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Yucca Mountain Site Characterization Project

Fracture Analysis and Rock Quality Designation Estimation for the Yucca Mountain Site Characterization Project

M. Lin, M. P. Hardy, S. J. Bauer

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
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FRACTURE ANALYSIS AND ROCK QUALITY DESIGNATION ESTIMATION FOR THE YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

by

M. Lin
M. P. Hardy
J. F. T. Agapito & Associates, Inc.
Grand Junction, CO 81506

and

S. J. Bauer
Sandia National Laboratories
Albuquerque, NM 87185

ABSTRACT

Within the Yucca Mountain Site Characterization Project, the design of drifts and ramps and evaluation of the impacts of thermomechanical loading of the host rock requires definition of the rock mass mechanical properties. Ramps and exploratory drifts will intersect both welded and nonwelded tuffs with varying abundance of fractures. The rock mass mechanical properties are dependent on the intact rock properties and the fracture joint characteristics. An understanding of the effects of fractures on the mechanical properties of the rock mass begins with a detailed description of the fracture spatial location and abundance, and includes a description of their physical characteristics. This report presents a description of the abundance, orientation, and physical characteristics of fractures and the Rock Quality Designation in the thermomechanical stratigraphic units at the Yucca Mountain site. Data was reviewed from existing sources and used to develop descriptions for each unit. The product of this report is a data set of the best available information on the fracture characteristics.

The work in this report was performed under WBS 1.2.4.2.1.2.

The data in this report was developed subject to QA controls in QAGR S124212A, Revision 0, PCA 2.0, Task 2.1; the data is qualified and therefore can be used for licensing.

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1.0 INTRODUCTION

1.1 Background

Rock mass mechanical properties are an important component to be used in assessing the design and performance of a potential high-level nuclear waste repository at Yucca Mountain, Nevada, and are known to be dependent on both the intact properties and the presence of inhomogeneities and discontinuities. Although the intact properties can be determined through laboratory testing, effects of inhomogeneities must be quantified through a combination of laboratory testing and field observations. An understanding of the effects of discontinuities such as fractures upon mechanical properties of rocks begins with a detailed description of their spatial location and abundance, and includes information about their physical characteristics.

This report presents the results of a study on the abundance, orientation, and physical characteristics of rock fractures in the rock comprising the six thermomechanical units where repository and Exploratory Studies Facility (ESF) excavations are currently planned at Yucca Mountain. These data will be used for estimation of rock mass quality for these thermomechanical units to provide a basis for using empirical classification systems to derive estimates of rock mass properties. This work was undertaken in support of the Yucca Mountain Site Characterization Project (YMP) which is investigating the feasibility of potentially locating a high-level nuclear waste repository at Yucca Mountain, Nevada.

1.2 Scope

To achieve the end goal of this work, a complete data set was required, which fostered a search for all relevant information. The product of the search was a data set comprising the best available information in the professional judgment of the authors. This judgment was made with consideration of the uncertainties in the existing data and the recognition that significant work remains to be done in characterization of the Yucca Mountain site.

Data on fracture occurrence were collected and reported by various participants in the YMP. These reports were reviewed to determine fracture abundance and orientation, fracture roughness, fracture fillings and coatings, and Rock Quality Designation (RQD) for the thermomechanical units above and immediately below the potential repository horizon. This data formed the basis for estimation of rock mass quality indices and mechanical properties by Lin et al. (1992). Two rock mass classification systems have been adopted for development of rock mass quality indices: the Norwegian Geotechnical Institute System (Q), developed by Barton et al. (1974), and the Geomechanics Classification System (RMR), developed by Bieniawski (1979).

This report is divided into seven chapters. Chapter 1 presents the introductory material and scope of this study. The Yucca Mountain stratigraphy is briefly described in Chapter 2. Chapter 3 presents the spatial abundance and orientation of fractures logged in the existing four core holes in or near the repository boundary and the calculations for the fracture spacings. The fracture characteristics are discussed in Chapter 4. Chapter 5 presents RQD calculated from data in the core logs and relative rock mass quality for each unit; and Chapter 6 presents the conclusions. A list of references is provided in Chapter 7.

2.0 YUCCA MOUNTAIN STRATIGRAPHY

The stratigraphy of Yucca Mountain, as defined by Ortiz et al. (1985), is illustrated in Figure 2-1. The geologic members are defined based on classical geologic rules of nomenclature; repository design efforts are based on thermomechanical units that are grouped by similarities in rock mass thermal and mechanical properties. Descriptions for each of these thermomechanical units are explained in Table 2-1 and are shown relative to the geologic members in Figure 2-1.

The excavations for the ESF will pass through six thermomechanical units: the Tiva Canyon welded unit (TCw); the Upper Paintbrush nonwelded unit (PTn); the Topopah Spring welded unit, lithophysae-rich layer (TSw1); the Topopah Spring welded unit, lithophysae-poor layer (TSw2); the Topopah Spring welded unit, vitrophyre (TSw3); and the Calico Hills and Lower Paintbrush nonwelded unit (CHn1). This study focuses on these six units.

A preliminary definition of the intervals and base elevations for the thermomechanical units was proposed by Ortiz et al. (1985). These intervals and base elevations are the basis for this study, except in the Topopah Spring Member where changes in the location of the TSw1/TSw2 contacts has been recommended. The thermomechanical unit, TSw1, was defined to be the lithophysae-rich portion of the welded, devitrified Topopah Spring Member which contains more than 10% lithophysal cavities. The contact between TSw1 and TSw2 was placed at the base of the lowest ash flow in the Topopah Spring Member that contained 20% or more lithophysae (lithophysal cavities and vapor-phase-altered material) based on the assumption that lithophysal cavities account for one-half of the lithophysae. Reevaluation of the contact between TSw1 and TSw2 has recently been conducted by the Sample Overview Committee for the YMP. They pointed out in their reevaluation report that contacts chosen by Ortiz et al. (1985) for USW G-1 and UE-25a#1 were not consistent with application of the above criteria to contacts chosen in other drill holes or outcrops. Table 2-2 lists the base elevations for the six units from the four drill holes within or near the repository boundary. These values are from Ortiz et al. (1985), with the exception that the contacts between TSw1 and TSw2 for drill holes USW G-1 and UE-25a#1 are the updated values based on the reevaluation report by the Sample Overview Committee. The reevaluation report is attached in Appendix A.

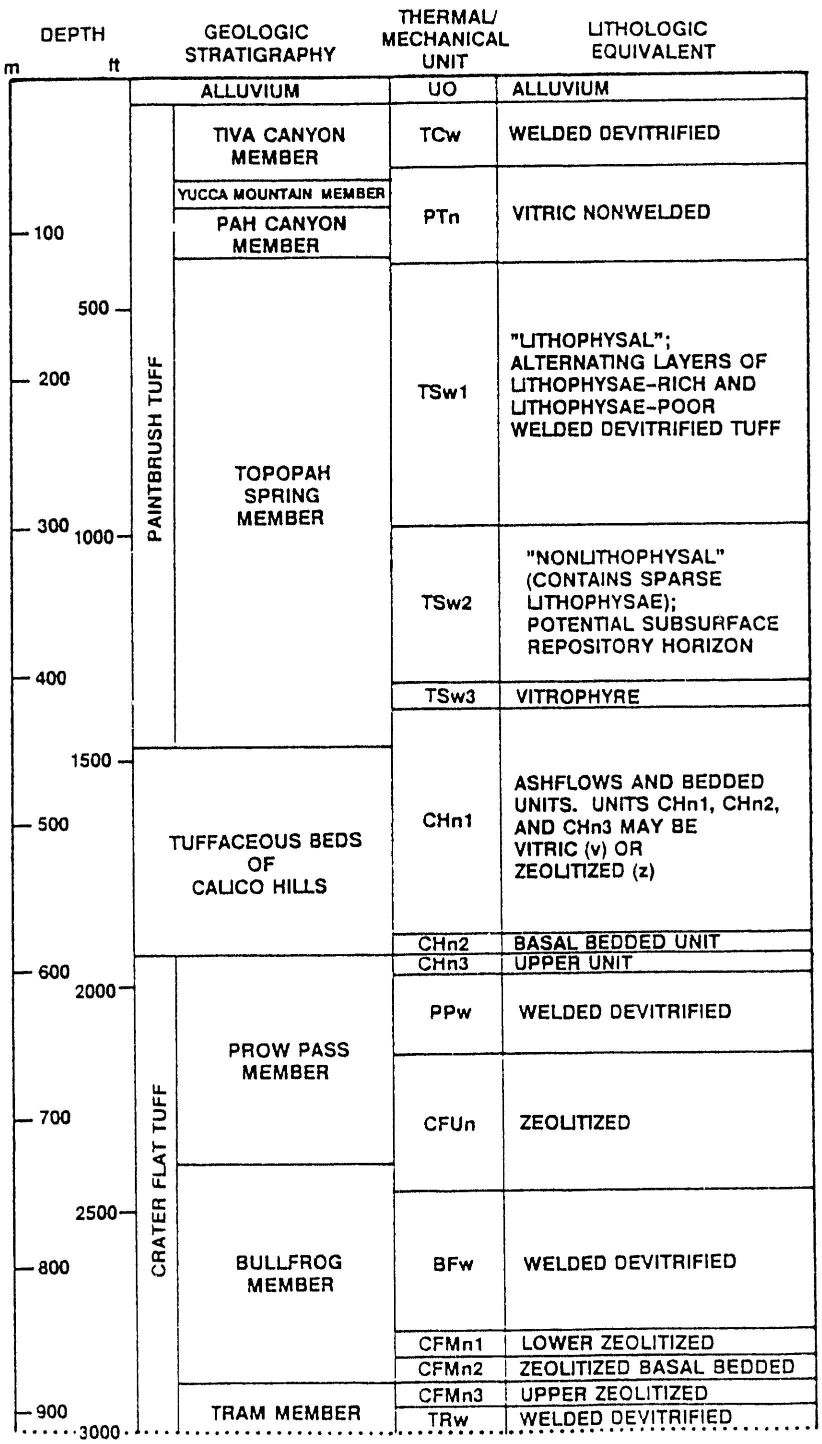


Figure 2-1. Yucca Mountain Stratigraphy

TABLE 2-1. DESCRIPTION OF THERMOMECHANICAL UNITS (after Ortiz et al., 1985)

Reference Stratigraphy Unit Name (Designator)	Description
Undifferentiated Overburden (UO)	Alluvium; colluvium; nonwelded, vitric ash flow tuff of the Tiva Canyon Member of the Paintbrush tuff; any other tuff units that stratigraphically overlie the welded, devitrified Tiva Canyon Member.
Tiva Canyon welded unit (TCw)	Moderately to densely welded, devitrified ash flow tuff of the Tiva Canyon Member of the Paintbrush tuff.
Upper Paintbrush nonwelded unit (PTn)	Partially welded to nonwelded, vitric and occasionally devitrified tuffs of the lower Tiva Canyon, Yucca Mountain, Pah Canyon, and Topopah Spring Members of the Paintbrush tuff.
Topopah Spring welded unit, lithophysae-rich (TSw1)	Moderately to densely welded, devitrified ash flows of the Topopah Spring Member of the Paintbrush tuff that locally contains more than approximately 10% by volume lithophysal cavities.
Topopah Spring welded unit, lithophysae-poor (TSw2)	Moderately to densely welded, devitrified ash flows of the Topopah Spring Member of the Paintbrush tuff that contains less than approximately 10% by volume lithophysal cavities. This is the proposed repository host rock.
Topopah Spring welded unit, vitrophyre (TSw3)	Vitrophyre near the base of the Topopah Spring Member of the Paintbrush tuff.
Calico Hills and Lower Paintbrush nonwelded unit (CHn1)	Nonwelded ash flows, bedded and reworked tuffs of the lower Topopah Spring Member of the Paintbrush tuff and the tuffaceous beds of Calico Hills.
Calico Hills and Lower Paintbrush nonwelded unit (CHn2)	Basal bedded and reworked zones of the tuffaceous beds of the Calico Hills.
Calico Hills and Lower Paintbrush nonwelded unit (CHn3)	Upper partially welded ash flows of the Prow Pass Member of the Crater Flat tuff.
Prow Pass welded unit (PPw)	Moderately welded, devitrified ash flows of the Prow Pass Member of the Crater Flat tuff.
Upper Crater Flat nonwelded unit (CFUn)	Zeolitic, nonwelded to partially welded ash flows and bedded, reworked portions of the lower Prow Pass Member and the upper Bullfrog Member of the Crater Flat tuff.
Bullfrog welded unit (BFw)	Moderately to densely welded, devitrified ash flows of the Bullfrog Member of the Crater Flat tuff.
Middle Crater Flat nonwelded unit (CFMn1)	Zeolitic, partially welded to nonwelded ash flows of the lower Bullfrog Member of the Crater Flat tuff.
Middle Crater Flat nonwelded unit (CFMn2)	Zeolitic, basal bedded, reworked portion of the Bullfrog Member of the Crater Flat tuff.
Middle Crater Flat nonwelded unit (CFMn3)	Zeolitic, partially welded ash flows of the upper portion of the Tram Member of the Crater Flat tuff.
Tram welded unit (TRw)	Moderately welded, devitrified ash flows of the Tram Member of the Crater Flat tuff.

TABLE 2-2. BASE ELEVATIONS OF THERMOMECHANICAL UNITS FOR THE DRILL HOLES IN THE YUCCA MOUNTAIN SITE (from Ortiz et al., 1985)

Units	USW G-1 (4349 ft)[a]	USW G-4 (4165 ft)[a]	USW GU-3 (4857 ft)[a]	UE-25a#1 (3934 ft)[a]
TCw	Absent	4047	4514	3739
PTn	4069	3922	4427	3657
TSw1	3634[b]	3495	4167	3314[b]
TSw2	3062	2872	3670	2672
TSw3	3007	2820	3588	2617
CHn1	2613	2460	3350	2145

[a] *Surface elevation.*
[b] *From Appendix A.*

In most of the data sources utilized for this report, the geological stratigraphic members have been used to group and summarize data. Because individual data were not available for some parameters (e.g., fracture orientation), the data are discussed by geological stratigraphic member. To prevent confusion, geologic members are always referred to using their full name. Where possible, data are regrouped by thermomechanical unit, which are referred to by their abbreviations throughout the remainder of this report.

