive lost core and rubble zones may prevent the estimate on specific core runs. The estimate is based on comparison of the core with charts designed for estimating the proportions of various rock or mineral components. Estimates are then spot checked using a quantitative graphical summation technique to calculate the percent area occupied by lithophysal cavities in core photographs or video tape.

The estimated percent cavities volume for core runs is used to calculate a run length, weighted average for even 10-ft intervals. (Runs for which percent cavities cannot be determined are assumed to have the average percentage for the 10-ft interval; intervals for which the percent cavities was not estimated are labeled "Not Measured;" zones containing vapor-phase alteration and very small or no lithophysal cavities are labeled as <1%).

USW SD-12 (1 of 3)

Stratigraphic and Thermal-Mechanical Units Summary

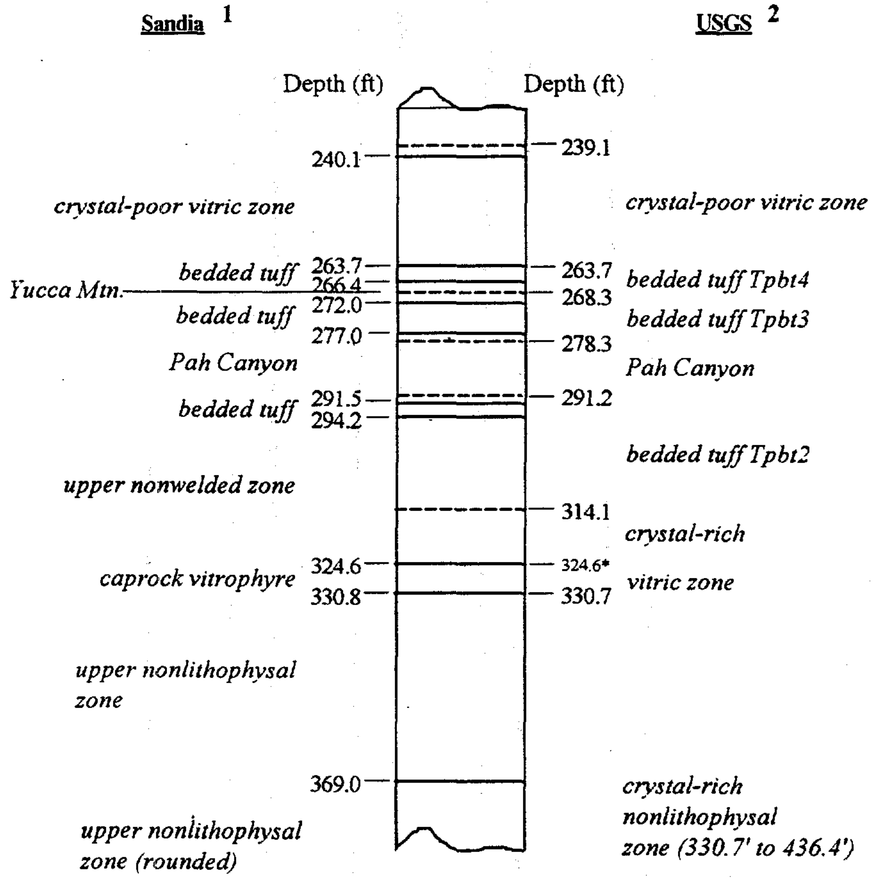
0 - 881 ft



Date: 2/21/95

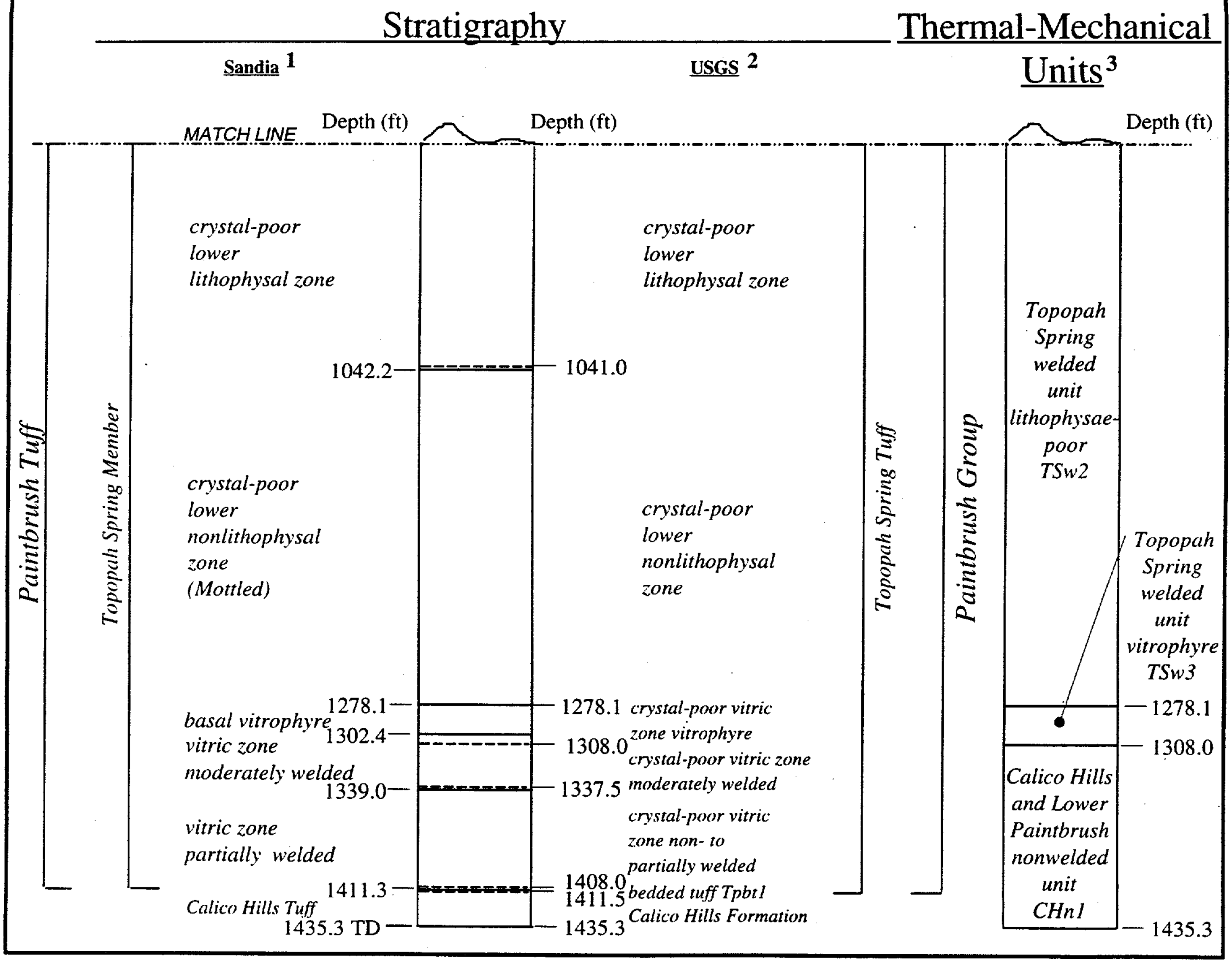
USW SD-12 Stratigraphy (2 of 3)
Stratigraphic and Thermal-Mechanical Units Summary
Detail 239.1 - 369.0 ft

Stratigraphy



*Break between welded and moderately welded subzones at 324.6'.

USW SD-12 (3 of 3)
Stratigraphic and Thermal-Mechanical Units Summary
881 - 1435.3 ft



Date: 3/1/95

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[1] Lithologic log of Borehole USW SD-12. Dale Engstrom, unpublished data.

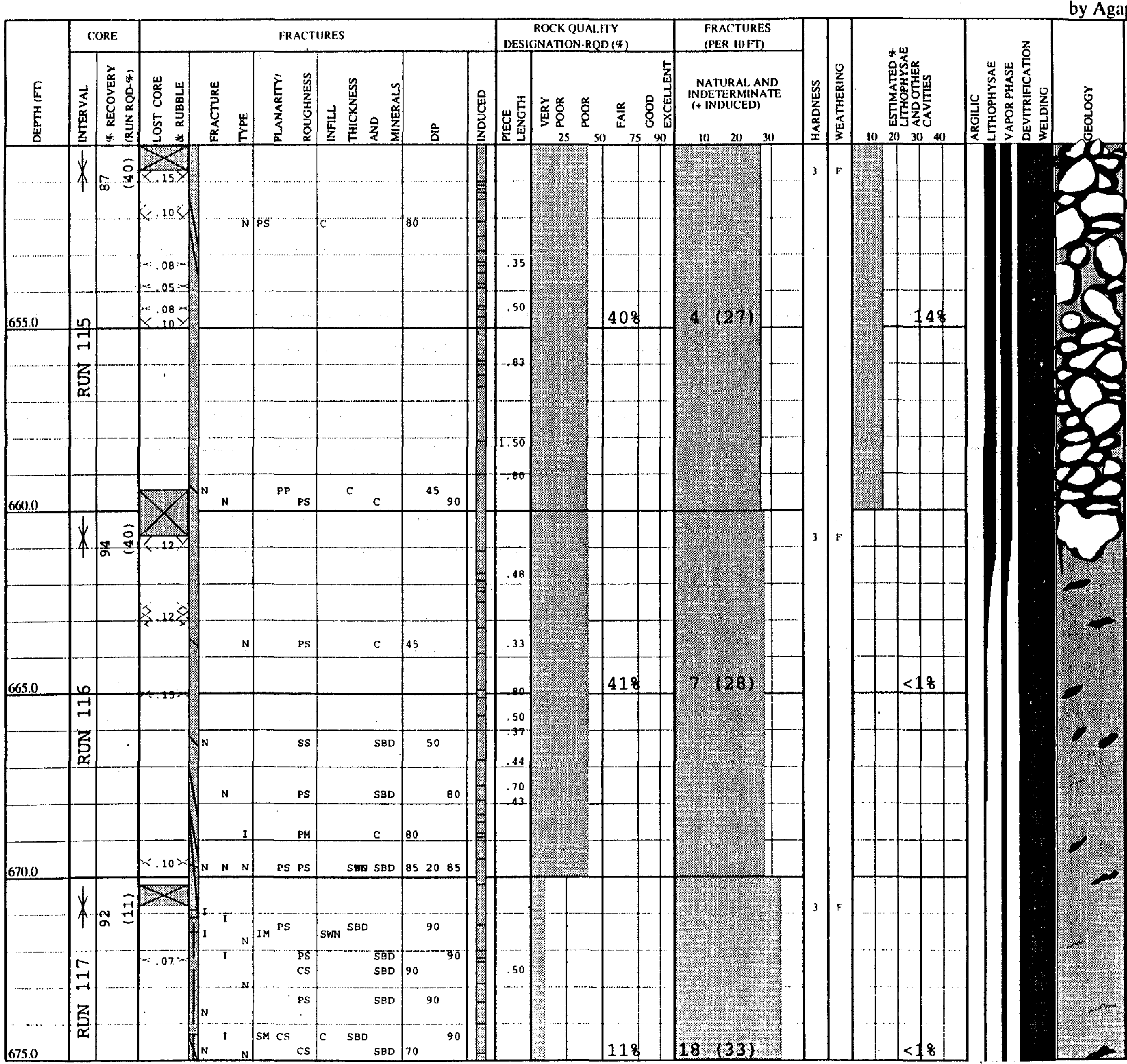
[2] U.S. Geological Survey - Graphical Lithologic Log of Borehole USW SD-12, J.K. Geslin and J.R. Wunderlich, DTN: GS940908314211.045

[3] Thermal-mechanical units as defined by Buesch, et al., USGS Open File Report 94-469, 1996. "Revised stratigraphic nomenclature and macroscopic identification of lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain, Nevada."

YUCCA MTN, Drillhole SD-12

GEOLOGY AND ROCK STRUCTURE LOG

Sandia National Laboratories
by Agapito Associates, Inc.



432.0-661.5 TOPOPAH SPRING CRYSTAL-POOR UPPER LITHOPHYSAL ZONE. Light red-gray (5RP7/2), densely welded, devitrified, crystal-poor, 4-5% white sanidine, plagioclase phenocrysts, 0.1% biotite, 15-25% medium to large size oval shaped lithophysae lined with 3-4mm very light gray vapor-phase mineralization, 4-6mm border of blue vapor-phase alteration, pervasive blue alteration replaces 60-65% groundmass, 4-5% exotic crystal-rich soft lithics of quartz latite, extremely broken suggests very large lithophysal cavities.

659.4-661.1 Rubble

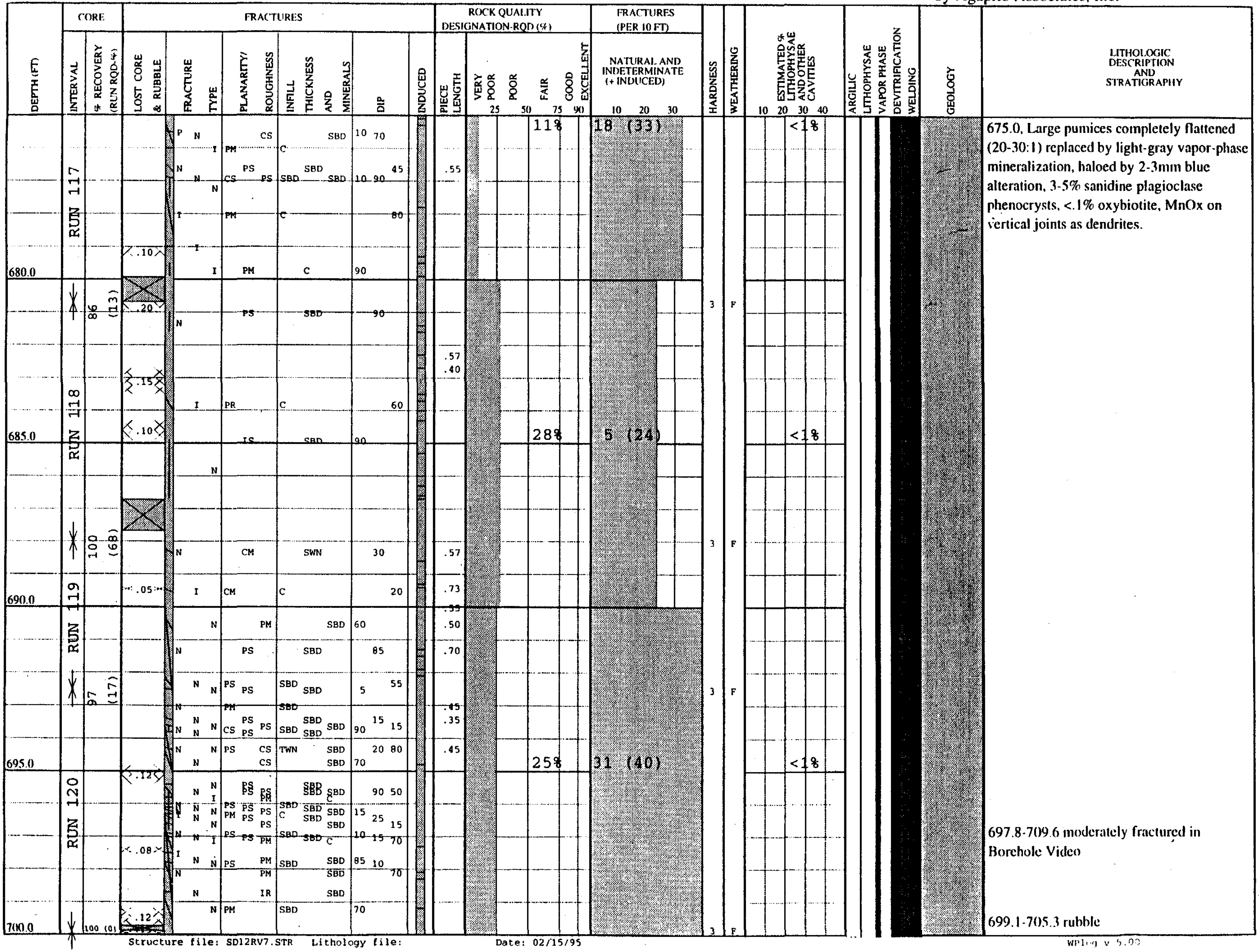
661.5 (sharp contact), TOPOPAH SPRING Crystal-Poor Middle Nonlithophysal Zone. Pale orange-gray (10R6/4) densely welded, devitrified, speckled/streaked by pale vapor-phase alteration wisps after 3-8mm flat pumice, 12-15% nearly invisible pumice flattened to 20:1, weak blue vapor-phase alteration halos around white vapor-phase mineralization in open pumice and replaces other pumice, occasional lithophysae (weakens downward) accompanied by light pink-gray vapor-phase alteration halo, 5% white sanidine plagioclase phenocrysts, straight vertical jointing weakly scattered lithophysae to 669.0. Strong fracture set N-S vertical, NNE vertical and ENE dipping SE at 670.8-683.7.