3.0 FRACTURE ORIENTATION AND FREQUENCY

The existing raw data from U.S. Geological Survey open-file reports of core holes USW G-1 (Spengler et al., 1981), USW GU-3 (Scott and Castellanos, 1984), USW G-4 (Spengler and Chornack, 1984), and UE-25a#1 (Spengler et al., 1979) were used to determine the fracture orientation and frequency. Figure 3-1 shows a surface projection of the potential repository and the location of the four drill holes.

3.1 Fracture Orientation

The orientation of fracture planes in three-dimensional space are defined by strike and dip, and direction of dip. The strike is the azimuth of a horizontal line in the plane of the fracture. The dip is the angle of the plane of the fracture from horizontal downward, measured perpendicular to the strike. The dip direction is the azimuth at direction perpendicular to strike and pointing down the fracture plane. Currently available information on the strike and dip directions of fractures is discussed in Section 3.1.1 for the limited amount of oriented core available. Most of the coring was not oriented, therefore, only the dip of the fractures could be measured, assuming the borehole axis was vertical. The recorded dip data are presented in Section 3.1.2.

3.1.1 Strike and Dip of Fractures

Orientation of fracture sets was derived from very limited data gathered in holes USW GU-3 and USW G-4. Oriented core was taken in select 3-m (10-ft) intervals within each geologic member, and fracture strikes and dips were measured on fractures within these intervals. A more continuous sampling was performed using borehole television which measured the fracture strike only. Individual fracture measurements were not available and the results reported in Spengler and Chornack (1984) and Scott and Castellanos (1984) were in the form of stereonets and strike histograms for the oriented core and borehole television data, respectively.

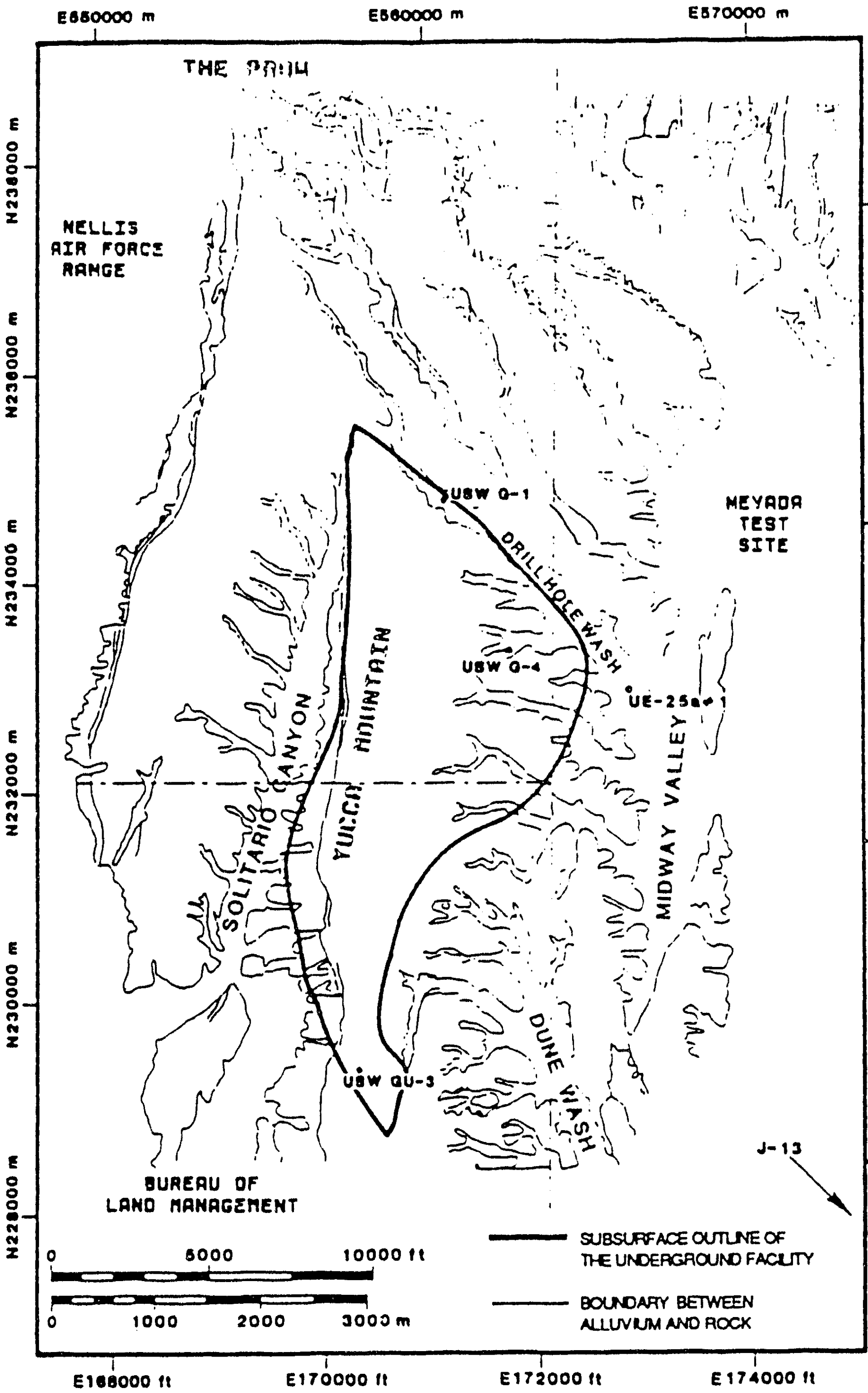


Figure 3-1. Map Showing the Subsurface Outline for the Underground Facility at Yucca Mountain and the Location of Drill Holes USW G-1, USW G-4, UE-25a#1, and USW GU-3 (modified from Mansure and Ortiz, 1984)

Note: Drill holes USW G-3 and USW GU-3 were drilled approximately 30 m (100 ft) apart as part of a two-state, coordinated drilling and geophysical logging program. USW GU-3 was cored in the unsaturated zone; USW G-3 was cored largely in the saturated zone. Because the holes are so closely spaced, only the location of drill hole USW GU-3 is shown.

Strike and dip data recorded within the Tiva Canyon and Topopah Spring Members in holes USW GU-3 and USW G-3 comprised 14% and 2% of the total fractures logged, respectively. The oriented core data are shown in the lower hemisphere stereographic projections in Figure 3-2. In the Tiva Canyon Member, the stereonet indicates two concentrations of joint orientations: a broad trend striking N30°W due north with near vertical dips in both the northeast and southwest directions, and a more concentrated set striking roughly N50°W with dips of 12°NE. These orientations are present in the strike rosette developed from borehole television observations of 133 fractures, but are not the dominant orientation. The borehole television measurements indicate a dominant trend between N18°W and N36°E (dip not recorded).

Joints within the Topopah Spring Member in USW GU-3 and USW G-3 exhibited some trends similar to the Tiva Canyon Member. Concentrations were observed with a N10°W strike dipping 75° to 90°NE and SW, and a concentration with strike trending N25°E and dipping 10°SE. A thick concentration was observed striking N45°E with dips 80° to 90°NW and SE. Borehole television data extended only 10 m into the Topopah Spring Member.

Strike and dip data recorded in hole USW G-4 comprised only 5% and 4% of the total fractures logged in the Tiva Canyon and Topopah Spring Members. Joint pole data measured on the oriented core are shown in Figure 3-3. The major concentration of joint poles in the Tiva Canyon Member indicate a strike of N22°E with dips of 65° to 90°NW, which agrees well with the USW GU-3/G-3 data. Other concentrations occur that indicate strike trends of N50°W and oriented east-west with high-angle dips. The strike data recorded with the borehole television system indicates a relatively uniform distribution of strikes between N45°W and N60°E, with a local maximum at due north.

Joints within the Topopah Spring Member in hole USW G-4 showed a similar concentration of north-striking joints with high angle of dip. The strike data recorded with the borehole television indicates strikes distributed between N15°W and N60°E, with local concentrations at due north and N40°E.

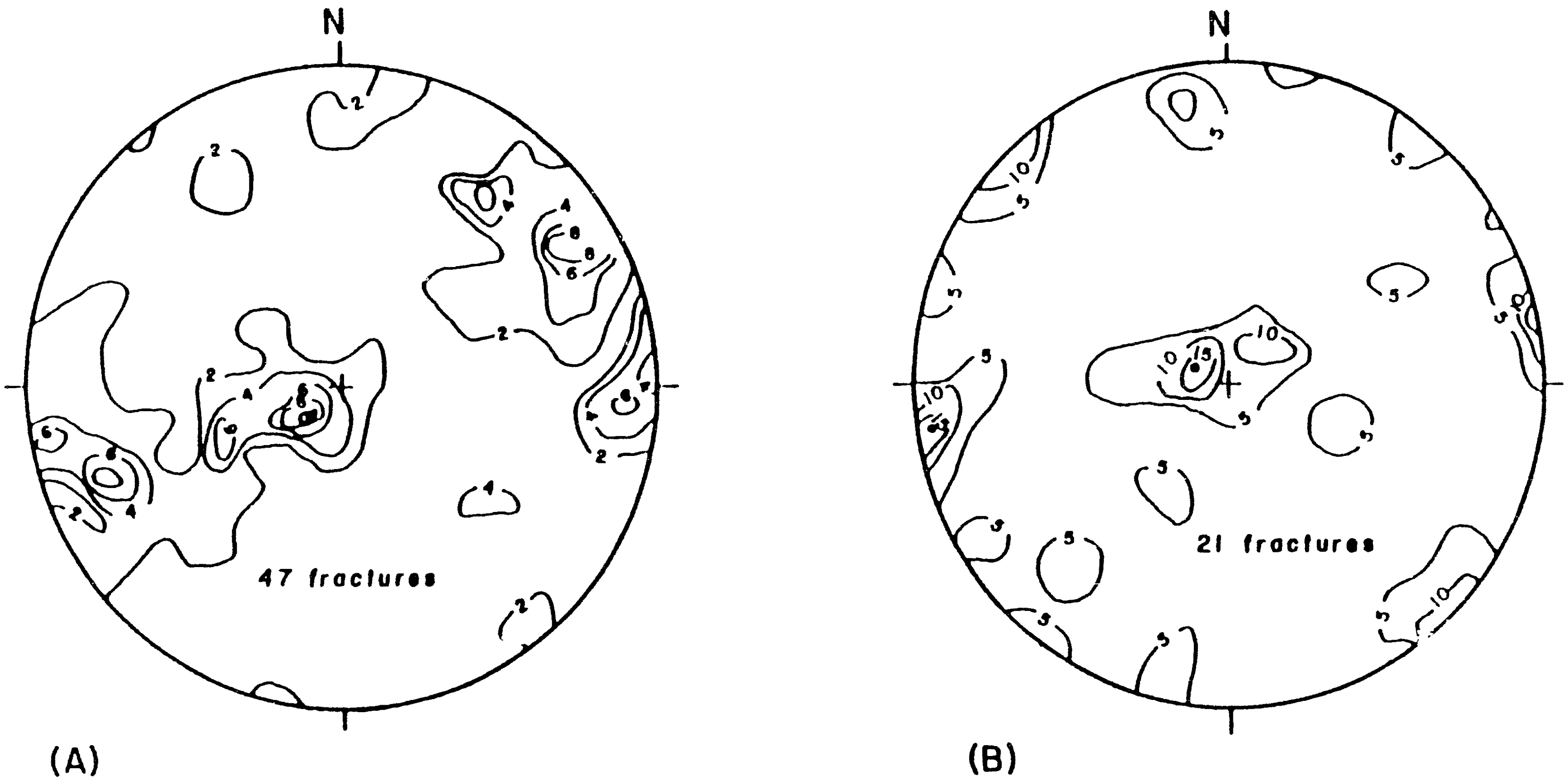


Figure 3-2. Contour Diagrams of Percentages of Fracture Poles in the (a) Densely Welded Zone of Tiva Canyon Member, and the (b) Densely Welded Zone of Topopah Spring Member for Drill Hole USW GU-3 (after Scott and Castellanos, 1984)

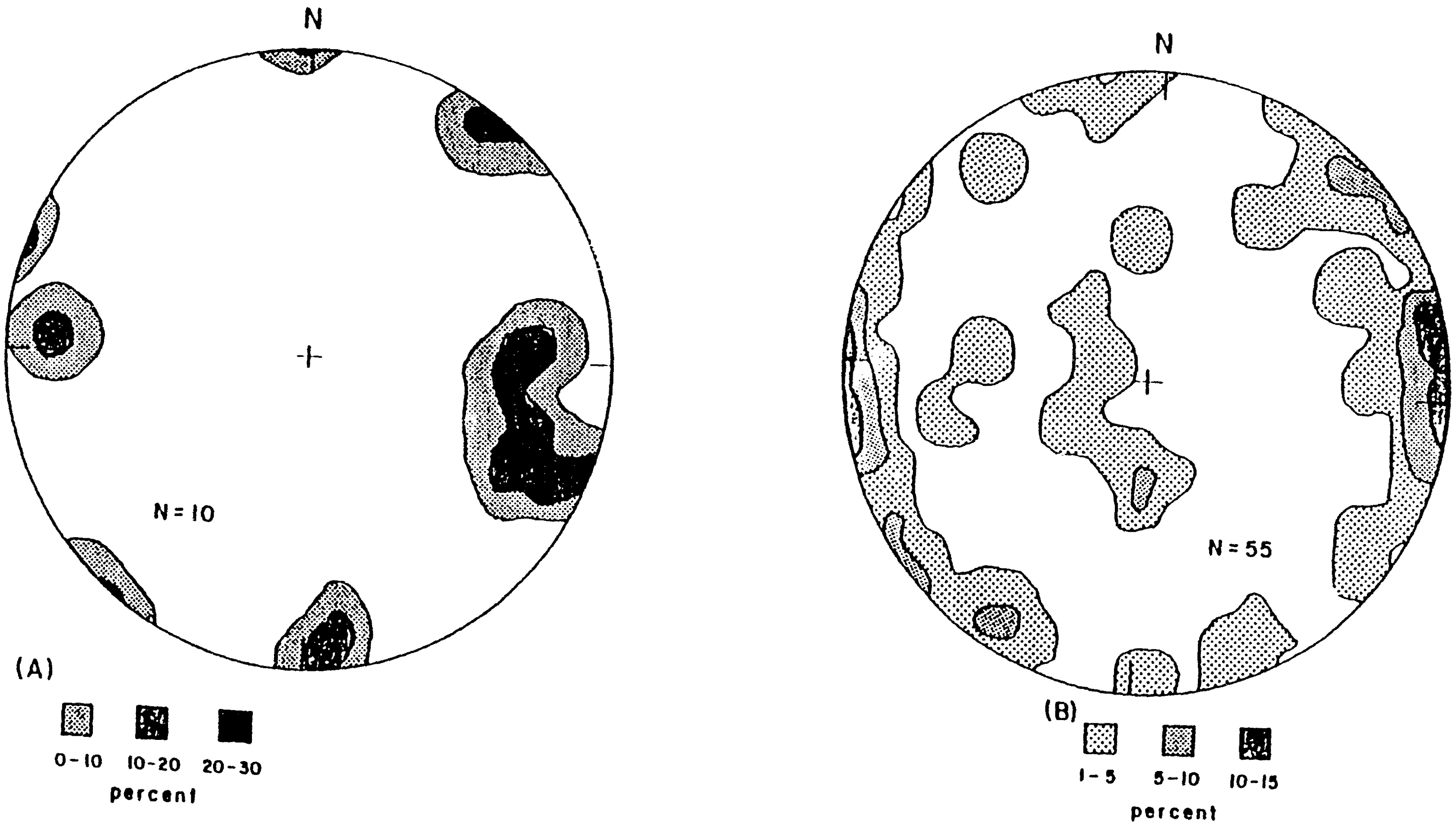


Figure 3-3. Contour Diagrams of Percentages of Fracture Poles in the (a) Densely Welded Zone of Tiva Canyon Member, and the (b) Densely Welded Zone of Topopah Spring Member for Drill Hole USW G-4 (after Spengler and Chornack, 1984)

The trends in the fracture orientation data are summarized in Table 3-1 and indicate that all of the data suggest a dominant fracture set striking generally north with high-angle dips to both the east and west. A minor set may occur as joints with relatively low-angle dips with strikes ranging from N25°E to N50°W. Other minor sets may occur locally as subsets of the major trend where strikes vary E-W and N50°W in the Tiva Canyon Member or N45°E in the Topopah Spring Member. These subsets have high dip angles.

TABLE 3-1. FRACTURE ORIENTATIONS AS ESTIMATED FOR ORIENTED CORE AND BOREHOLE TELEVISION SURVEYS

	USW GU-3		USW G-4	
Geologic Member	**Strike**	**Dip**	**Strike**	**Dip**
Tiva Canyon Member	N18°W-N36°E	85°-90°SW/NE	N-N22°E	65°-90°NW
	N50°W	12°NE	---	---
	---	---	E-W	70°-90°N/S
	---	---	N50°W	70°-90°NE/SW
Topopah Spring Member	N10°W	75°-90°NE/SW	N°12W	80°-90°NE/SW
	N25°E	10°SE	---	---
	N45°E	80°-90°SE/NW	N-N40°E	*NM*

NM *Not measured by borehole television system.*
--- *No corresponding joint was observed.*

This interpretation is based on very limited data, but suggests that the number of fracture sets may range between one and three. The general occurrence may be the dominant north trend with random high-angle fractures with different strikes. However, locally, the three indicated trends may appear as distinct sets.

3.1.2 Fracture Dips

The great majority of core was not oriented and only the dip of fractures could be determined. Individual fracture dips were not available; the dip data was summarized by geologic member and presented by Spengler et al. (1981), Scott and Castellanos (1984), Spengler and Chornack (1984), and Spengler et al. (1979). The data are discussed by geologic member and the indicated trends in the data are extrapolated to the pertinent thermomechanical units.

Table 3-2 lists the percentages of joints in 10° dip increments derived from rose diagrams for the densely welded part of the Tiva Canyon Member; non- to moderately-welded parts of the Tiva Canyon, Yucca Mountain, Pah Canyon, and Topopah Spring Members; the densely welded part of the Topopah Spring Member; and the non- to partially-welded part of the Topopah Spring Member and tuffaceous beds of Calico Hills. The percentage data that was derived from the rose diagram in the report of drill hole USW GU-3 (Scott and Castellanos, 1984) had been processed using the Terzaghi correction procedure (Terzaghi, 1965). The USW GU-3 data presented in Table 3-2 has, therefore, been converted to the original percentage data to be similar to data from other drill holes.

Table 3-3 presents the dip data summarized for a low- and high-angle grouping which assumes the low-angle set is inclined between 0° and 30°, and the high-angle set is inclined between 60° and 90°. Within the densely welded part of the Tiva Canyon Member and non- to moderately-welded parts of the Tiva Canyon, Yucca Mountain, Pah Canyon, and Topopah Spring Members, the proportion of low-angle fractures equals the high-angle fractures, except in drill hole USW GU-3 where 62% of the fractures are in the high-angle set and only 20% are in the low-angle set. More than 60% of fractures in the densely welded part of the Topopah Spring Member belong to the high-angle set for all drill holes, except USW G-4 where only 46% are in the high-angle set. The high-angle fracture set was dominant for the non- to partially-welded part of the Topopah Spring Member and tuffaceous beds of Calico Hills.

The general dominance of the high-angle fractures is greatly magnified when the dip data is corrected for sampling bias by using the Terzaghi correction procedure. The percentage data (in parentheses) listed in Table 3-3 are the corrected data. Applying the Terzaghi correction procedure greatly magnified the percentage for the high-angle set. For example, the corrected data presented for the Topopah Spring Member in the drill hole report of USW GU-3 indicate that the high-angle set accounts for 94% of the fractures, compared to 69% in the original data (Table 3-3). This corrected data is the basis for the conclusion that the high-angle set of fracture inclinations is strongly dominant. Dips at moderate angles (30° to 60°) are a very small portion of the corrected total.

TABLE 3-2. PERCENTAGE OF MAPPED FRACTURES IN EACH 10° INCLINATION ANGLE

Units	Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
Tiva Canyon Member	USW G-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
	USW G-4	12	21	12	10	5	6	10	7	17
	USW GU-3*	6	8	6	4	6	8	17	21	24
	UE-25a#1	4	10	14	19	10	10	13	13	7
Pah Canyon Member	USW G-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
	USW G-4	17	18	11	4	10	7	11	5	17
	USW GU-3*	NA	NA	NA	NA	NA	NA	NA	NA	NA
	UE-25a#1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Topopah Spring Member	USW G-1	6	12	7	4	4	4	9	24	30
	USW G-4	12	14	10	6	6	6	9	12	25
	USW GU-3*	7	7	5	5	4	3	5	27	37
	UE-25a#1	3	3	8	8	8	6	12	21	30
Tuffaceous Beds of Calico Hills	USW G-1	20	20	0	0	0	0	20	20	20
	USW G-4	0	0	0	0	6	19	14	44	17
	USW GU-3*	12	12	11	10	9	7	7	6	26
	UE-25a#1	3	8	5	0	3	14	12	20	35

* *The percentage data presented in the rose diagram of Scott and Castellanos (1984) are the corrected data through Terzaghi's (1965) procedure. The data presented in this table have been converted to the original percentage data.*

NA *Data not available.*

Note: Interval percentages were adjusted based on engineering judgment to total 100%.

TABLE 3-3. PERCENTAGE OF LOW- AND HIGH-ANGLE FRACTURE SETS

	Tiva Canyon Member	Pah Canyon Member	Topopah Spring Member	Tuffaceous Beds of Calico Hills
Low-angle set (0° to 30°)				
USW G-1	NA	NA	25 (5)	40 (10)
USW G-4	45 (15)*	46 (15)	36 (9)	0 (0)
USW GU-3	20 (5)	NA	19 (3)	35 (9)
UE-25a#1	28 (12)	NA	14 (3)	16 (3)
High-angle set (60° to 90°)				
USW G-1	NA	NA	63 (91)	60 (90)
USW G-4	34 (76)	33 (75)	46 (85)	75 (91)
USW GU-3	62 (89)	NA	69 (94)	39 (82)
UE-25a#1	33 (66)	NA	64 (91)	67 (92)

* *The percentage data after applying the Terzaghi correction procedure, detail see Section 3.2.2.*
NA *Data not available.*

3.2 Fracture Frequency

The abundance of fractures in the rock mass can be quantitatively represented by the fracture frequency. Three types of fracture frequencies are calculated and discussed in this section: linear fracture frequency along the drill hole axis (λ_l), corrected linear fracture frequency (CLFF) for each joint set inclined in 10° intervals (λ_{ti}), and volumetric fracture frequency in a unit volume of rock (λ_v). These three types of frequencies are interrelated and have to be calculated sequentially.

3.2.1 Linear Fracture Frequency Along the Drill Hole Axis (λ_l)

The number of fractures identified in each 10-ft (3-m) interval were recorded by Spengler et al. (1981), Scott and Castellanos (1984), Spengler and Chornack (1984), and Spengler et al. (1979). The total number of fractures in each thermomechanical unit was calculated by summing all the fractures recorded in 10-ft (3-m) intervals within each unit, and linear fracture frequency along the drill hole axis (λ_l) was then computed by dividing the number of fractures by the thickness of the unit.

Histograms for the number of occurrences versus the number of fractures in 10-ft intervals for the six units are presented in Figures 3-4 to 3-9. These figures show that the nonwelded units (PTn, Figure 3-5, and CHn1, Figure 3-9) have fewer fractures than the welded tuff units. Most of the 10-ft intervals in the nonwelded tuff units have less than two fractures each. For the welded tuff units, the fracture frequencies are more evenly distributed. Sixty percent of the intervals have more than 10 fractures each for drill hole USW GU-3 within the TCw unit; all of the intervals have more than 14 fractures each for drill hole USW G-4. Between 60% and 80% of the intervals in the TSw2 unit have more than 10 fractures for drill holes USW G-4 and USW GU-3, respectively.

Table 3-4 lists the calculated number of fractures, the corresponding thickness of each thermomechanical unit, and the linear fracture frequency along the drill hole axis (λ_l) for the four drill holes. Wide variation of the fracture frequency results is observed for the welded tuff units. Three to ten times the difference for the fracture frequency exists for the lateral variation along these units. An average linear fracture frequency is calculated to provide an index for each individual unit (Table 3-5). This average linear fracture frequency is obtained by summing all the fractures in four drill holes and dividing with the total thickness. The total number of fractures, thickness, and the average fracture frequency are presented in Table 3-5. The TCw unit has the highest average linear fracture frequency of 4.1 among all the units. The TSw2 unit has the most fractures (2140 fractures) and the second highest average linear fracture frequency (3.0).

3.2.2 Corrected Linear Fracture Frequency for Each Joint Set Inclined in 10° Intervals (λ_{ti})

The CLFF was defined as the number of fractures that would exist for a unit length along a line perpendicular to the fracture plane. Terzaghi's (1965) correction procedure was applied to eliminate the sampling bias caused by the angle between the borehole axis and each fracture plane. Fractures were grouped into 10° dip intervals; and the CLFF was calculated using the following equation:

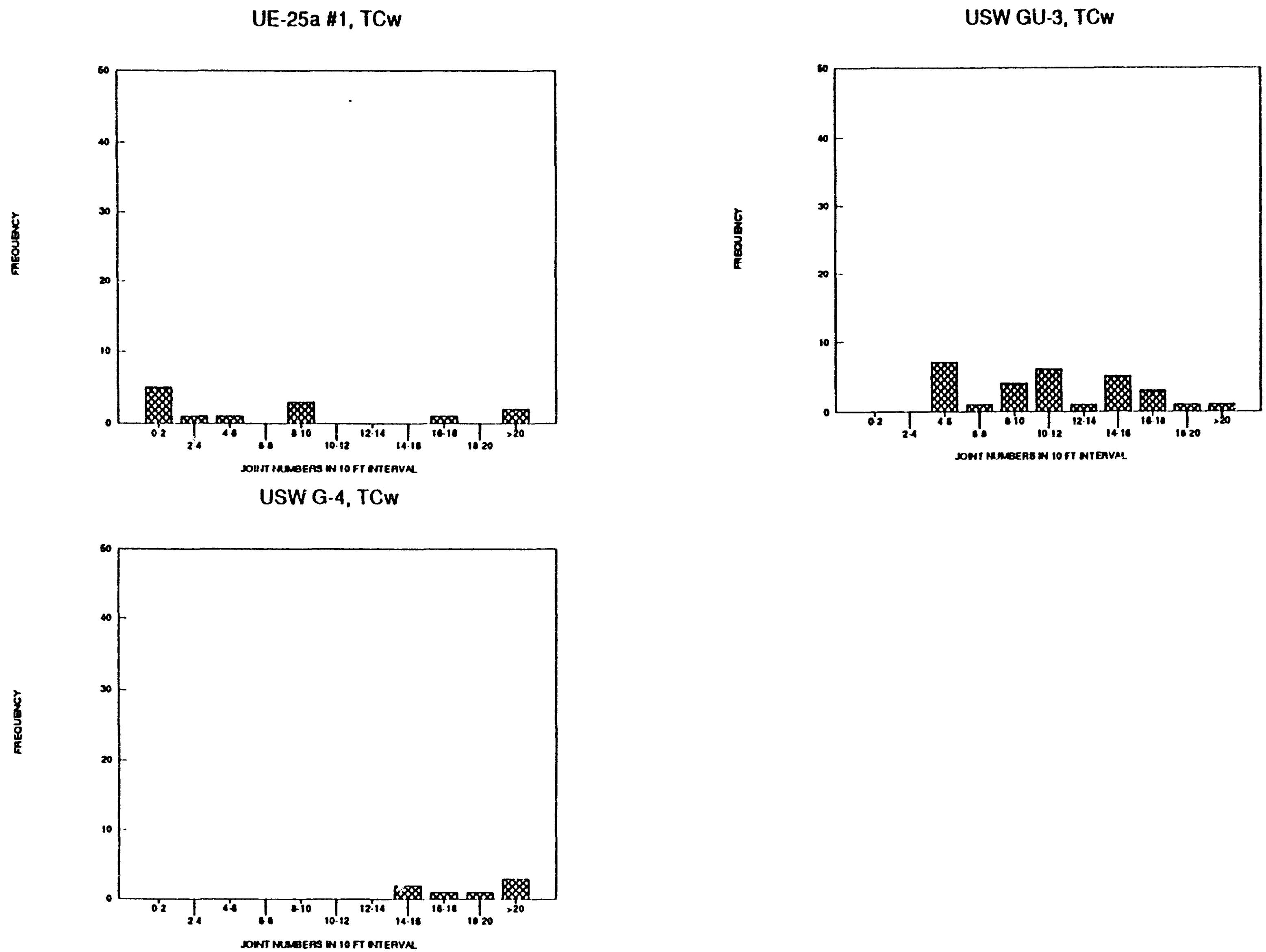


Figure 3-4. Histogram of Frequency Versus Number of Fractures in 10-ft Intervals for the Tiva Canyon Welded Unit (TCw)