Structure file: SD12RV7.STR Lithology file: Date: 02/15/95 WPlot v 5.00

YUCCA MTN, Drillhole SD-12

GEOLOGY AND ROCK STRUCTURE LOG

Sandia National Laboratories
by Agapito Associates, Inc.



675.0, Large pumices completely flattened (20-30:1) replaced by light-gray vapor-phase mineralization, haloed by 2-3mm blue alteration, 3-5% sanidine plagioclase phenocrysts, <.1% oxybiotite, MnOx on vertical joints as dendrites.

697.8-709.6 moderately fractured in Borehole Video

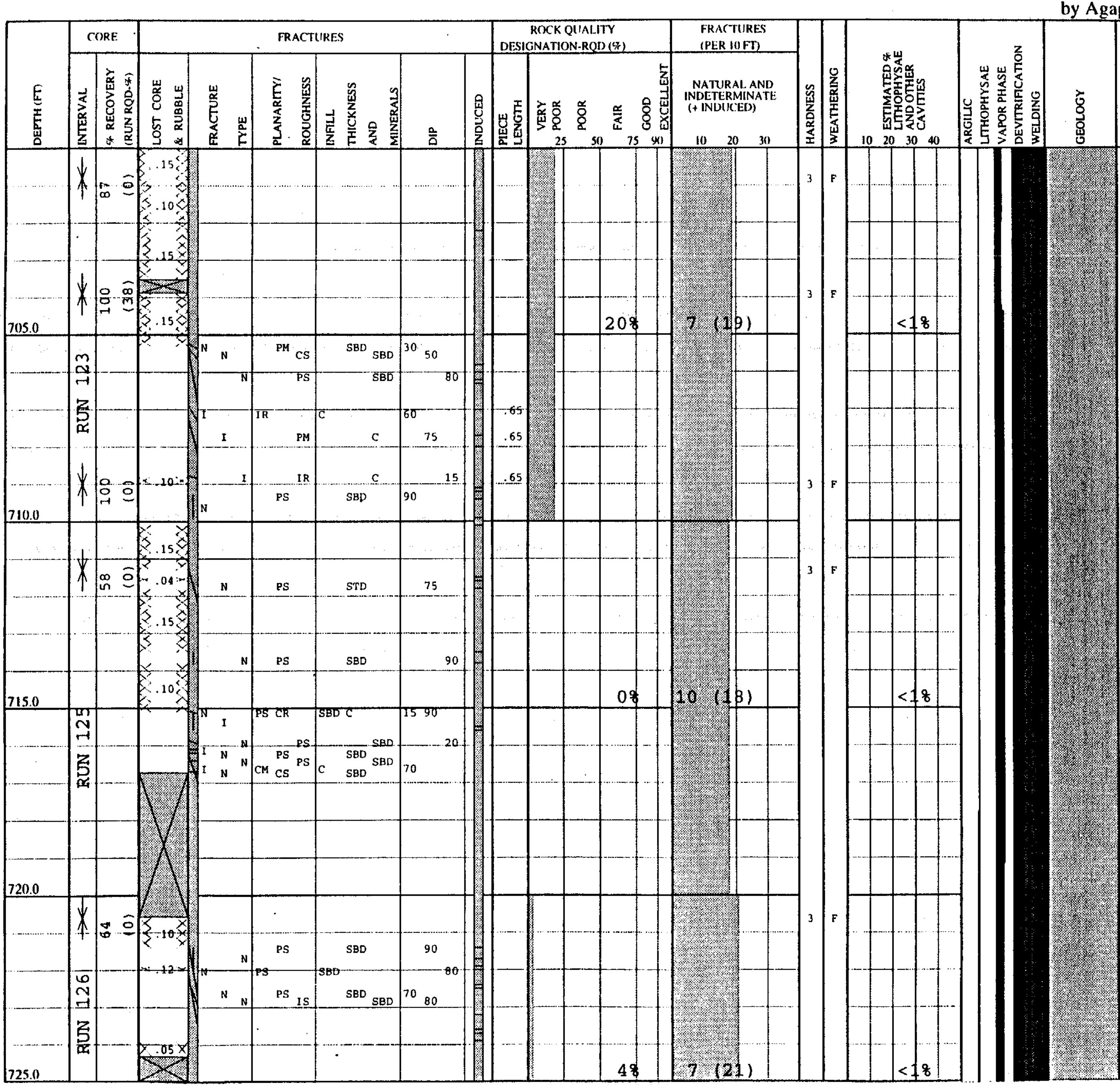
699.1-705.3 rubble

Structure file: SD12RV7.STR Lithology file: Date: 02/15/95 WPlog v 5.03

YUCCA MTN. Drillhole SD-12

GEOLOGY AND ROCK STRUCTURE LOG

Sandia National Laboratories
by Agapito Associates, Inc.



699.1-705.3 rubble

<u>TOPOPAH SPRING Crystal-Poor Middle Nonlithophysal</u> (cont.). Pale orange-gray (10R6/4) densely welded, devitrified, 12-15% speckled/streaked by 3-8mm wisps of light-gray vapor-phase alteration after mm-size nearly invisible pumice flattened to 15-20:1, former large pumice completely flat (30:1) becoming more rare downward, replaced by light gray vapor-phase mineralization, 2-3mm blue vapor-phase alteration halo, 3-5% white sanidine plagioclase phenocrysts, biotite not seen, severely broken, MnOx speckled on fractures.

708.8-729.9 broken

716.7-720.6 unrecovered

724.3-726.4 unrecovered

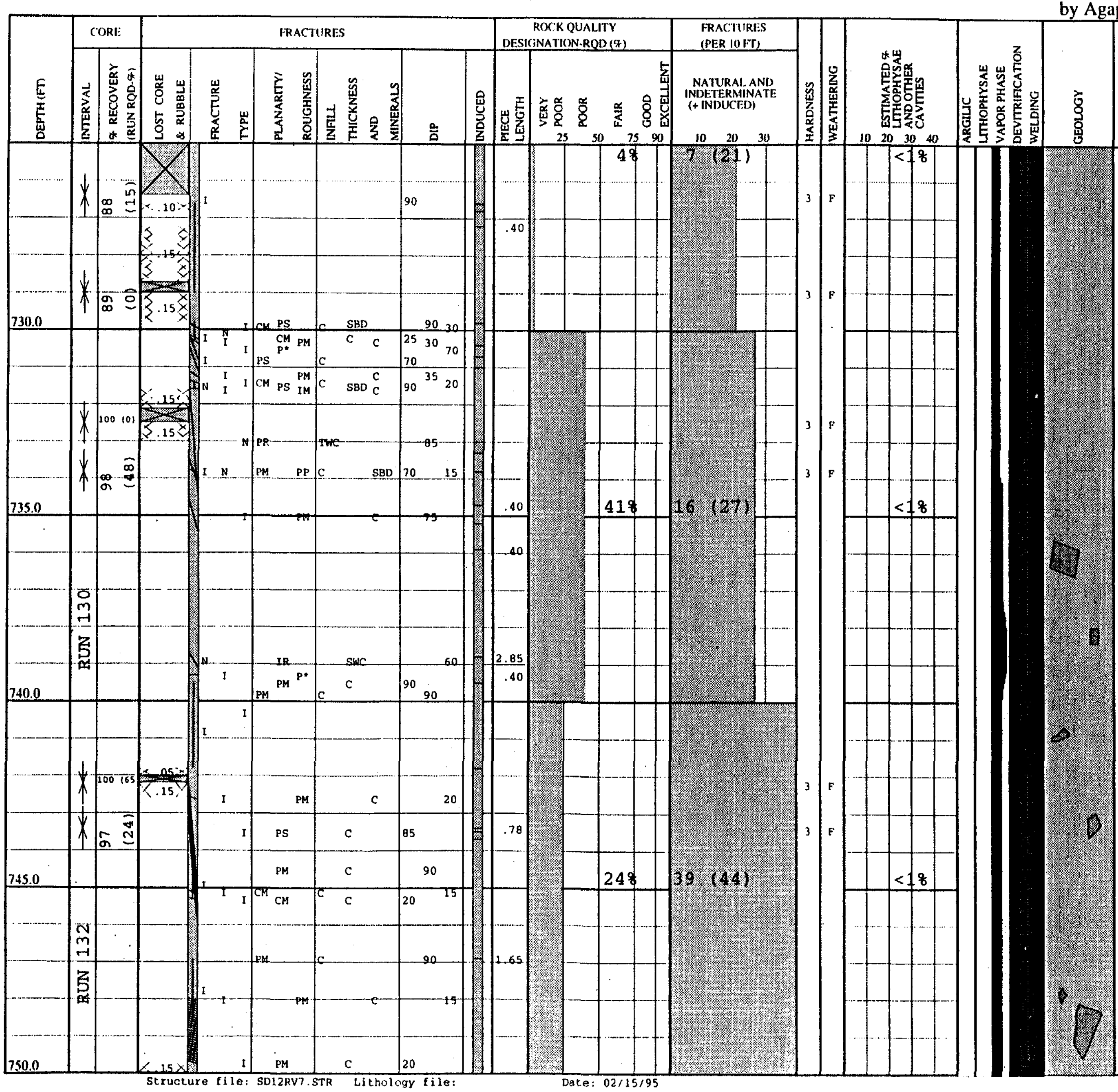
Structure file: SD12RV7.STR Lithology file: Date: 02/15/95

WPlog v 5.00

YUCCA MTN, Drillhole SD-12

GEOLOGY AND ROCK STRUCTURE LOG

Sandia National Laboratories
by Agapito Associates, Inc.



LITHOLOGIC DESCRIPTION AND STRATIGRAPHY

<u>TOPOPAH SPRING Crystal-Poor Middle Nonlithophysal</u> (cont.). Pale orange-gray (10R6/4) densely welded, devitrified, 12-15% speckled/streaked by 3-8mm wisps of light-gray vapor-phase alteration after mm-size nearly invisible pumice flattened to 15-20:1, former large pumice completely flat (30:1) becoming more rare downward, replaced by light gray vapor-phase mineralization, 2-3mm blue vapor-phase alteration halo, 3-5% white sanidine plagioclase phenocrysts, biotite not seen, severely broken, MnOx speckled on fractures.

734.5, Increased size and number of speckles and halos, also increase in lithics, mostly (80%) small subrounded cognate flattened and soft. 17% of lithics hard exotic crystal-rich quartz latite and 3-4% very small rhyolite hard lithics, 738.0-739.0 slight increase in blue alteration.

734.8, 25mm rhyolite lithic

739.9-742.5 rubble

747.4, 20mm rhyolite lithic

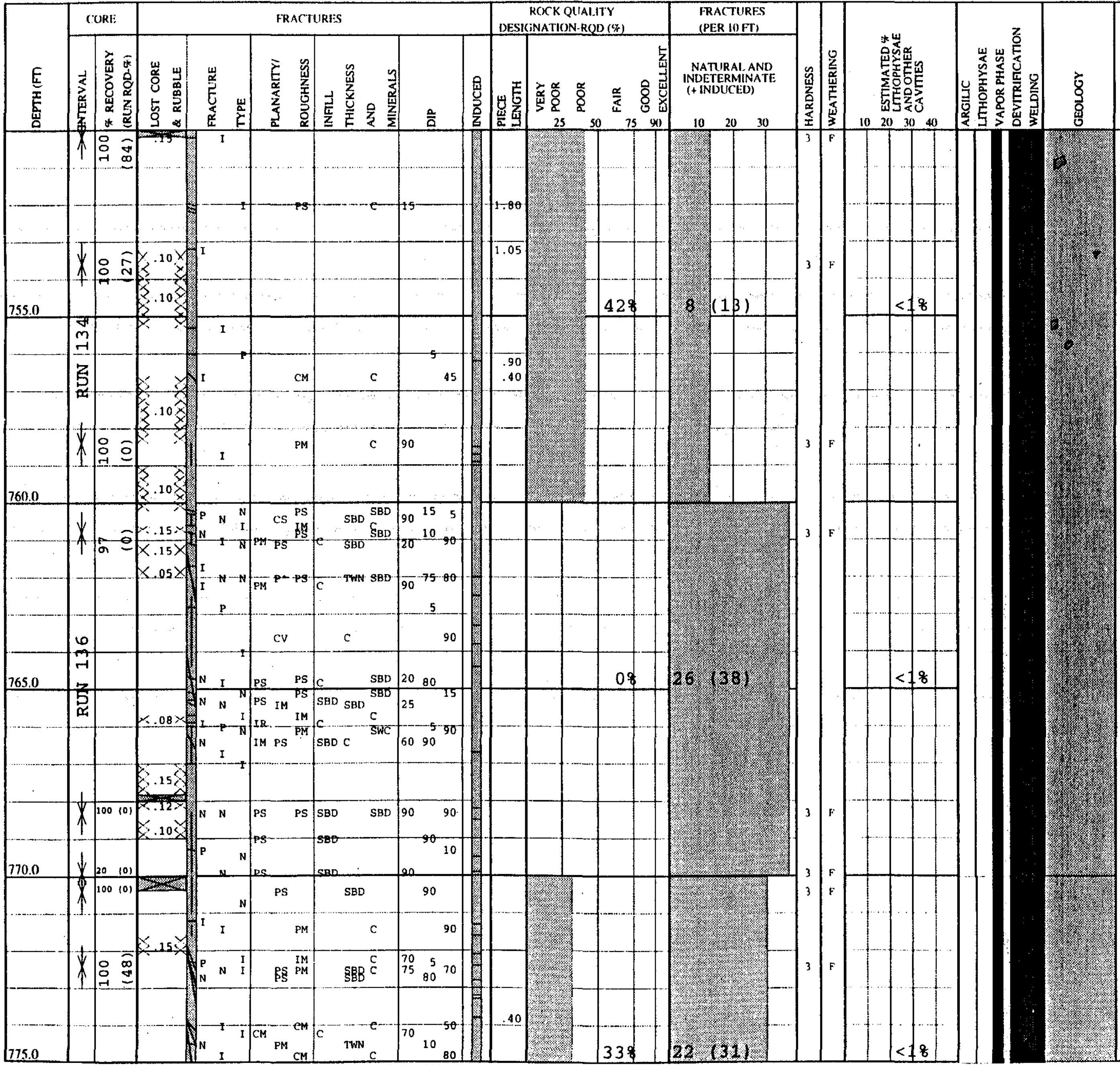
747.9-750.0 rubble

Structure file: SD12RV7.STR Lithology file: Date: 02/15/95 WPlog v 5.00

YUCCA MTN, Drillhole SD-12

GEOLOGY AND ROCK STRUCTURE LOG

Sandia National Laboratories
by Agapito Associates, Inc.



Pale red (10R6/2) fine, dense grained, densely welded, devitrified, 10-15% speckled by light tan-gray vapor-phase alteration streaks nucleated by micropumice and small lithics; below 750 most small pumice weakly blue altered with light tan-gray 1-2mm halo; 3-4% small subround crystal-rich quartz latite hard lithics, 1% very small rhyolite hard lithics, 1% sanidine phenocrysts, no biotite seen, severely broken, most natural fractures coated and hardened by vapor phase SiO2 and speckled by 2-3mm MnOx spots.

753.1-755.0 rubble

756.6-759.8 rubble

762.0-787.0, Hairline vapor phase SiO2 veinlets with 2-3mm light-gray vapor-phase alteration halo.