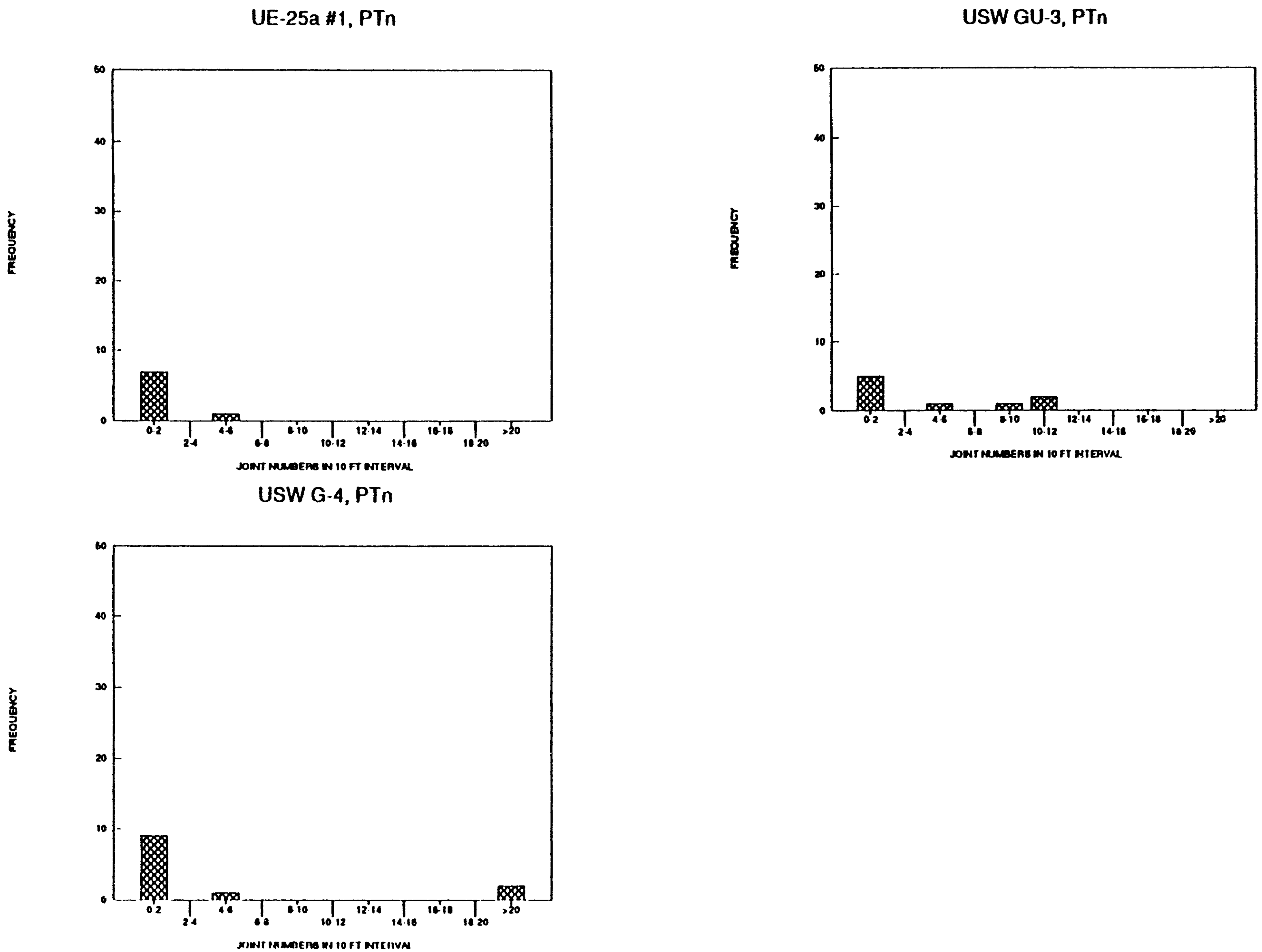


Figure 3-5. Histogram of Frequency Versus Number of Fractures in 10-ft Intervals for the Upper Paintbrush Nonwelded Unit (PTn)

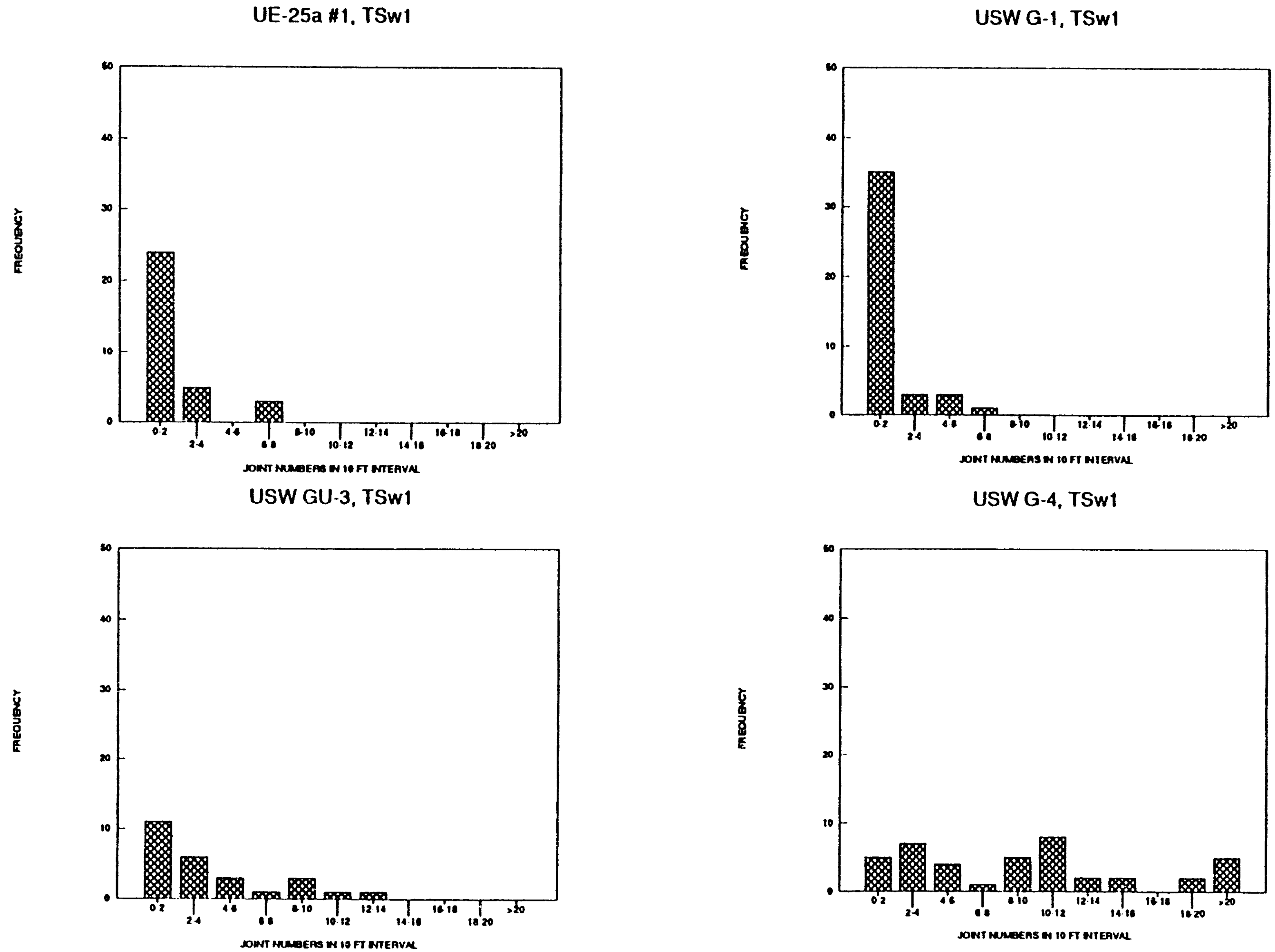


Figure 3-6. Histogram of Frequency Versus Number of Fractures in 10-ft Intervals for the Topopah Spring Welded Unit, Lithophysae-Rich Layer (TSw1)

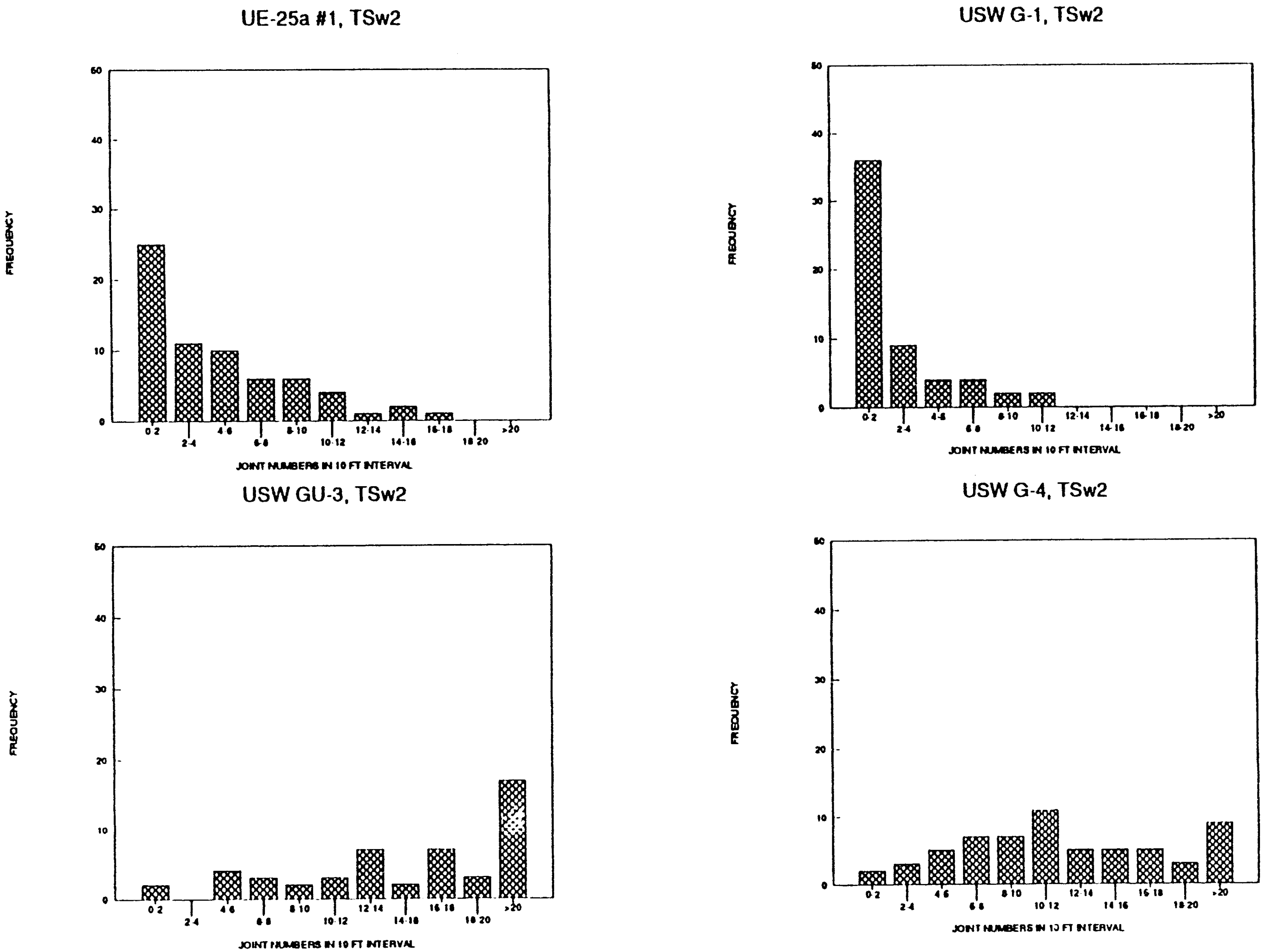


Figure 3-7. Histogram of Frequency Versus Number of Fractures in 10-ft Intervals for the Topopah Spring Welded Unit, Lithophysae-Poor Layer (TSw2)

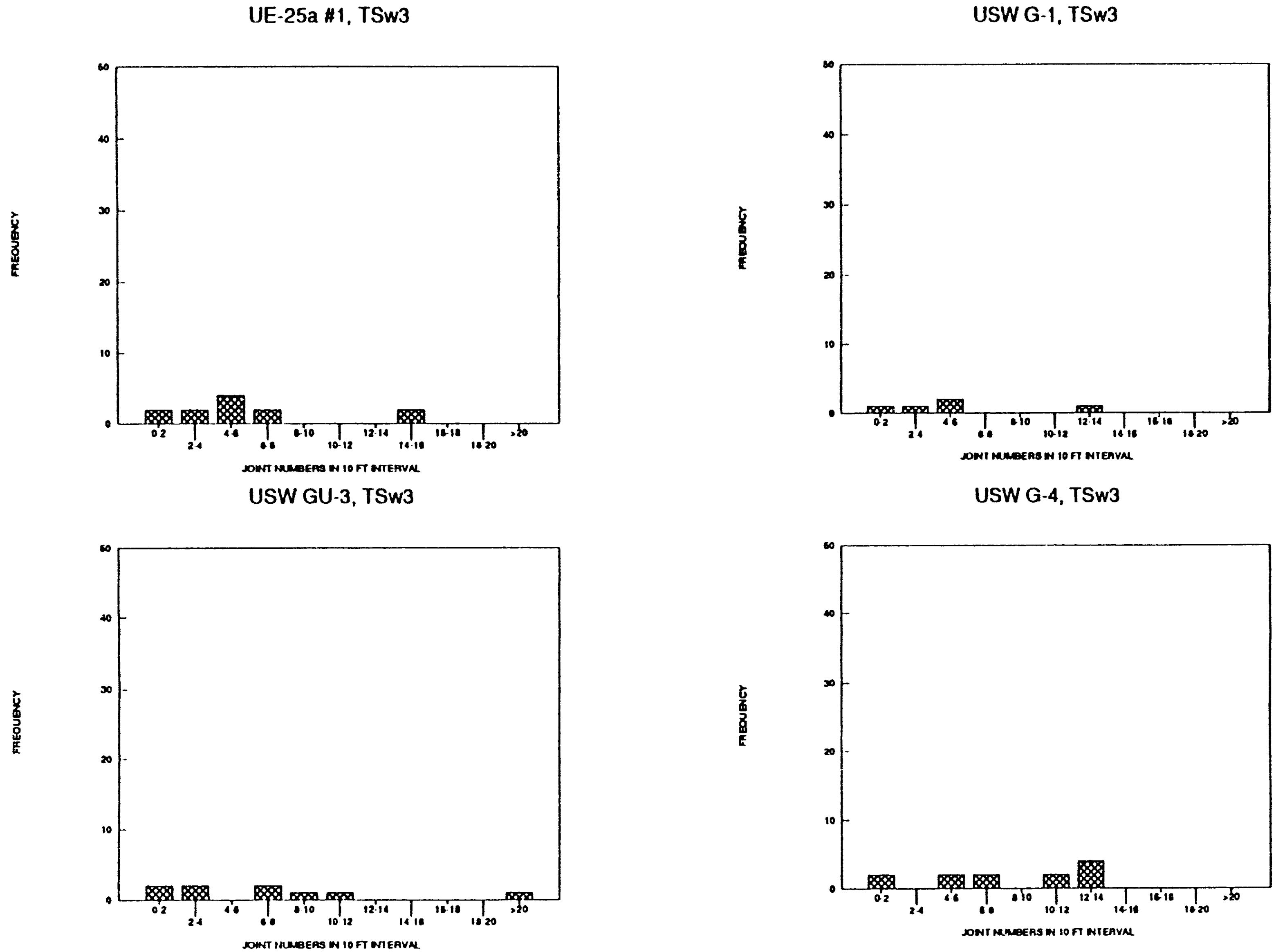


Figure 3-8. Histogram of Frequency Versus Number of Fractures in 10-ft Intervals for the Topopah Spring Welded Unit, Vitrophyre (TSw3)

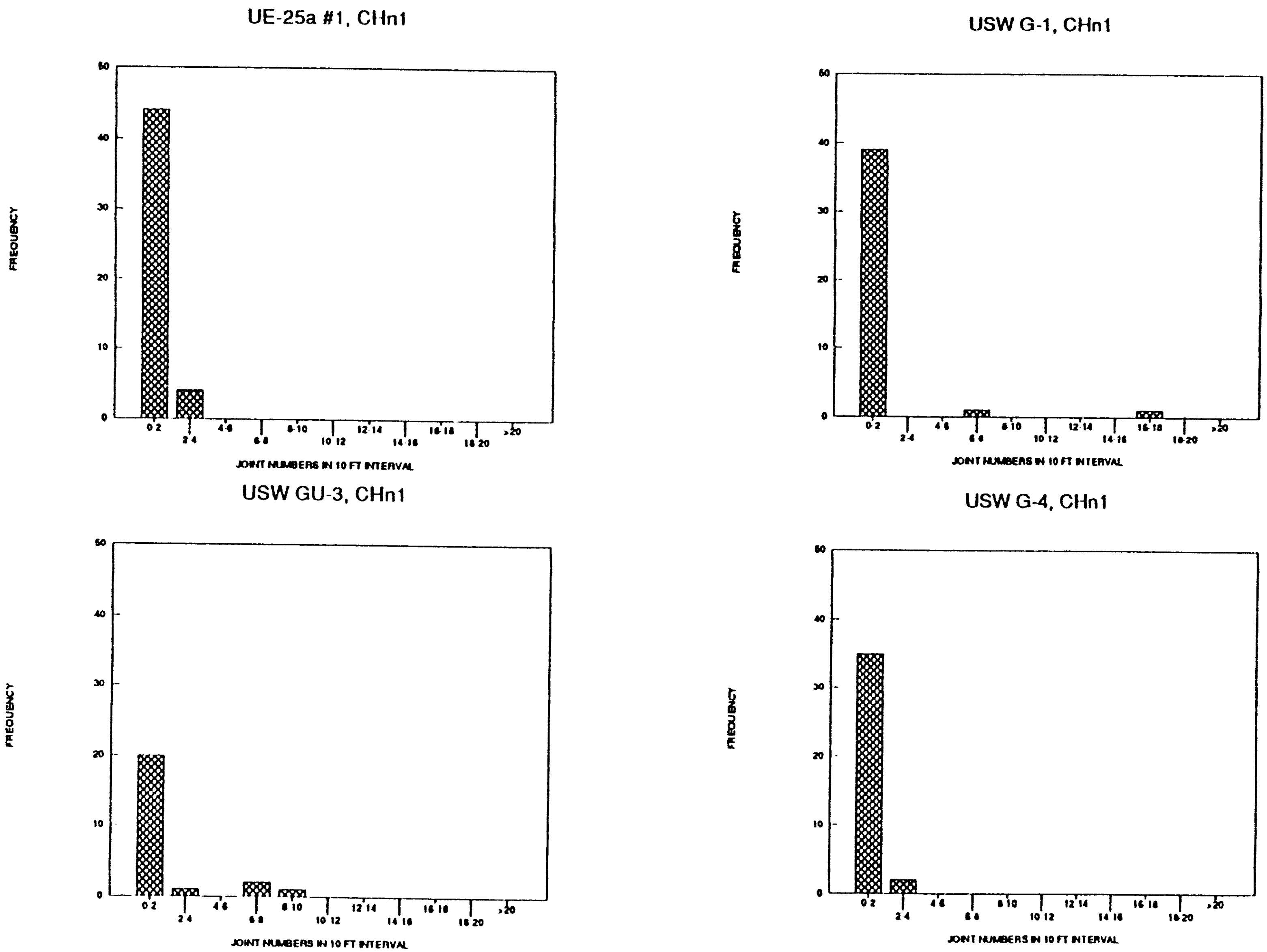


Figure 3-9. Histogram of Frequency Versus Number of Fractures in 10-ft Intervals for the Calico Hills and Lower Paintbrush Nonwelded Unit (CHn1)

TABLE 3-4. THICKNESS, NUMBERS OF FRACTURES, AND LINEAR FRACTURE FREQUENCIES IN TUFF UNITS

Thermomechanical Units		USW G-1	USW G-4	USW GU-3	UE-25a#1
TCw	Interval (m)	NA	9.1-36.0	12.2-104.5	9.1-59.4
	Thickness (m)	NA	26.8	92.4	50.3
	Fractures	NA	207	349	138
	Frequency (m^{-1})	NA	7.7	3.8	2.7
PTn	Interval (m)	18.3-85.3	36.0-74.1	104.5-131.1	59.4-84.4
	Thickness (m)	67.1	38.1	26.5	25
	Fractures	NA	38	41	10
	Frequency (m^{-1})	NA	1.0	1.5	0.4
TSw1	Interval (m)	85.3-217.9	74.1-204.2	131.1-210.3	84.4-189.0
	Thickness (m)	132.6	130.1	79.2	104.5
	Fractures	62	561	105	46
	Frequency (m^{-1})	0.5	4.3	1.3	0.4
TSw2	Interval (m)	217.9-392.3	204.2-394.1	210.3-361.8	189.0-384.7
	Thickness (m)	174.3	189.9	151.5	195.7
	Fractures	152	790	860	339
	Frequency (m^{-1})	0.9	4.2	5.7	1.7
TSw3	Interval (m)	392.3-409.0	394.1-410.0	361.8-386.8	384.7-401.4
	Thickness (m)	16.8	15.8	25	16.8
	Fractures	42	53	43	33
	Frequency (m^{-1})	2.5	3.4	1.7	2.0
CHn1	Interval (m)	409.0-529.1	410.0-519.7	386.8-459.3	401.4-545.3
	Thickness (m)	120.1	109.7	72.5	143.9
	Fractures	12	25	35	28
	Frequency (m^{-1})	0.1	0.2	0.5	0.2

NA *Data not available.*

TABLE 3-5. SUMMARY OF LINEAR FRACTURE FREQUENCY DATA FOR THERMOMECHANICAL UNITS

	TCw	PTn	TSw1	TSw2	TSw3	CHn1
Total thickness (m)	169.5	89.6	446.4	711.4	74.4	446.2
Total number of fractures	694	89	774	2140	170	100
Average fracture frequency (m^{-1})	4.1	1.0	1.7	3.0	2.3	0.2

$$\lambda_{ti} = \lambda_l \frac{P(\phi_i)}{\cos(90 - \phi_i)} \quad , \tag{3-1}$$

where ϕ_i = the angle between the fracture plane and borehole axis, and
$P(\phi_i)$ = the measured percentage of fractures in the sampled dip interval.

Our confidence in the calculated value of the CLFF becomes less as the fracture inclination approaches the axis of the drill hole because as the inclination becomes parallel to the core axis, the correction factor approaches infinity. For fractures dipping between 80° and 90° in a vertical borehole, the correction factor is 11.3. This correction factor may overestimate the number of vertical fractures in a vertical hole. To verify the accuracy of the Terzaghi correction at small angles of ϕ_i, a statistical numerical procedure generating the two-dimensional fracture network was developed. Terzaghi's correction factors were regenerated by sampling the fractures along the scanlines through the resulting fracture networks generated. CLFF values were very close to the mean fracture frequencies input to the statistical procedure suggesting the correction was valid. Details on the statistical approach that generated the fracture network are presented in Appendix B.

The CLFFs calculated using Equation 3-1 and data from Tables 3-2 and 3-4 are listed in Tables 3-6 to 3-11 for each thermomechanical unit. Because the percentage data for the fracture inclination were calculated based on the geological stratigraphic units, they were not completely compatible with the data derived for the thermomechanical units. The percentage data for the fracture dips were assumed to be the same for different thermomechanical units (e.g., TSw1, TSw2, and TSw3) within one geological stratigraphic member (e.g., Topopah Spring Member). Also included in Tables 3-6 to 3-11 are the upper range, lower range, and arithmetic mean of the fracture frequencies in each interval. Calculated frequencies less than 0.05 fractures per meter were set equal to 0.05 fractures per meter following the logic applied in the Site Characterization Plan, Conceptual Design Report (SCP-CDR) [Sandia National Laboratories (SNL), 1987].

TABLE 3-6. CORRECTED LINEAR FRACTURE FREQUENCY FOR TCw UNIT (m^{-1})

Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
USW G-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
USW G-4	0.93	1.68	1.02	0.94	0.55	0.81	1.83	2.09	15.05
USW GU-3	0.23	0.31	0.25	0.18	0.32	0.53	1.52	3.06	10.37
UE-25a#1	0.11	0.28	0.42	0.64	0.39	0.48	0.84	1.38	2.20
Mean	0.42	0.76	0.57	0.59	0.42	0.60	1.40	2.17	9.21
Upper range	0.93	1.68	1.02	0.94	0.55	0.81	1.83	3.06	15.05
Lower range	0.11	0.28	0.25	0.18	0.32	0.48	0.84	1.38	2.20

NA *Data not available.*

TABLE 3-7. CORRECTED LINEAR FRACTURE FREQUENCY FOR PTn UNIT (m^{-1})

Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
USW G-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
USW G-4	0.17	0.19	0.12	0.05	0.14	0.12	0.26	0.19	1.94
USW GU-3	NA	NA	NA	NA	NA	NA	NA	NA	NA
UE-25a#1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA
Upper range	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lower range	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA *Data not available.*

TABLE 3-8. CORRECTED LINEAR FRACTURE FREQUENCY FOR TSw1 UNIT (m^{-1})

Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
USW G-1	0.05	0.06	0.05	0.05	0.05	0.05	0.10	0.43	1.61
USW G-4	0.52	0.62	0.48	0.32	0.37	0.45	0.92	2.00	12.35
USW GU-3	0.09	0.10	0.07	0.08	0.07	0.07	0.16	1.38	5.62
UE-25a#1	0.05	0.05	0.05	0.05	0.05	0.05	0.12	0.35	1.55
Mean	0.18	0.21	0.16	0.12	0.14	0.15	0.32	1.04	5.28
Upper range	0.52	0.62	0.48	0.32	0.37	0.45	0.92	2.00	12.35
Lower range	0.05	0.05	0.05	0.05	0.05	0.05	0.10	0.35	1.55

TABLE 3-9. CORRECTED LINEAR FRACTURE FREQUENCY FOR TSw2 UNIT (m^{-1})

Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
USW G-1	0.05	0.11	0.07	0.05	0.05	0.06	0.19	0.81	2.99
USW G-4	0.50	0.60	0.46	0.30	0.35	0.44	0.89	1.93	11.92
USW GU-3	0.40	0.41	0.31	0.35	0.32	0.30	0.67	5.92	24.07
UE-25a#1	0.05	0.05	0.15	0.17	0.20	0.18	0.49	1.40	6.14
Mean	0.25	0.29	0.25	0.22	0.23	0.24	0.56	2.51	11.28
Upper range	0.50	0.60	0.46	0.35	0.35	0.44	0.89	5.92	24.07
Lower range	0.05	0.05	0.07	0.05	0.05	0.06	0.19	0.81	2.99

TABLE 3-10. CORRECTED LINEAR FRACTURE FREQUENCY FOR TSw3 UNIT (m^{-1})

Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
USW G-1	0.15	0.31	0.19	0.12	0.14	0.17	0.53	2.29	8.49
USW G-4	0.40	0.49	0.37	0.25	0.28	0.35	0.71	1.55	9.61
USW GU-3	0.12	0.12	0.09	0.10	0.10	0.09	0.20	1.77	7.21
UE-25a#1	0.06	0.06	0.17	0.19	0.22	0.21	0.56	1.59	6.98
Mean	0.18	0.24	0.21	0.17	0.19	0.20	0.50	1.80	8.07
Upper range	0.40	0.49	0.37	0.25	0.28	0.35	0.71	2.29	9.61
Lower range	0.06	0.06	0.09	0.10	0.10	0.09	0.20	1.55	6.98

TABLE 3-11. CORRECTED LINEAR FRACTURE FREQUENCY FOR CHn1 UNIT (m^{-1})

Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
USW G-1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.08	0.23
USW G-4	0.05	0.05	0.05	0.05	0.05	0.08	0.08	0.39	0.44
USW GU-3	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.11	1.44
UE-25a#1	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.15	0.78
Mean	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.18	0.72
Upper range	0.06	0.06	0.06	0.06	0.06	0.08	0.08	0.39	1.44
Lower range	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.08	0.23

3.2.3 Volumetric Fracture Frequency in a Unit Volume of Rock (λ_v)

Volumetric fracture frequency is a nondirectional parameter that includes consideration of sample bias. It serves as an index for the fracture abundance in the rock mass (Spengler and Chornack, 1984; Scott and Castellanos, 1984).