767.8-769.0 rubble

772.4. Groundmass color darkens slightly due to lifting of pervasive vapor-phase mask.

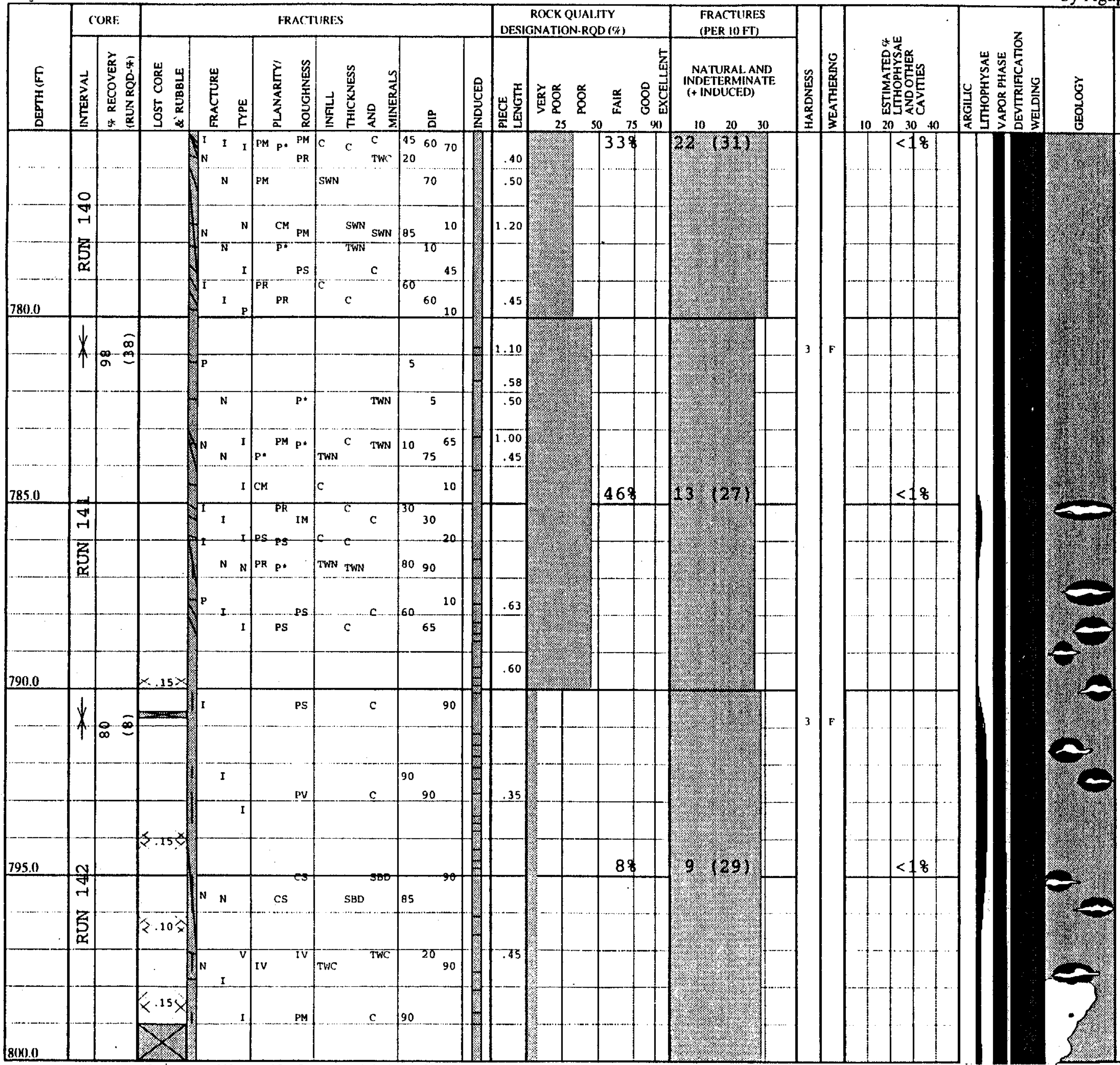
Structure file: SD12RV7.STR Lithology file: Date: 02/15/95

WPlog v 5.00

YUCCA MTN, Drillhole SD-12

GEOLOGY AND ROCK STRUCTURE LOG

Sandia National Laboratories
by Agapito Associates, Inc.



LITHOLOGIC DESCRIPTION AND STRATIGRAPHY

<u>TOPOPAH SPRING Crystal-Poor Middle Nonlithophysal</u>. Pale red-gray (10R6/2) fine, dense grained, densely welded, devitrified, 8-10% speckled by wisps of light pink-gray vapor-phase alteration nucleated by small pumice and lithics, most of pumice weakly blue altered with 1-2mm light tan-gray vapor-phase alteration halo, 2-3% dark blue-lavender vapor-phase halos rim light pink-gray wisps but also streak off into groundmass, 3-5% mixed exotic quartz latite and rhyolite small hard lithics, 1% sanidine phenocrysts, biotite not seen, severely broken, MnOx specks on fractures.

785.0, <u>TOPOPAH SPRING Crystal-Poor Lower Lithophysal Zone</u>. Similar to description above except for appearance of lithophysae, uppermost lithophysae at 785.0 in 15mm halo of light pink-tan vapor-phase alteration, more pumice is evident, replaced by weak blue vapor-phase, halo of light pink alteration and blue vapor-phase alteration rim, small lithophysal pumice 2-12" apart in 30mm light pink-tan vapor-phase alteration spot, groundmass weakly to pervasively altered by blue vapor-phase up to 60% in places.

787.1, Distinct lithophysal zone contact on Borehole Video, growing larger, fractured downward, especially 792.0, much more intense 800.2-908.3 creating broken/ unrecovered zones, then small to medium size, moderately-spaced lithophysae.

798.4-801.0 rubble

799.0-801.0 unrecovered

Structure file: SD12RV7.STR Lithology file: Date: 02/15/95 WPl-q v 5.0

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
CORE HOLE ROCK STRUCTURAL DATA SUMMARY
Hole USW SD-12, 650–800 ft, Middle Nonlithophysal Zone

Sandia National Laboratories
Print Date: 6/30/95
WBS 1.2.3.2.6.2
QA:L
Revision 1

REVISION HISTORY

Revision 1 Enhanced RQDs at 670-680 and 770-780 ft were revised. Revision 0 superseded in its entirety.

CODING EXPLANATION

STRATIGRAPHIC ABBREVIATIONS

T.C.	Tiva Canyon Tuff	C.P. M. Nonlith.	Crystal-Poor Middle Nonlithophysal Zone
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone
	Bedded Tuff		
Y.M.	Yucca Mountain Tuff		
	Bedded Tuff		
P.C.	Pah Canyon Tuff		
	Bedded Tuff		
T.S.	Topopah Spring Tuff	C.R. Vitric	Crystal-Rich Vitric Zone
		C.R. Nonlith.	Crystal-Rich Nonlithophysal Zone
		C.R. Lith.	Crystal-Rich Lithophysal Zone
		C.P. U. Lith.	Crystal-Poor Upper Lithophysal Zone
		C.P. M. Nonlith.	Crystal-Poor Middle Nonlith.
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone Vitrophyre
		C.P. Vitric NW	Crystal-Poor Vitric Zone Non- to Partially Welded and Moderately Welded
	Bedded Tuff		
C.H.	Calico Hills Formation		

THERMOMECHANICAL UNITS

UO—Undifferentiated Overburden
TCw—Tiva Canyon Welded Unit
PTn—Upper Paintbrush Nonwelded Unit
TSw1—Topopah Spring Welded Unit—Lithophysae Rich
TSw2—Topopah Spring Welded Unit—Lithophysae Poor
TSw3—Topopah Spring Welded Unit—Vitrophyre
CHn1—Calico Hills and Lower Paintbrush Nonwelded Unit

COLUMN INFORMATION (Page 3)

RQD (%)	$RQD\ (\%) = \frac{\sum \text{Piece lengths} \geq 0.33\ ft}{\text{Interval length}} \times 100.$
CORE RQD	Core RQD based on piece lengths defined by all types of fractures (C, I, N and V).
ENHANCED RQD	Effect of fractures identified as coring induced (Type C) are filtered from the piece lengths.

LITHOPHYSAL (and other cavities)

Percent void due to lithophysae and other cavities, estimated visually by counting the number of cavities, estimating the average diameter, calculating the void volume assuming spherical cavities, and normalizing to the core volume.
NM—Not Measured

WEATHERING

Subjective evaluation of rock degradation by mechanical/chemical agents:
F: Fresh
S: Slightly weathered
M: Moderately weathered
I: Intensely weathered
D: Decomposed

HARDNESS

Subjective evaluation of resistance to breakage:
1: Extremely hard
2: Very hard
3: Hard
4: Moderately hard
5: Moderately soft
6: Soft
7: Very soft
8: Soil-like, cohesive
9: Soil-like, non-cohesive

COLUMN INFORMATION (Page 4)

FEATURE TYPE

Following codes indicate origin of feature:
N: Natural—indicated by mineral coating or evidence of weathering, slickensides, lack of fit between sides.
I: Indeterminate—origin questionable, rotated so that coatings possibly removed.
C: Coring induced—fresh, clean, tightly fitting breaks.
V: Vug or large void.

INCLINATION (degrees)

Angle between plane normal to core axis and plane of fracture (Type N and I only).

MINERAL INFILLING

Describes the infilling on fracture surfaces (Type N and I only):
C: Clean
WC: White crystalline
WN: White noncrystalline
BC: Black crystalline
BD: Black dendritic
TD: Brown dendritic
TC: Tan crystalline
CA: Calcite
SI: Silica
MN: Manganese
CL: Clay
TN: Tan noncrystalline
FE: Iron oxide
BN: Brown noncrystalline

INFILL THICKNESS

Describes the thickness of mineral infillings on the fracture surface (Type N and I only):
S: Very thin, surface sheen
T: Thin (up to 0.1 inches)
M: Moderately thick (0.1-0.4 inches)
V: Very thick (0.4 - 1.0 inches)
E: Extremely thick, greater than 1.0 inches

PLANARITY

Describes the overall shape of the feature (Type N and I only):
P: Planar
C: Curved
S: Stepped
I: Irregular

ROUGHNESS

Describes the local relief of the surface (Type N and I only):
V: Very rough—stepped, near-normal steps and ridges occur.
R: Rough—large angular asperities can be seen.
M: Moderately rough—asperities clearly visible, surface has abrasive feel.
S: Smooth—no asperities, smooth to the touch.
P: Polished—slickensided, extremely smooth and shiny.

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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
Core Hole Structural Data Summary
Hole USW SD-12
Interval—650–800 ft, Middle Nonlithophysal Zone

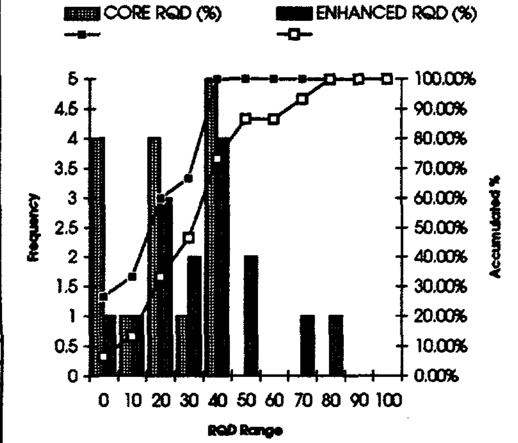
BASE OF 10-FT INTERVAL	STRATI-GRAPHY ZONE	THERMO-MECHANICAL UNIT	CORE RQD* %	ENHANCED RQD** %	ESTIMATED % CAVITIES	LOST CORE (ft)	RUBBLE ZONE (ft)	WEATHERING (ft in 10-ft interval)***					HARDNESS (ft in 10-ft interval)***							
													ROCK							
								F	S	M	I	D	1	2	3	4	5	6	7	8
660	T.S. C.P. U. Lith.	TSw1	40	59	14	1.3	1.5	10.0							10.0					
670	T.S. C.P. M. Nonlith.	TSw2	41	75	<1	0.7	1.5	10.0							10.0					
680	T.S. C.P. M. Nonlith.	TSw2	11	25	<1	0.7	0.4	10.0							10.0					
690	T.S. C.P. M. Nonlith.	TSw2	28	38	<1	1.7	1.8	10.0							10.0					
700	T.S. C.P. M. Nonlith.	TSw2	25	42	<1	0.2	1.4	10.0							10.0					
710	T.S. C.P. M. Nonlith.	TSw2	20	33	<1	0.4	5.1	10.0							10.0					
720	T.S. C.P. M. Nonlith.	TSw2	0	0	<1	3.3	4.3	10.0							10.0					
730	T.S. C.P. M. Nonlith.	TSw2	4	21	<1	3.0	3.8	10.0							10.0					
740	T.S. C.P. M. Nonlith.	TSw2	41	59	<1	0.4	1.0	10.0							10.0					
750	T.S. C.P. M. Nonlith.	TSw2	24	25	<1	0.2	0.9	10.0							10.0					
760	T.S. C.P. M. Nonlith.	TSw2	42	42	<1	0.2	4.9	10.0							10.0					
770	T.S. C.P. M. Nonlith.	TSw2	0	14	<1	0.2	2.7	10.0							10.0					
780	T.S. C.P. M. Nonlith.	TSw2	33	40	<1	0.4	0.5	10.0							10.0					
790	T.S. C.P. M. Nonlith.	TSw2	46	89	<1	0.0	0.2	10.0							10.0					
800	T.S. C.P. L. Lith.	TSw2	8	40	<1	1.2	1.6	10.0							10.0					

* CORE RQD—Determined from piece lengths formed by all types of fractures (C, I, N and V).

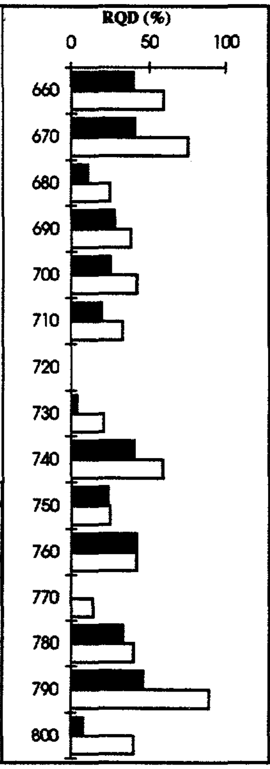
** ENHANCED RQD—Determined by filtering the effects of fractures identified as coring induced (Type C) from the piece lengths.

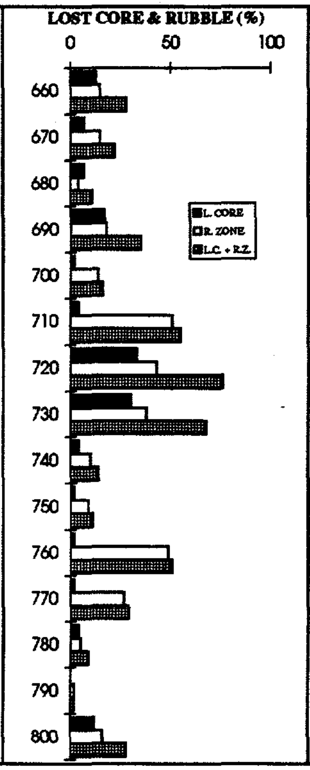
*** Footage in interval may not equal 10 ft because of lost core, rubble, or ommission during logging.

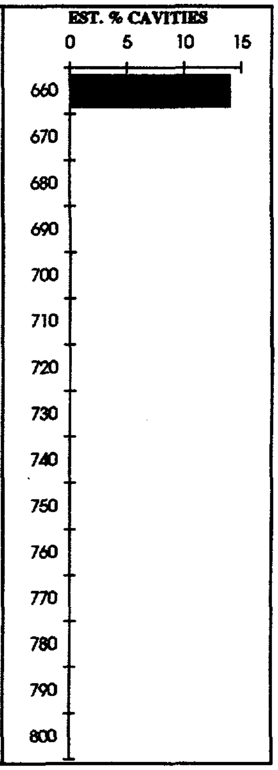
9



CORE RQD Summary		*ENHANCED RQD Summary*	
Mean	24.20	Mean	40.13
Median	25	Median	40
Mode	41	Mode	59
Standard Deviation	16.3	Standard Deviation	23.1
Variance	266.6	Variance	535.4
Range	46	Range	89
Minimum	0	Minimum	0
Maximum	46	Maximum	89
Sum	363	Sum	602
Count	15	Count	15



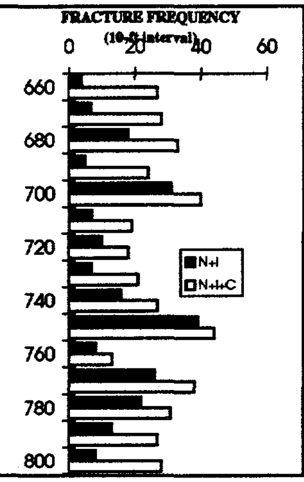




YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

Core Hole Structural Data Summary
Hole USW SD-12
Interval—650–800 ft, Middle Nonlithophysal Zone

BASE OF 10-FT INTERVAL	STRATIGRAPHY ZONE	THERMO-MECHANICAL UNIT	FEATURE TYPE				NO. OF FRACTURES W/INCLINATION (degrees)								
			N	I	C	V	10	20	30	40	50	60	70	80	90
660	T.S. C.P. U. Lith.	TSw1	4		23						1			2	1
670	T.S. C.P. M. Nonlith.	TSw2	6	1	21			1			2			2	2
680	T.S. C.P. M. Nonlith.	TSw2	9	9	15		7				1		2	1	7
690	T.S. C.P. M. Nonlith.	TSw2	3	2	19			1	1			1			2
700	T.S. C.P. M. Nonlith.	TSw2	27	4	9		12	6	1		1	2	4	1	4
710	T.S. C.P. M. Nonlith.	TSw2	4	3	12			1	1		1	1		2	1
720	T.S. C.P. M. Nonlith.	TSw2	7	3	8		4	2					1	1	2
730	T.S. C.P. M. Nonlith.	TSw2	5	2	14				1				1	2	3
740	T.S. C.P. M. Nonlith.	TSw2	4	12	11		2	2	2	1		1	3	1	4
750	T.S. C.P. M. Nonlith.	TSw2		39	5			33							6
760	T.S. C.P. M. Nonlith.	TSw2		8	5		3	3			1				1
770	T.S. C.P. M. Nonlith.	TSw2	16	10	12		7	4	1			1		3	10
780	T.S. C.P. M. Nonlith.	TSw2	9	13	9		4	1			3	3	5	3	3
790	T.S. C.P. M. Nonlith.	TSw2	5	8	14		4	1	2			1	2	2	1
800	T.S. C.P. L. Lith.	TSw2	3	5	20	1	1								7
TOTAL			102	119	197	1	44	55	9	1	10	10	18	20	54
PERCENT OF OCCURRENCE			24.3	28.4	47	0.24	19.9	24.9	4.07	0.45	4.52	4.52	8.14	9.05	24.