The estimated number of fractures in a sphere with a diameter of 1 m was obtained by summing the corrected fracture frequencies for all 10° intervals. A sphere with volume of 1 m^3 has a diameter of 1.24 m, which was used as the interval length for determination of the number of fractures. The following equation was used to calculate the volumetric fracture frequency in a unit volume of 1 m^3 (Scott et al., 1983):

$$\lambda_v = \sum_{i=1}^{9} \lambda_{ti} \times 1.24 \quad , \qquad (3\text{-}2)$$

where i = dip interval, and

λ_{ti} = corrected fracture frequency of interval i.

The results of this calculation for each unit and drill hole are shown in Table 3-12. These results have been compared with the volumetric fracture frequencies presented in Spengler and Chornack (1984) for USW G-4 and Scott and Castellanos (1984) for USW GU-3, which are summarized in Table 3-13, and were found to be in general agreement.

Lateral variations based upon the differences between drill holes are observed within most of the welded tuff units. The volumetric fracture frequency for the TCw unit ranges from 8.36 to 30.87 fractures per cubic meter; for the TSw1 unit, the range is from 2.87 to 22.35 fractures per cubic meter; and for the TSw2 unit, it is from 5.41 to 40.61 fractures per cubic meter. The arithmetic mean of the volumetric fracture frequencies for each unit are also listed in Table 3-12.

These values are consistent with the average linear fracture frequencies along the drill hole axis, calculated based upon the raw data in Section 3.2.1.

TABLE 3-12. VOLUMETRIC FRACTURE FREQUENCY IN A UNIT VOLUME OF ROCK (m^{-3})

Drill Hole	TCw	PTn	TSw1	TSw2	TSw3	CHn1
USW G-1	NA	NA	3.04	5.41	15.36	0.81
USW G-4	30.87	3.95	22.35	21.56	17.39	1.53
USW GU-3	20.79	NA	9.48	40.61	12.16	2.46
UE-25a#1	8.36	NA	2.87	10.96	12.45	1.59
Mean	20.01	NA	9.44	19.64	14.34	1.60

NA *Data not available.*

TABLE 3-13. VOLUMETRIC FRACTURE FREQUENCY PRESENTED IN SPENGLER AND CHORNACK (1984) AND SCOTT AND CASTELLANOS (1984)

Drill Hole	Tiva Canyon Member	Pah Canyon Member	Topopah Spring Member	Tuffaceous Beds of Calico Hills
USW G-4	33.5-41.3	0.5-1.3	3.5-35.6	1.1-2.0
USW GU-3	22.0	NA	8.0-42.0	3.0

NA *Data not available.*

4.0 FRACTURE CHARACTERISTICS

The surface roughness, fillings, and coatings of the fractures are considered in this section. These data will be used in estimating the rock mass mechanical properties (strength and deformability) and for assessing rock mass quality indices.

4.1 Fracture Roughness

Fracture roughness has been estimated by a number of investigators using both core logging and outcrop mapping data.

Joint roughness has been described using both a qualitative narrative description (e.g., smooth, planar) and a qualitative numerical index called the Joint Roughness Coefficient (JRC), proposed by Barton (1973). Both approaches are utilized for development of rock mass properties. Qualitative narrative descriptions are used to establish the value of the Joint Roughness Number (JR) used to estimate rock mass quality in the Q system, proposed by Barton et al. (1974). JRC values are used in an empirical method to estimate shear strength of joints, proposed by Barton (1973).

The roughnesses for the fractures on outcrops of the Tiva Canyon Member in the vicinity of drill hole USW G-4 have been analyzed by Barton et al. (1989). Measurements were made on 5000 fractures at 50 outcrop stations with roughness expressed as the JRC, defined by Barton and Choubey (1977). A normal distribution of JRC was observed at a majority of the stations. The statistical mean and standard deviation of JRC were calculated for each station; the mean JRC ranged from 3.6 ± 3.2 to 8.2 ± 3.4. Table 4-1 lists the mean and standard deviation for normal distribution fits and type of best fit data distribution for each station. Excluding data for the exponential and logarithmic distributions, the mean JRC was 6.3, and the average of the standard deviations was 3.3.

Values for the JRC were also determined by Klavetter in the SCP-CDR (SNL, 1987) for welded and nonwelded tuff thermomechanical units. Ranges for the JRC of 6 to 12 and 2 to 8

TABLE 4-1. JOINT ROUGHNESS COEFFICIENT STATISTICS (after Barton et al., 1989)

Station	Mean JRC	Standard Deviation	Curve Distribution
1	6.5	2.6	Normal
2	5.9	2.8	Normal
3	5.1	3.2	Normal
4	6.2	3.6	Normal
5	5.4	3.4	Normal
6	6.4	4.3	Normal
7	7.7	4.7	Normal
8	5.3	3.9	Exponential
9	4.1	3.6	Logarithmic
10	7.3	3.5	Normal
11	5.7	3.5	Normal
12	6.2	3.3	Normal
13	5.3	3.5	Normal
14	4.7	4.2	Exponential
15	4.2	3.7	Exponential
16	5.8	3.3	Normal
17	6.5	2.7	Normal
18	3.6	3.2	Logarithmic
19	6.1	3.3	Normal
20	6.2	2.9	Normal
21	4.9	3.5	Normal
22	6.0	3.2	Normal
23	4.4	2.6	Normal
24	6.2	3.3	Normal
25	6.8	4.1	Normal
26	7.8	4.1	Normal
27	7.6	2.8	Normal
28	5.3	2.8	Normal
29	4.3	2.8	Normal
30	4.5	1.9	Normal
31	6.5	3.1	Normal
32	6.4	3.0	Normal
33	3.6	3.3	Exponential
34	5.3	3.0	Normal
35	5.8	3.4	Normal
36	6.6	3.4	Normal
37	6.2	3.4	Normal
38	5.8	3.7	Normal
39	6.5	3.6	Normal
40	7.0	3.4	Normal
41	5.6	3.5	Normal
42	6.2	3.9	Normal
43	5.5	3.4	Normal
44	6.1	3.8	Normal
45	6.8	3.3	Normal
46	8.0	3.8	Normal
47	7.8	3.4	Normal
48	7.2	4.1	Normal
49	8.2	3.4	Normal
50	7.7	2.7	Normal

were reported to represent the joint roughness for welded and nonwelded tuff units, respectively. No differentiation beyond welded or nonwelded tuff was mentioned.

Peters et al. (1984) described qualitatively the fracture roughness for five tuff core samples. Three densely welded tuff samples have fracture surfaces described as "rough, but planar surface"; "smooth, curved surface"; and "smooth, planar surface." Two moderately consolidated tuff samples have fracture surfaces described as "undulating surface" and "planar surface."

Langkopf and Gnirk (1986), in estimating the range of rock mass quality, described the fracture roughness for the Topopah Spring Member and tuffaceous beds of Calico Hills using the planarity information reported in the fracture descriptions of USW G-1, USW GU-3, and USW G-4 by the U.S. Geological Survey. The planarity descriptions for fractures in these two thermomechanical units are summarized in Tables 4-2 and 4-3. Each table is divided into those fractures inclined at greater than and at less than 45°. More weight was given to the description for fractures inclined at greater than 45° because of the dominance of nearly vertical fractures. They described the fracture surface for the Topopah Spring Member as "discontinuous" to "smooth, undulating"; and those for the tuffaceous beds of Calico Hills as "smooth, undulating" to "smooth, planar." These descriptions were used to assign the JR in the Q system proposed by Barton et al. (1974).

In summary, available data on joint roughness suggests that fracture roughness differs between the welded and nonwelded tuff rocks. Table 4-4 lists the quantitative narrative and numerical index values adopted for the two types of tuff. The mean (6.3) and average of the standard deviation (3.3) of JRC from the outcrop mapping of the Tiva Canyon Member (Barton et al., 1989) are recommended as the basis of a credible range for the welded tuff thermo-mechanical units. The range for JRC of 2 to 8 is recommended for the nonwelded tuff units (SNL, 1987). The qualitative descriptions derived by Langkopf and Gnirk (1986) for the Topopah Spring Member and Calico Hills are recommended as the descriptions for the welded and nonwelded units, respectively.

TABLE 4-2. PLANARITY INFORMATION FROM DRILL HOLES IN THE TOPOPAH SPRING UNIT (after Langkopf and Gnirk, 1986)

Planarity Description	Percentage of Descriptions for Fractures Inclined at >45°				
	UE-25a#1	USW G-1(a)	USW G-1(b)	USW GU-3	USW G-4
Nonplanar	0	76	89	50	27
Nearly planar or slightly planar	0	13	0	21	65
Planar	0	3	4	24	8
No definition	100	7	7	4	0
	Percentage of Descriptions for Fractures Inclined at <45°				
	UE-25a#1	USW G-1(a)	USW G-1(b)	USW GU-3	USW G-4
Nonplanar	0	75	50	44	9
Nearly planar or slightly planar	0	11	0	20	91
Planar	0	3	17	34	0
No definition	100	9	33	4	0

TABLE 4-3. PLANARITY INFORMATION FROM DRILL HOLES IN THE CALICO HILLS UNIT (after Langkopf and Gnirk, 1986)

Planarity Description	Percentage of Descriptions for Fractures Inclined at >45°				
	UE-25a#1	USW G-1(a)	USW G-1(b)	USW GU-3	USW G-4
Nonplanar	0	78	0	NP	6
Nearly planar or slightly planar	0	11	0	NP	82
Planar	0	11	0	NP	12
No definition	100	0	100	NP	0
	Percentage of Descriptions for Fractures Inclined at <45°				
	UE-25a#1	USW G-1(a)	USW G-1(b)	USW GU-3	USW G-4
Nonplanar	0	100	100	NP	0
Nearly planar or slightly planar	0	0	0	NP	80
Planar	0	0	0	NP	20
No definition	100	0	0	NP	0

NP *Not present.*

TABLE 4-4. RECOMMENDED RANGE OF JOINT ROUGHNESS

	JRC		Narrative Description	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
TCw	3.0	9.6	Discontinuous	Smooth, undulating
PTn	2.0	8.0	Smooth, undulating	Smooth, planar
TSw1	3.0	9.6	Discontinuous	Smooth, undulating
TSw2	3.0	9.6	Discontinuous	Smooth, undulating
TSw3	3.0	9.6	Discontinuous	Smooth, undulating
CHn1	2.0	8.0	Smooth, undulating	Smooth, planar

4.2 Fillings and Coatings Along the Fracture Surfaces

For both the RMR (Bieniawski, 1979) and Q (Barton et al., 1974) rock mass classification systems, the type of mineral fillings and coatings affect the ratings of rock mass. For example, the presence of a soft or low friction clay mineral coating or thick infillings will reduce shear strength of joints, therefore, the rock mass quality in each of the two systems will be reduced.

Descriptions of the mineral fillings and coatings along the fractures were provided in the four drill hole reports: Scott and Castellanos (1984), Spengler and Chornack (1984), Spengler et al. (1979) and Spengler et al. (1981). Bar graphs showing the fracture fillings and coatings and their frequency of occurrence on the fractures logged in the core are given in Figures 4-1 to 4-4, where the frequency of the fracture coatings and fillings can sum to more than 100% because more than one mineral type may occur along a single fracture. Because the Mohs scale of hardness values for clay, calcite, and manganese oxides are lower than 3, these minerals are grouped as soft infilling in this study. The infilling minerals that affect the rock mass rating are summarized below based upon the drill hole reports.

Manganese oxides are the dominant type of fracture coating in the Tiva Canyon welded unit and the Upper Paintbrush nonwelded unit. Eighty-three percent of the fractures in USW G-4 core are stained with manganese oxides, over 50% in the core from drill hole UE-25a#1, and nearly 40% from drill hole USW G-3. Fifteen percent of the fractures from UE-25a#1 contain calcite and 12% of the fractures contain clay.