NO. OF FRACTURES W/MINERAL INFILLING TYPE														NO. OF FRACTURES W/INFILL THICKNESS					NO. OF FRACTURES W/PLANARITY CODE				NO. OF FRACTURES W/ROUGHNESS CODE				
C	WC	WN	BC	BD	TD	TC	CA	SI	MN	CL	TN	FE	BN	S	T	M	V	E	P	C	S	I	V	R	M	S	P
4																			4							3	1
2		1		4										5					6		1				1	6	
7		1		10										11					8	5	1	1			5	10	
2		1		2										3					2	2		1		1	2	2	
4		1		26										26	1				26	3		1		1	8	21	
3				4										4					4	1		2		2	2	3	
3				6	1									7					6	3				1	1	7	
2				5										5					4	1		1			1	5	
12	2			2										3	1				12	2		2		2	9	2	1
39																			37	2					35	4	
8																			4	1					2	3	
10	1	1		14										15	1				17	2		5	1	1	7	14	
13	1	5		3										6	3				16	4		1		3	12	4	
8		5													5				11	1		1		2	3	4	
5	1			2										2	1				3	2		1	2		1	3	
122	5	15	0	78	1	0	0	0	0	0	0	0	0	87	12	0	0	0	160	29	2	16	3	13	89	91	2
55.2	2.26	6.79	0	35.3	0.45	0	0	0	0	0	0	0	0	87.9	12.1	0	0	0	77.3	14	0.97	7.73	1.52	6.57	44.9	46	1.01

REVISION HISTORY

Revision 1	Jn and SRF parameters revised due to inclusion of additional data from mapping of the North Ramp tunnel.

EXPLANATION OF CALCULATION

Rock mass quality indices, Q (Barton et al., 1974) and RMR (Bieniawski, 1979), have been estimated for 10-ft intervals using Rock Structural Data Summaries developed from structural logging of the core, observations of rock conditions in the North Ramp Starter Tunnel and North Ramp tunnel, and laboratory testing data.

- Q is developed to evaluate the distribution of rock mass quality as a basis for developing the range of credible rock mass quality to establish the ground support requirements within rock units and to derive rock mass mechanical properties according to the methodology proposed by Hardy and Bauer (1991), Procedures used in the calculation were:

$$Q = \frac{RQD^{**}}{Jn^{*}} \bullet \frac{Jr}{Ja} \bullet \frac{Jw}{SRF^{*}}$$

Note: Any spatial correlation may be masked by Monte Carlo simulation of Jn and SRF.

where RQD** = Core RQD where all fractures types [natural (N), indeterminate (I), coring induced (C) and vugs (V)] have been considered in determination of RQD. If the RQD is less than 10%, the value used is set to 10 as per Barton et al. (1974). By definition, soil-like materials are considered to have zero RQD.

Jn* = Joint Set Numbers: Cannot be determined from the core log data and are generated by Monte-Carlo simulation assuming a uniform distribution of values between 1 and 12 derived from mapping of the North Ramp tunnel.

Jr = Joint Roughness Number: A weighted average value derived based on the N and I type fractures in the 10-ft interval.

Ja = Joint Alteration Number: A weighted average value derived from the description of N and I type fractures in the interval.

Jw = Joint Water Factor: Set equal to 1.0 assuming dry conditions.

SRF* = Stress Reduction Factor: For nonwelded units, SRF is determined from the ratio of UCS/σ_1 (UCS = unconfined compressive strength, σ_1 = overburden stress). If unconfined compressive strength data is not available for the 10-ft interval, a compressive strength is generated by Monte Carlo simulation using laboratory test data for the thermomechanical units. For welded tuff units, SRF cannot be determined from core log data and is generated by Monte Carlo simulation assuming a distribution derived from mapping of the North Ramp tunnel.

- The use of the Core RQD is conservative since it includes the effect of coring induced breaks. Filtering the effects of coring induced breaks from the RQD calculation ("Enhanced RQD") produced an increase in the mean RQD. The mean values for thermomechanical units in USW SD-12 are:

	Core RQD	Enhanced RQD
TCw	35.6%	55.7%
PTn	80.1%	88.8%
TSw1	35.5%	55.3%
TSw2	13.7%	23.5%

- RMR is estimated based on the Rock Structural Summary log data, and rock strength data. Procedures used in the calculation were:

$$RMR = C + RQD\text{-}I + JS + JC + JW$$

where C = Rock Strength Index: Derived from compressive strength estimated by unconfined compressive strength laboratory test data for the 10-ft interval. If data is not available for the 10-ft interval, a compressive strength is generated by Monte-Carlo simulation using laboratory test data for the thermomechanical unit.

RQD-I = RQD Index: Derived using the Core RQD value for the 10-ft interval.

JS = Joint Spacing Index: Derived from the rock structural data for the 10-ft interval, excludes coring induced features.

JC = Discontinuity Condition Index: Derived from the description of fractures in the 10-ft interval.

JW = Groundwater Index: Assumed dry conditions

- Q and RMR data are presented in log format to associate parameters with depth intervals in the core log; however, any spatial correlation may be masked by Monte-Carlo simulation.

STRATIGRAPHIC ABBREVIATIONS

T.C.	Tiva Canyon Tuff	C.P. M. Nonlith.	Crystal-Poor Middle Nonlithophysal Zone
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone
	Bedded Tuff		
Y.M.	Yucca Mountain Tuff		
	Bedded Tuff		
P.C.	Pah Canyon Tuff		
	Bedded Tuff		
T.S.	Topopah Spring Tuff	C.R. Vitric	Crystal-Rich Vitric Zone
		C.R. Nonlith.	Crystal-Rich Nonlithophysal Zone
		C.R. Lith.	Crystal-Rich Lithophysal Zone
		C.P. U. Lith.	Crystal-Poor Upper Lithophysal Zone
		C.P. M. Nonlith.	Crystal-Poor Middle Nonlithophysal Zone
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone Vitrophyre
		C.P. Vitric NW	Crystal-Poor Vitric Zone Non- to Partially Welded and Moderately Welded
	Bedded Tuff		
C.H.	Calico Hills Formation		

THERMOMECHANICAL UNITS

UO—Undifferentiated Overburden
TCw—Tiva Canyon Welded Unit
PTn—Upper Paintbrush Nonwelded Unit
TSw1—Topopah Spring Welded Unit—Lithophysae Rich
TSw2—Topopah Spring Welded Unit—Lithophysae Poor
TSw3—Topopah Spring Welded Unit—Vitrophyre
CHn1—Calico Hills and Lower Paintbrush Nonwelded Unit

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
Estimated Rock Mass Quality Indices Based on Core Log Data
Hole USW SD-12
Interval — 650–800 ft, Middle Nonlithophysal Zone

END DEPTH	STRATIGRAPHY ZONE	THERMO-MECHANICAL UNIT	Q CLASSIFICATION SYSTEM [1] Barton et al. (1974)							RMR CLASSIFICATION SYSTEM [2] Bieniawski (1979)					
			RQD** (%	Jn*	Jr	Ja	Jw	SRF*	Q*	C	RQD-I	JS	JC	JW	RMR
660	T.S. C.P. U. Lith.	TSw1	40	6.00	0.88	1.00	1.00	5.00	1.17	4	8	8	17.6	15	52.6
670	T.S. C.P. M. Nonlith.	TSw2	41	9.00	1.29	1.29	1.00	5.00	0.91	15	8	8	18.4	15	64.4
680	T.S. C.P. M. Nonlith.	TSw2	11	9.00	1.47	1.11	1.00	5.00	0.32	12	3	8	20.7	15	58.7
690	T.S. C.P. M. Nonlith.	TSw2	28	9.00	1.80	1.40	1.00	5.00	0.80	12	8	8	20.7	15	63.7
700	T.S. C.P. M. Nonlith.	TSw2	25	9.00	1.33	1.06	1.00	5.00	0.70	7	8	8	19.0	15	57.0
710	T.S. C.P. M. Nonlith.	TSw2	20	3.00	1.86	1.00	1.00	1.00	12.38	12	3	8	22.1	15	60.1
720	T.S. C.P. M. Nonlith.	TSw2	0	9.00	2.10	1.22	1.00	7.50	0.26	12	3	5	23.1	15	58.1
730	T.S. C.P. M. Nonlith.	TSw2	4	9.00	1.33	1.00	1.00	5.00	0.30	7	3	5	20.5	15	50.5
740	T.S. C.P. M. Nonlith.	TSw2	41	9.00	1.89	1.00	1.00	7.50	1.15	12	8	8	20.8	15	63.8
750	T.S. C.P. M. Nonlith.	TSw2	24	6.00	1.90	1.00	1.00	5.00	1.52	12	3	8	19.6	15	57.6
760	T.S. C.P. M. Nonlith.	TSw2	42	9.00	1.40	1.00	1.00	5.00	1.31	15	8	8	19.5	15	65.5
770	T.S. C.P. M. Nonlith.	TSw2	0	9.00	1.61	1.08	1.00	5.00	0.33	15	3	8	20.5	15	61.5
780	T.S. C.P. M. Nonlith.	TSw2	33	6.00	1.84	1.45	1.00	5.00	1.39	12	8	8	18.6	15	61.6
790	T.S. C.P. M. Nonlith.	TSw2	46	9.00	1.67	1.77	1.00	5.00	0.96	7	8	8	16.8	15	54.8
800	T.S. C.P. L. Lith.	TSw2	8	6.00	1.67	1.00	1.00	5.00	0.56	12	3	8	21.8	15	59.8

Jn*, SRF* = interval values generated by Monte Carlo simulation; to calculate Q*.

RQD**: If RQD is less than 10, the value 10 is used in the calculation of Q* as per Barton et al. (1974).

[1] Barton, N., R. Lien, and J. Lunde, "Engineering Classification of Rock Masses for the Design of Tunnel Support," Rock Mechanics, 6:189-236 (Springer Verlag, 1974).

[2] Bieniawski, Z.T., "The Geomechanics Classification in Rock Engineering Applications," Proceedings, 4th International Congress on Rock Mechanics, Montreaux, Switzerland, 2:41-48 (A. A. Balkema, 1979).

Q

Jn — Joint Set Number
Jr — Joint Roughness Number
Ja — Joint Alteration Number
Jw — Joint Water Reduction Factor
SRF — Stress Reduction Factor

Q = (RQD/Jn)(Jr/Ja)(Jw/SRF)

RMR

C— Strength Index
RQD-I — RQD Index
JS — Joint Spacing Index
JC — Discontinuity Condition Index
JW — Groundwater Index

RMR - C + RQD-I + JS + JC +JW

USW UZ-14 CORE LOGS AND DATA

Geology and Rock Structure Log

Core Hole Rock Structural Data Summary

Estimated Rock Mass Quality Indices Based on Core Log Data

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
GEOLOGY AND ROCK STRUCTURE LOG
Hole USW UZ-14, 700-850 ft

Sandia National Laboratories
Print Date: 8/2/95
WBS 1.2.3.2.6.2.1
QA:L
Revision 0

BOREHOLE ID: USW UZ-14
STUDY PLAN NO: 8.3.1.2.2.1
CORE SIZE: HQ
DRILL DATES: 6/9/93–6/24/93
GROUND ELEV: 4425.40
COORDINATES: N771309.80
E560141.57

TOTAL DEPTH: 700–850 ft (partial)
ANGLE FROM VERT: 0°
AZIMUTH: NA

Field Rock Structure

Logged by:

M. Wagner	Drilling Support Division, Drilling Support and Sample Management Department, T&MSS
R. Myers	
M. Pitterle	
R. Wilcoxon	
A. Mendenhall	
C. Hermes	
D. Switzer	
M. Edwards	
R. Morris	

Relogged by:

Dick Lippoth	Agapito Associates, Inc.
Eric R. Martin	Agapito Associates, Inc.

Lithology and Stratigraphy

Logged by:

D. Engstrom	Sandia National Laboratories

Checked by:

Eric R. Martin	Agapito Associates, Inc.

Log prepared by Agapito Associates, Inc. for Sandia National Laboratories

EXPLANATION
GEOLOGY AND ROCK STRUCTURE

FRACTURE TYPE OR FEATURE

N Natural fractures are indicated by mineral coatings, evidence of weathering, slickensides, lack of rematch/fit between sides or by surfaces that form an ellipse in the core.

C Coring-induced fractures are generally normal to the axis of the core or indicate some torquing of the core. They are typically clean, fresh and fit tightly back together.

I Indeterminate fractures are those not clearly described as "N" or "C." This includes fracture surfaces that have been shaped by drilling rotation.

H Handling-induced fractures are formed in the core by removal from the core barrel or placement in the core box. These fractures are witnessed and, according to BTP-SMF-008, are marked by the SMF personnel by lines parallel to the fracture on both sides of the core. "H" fractures are typically not recorded in the log unless there is a specific reason.

V Vug or large void.

P Foliation plane due to gravity flattening upon deposition, not a fracture.

LOST CORE AND RUBBLE

☒ LOST CORE

|×.20 ×| RUBBLE ZONE
(with average maximum diameter of rubble pieces to nearest 0.01 ft;
NM = not measured)

HARDNESS (Subjective estimate, YMP procedures do not allow core to be broken or scratched etc.)

1 Extremely Hard—Cannot be scratched, chipped only with repeated heavy hammer blows.
2 Very Hard—Cannot be scratched, broken only with repeated heavy hammer blows.
3 Hard—Scratched with heavy pressure, breaks with heavy hammer blow.
4 Moderately Hard—Scratched with light-moderate pressure, breaks with moderate hammer blow.
5 Moderately Soft—Grooved (16th in.) with moderate heavy pressure, breaks with light hammer blow.
6 Soft—Grooved easily with light pressure, scratched with fingernail, breaks with light-moderate manual pressure.
7 Very Soft—Readily gouged with fingernail, breaks with light manual pressure.
8 Soil Like—Cohesive
9 Soil Like—Non-cohesive

WEATHERING

F Fresh—Rock and fractures not oxidized or discolored, no separation of grains, change of texture or solutioning.

S Slightly Weathered—Oxidized or discolored fractures and nearby rock, some dull feldspars, no separation of grains, minor leaching.

M Moderately Weathered—Fractures and most of rock oxidized or discolored, partial separation of grains, crystals rusty or cloudy, moderate leaching of soluble minerals.

I Intensely Weathered—Fractures and rock totally oxidized or discolored, extensive clay alteration, leaching complete, grain separation extensive, rock is friable.

D Decomposed—Grain separation and clay alteration complete.

PLANARITY

P Planar
C Curved
S Stepped
I Irregular

ROUGHNESS

V Very rough, stepped, near-normal steps and ridges occur.
R Rough, large angular asperities can be seen.
M Moderately rough, asperities clearly visible, surface has an abrasive feel; to slightly rough, small asperities are visible and can be felt.
S Smooth, no asperities, smooth to the touch.
P Polished, slickensided, extremely smooth and shiny.

INFILLING THICKNESS AND MINERALIZATION

C Clean, no filling.
S Very thin, surface sheen
T Thin (up to 0.1 inches)
M Moderately thick (0.1 - 0.4 inches)
V Very thick (0.4 - 1.0 inches)
E Extremely thick, greater than 1.0 inches)

C Clean
WC White, crystalline
WN White, non-crystalline
TD Brown dendritic
TC Tan crystalline
TN Tan, non-crystalline

CA Calcite
SI Silica
MN Manganese
CL Clay
BC Black crystalline
BD Black dendritic

USW UZ-14 8/2/95

EXPLANATION (concluded)
GEOLOGY AND ROCK STRUCTURE

CORE RQD

Core RQD is calculated using piece lengths that are defined by all fractures (type N, I, and C) that exist in the core when it is removed from the core barrel. Only handling-induced breaks are discounted in piece length determination. RQD is calculated as:

$$RQD = \frac{\sum \textit{Piece lengths} \geq 0.33\,ft}{\textit{Interval length}} \times 100.$$

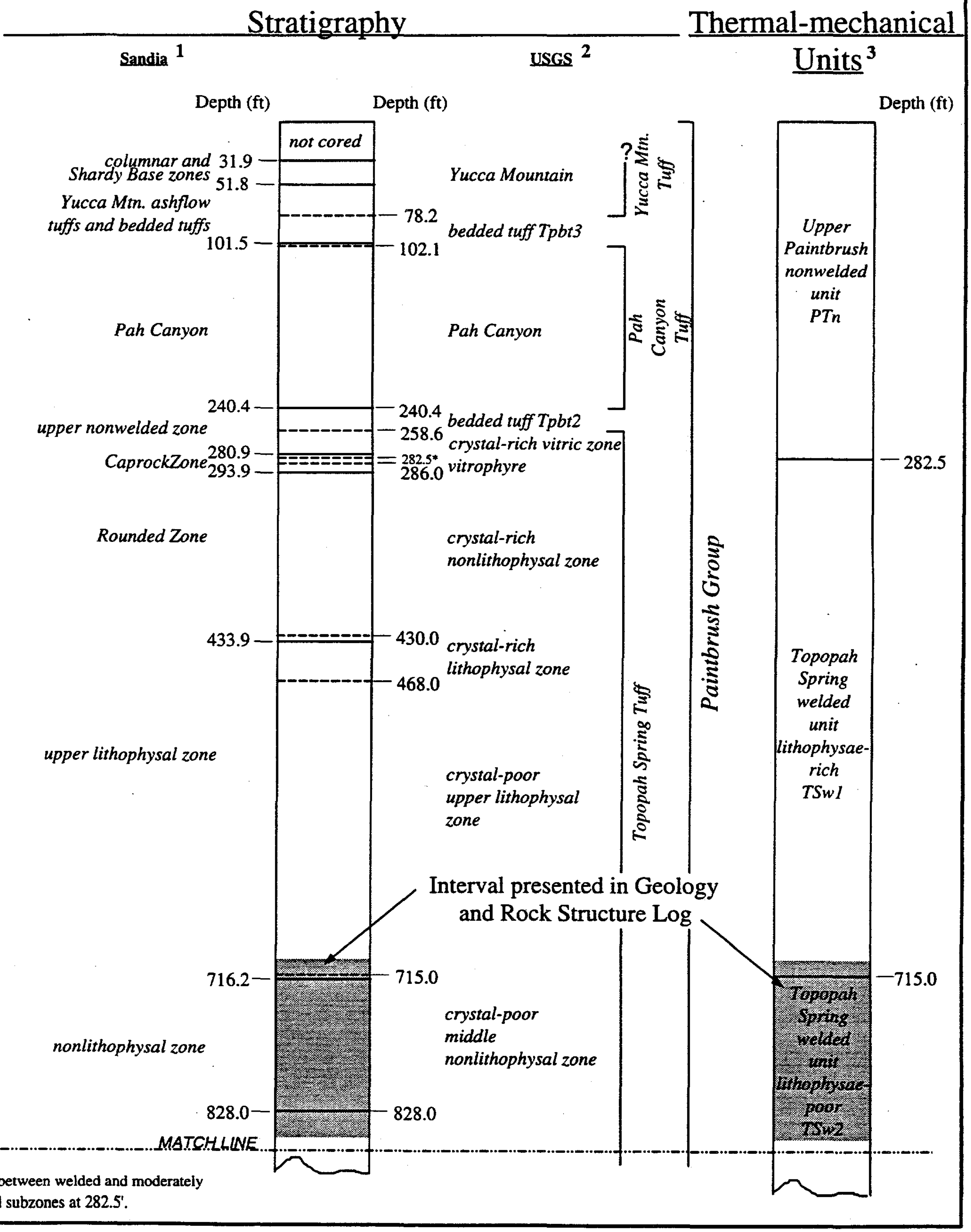
RQD is calculated for both the core run interval (run RQD) and even 10-ft intervals. If a piece length $\geq$ 0.33 ft crosses over a 10-ft interval boundary, the portion of the piece length that occurs in the 10-ft interval is included in the summation.

ESTIMATED PERCENTAGE LITHOPHYSAE & OTHER CAVITIES

The percentage of lithophysal voids and other cavities is estimated for each core run interval where sufficient whole core is available. Excessive lost core and rubble zones may prevent the estimate on specific core runs. The estimate is based on comparison of the core with charts designed for estimating the proportions of various rock or mineral components. Estimates are then spot checked using a quantitative graphical summation technique to calculate the percent area occupied by lithophysal cavities in core photographs or video tape.

The estimated percent cavities volume for core runs is used to calculate a run length, weighted average for even 10-ft intervals. (Runs for which percent cavities cannot be determined are assumed to have the average percentage for the 10-ft interval; intervals for which the percent cavities were not estimated are labeled "Not Measured;" zones containing vapor-phase alteration and very small or no lithophysal cavities are labeled as <1%).

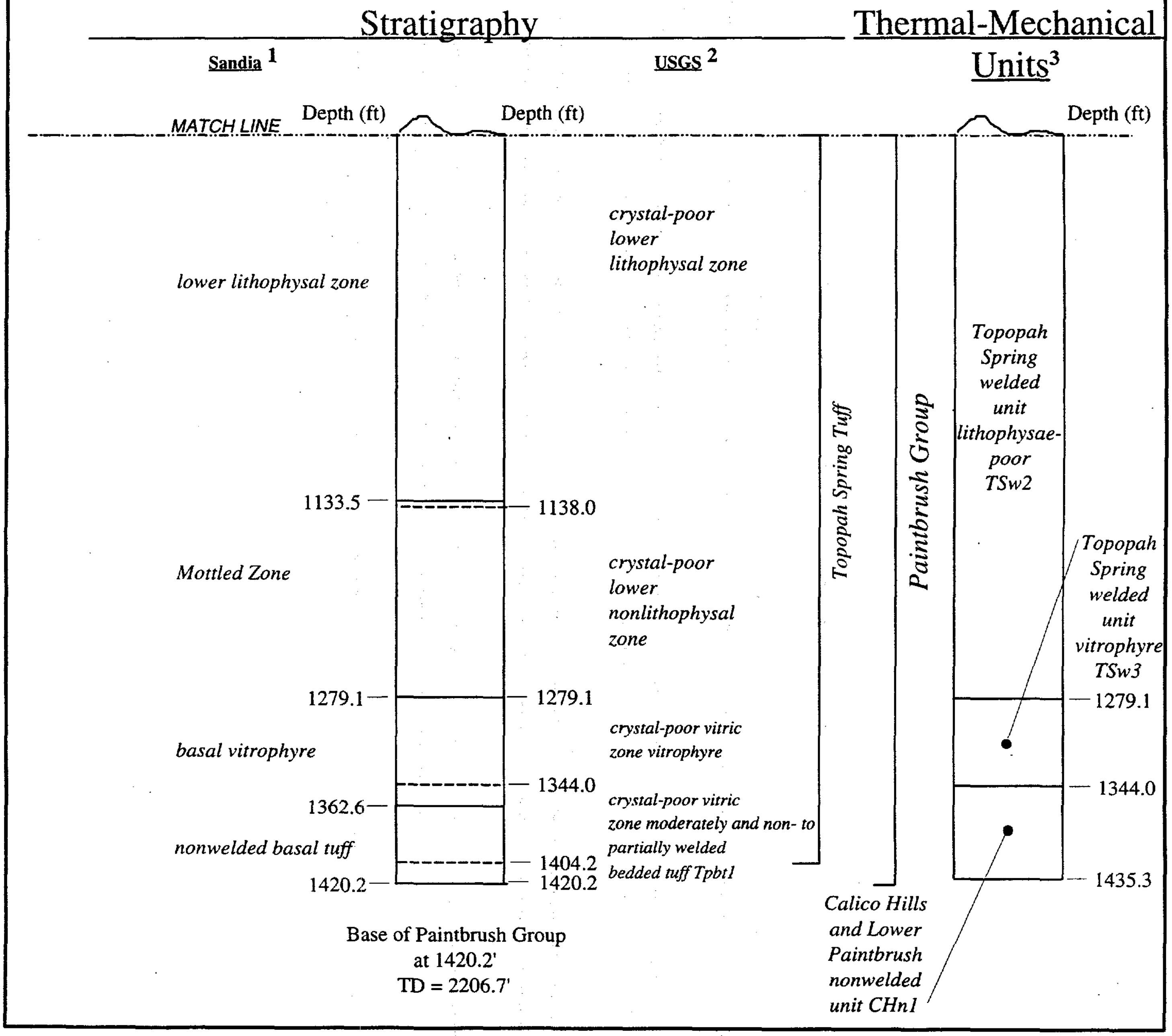
UZ-14 (1 of 2)
Stratigraphic and Thermal-Mechanical Units Summary
0 - 860 ft



*Break between welded and moderately welded subzones at 282.5'.

Date: 8/2/95

UZ-14 (2 of 2)
Stratigraphic and Thermal-Mechanical Units Summary
860 - 1420.2 ft



Date: 8/2/95

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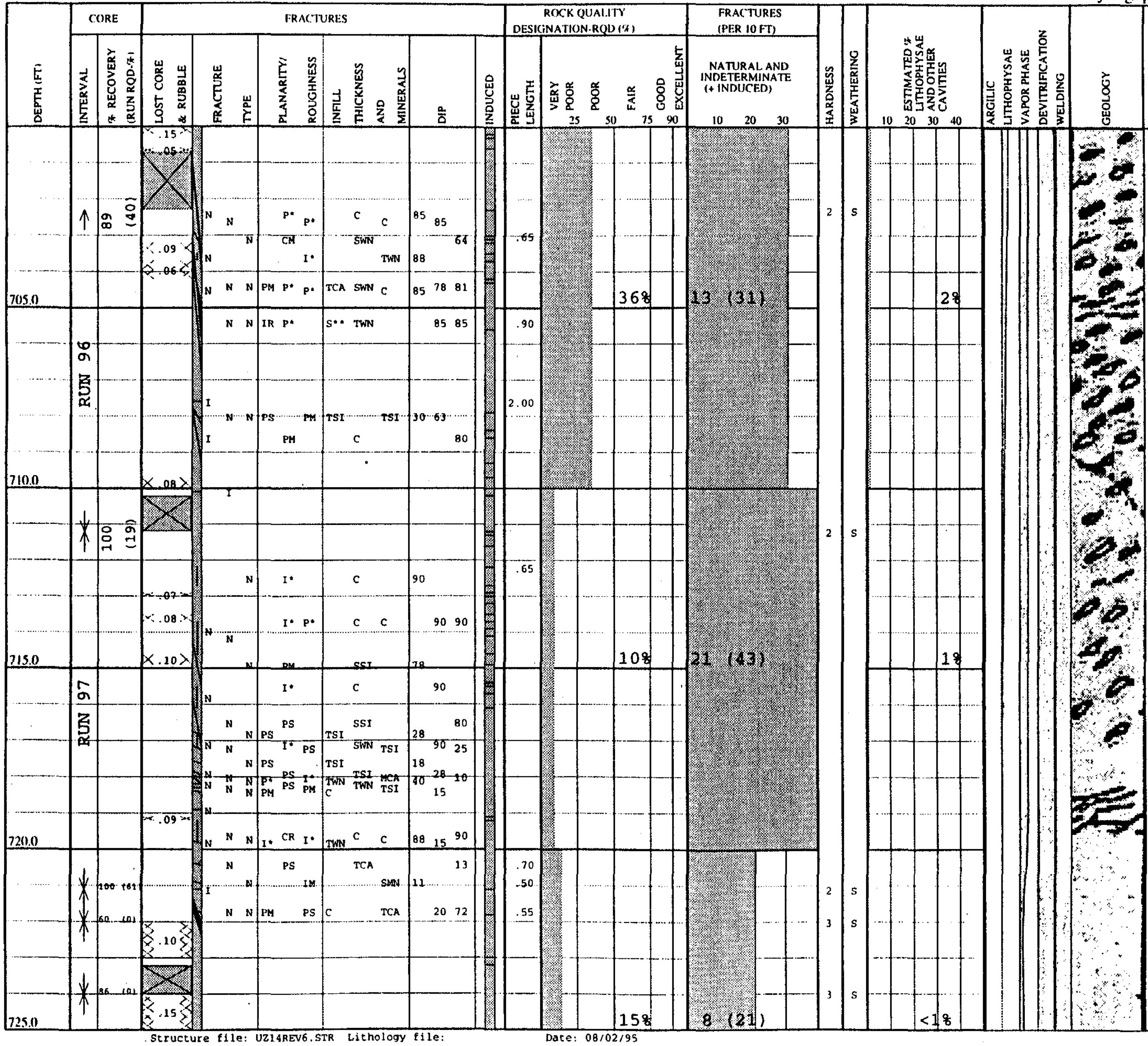
[1] Lithologic log of Borehole UZ-14. Dale Engstrom, unpublished data. Terminology based on nomenclature of Scott & Bonk, USGS OFR 84-494.

[2] Summary of lithologic logging of new and existing boreholes at Yucca Mountain, Nevada, July 1994 to November 1994. T.C. Moyer, J.K. Geslin, and D.C. Buesch; USGS OFR 95-102, in press.

[3] Thermal-mechanical units as defined by Buesch, et al., USGS Open File Report 94-469, 1996. "Revised stratigraphic nomenclature and macroscopic identification of lithostratigraphic units of the Paintbrush Group exposed at Yucca Mountain, Nevada."

GEOLOGY AND ROCK STRUCTURE LOG

USW UZ-14
by Agapito Associates, Inc.



. Structure file: UZ14REV6.STR Lithology file:

Date: 08/02/95

WPlog v 6.00

LITHOLOGIC DESCRIPTION AND STRATIGRAPHY

433.7-716.2 ft. TOPOPAH SPRING, UPPER LITHOPHYSAL (cont'd.) Light red gray, densely welded, devitrified, lithophysal intensity decreases downward until cavities are flat, thin, vuggy, coated by crystalline vapor-phase mineralization; circular light pink-tan alteration halo around lithophysae, 50-60% of groundmass is pervasively blue altered; islands of unaltered groundmass; 1-3% quartz latite soft lithic clasts to 50mm, 2-3% feldspar phenocrysts, trace biotite.

704.7-705.1 ft. Zone of reduced lithophysal intensity.

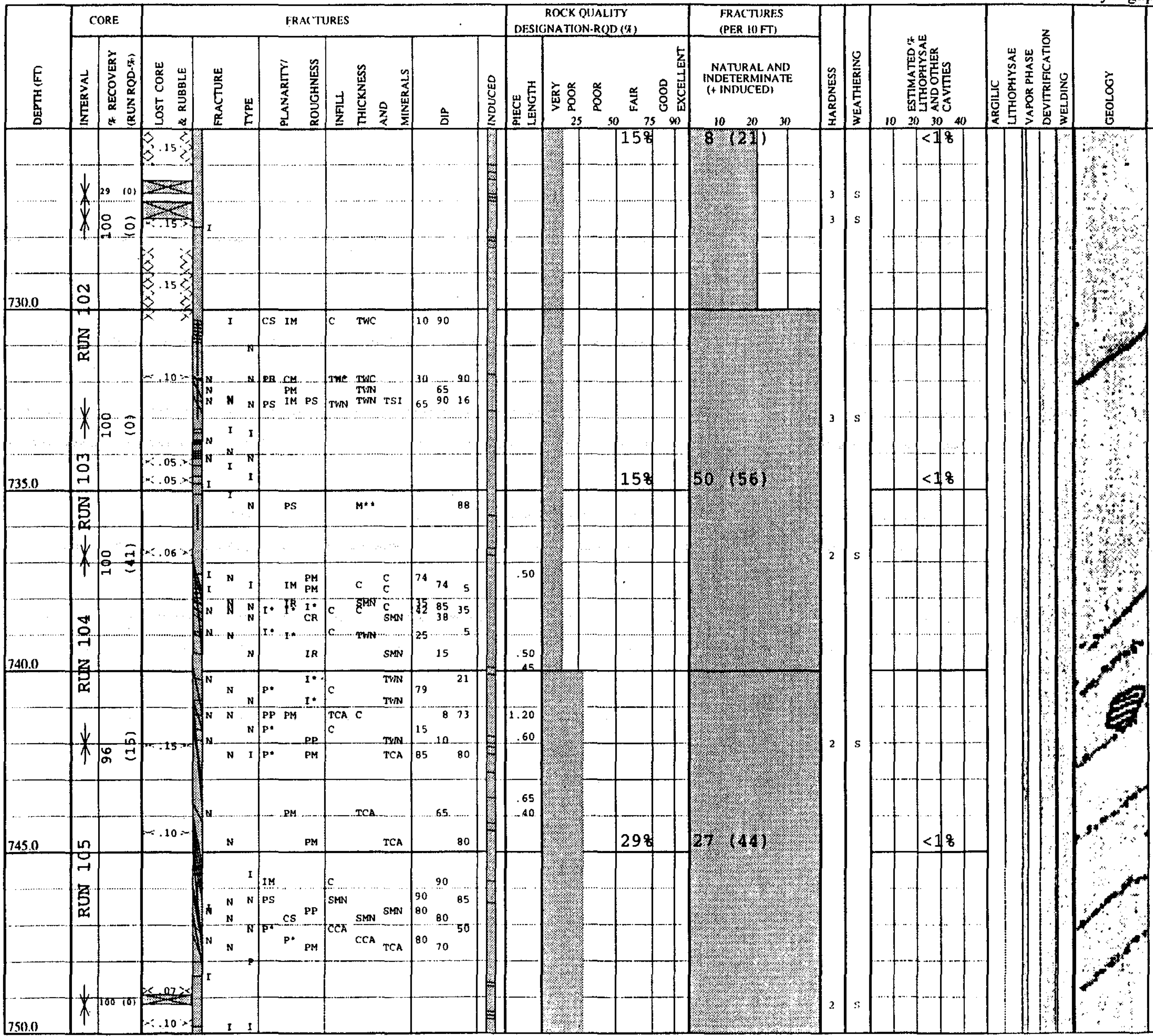
708.9 ft. Decrease in percentage of 1-3cm lithophysae. The amount of lithophysae (1-3cm diameter) decreases below 694.4 ft (possibly 693.9) and definitely below 702.5 ft.