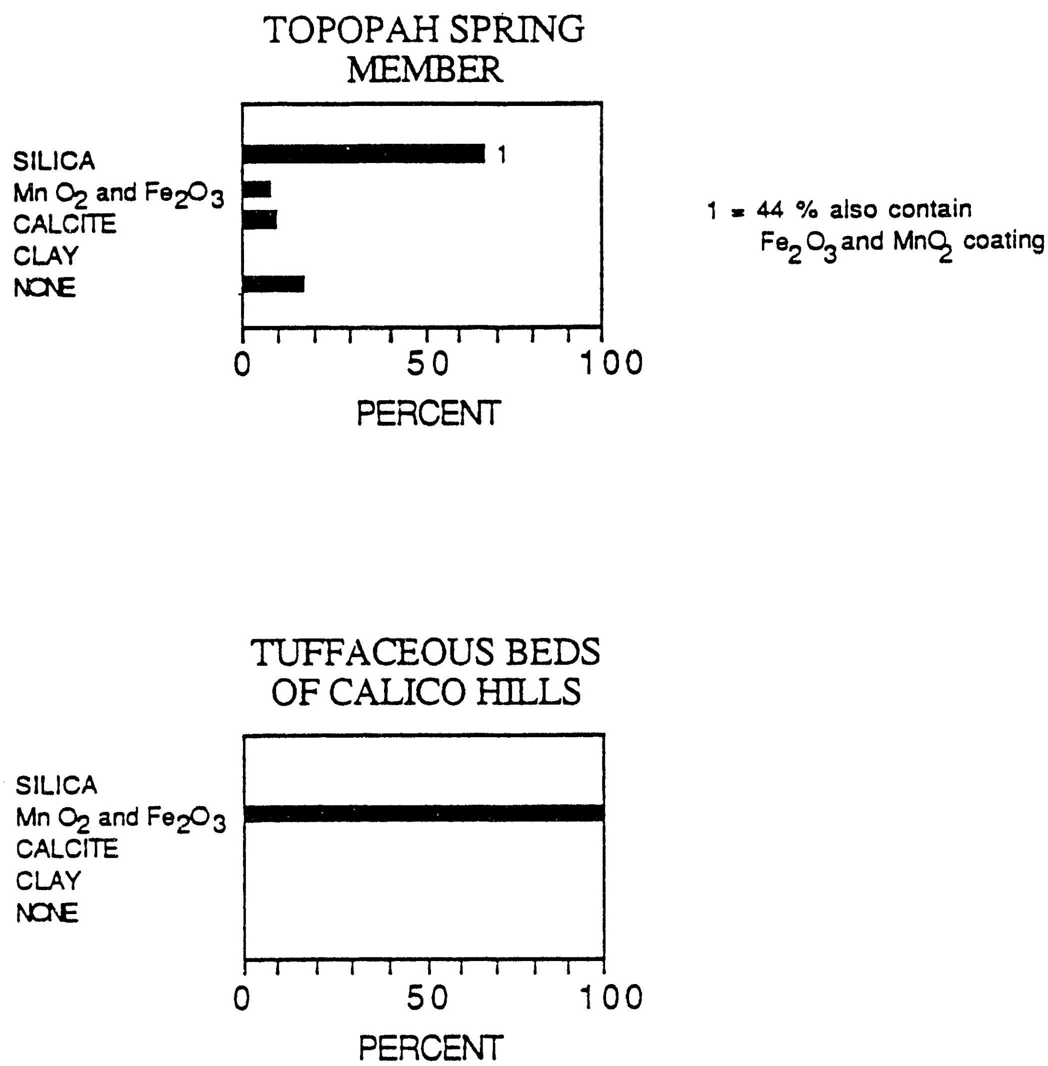


Figure 4-1. Fracture Coating and Fillings of USW G-1 (after Spengler et al., 1981)

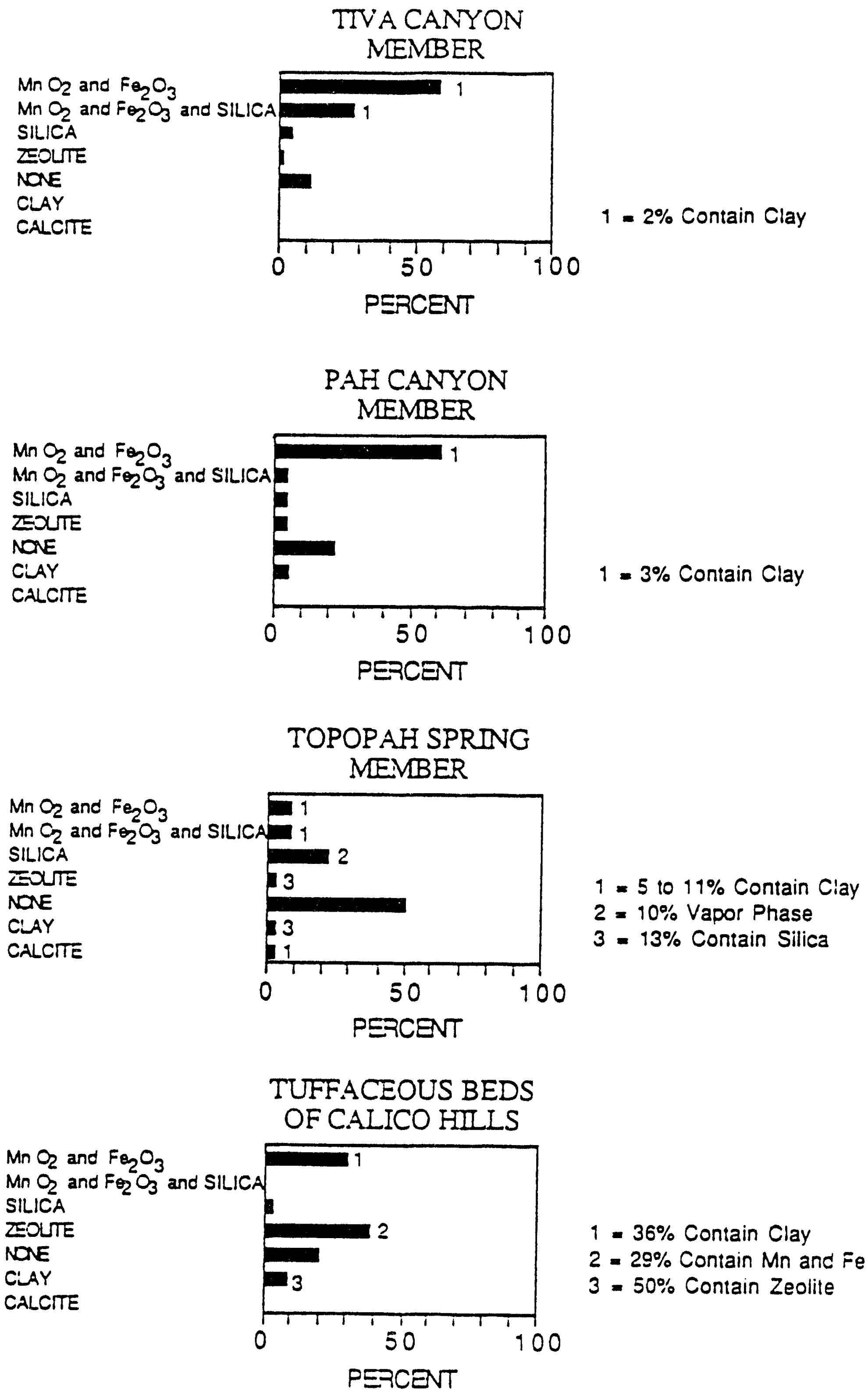


Figure 4-2. Fracture Coating and Fillings of USW G-4 (after Spengler and Chornack, 1984)

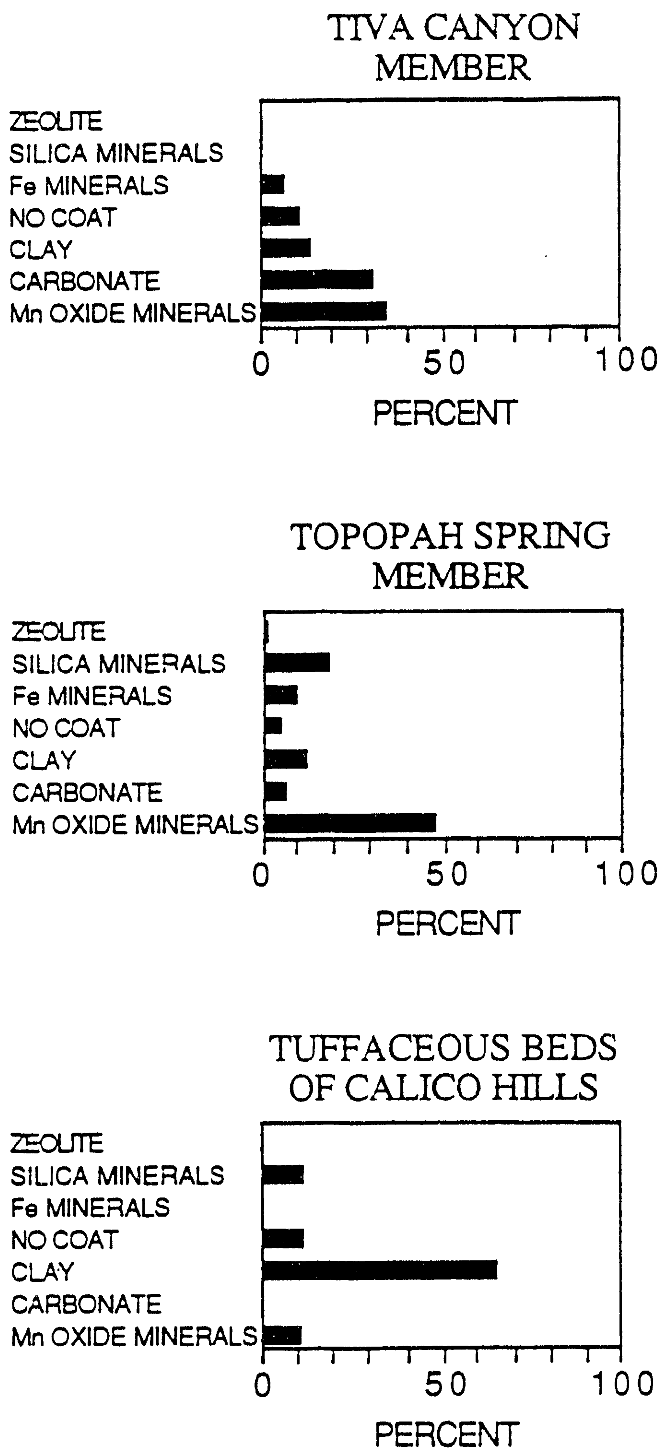


Figure 4-3. Fracture Coating and Fillings of USW GU-3 (after Scott and Castellanos, 1984)

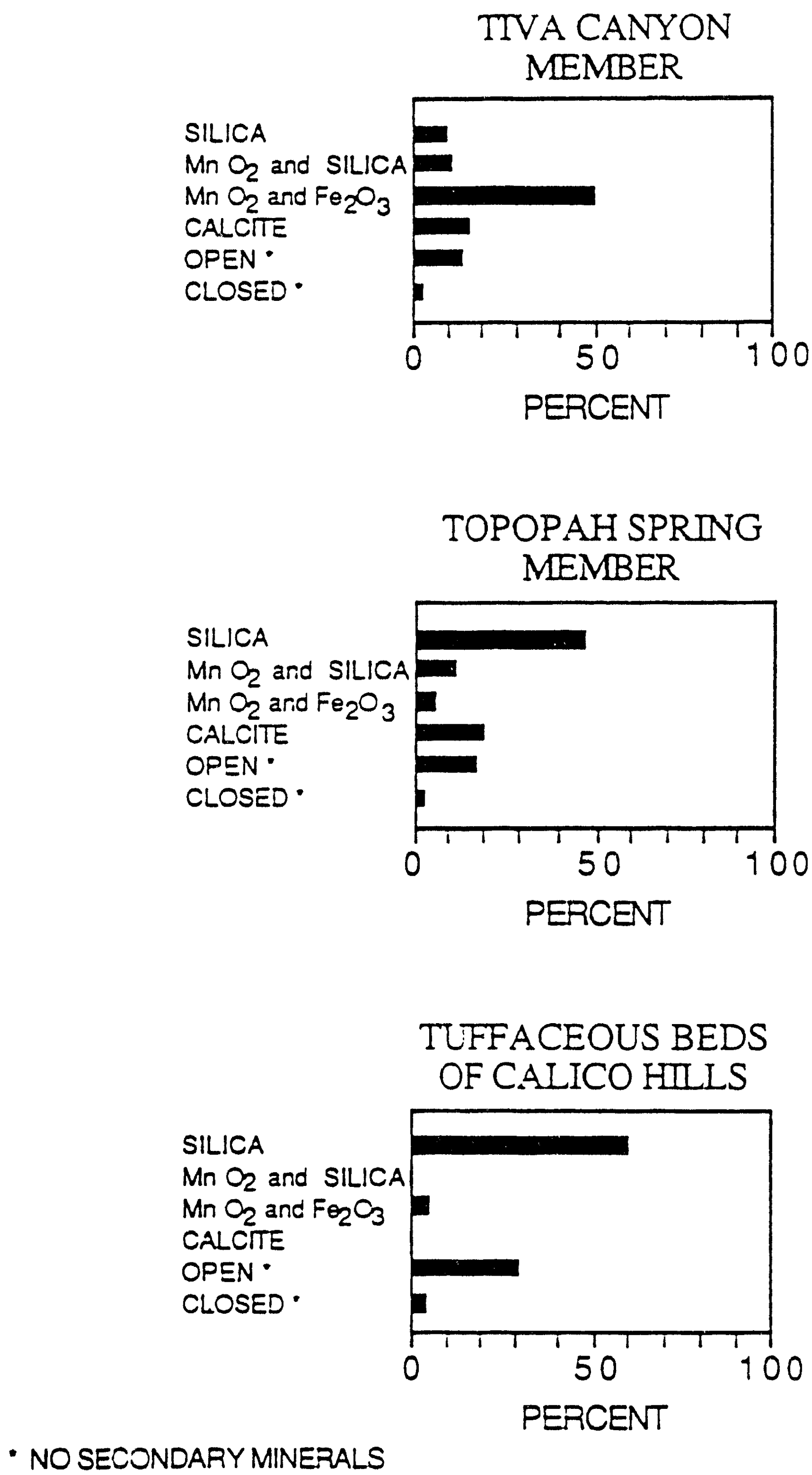


Figure 4-4. Fracture Coating and Fillings of UE-25a#1 (after Spengler et al., 1979)

For the Topopah Spring Member, manganese oxides were the major components of the fracture fillings. They existed on over 58% of the fractures for drill hole UE-25a#1. For USW GU-3, 48% of the fracture fillings were stained with manganese oxides. In drill hole UE-25a#1, approximately 20% of the fractures were coated with calcite.

In the tuffaceous beds of Calico Hills, all fracture fillings contained manganese oxides and 70% of the fractures from USW GU-3 had a clay coating.

The influence of infillings on the mechanical response of fractures have been examined by Goodman (1970) and Barton et al. (1974), who indicated that infillings have to be relatively thick to affect the frictional behavior of the fractures. Quantitative measurements of the thickness of fillings for the fractures at Yucca Mountain were not available. According to Langkopf and Gnirk (1986), the fracture fillings were generally thin, both in the Topopah Spring Member and Calico Hills, with approximately half of the fracture surfaces within the interval of the Topopah Spring Member in USW G-4 described as merely discolored (i.e., the fracture fillings are thin). Similarly, approximately 80% of the fracture surfaces within the interval of Calico Hills were described as discolored. Based on the observed thin infillings, the impact of infilling on the mechanical behavior of fractures at Yucca Mountain was considered to be minor.

5.0 ESTIMATION OF ROCK QUALITY

5.1 Calculation of Rock Quality Designation

The RQD index is widely used as an index of rock quality in rock mechanics practice. Deere et al. (1967) introduced the concept of RQD and defined it as a modified core-recovery percentage that incorporated only unbroken pieces of core that are 100 mm (4 in.) or greater in length. The relationship between the RQD index and the relative quality of the rock listed in Table 5-1 was proposed by Deere (1968).