716.2-828.0 ft. TOPOPAH SPRING, MIDDLE NONLITHOPHYSAL ZONE. Sudden color change to weakly mottled texture. Densely welded, devitrified. Blue alteration disappears. Orange-gray groundmass has weak vapor-phase speckles (7mm) around hairline replacement of very flat pumice (extreme welding). 1-2% feldspar phenocrysts, trace biotite.

Sandia National Laboratories

GEOLOGY AND ROCK STRUCTURE LOG

USW UZ-14
by Agapito Associates, Inc.



LITHOLOGIC DESCRIPTION AND STRATIGRAPHY

716.2-828.0 ft. TOPOPAH SPRING, MIDDLE NONLITHOPHYSAL ZONE cont'd (tm). Pale red-gray, densely welded, devitrified, 10% nearly invisible pumice, orange-gray groundmass has weak vapor-phase alteration speckles around hairline replacement of very flat pumice, 2-4% light gray porphyritic volcanic clasts, 2% feldspar phenocrysts, trace biotite.
724.2-732.0 ft. Broken.

732.0 ft. 1mm vapor-phase veinlet.

738.5-748.0 ft. Zone of 1/2 to 1mm vapor-phase veinlets spaced approximately each foot, with alteration haloes.

740.9 ft. 4x6cm rhyolite xenolith.

742.5 ft. 3x5cm rhyolite xenolith.

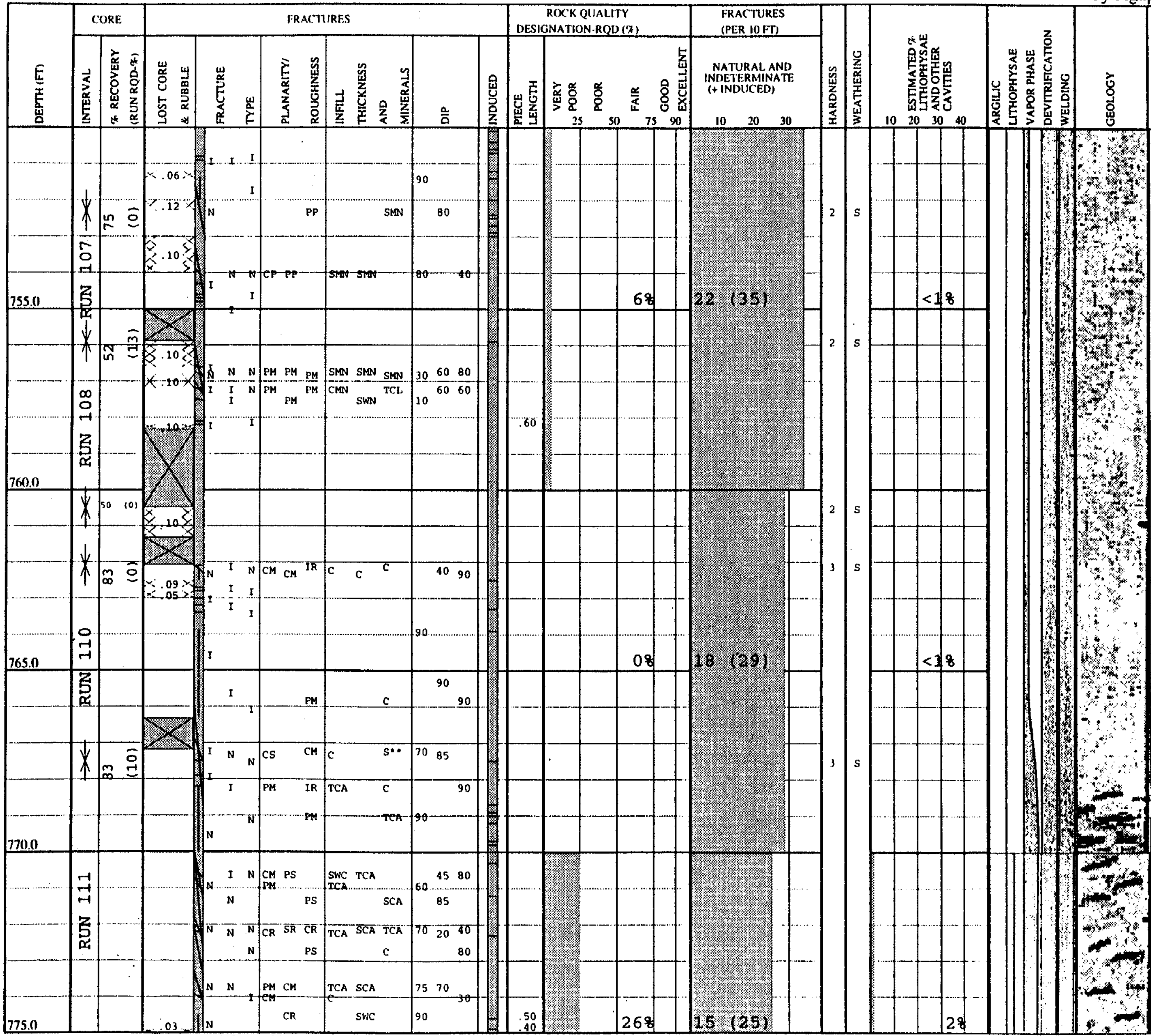
744.5-757.3 ft. Shattered.

Structure file: UZ14REV6.STR Lithology file: Date: 08/02/95 WPlog v 6.00

Sandia National Laboratories

GEOLOGY AND ROCK STRUCTURE LOG

USW UZ-14
by Agapito Associates, Inc.



716.2-828.0 ft. TOPOPAH SPRING, MIDDLE NONLITHOPHYSAL ZONE cont'd (tm). Pale red-gray, densely welded, devitrified, 10% nearly invisible pumice, orange-gray groundmass has weak vapor-phase alteration speckles around hairline replacement of very flat pumice, 2-4% light gray porphyritic volcanic clasts, 2% feldspar phenocrysts, trace biotite. 744.5-757.3 ft. Shattered.

760.5-762.1 ft. Broken.

768.2 ft. LITHOPHYSAE-BEARING SUBZONE. Blue moderate to intense vapor-phase alteration composes as much as 90% of rock volume. Vapor-phase alteration rims very flat pumice/hairline replacement mineralization. Patchy blue alteration texture mixed with vapor-phase alteration, 1mm hairline crystalline mineralization replaces pumice, 5mm blue-gray alternation haloes, all 95% blue pervasive alteration with rare islands of devitrified groundmass.

Structure file: UZ14REV6.STR Lithology file: Date: 08/02/95 WPlog v 6.00

GEOLOGY AND ROCK STRUCTURE LOG

USW UZ-14
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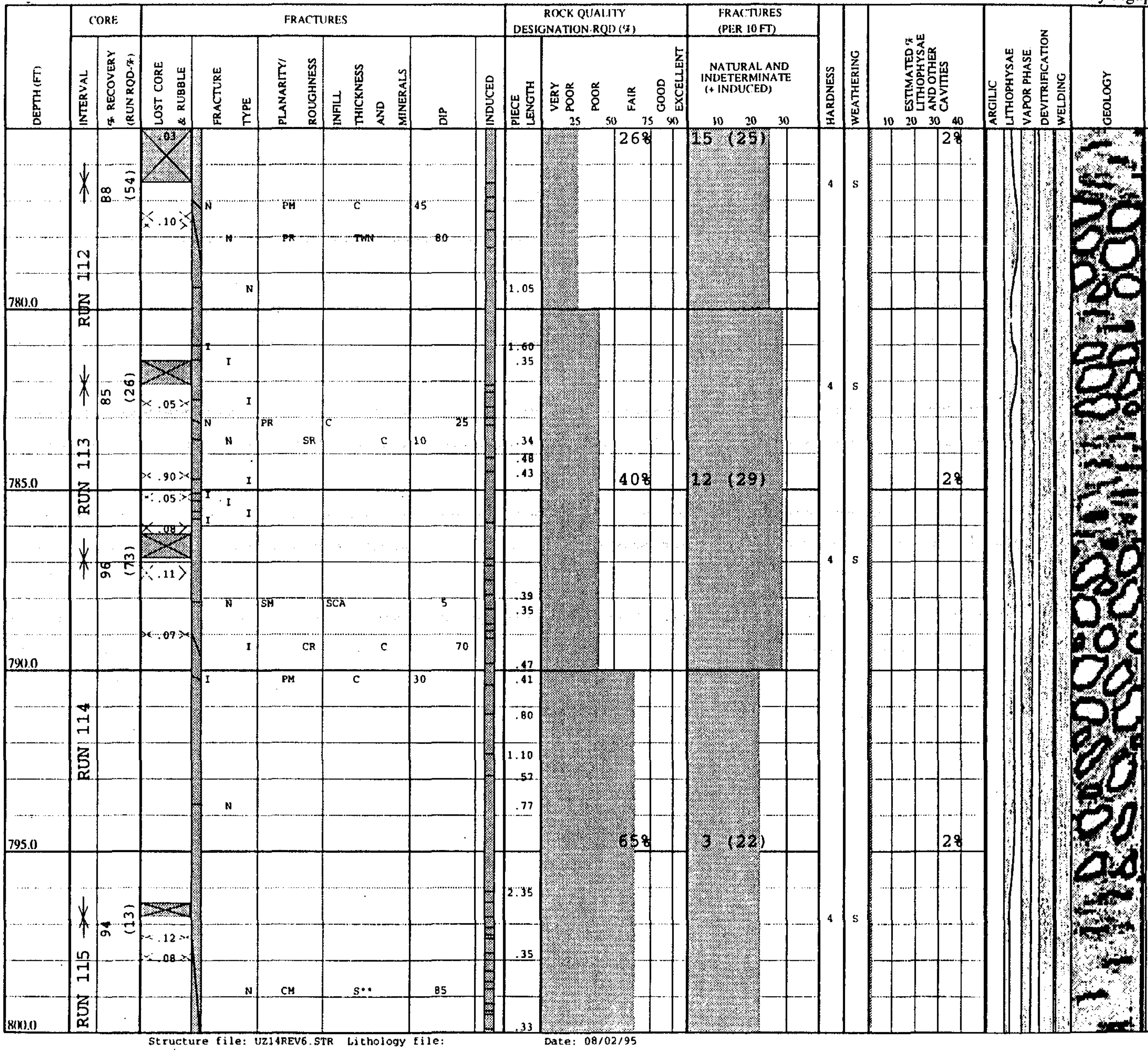


LITHOLOGIC DESCRIPTION AND STRATIGRAPHY

716.2-828.0 ft. TOPOPAH SPRING, MIDDLE NONLITHOPHYSAL ZONE cont'd (tm). Light red-gray, densely welded, devitrified, patchy eutaxitic groundmass texture; most pumice flattened to hairline replaced by vapor-phase mineralization; circular 10-20mm light pink gray alteration haloes around pumice, 1-2mm blue alteration border, 2-3% feldspar phenocrysts, trace biotite; intervals of large close-spaced lithophysae from 771.1-779.5, 781.0-783.0, and 786.5-796.0, and wide-spaced, large lithophysae from 835.5-878.0.

775.0-778.0 ft. Broken.

778.0-786.5 ft. 2-5% lithophysae in light pink-gray alteration spots.

784.5-787.5 ft. Broken

786.5-796.0 ft. Large lithophysae.

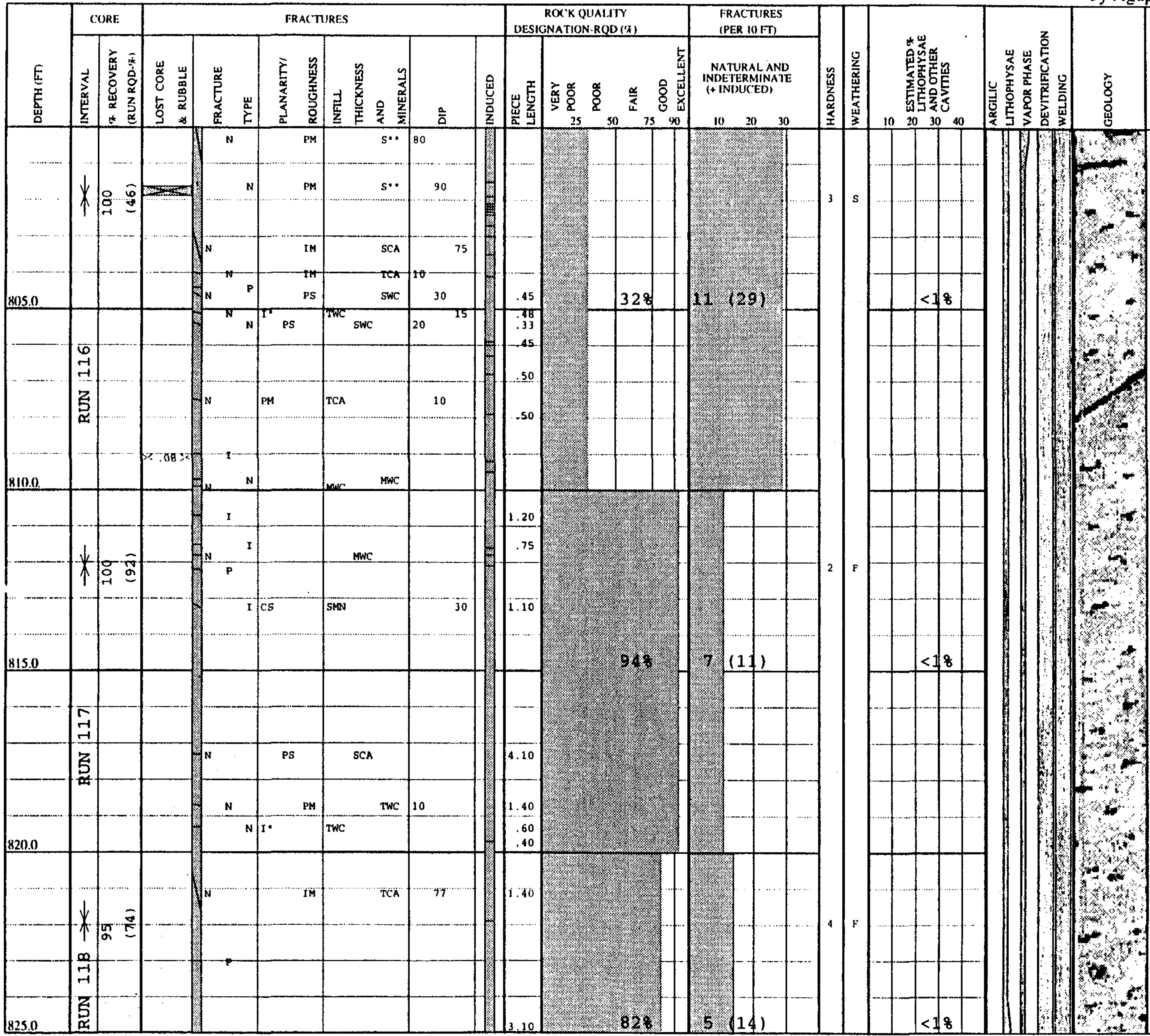
799.0-807.9 ft. Increase in light gray streaks to as much as 4%.

WPlog v 6.00

Sandia National Laboratories

GEOLOGY AND ROCK STRUCTURE LOG

USW UZ-14
by Agapito Associates, Inc.



716.2-828.0 ft. TOPOPAH SPRING, MIDDLE NONLITHOPHYSAL ZONE cont'd (tm). Light red-gray, densely welded, devitrified, patchy eutaxitic texture, crystal-lined pumice sites (veinlets) face downward. Weak alteration halo, 1-2mm wide across very flat pumice sites, primary vapor-phase crystalline mineralization gone from pumice; occasional rare veinlet of white vapor-phase mineralization.
803.1 ft. Trace porphyritic volcanic lithic clasts.
804.5-805.3 ft. Vapor-phase alteration decreasing until groundmass medium red.
808.0 ft. Light red gray.

819-819.7, 820.1-820.5, 821.2-821.3, 823.8-824.0 ft. Zones of blue vapor-phase alteration.

824.6-831.3 ft. Lithophysae intensity increasing.

Structure file: UZ14REV6.STR Lithology file: Date: 08/02/95 WPlog v 6.00

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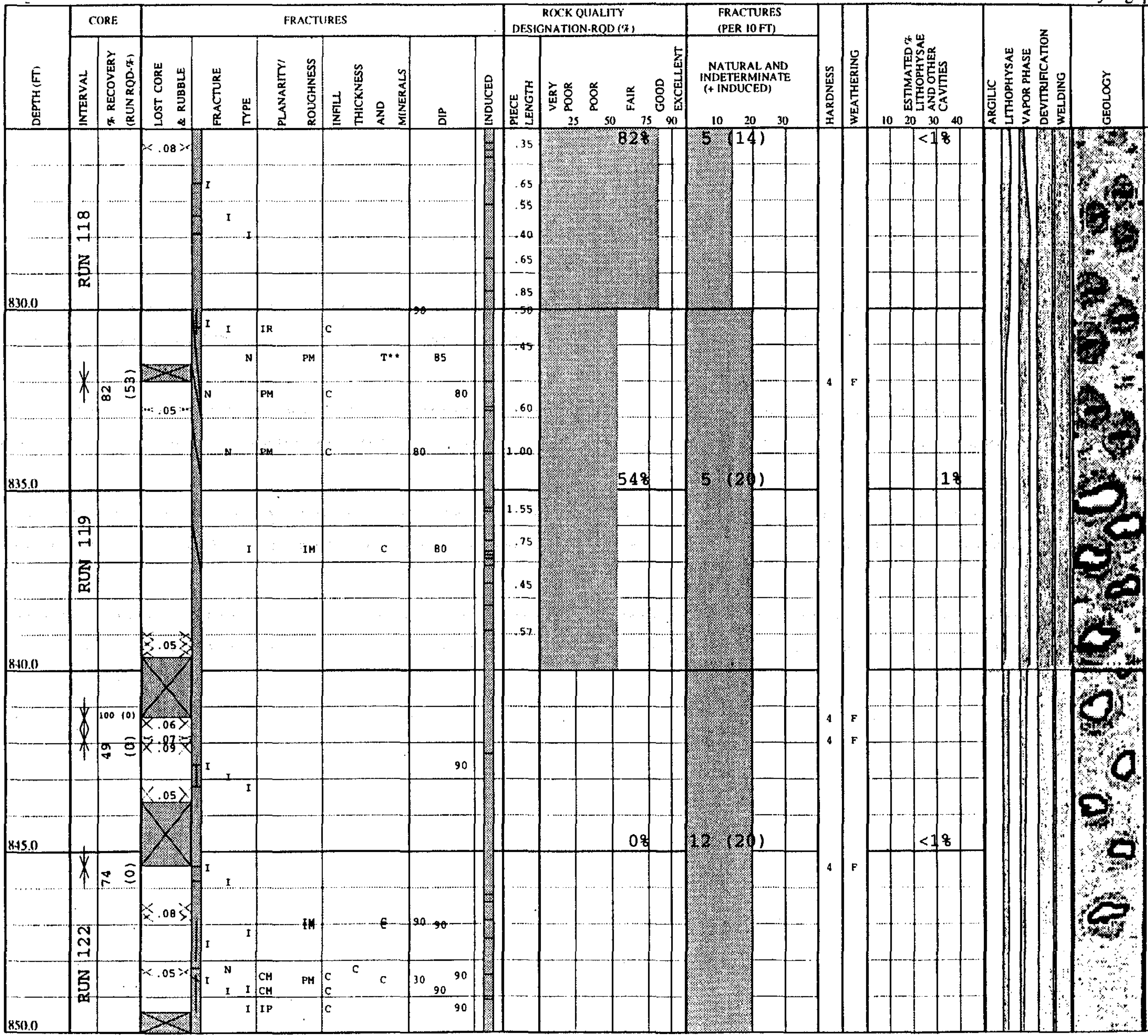
GEOLOGY AND ROCK STRUCTURE LOG

USW UZ-14
by Agapito Associates, Inc.



LITHOLOGIC DESCRIPTION AND STRATIGRAPHY

716.2-828.0 ft. TOPOPAH SPRING, MIDDLE NONLITHOPHYSAL ZONE cont'd (tm). Light red-gray, densely welded, devitrified, patchy altered texture, small alteration streaks.

824.6-831.3 ft. Lithophysae intensity increasing.

827.0-849.0 ft. Large diameter (40mm) circular spots of pink vapor-phase alteration around a flat white vapor-phase mineralization replacing pumice.

828-1133.5 ft. TOPOPAH SPRING, LOWER LITHOPHYSAL ZONE. Light red-gray, densely welded, devitrified ash-flow crystalline tuff. Small widely-spaced lithophysae return, rimmed by light pink vapor-phase alteration, in turn with blue, moderate to intense vapor-phase alteration. White, co-crystalline vapor-phase mineralization lines lithophysal cavities.

835.5-846.9 ft. Large widely-spaced lithophysae zone.

838.7-848.4 ft. Broken.

848.4 ft. Shattered.

Structure file: U214REV6.STR Lithology file: Date: 08/02/95 WPlog v 6.00

CODING EXPLANATION

STRATIGRAPHIC ABBREVIATIONS

T.C.	Tiva Canyon Tuff	C.P. M. Nonlith.	Crystal-Poor Middle Nonlithophysal Zone
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone
	Bedded Tuff		
Y.M.	Yucca Mountain Tuff		
	Bedded Tuff		
P.C.	Pah Canyon Tuff		
	Bedded Tuff		
T.S.	Topopah Spring Tuff	C.R. Vitric	Crystal-Rich Vitric Zone
		C.R. Nonlith.	Crystal-Rich Nonlithophysal Zone
		C.R. Lith.	Crystal-Rich Lithophysal Zone
		C.P. U. Lith.	Crystal-Poor Upper Lithophysal Zone
		C.P. M. Nonlith.	Crystal-Poor Middle Nonlith.
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone Vitrophyre
		C.P. Vitric NW	Crystal-Poor Vitric Zone Non- to Partially Welded and Moderately Welded
	Bedded Tuff		
C.H.	Calico Hills Formation		

THERMOMECHANICAL UNITS

UO—Undifferentiated Overburden
TCw—Tiva Canyon Welded Unit
PTn—Upper Paintbrush Nonwelded Unit
TSw1—Topopah Spring Welded Unit—Lithophysae Rich
TSw2—Topopah Spring Welded Unit—Lithophysae Poor
TSw3—Topopah Spring Welded Unit—Vitrophyre
CHn1—Calico Hills and Lower Paintbrush Nonwelded Unit

COLUMN INFORMATION (Page 3)

RQD (%)	$RQD\ (\%) = \frac{\sum Piece\ lengths \geq 0.33\ ft}{Interval\ length} \times 100.$
CORE RQD	Core RQD based on piece lengths defined by all types of fractures (C, I, N and V).
ENHANCED RQD	Effect of fractures identified as coring induced (Type C) are filtered from the piece lengths.
LITHOPHYSAL (and other cavities)	Percent void due to lithophysae and other cavities, estimated visually by counting the number of cavities, estimating the average diameter, calculating the void volume assuming spherical cavities, and normalizing to the core volume. NM—Not Measured

WEATHERING
Subjective evaluation of rock degradation by mechanical/chemical agents:

F: Fresh
S: Slightly weathered
M: Moderately weathered
I: Intensely weathered
D: Decomposed

HARDNESS
Subjective evaluation of resistance to breakage:

1: Extremely hard
2: Very hard
3: Hard
4: Moderately hard
5: Moderately soft
6: Soft
7: Very soft
8: Soil-like, cohesive
9: Soil-like, non-cohesive

COLUMN INFORMATION (Page 4)

FEATURE TYPE
Following codes indicate origin of feature:

N: Natural—indicated by mineral coating or evidence of weathering, slickensides, lack of fit between sides.
I: Indeterminate—origin questionable, rotated so that coatings possibly removed.
C: Coring induced—fresh, clean, tightly fitting breaks.
V: Vug or large void.

INCLINATION (degrees)
Angle between plane normal to core axis and plane of fracture (Type N and I only).

MINERAL INFILLING
Describes the infilling on fracture surfaces (Type N and I only):

C: Clean
WC: White crystalline
WN: White noncrystalline
BC: Black crystalline
BD: Black dendritic
TD: Brown dendritic
TC: Tan crystalline
CA: Calcite
SI: Silica
MN: Manganese
CL: Clay
TN: Tan noncrystalline
FE: Iron oxide
BN: Brown noncrystalline

INFILL THICKNESS
Describes the thickness of mineral infillings on the fracture surface (Type N and I only):

S: Very thin, surface sheen
T: Thin (up to 0.1 inches)
M: Moderately thick (0.1-0.4 inches)
V: Very thick (0.4 - 1.0 inches)
E: Extremely thick, greater than 1.0 inches

PLANARITY
Describes the overall shape of the feature (Type N and I only):

P: Planar
C: Curved
S: Stepped
I: Irregular

ROUGHNESS
Describes the local relief of the surface (Type N and I only):

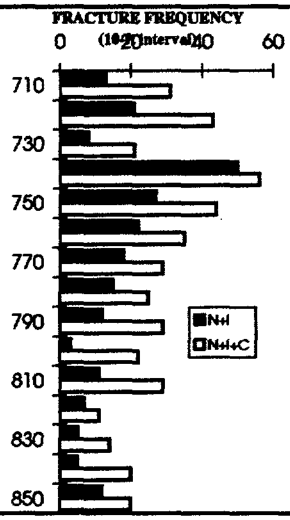
V: Very rough—stepped, near-normal steps and ridges occur.
R: Rough—large angular asperities can be seen.
M: Moderately rough—asperities clearly visible, surface has abrasive feel.
S: Smooth—no asperities, smooth to the touch.
P: Polished—slickensided, extremely smooth and shiny.

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

Core Hole Structural Data Summary

Hole USW UZ-14

Interval — 700-850 ft, Middle Nonlithophysal Zone

BASE OF 10-FT INTERVAL	STRATIGRAPHY ZONE	THERMO-MECHANICAL UNIT	FEATURE TYPE				FRACTURE FREQUENCY	NO. OF FRACTURES W/INCLINATION (degrees							
			N	I	C	V		10	20	30	40	50	60	70	80
710	T.S. C.P. U. Lith.	TSw1	11	2	18			1		1				2	2
720	T.S. C.P. U. Lith.	TSw1	20	1	22			5	3	3	1				2
730	T.S. C.P. M. Nonlith	TSw2	6	2	13			2	3						3
740	T.S. C.P. M. Nonlith	TSw2	31	19	6			30	2	2	3	1		2	2
750	T.S. C.P. M. Nonlith	TSw2	21	6	17			7	1	1		1		2	11
760	T.S. C.P. M. Nonlith	TSw2	7	15	13			13		1	1		3		3
770	T.S. C.P. M. Nonlith	TSw2	6	12	11			9			1			1	
780	T.S. C.P. M. Nonlith	TSw2	13	2	10			1	1	1	1	2	1	2	4
790	T.S. C.P. M. Nonlith	TSw2	3	9	17			10		1				1	
800	T.S. C.P. M. Nonlith	TSw2	2	1	19			1		1					
810	T.S. C.P. M. Nonlith	TSw2	10	1	18			5	2	1					2
820	T.S. C.P. M. Nonlith	TSw2	4	3	4			6		1					
830	T.S. C.P. M. Nonlith	TSw2	1	4	9			3							1
840	T.S. C.P. L. Lith.	TSw2	3	2	15			1							3
850	T.S. C.P. L. Lith.	TSw2	1	11	8			5		1					
TOTAL			139	90	200	0		99	12	14	7	4	4	10	33
PERCENT OF OCCURRENCE			32	21	47	0		43	5.2	6.1	3.1	1.7	1.7	4.4	14

NO. OF FRACTURES W/MINERAL INFILLING TYPE													NO. OF FRACTURES W/INFILL THICKNESS					NO. OF FRACTURES W/PLANARITY CODE				NO. OF FRACTURES W/ROUGHNESS CODE				
WC	WN	BC	BD	TD	TC	CA	SI	MN	CL	TN	FE	BN	S	T	M	V	E	P	C	S	I	V	R	M	S	P
	4					1	2						3	5				9	1		2		1	4	1	
	4					1	7						3	8	1			11	1		7		1	3	6	
						2		1					1	2				5			1			4	2	
9	6						1	3					3	17	2			11	3		19		4	18	6	
	3					10		4					4	11				18	1		3			9	2	4
	1							7	1				7	1				8	1					6		3
						2							1	2				3	4		2		2	6	1	
2	1					8							5	6				7	6	1			5	6	3	
						1							1					1	1	2			3	1		
													1					1	1					2		
5						3							5	3	2			5			3			5	2	
3						1		1					2	2	1			2	1		1			1	2	
						1								1							1			1		
														1				3			2		1	4		
																		1	2		3			5		1
19	19	0	0	0	0	30	10	16	1	0	0	0	36	59	6	0	0	85	22	3	44	0	17	75	25	8
8.3	8.3	0	0	0	0	13	4.4	7	0.4	0	0	0	36	58	5.9	0	0	55	14	1.9	29	0	14	60	20	6.4

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

Core Hole Structural Data Summary

Hole USW UZ-14

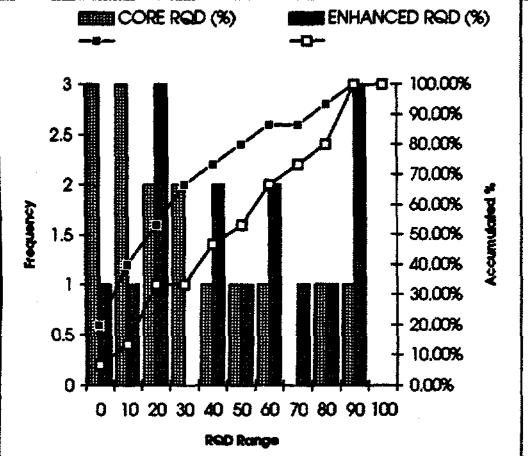
Interval — 700-850 ft, Middle Nonlithophysal Zone

BASE OF 10-FT INTERVAL	STRATI-GRAPHY ZONE	THERMO-MECHANICAL UNIT	CORE RQD* %	ENHANCED RQD** %	ESTIMATED % CAVITIES	LOST CORE (ft)	RUBBLE ZONE (ft)	WEATHERING (ft in 10-ft interval)***					HARDNESS (ft in 10-ft interval)***							
													ROCK							SO
								F	S	M	I	D	1	2	3	4	5	6	7	8
710	T.S. C.P. U. Lith.	TSw1	36	61	2	1.6	1.4		7.7					7.7						
720	T.S. C.P. U. Lith.	TSw1	10	47	1	1.0	0.7		10.0					10.0						
730	T.S. C.P. M. Nonlith	TSw2	15	25	<1	1.7	4.9		10.0					2.0	8.0					
740	T.S. C.P. M. Nonlith	TSw2	15	29	<1	0.0	1.0		10.0					3.2	6.8					
750	T.S. C.P. M. Nonlith	TSw2	29	40	<1	0.3	0.6		10.0					10.0						
760	T.S. C.P. M. Nonlith	TSw2	6	21	<1	2.6	2.7		10.0					10.0						
770	T.S. C.P. M. Nonlith	TSw2	0	9	<1	2.2	1.2		10.0					2.1	7.9					
780	T.S. C.P. M. Nonlith	TSw2	26	51	2	1.5	0.6		10.0						6.5	3.5				
790	T.S. C.P. M. Nonlith	TSw2	40	61	2	1.4	1.5		10.0							10.0				
800	T.S. C.P. M. Nonlith	TSw2	65	93	2	0.4	0.3		10.0							10.0				
810	T.S. C.P. M. Nonlith	TSw2	32	85	<1	0.3	0.2		10.0						8.1	1.9				
820	T.S. C.P. M. Nonlith	TSw2	94	97	<1	0.0		7.9	2.1					7.9	2.1					
830	T.S. C.P. M. Nonlith	TSw2	82	98	<1	0.0	0.2	10.0						1.9		8.1				
840	T.S. C.P. L. Lith.	TSw2	54	71	1	0.9	0.8	10.0								10.0				
850	T.S. C.P. L. Lith.	TSw2	0	10	<1	3.7	1.9	10.0								10.0				

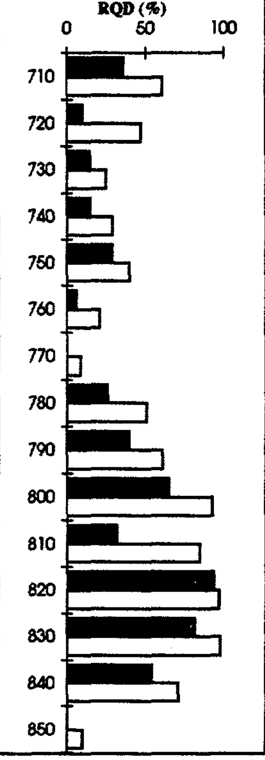
* CORE RQD—Determined from piece lengths formed by all types of fractures (C, I, N and V).

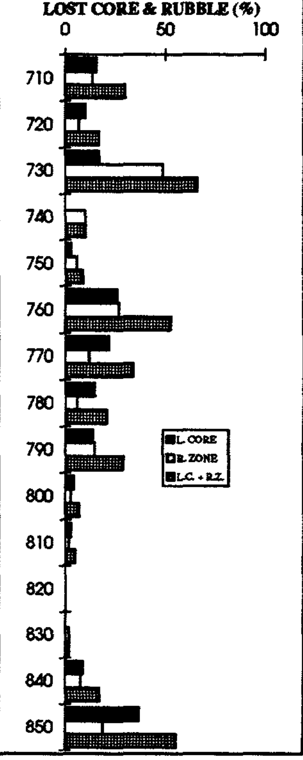
** ENHANCED RQD—Determined by filtering the effects of fractures identified as coring induced (Type C) from the piece lengths.

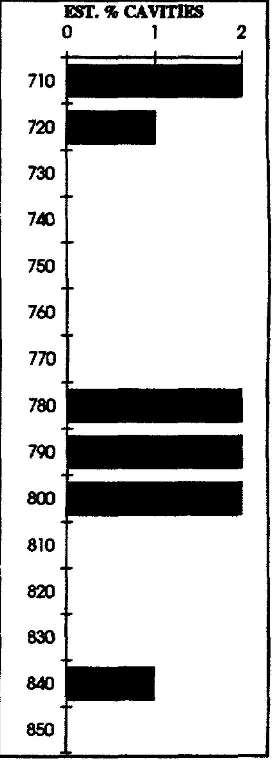
*** Footage in interval may not equal 10 ft because of lost core, rubble, or ommission during logging.



CORE RQD Summary		ENHANCED RQD Summary	
Mean	33.60	Mean	53.20
Median	29	Median	51
Mode	15	Mode	61
Standard Deviation	29.0	Standard Deviation	31.0
Variance	842.1	Variance	958.2
Range	94	Range	89
Minimum	0	Minimum	9
Maximum	94	Maximum	98
Sum	504	Sum	798
Count	15	Count	15







EXPLANATION OF CALCULATION

Rock mass quality indices, Q (Barton et al., 1974) and RMR (Bieniawski, 1979), have been estimated for 10-ft intervals using Rock Structural Data Summaries developed from structural logging of the core, observations of rock conditions in the North Ramp Starter Tunnel and North Ramp tunnel, and laboratory testing data.

- Q is developed to evaluate the distribution of rock mass quality as a basis for developing the range of credible rock mass quality to establish the ground support requirements within rock units and to derive rock mass mechanical properties according to the methodology proposed by Hardy and Bauer (1991). Procedures used in the calculation were:

$$Q = \frac{RQD^{**}}{Jn^{*}} \bullet \frac{Jr}{Ja} \bullet \frac{Jw}{SRF^{*}}$$

Note: Any spatial correlation may be masked by Monte Carlo simulation of Jn and SRF.

where RQD** = Core RQD where all fractures types [natural (N), indeterminate (I), coring induced (C) and vugs (V)] have been considered in determination of RQD. If the RQD is less than 10%, the value used is set to 10 as per Barton et al. (1974). By definition, soil-like materials are considered to have zero RQD.

Jn* = Joint Set Numbers: Cannot be determined from the core log data and are generated by Monte-Carlo simulation assuming a uniform distribution of values between 1 and 12 derived from mapping of the North Ramp tunnel.

Jr = Joint Roughness Number: A weighted average value derived based on the N and I type fractures in the 10-ft interval.

Ja = Joint Alteration Number: A weighted average value derived from the description of N and I type fractures in the interval.

Jw = Joint Water Factor: Set equal to 1.0 assuming dry conditions.

SRF* = Stress Reduction Factor: For nonwelded units, SRF is determined from the ratio of UCS/σ_1 (UCS = unconfined compressive strength, σ_1 = overburden stress). If unconfined compressive strength data is not available for the 10-ft interval, a compressive strength is generated by Monte Carlo simulation using laboratory test data for the thermomechanical units. For welded tuff units, SRF cannot be determined from core log data and is generated by Monte Carlo simulation assuming a distribution derived from mapping of the North Ramp tunnel.

- The use of the Core RQD is conservative since it includes the effect of coring induced breaks. Filtering the effects of coring induced breaks from the RQD calculation ("Enhanced RQD") produced an increase in the mean RQD. The mean values for thermomechanical units in USW UZ-14, 700–850 ft, Middle Nonlithophysal Zone are:

	Core RQD	Enhanced RQD
Middle Nonlithophysal Zone	33.6%	55.2%

- RMR is estimated based on the Rock Structural Summary log data, and rock strength data. Procedures used in the calculation were:

$$RMR = C + RQD\text{-}I + JS + JC + JW$$

where C = Rock Strength Index: Derived from compressive strength estimated by unconfined compressive strength laboratory test data for the 10-ft interval. If data is not available for the 10-ft interval, a compressive strength is generated by Monte-Carlo simulation using laboratory test data for the thermomechanical unit.

RQD-I = RQD Index: Derived using the Core RQD value for the 10-ft interval.

JS = Joint Spacing Index: Derived from the rock structural data for the 10-ft interval, excludes coring induced features.

JC = Discontinuity Condition Index: Derived from the description of fractures in the 10-ft interval.

JW = Groundwater Index: Assumed dry conditions

- Q and RMR data are presented in log format to associate parameters with depth intervals in the core log; however, any spatial correlation may be masked by Monte-Carlo simulation.

STRATIGRAPHIC ABBREVIATIONS

T.C.	Tiva Canyon Tuff	C.P. M. Nonlith.	Crystal-Poor Middle Nonlithophysal Zone
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone
	Bedded Tuff		
Y.M.	Yucca Mountain Tuff		
	Bedded Tuff		
P.C.	Pah Canyon Tuff		
	Bedded Tuff		
T.S.	Topopah Spring Tuff	C.R. Vitric	Crystal-Rich Vitric Zone
		C.R. Nonlith.	Crystal-Rich Nonlithophysal Zone
		C.R. Lith.	Crystal-Rich Lithophysal Zone
		C.P. U. Lith.	Crystal-Poor Upper Lithophysal Zone
		C.P. M. Nonlith.	Crystal-Poor Middle Nonlithophysal Zone
		C.P. L. Lith.	Crystal-Poor Lower Lithophysal Zone
		C.P. L. Nonlith.	Crystal-Poor Lower Nonlithophysal Zone
		C.P. Vitric	Crystal-Poor Vitric Zone Vitrophyre
		C.P. Vitric NW	Crystal-Poor Vitric Zone Non- to Partially Welded and Moderately Welded
	Bedded Tuff		
C.H.	Calico Hills Formation		

THERMOMECHANICAL UNITS

UO—Undifferentiated Overburden
TCw—Tiva Canyon Welded Unit
PTn—Upper Paintbrush Nonwelded Unit
TSw1—Topopah Spring Welded Unit—Lithophysae Rich
TSw2—Topopah Spring Welded Unit—Lithophysae Poor
TSw3—Topopah Spring Welded Unit—Vitrophyre
CHn1—Calico Hills and Lower Paintbrush Nonwelded Unit

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
Estimated Rock Mass Quality Indices Based on Core Log Data
Hole USW UZ-14
Interval — 700–850 ft, Middle Nonlithophysal Zone

END DEPTH	STRATIGRAPHY ZONE	THERMO-MECHANICAL UNIT	Q CLASSIFICATION SYSTEM [1] Barton et al. (1974)							RMR CLASSIFICATION SYSTEM [2] Bieniawski (1979)					
			RQD** (%)	Jn*	Jr	Ja	Jw	SRF*	Q*	C	RQD-I	JS	JC	JW	RMR
710	T.S. C.P. U. Lith.	TSw1	36	6.00	2.17	1.62	1.00	5.00	1.61	12	8	8	18.0	15	61.0
720	T.S. C.P. U. Lith.	TSw1	10	9.00	2.10	1.62	1.00	5.00	0.29	7	3	8	18.9	15	51.9
730	T.S. C.P. M. Nonlith.	TSw2	15	9.00	1.83	1.00	1.00	5.00	0.61	12	3	5	20.1	15	55.1
740	T.S. C.P. M. Nonlith.	TSw2	15	12.00	2.46	1.44	1.00	7.50	0.29	12	3	5	22.8	15	57.8
750	T.S. C.P. M. Nonlith.	TSw2	29	9.00	1.67	1.22	1.00	7.50	0.59	7	8	8	18.6	15	56.6
760	T.S. C.P. M. Nonlith.	TSw2	6	3.00	1.50	1.18	1.00	1.00	4.23	12	3	5	17.4	15	52.4
770	T.S. C.P. M. Nonlith.	TSw2	0	2.00	2.11	1.00	1.00	1.00	10.56	12	3	8	23.3	15	61.3
780	T.S. C.P. M. Nonlith.	TSw2	26	9.00	1.86	1.13	1.00	5.00	0.95	7	8	8	21.2	15	59.2
790	T.S. C.P. M. Nonlith.	TSw2	40	3.00	2.50	1.00	1.00	1.00	33.33	7	8	8	25.1	15	63.1
800	T.S. C.P. M. Nonlith.	TSw2	65	9.00	2.00	1.00	1.00	5.00	2.89	7	13	8	21.8	15	64.8
810	T.S. C.P. M. Nonlith.	TSw2	32	9.00	2.14	1.91	1.00	5.00	0.80	4	8	8	20.2	15	55.2
820	T.S. C.P. M. Nonlith.	TSw2	94	6.00	1.67	1.71	1.00	5.00	3.05	12	20	10	19.7	15	76.7
830	T.S. C.P. M. Nonlith.	TSw2	82	9.00	3.00	1.00	1.00	7.50	3.64	7	17	8	28.5	15	75.5
840	T.S. C.P. L. Lith.	TSw2	54	3.00	2.40	1.00	1.00	1.00	43.20	12	13	8	23.1	15	71.1
850	T.S. C.P. L. Lith.	TSw2	0	9.00	2.25	1.00	1.00	5.00	0.50	15	3	8	25.0	15	66.0

Jn*, SRF* = interval values generated by Monte Carlo simulation; to calculate Q*.

RQD**: If RQD is less than 10, the value 10 is used in the calculation of Q* as per Barton et al. (1974).

[1] Barton , N., R. Lien, and J. Lunde, "Engineering Classification of Rock Masses for the Design of Tunnel Support," Rock Mechanics, 6:189-236 (Springer Verlag, 1974).

[2] Bieniawski, Z.T., "The Geomechanics Classification in Rock Engineering Applications," Proceedings, 4th International Congress on Rock Mechanics, Montreaux, Switzerland, 2:41-48 (A. A. Balkema, 1979).

Q

Jn — Joint Set Number
Jr — Joint Roughness Number
Ja — Joint Alteration Number
Jw — Joint Water Reduction Factor
SRF — Stress Reduction Factor

Q = (RQD/Jn)(Jr/Ja)(Jw/SRF)

RMR

C— Strength Index
RQD-I— RQD Index
JS— Joint Spacing Index
JC— Discontinuity Condition Index
JW— Groundwater Index

RMR = C + RQD-I + JS + JC +JW

Appendix D

Key Block Analysis

Comparison of North Ramp and Main Drift Orientations

D.1 Introduction

Key block stability analyses have been conducted to compare potential key blocks based on joint structures mapped in the North Ramp to similar blocks created by Main Drift alignment. These analyses were designed to predict what rock mass conditions could be expected in the Main Drift assuming that the jointing conditions encountered so far in the North Ramp are also encountered in the Main Drift. Some changes in ground conditions can be expected if the assumed joint structure used in these analyses are consistent between both tunnel alignments.

D.2 Method of Analysis

The UNWEDGE[25] Version 2.2 key block stability analysis program was used to perform the comparative analyses. This program uses an ubiquitous, non-probabilistic approach to key block analysis which emphasizes the prediction of the formation of the maximum potential key block size given a particular joint set, tunnel orientation, and tunnel cross section. The UNWEDGE program is limited to a maximum of three joint sets in any particular analysis. UNWEDGE Version 2.2 has been verified in YMP document CSCI B0000000-01717-1200-30014 on February 2, 1995. The program and hardware used for this analysis was verified against the same problems.

Joint set data from tunnel mapping in the North Ramp were used to determine the mean joint set axes for the three joint sets. While the USBR has provided orientation data for five joint sets, only three of these sets have been used in this analysis. The USBR joint set No. 5 (as listed in Section 3.6) is a subhorizontal vapor-phase parting. Its sliding angle is very small compared to the other joint sets and observations in the North Ramp show that while this parting does act as a joint set at times, clearly visible breakage along this contact is observed only a small percentage of the time. Therefore, it has not been included in this analysis. The USBR joint set No. 4 is being assumed to be a subset of USBR joint set No. 1. This decision was based on the observation that it does not appear to coexist with joint set No. 1 frequently. The three joint set axes used in this analysis are summarized in Table D-1.

Table D-1. Joint Set Axes Used in Analysis

Joint Set Number	Dip (degrees)	Dip Direction
1	84	353
2	82	132
3	78	262

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[25] Carvalho et al.

Detailed mapping in the Tiva Canyon unit of the North Ramp has shown these to be the axes of the three primary joint sets. It is assumed for this analysis that these joint sets will also be encountered in the Topopah Spring unit of the Main Drift. The strength of this analysis rests upon the validity of this assumption.

Two sets of data were run in which the orientation of the 7.62-m-diameter circular tunnel has been varied. The first data set employs an orientation of 1° of dip on azimuth 299°; the second set employs 1° of dip on azimuth 3°. The results of a key block analysis on both data sets are compared in terms of the maximum potential key block volume, apex height, tonnage, and safety factor in Table D-2.

Table D-2. Comparison of North Ramp and Main Drift Results

	North Ramp Orientation				Main Drift Orientation			
Wedge No.	Volume (m^3)	Apex Height (m)	Tonnes	Safety Factor	Volume (m^3)	Apex Height (m)	Tonnes	Safety Factor
1	21.6807	7.8	59	0	58.7462	10.8	159	0
2	0.0007	0.3	<1	0.06		not formed		
3	0.0009	0.4	<1	0.55	0.0088	0.4	<1	0.55
4	21.6807	7.8	59	+inf	58.7462	10.8	159	+inf
5	0.0007	0.3	<1	0.53		not formed		
6	0.0009	0.4	<1	0.12	0.0088	0.4	<1	0.12

As shown by this comparison, the volume and tonnage of maximum potential key block formed in the crown increases roughly a factor of 3 in the Main Drift. This occurs in wedge No. 1 which increases from 59 to 159 tonnes. It is inferred from this information that under the assumptions noted above, the ground conditions in the Main Drift crown may have an increased potential of key block formation. It is difficult to state definitively the extent of this effect. With respect to roof bolt installation, the maximum potential block apex height increases from 7.8 to 10.8 m. However, both of these are beyond the bolt length (3-m bolts) currently being installed. The expected distribution of key block sizes can only be determined by a probabilistic key block analysis.

The effect on block formation in the tunnel walls is mixed. The North Ramp alignment allows the potential formation of four wedge types, whereas the Main Drift alignment allows only two. The block volume increases by a factor of 10 from 0.0009 to 0.009 m^3. However, these block sizes are both negligible with respect to ground control. In both cases, the apex height is 0.4 m. These results can be seen in Table D-2 by inspection of wedge Nos. 2, 3, 5, and 6.

The assumption of similar joint orientations suggests worse roof conditions in the Main Drift. The effect of jointing on the ground conditions in the tunnel walls is minor.

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