TABLE 5-1. RELATIVE ROCK QUALITY CORRELATED WITH ROCK QUALITY DESIGNATION (Deere, 1968)

RQD (%)	Rock Quality
< 25	Very poor
25 - 50	Poor
50 - 75	Fair
75 - 90	Good
90 - 100	Excellent

For RQD determination, the International Society for Rock Mechanics recommends a core size of at least NX size (54.7-mm diameter) drilled with double-tubed core barrels. All four drill holes were drilled using double-tubed core barrels (Langkopf and Gnirk, 1986). The diameters of most of the cores from Yucca Mountain ranged from 98.4 to 108.0 mm, except the Topopah Spring unit in drill hole UE-25a#1 which was NQ core (47.6-mm diameter).

RQD was not directly measured on the Yucca Mountain core, rather, a Core Index (CI) number was compiled by geologists. The CI number for an interval is calculated from an estimate of the joint frequency, core loss, and broken core (defined as core less than 100 mm or 4 in. in length) (Ege, 1983). The equation used to compute the CI is expressed as

$$CI = \frac{(\text{broken core} + \text{loss} + 1/3 \text{ joints})}{\text{cored interval}} \times 100 \quad . \qquad (5\text{-}1)$$

The equation defined by Deere et al. (1967) for calculating the RQD is

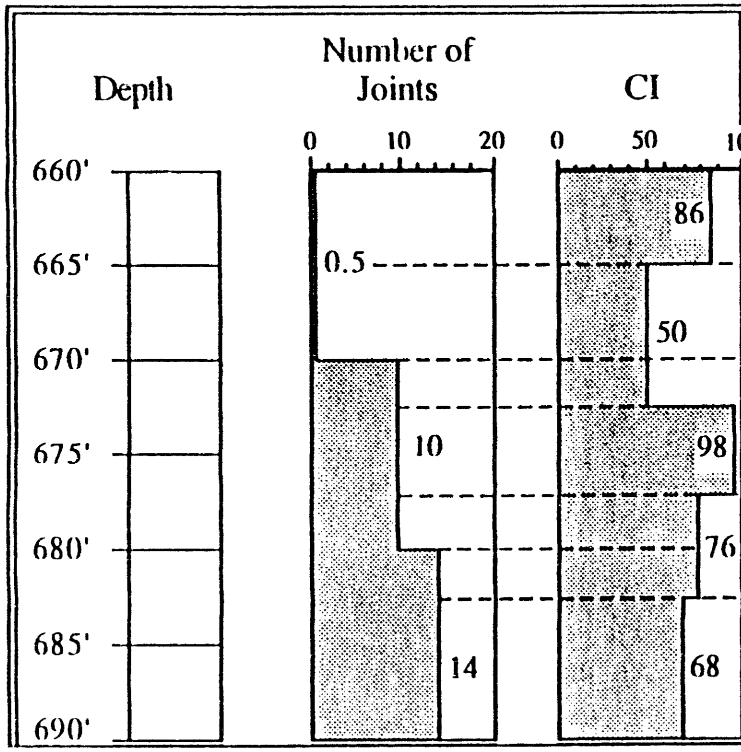
$$RQD = \frac{(\text{sum of core length} > 100 \text{ mm})}{\text{cored interval}} \times 100 \quad . \qquad (5\text{-}2)$$

Based on Equations (5-1) and (5-2), RQD can be derived for each cored interval using the CI and the number of fractures recorded in the CI sheets, provided that the core loggers followed the definition given by Ege (1983) for the broken-core parameter. RQD was, therefore, calculated using the following equations:

$$RQD = \frac{[\text{cored interval} - (\text{core loss} + \text{broken core})]}{\text{core interval}} \times 100 \quad , \qquad (5\text{-}3)$$

$$\text{where (core loss + broken core)} = \frac{CI \times \text{cored interval}}{100} - 1/3 \text{ joints} \quad . \qquad (5\text{-}4)$$

The procedure for calculating RQD, which assumes that fractures are equally distributed in the 10-ft interval, is illustrated in Figure 5-1. Based on the definition of RQD, the maximum number for RQD is 100%. However, RQDs greater than 100% were calculated in some intervals from the collected data of CI and joint number. For these intervals, the values of core loss and broken core back-calculated from Equation (5-4) are negative. Inconsistency in reporting the number of joints and CI may have caused this problem. RQD was cut off at 100% for those intervals with calculated RQD greater than 100%. Data on number of joints, CI, and cored interval from the CI logging sheets and the calculated RQD for each of the four drill holes are listed in Tables C-1 to C-4 of Appendix C.



Core Interval	Number of Joints	CI	Broken Core + Core Loss (Eq. 5-4)	RQD (Eq. 5-3)
5'	$0.5 \times \frac{5}{10} = 0.25$	86	4.22'	16
5'	$0.5 \times \frac{5}{10} = 0.25$	50	2.42'	52
2.5'	$10 \times \frac{2.5}{10} = 2.5$	50	0.42'	83
5'	$10 \times \frac{5}{10} = 5$	98	3.23'	35
2.5'	$10 \times \frac{2.5}{10} = 2.5$	76	1.07'	57
2.5'	$14 \times \frac{2.5}{10} = 3.5$	76	0.73'	71
7.5'	$14 \times \frac{7.5}{10} = 10.5$	68	1.60'	79

Figure 5-1. Procedure for Calculation of RQD from Joint Numbers and Core Index Recorded in Core Index Sheets

The RQD data represent a sampling of the vertical variation of rock quality in each hole within each thermomechanical unit and are the best available basis for estimating the range of lateral variation in rock quality that may be encountered. Average values of RQD are listed in Table 5-2 for each thermomechanical un·t, and can be used to establish the relative range of average rock quality for each unit. For the TCw unit, the average RQD ranges from fair to excellent; for the PTn unit, variability was low and fair rock quality was predicted for all drill holes; for the TSw1 and TSw2 units, poor to fair rock quality was predicted; for the TSw3 unit, RQD ranged from fair to good; and for the CHn1 unit, RQD ranged from poor to excellent.

TABLE 5-2. THE AVERAGE ROCK QUALITY DESIGNATION FOR EACH THERMOMECHANICAL UNIT

Drill Holes	TCw	PTn	TSw1	TSw2	TSw3	CHn1
USW G-1	NA	NA	52.5	35.8	75.8	77.4
USW G-4	96.1	50.0	59.8	53.0	51.8	90.3
USW GU-3	62.5	66.9	65.4	54.6	75.5	45.3
UE-25a#1	62.0	63.0	32.0	47.9	69.3	82.8

The CI number represents an estimate of the joint frequency, core loss, and broken core into one significant number. An increase in the CI corresponds to an increase in joint frequency, core loss, and/or broken core, and, therefore, relates to a decrease in structural quality. An increase in RQD, however, relates to an increase in rock quality. From the above rationale, low rock quality generally indicates a high CI number or low RQD value. However, high RQD values were calculated for some intervals with high CI numbers. For example, high CI numbers were recorded in most of the cored intervals for the TCw in USW G-4, and high RQD values were calculated for these intervals (average RQD = 96.1). Mathematically, this is mainly due to the high joint numbers counted in these intervals. In reality, high RQD and CI values both existed in the same cored interval, which presents a contradiction for defining the rock quality. Intervals with numbers of joints higher than 30 and CI less than 100 were actually recorded. According to the definition of CI, the maximum value of CI could be higher than 100. The CI logs in the drill hole reports, however, have maximum values of up to 100 only. Cutting off the CI number at 100 for those intervals with CI values higher than 100 might have been applied.

If this were the case, it would be impossible to calculate the correct RQD values for these intervals.

5.2 Rock Quality Designations for the Five Rock Quality Categories

The use of the average RQD for representing the rock quality of the entire unit would not be appropriate to account for the spatially variable conditions. Lateral variation of fracture frequency (Section 3.2.2) and RQD was suggested by the data from the four available core holes. A range of values to account for the lateral changes was recommended in the Drift Design Methodology proposed by Hardy and Bauer (1991). This was applied in this study for the selection of five rock quality categories representing the credible range of expected conditions.

Based on the assumption that the depth of the underground excavations was 20 ft, the RQD values were averaged for 20-ft intervals in each thermomechanical unit, which were used to develop the frequency of occurrence distributions. Tables C-5 to C-10 in Appendix C list the average 20-ft RQD for the six thermomechanical units. Based on the results in each table, the cumulative probability of occurrence of RQD for each unit is presented in Tables 5-3 to 5-8. Based on plots of the cumulative probability of occurrence versus RQD (Figures 5-2 to 5-7), RQDs for five rock quality categories were selected so that the percentage of rock with better RQD fell into the ranges of 95%, 80%, 60%, 30%, and 10%. Table 5-9 summarizes the RQD values for the five rock quality categories.

TABLE 5-3. CUMULATIVE FREQUENCIES FOR THE TCw UNIT

RQD	No. of Occurrence: USW GU-3	No. of Occurrence: USW G-4	No. of Occurrence: UE-25a#1	Sum of the No. of Occurrence	Percentage of Total Occurrence	Cumulative Frequency of Occurrence (%)
0 - 10	0	0	0	0	0.0	0.0
10 - 20	0	0	1	1	3.8	3.8
20 - 30	0	0	0	0	0.0	3.8
30 - 40	1	0	0	1	3.8	7.7
40 - 50	2	0	1	3	11.5	19.2
50 - 60	3	0	0	3	11.5	30.8
60 - 70	5	0	3	8	30.8	61.5
70 - 80	2	0	0	2	7.7	69.2
80 - 90	2	0	1	3	11.5	80.8
90 - 100	0	4	1	5	19.2	100.0
0 - 100	15	4	7	26	100.0	

TABLE 5-4. ROCK QUALITY DESIGNATION CUMULATIVE FREQUENCIES FOR PTn UNIT

RQD	No. of Occurrence: USW GU-3	No. of Occurrence: USW G-4	No. of Occurrence: UE-25a#1	Sum of the No. of Occurrence	Percentage of Total Occurrence	Cumulative Frequency of Occurrence (%)
0 - 10	0	0	0	0	0.0	0.0
10 - 20	0	0	0	0	0.0	0.0
20 - 30	0	1	0	1	7.1	7.1
30 - 40	0	1	0	1	7.1	14.3
40 - 50	0	1	0	1	7.1	21.4
50 - 60	1	0	1	2	14.3	35.7
60 - 70	1	2	2	5	35.7	71.4
70 - 80	2	1	1	4	28.6	100.0
80 - 90	0	0	0	0	0	100.0
90 - 100	0	0	0	0	0	100.0
0 - 100	4	6	4	14	100.0	

TABLE 5-5. ROCK QUALITY DESIGNATION CUMULATIVE FREQUENCIES FOR TSw1 UNIT

RQD	No. of Occurrence USW G-1	USW GU-3	USW G-4	UE-25a#1	Sum of the No. of Occurrence	Percentage of Total Occurrence	Cumulative Frequency of Occurrence (%)
0 - 10	1	0	0	3	4	5.7	5.7
10 - 20	1	0	4	4	9	12.9	18.6
20 - 30	2	0	0	1	3	4.3	22.9
30 - 40	3	2	1	2	8	11.4	34.3
40 - 50	1	2	2	2	7	10.0	44.3
50 - 60	5	0	0	3	8	11.4	55.7
60 - 70	2	2	1	2	7	10.0	65.7
70 - 80	0	5	3	0	8	11.4	77.1
80 - 90	6	0	3	0	9	12.9	90.0
90 - 100	0	2	5	0	7	10.0	100.0
0 - 100	21	13	19	17	70	100.0	

TABLE 5-6. ROCK QUALITY DESIGNATION CUMULATIVE FREQUENCIES FOR TSw2 UNIT

RQD	No. of Occurrence USW G-1	USW GU-3	USW G-4	UE-25a#1	Sum of the No. of Occurrence	Percentage of Total Occurrence	Cumulative Frequency of Occurrence (%)
0 - 10	2	0	0	0	2	1.7	1.7
10 - 20	3	2	3	2	10	8.7	10.4
20 - 30	9	3	3	5	20	17.4	27.8
30 - 40	4	3	3	4	14	12.2	40.0
40 - 50	1	4	5	8	18	15.7	55.7
50 - 60	3	3	5	4	15	13.0	68.7
60 - 70	1	2	4	3	10	8.7	77.4
70 - 80	2	3	3	3	11	9.6	87.0
80 - 90	0	3	3	2	8	7.0	93.9
90 - 100	2	2	2	1	7	6.1	100.0
0 - 100	27	25	31	32	115	100.0	

TABLE 5-7. ROCK QUALITY DESIGNATION CUMULATIVE FREQUENCIES FOR TSw3 UNIT

	No. of Occurrence				Sum of the No.	Percentage of	Cumulative Frequency
RQD	USW G-1	USW GU-3	USW G-4	UE-25a#1	of Occurrence	Total Occurrence	of Occurrence (%)
0 - 10	0	0	0	0	0	0.0	0.0
10 - 20	0	0	0	0	0	0.0	0.0
20 - 30	0	0	0	0	0	0.0	0.0
30 - 40	0	0	1	0	1	8.3	8.3
40 - 50	0	0	0	0	0	0.0	8.3
50 - 60	1	1	0	0	2	16.7	25.0
60 - 70	0	0	1	2	3	25.0	50.0
70 - 80	1	0	0	1	2	16.7	66.7
80 - 90	0	3	0	0	3	25.0	91.7
90 - 100	1	0	0	0	1	8.3	100.0
0 - 100	3	4	2	3	12	100.0	

TABLE 5-8. ROCK QUALITY DESIGNATION CUMULATIVE FREQUENCIES FOR CHn1 UNIT

	No. of Occurrence				Sum of the No.	Percentage of	Cumulative Frequency
RQD	USW G-1	USW GU-3	USW G-4	UE-25a#1	of Occurrence	Total Occurrence	of Occurrence (%)
0 - 10	0	1	1	0	2	2.7	2.7
10 - 20	0	1	0	0	1	1.4	4.1
20 - 30	0	3	0	0	3	4.1	8.2
30 - 40	0	1	0	0	1	1.4	9.6
40 - 50	1	1	0	0	2	2.7	12.3
50 - 60	2	1	0	5	8	11.0	23.3
60 - 70	3	1	0	2	6	8.2	31.5
70 - 80	4	1	1	3	9	12.3	43.8
80 - 90	5	1	1	0	7	9.6	53.4
90 - 100	5	1	15	13	34	46.6	100.0
0 - 100	20	12	18	23	73	100.0	

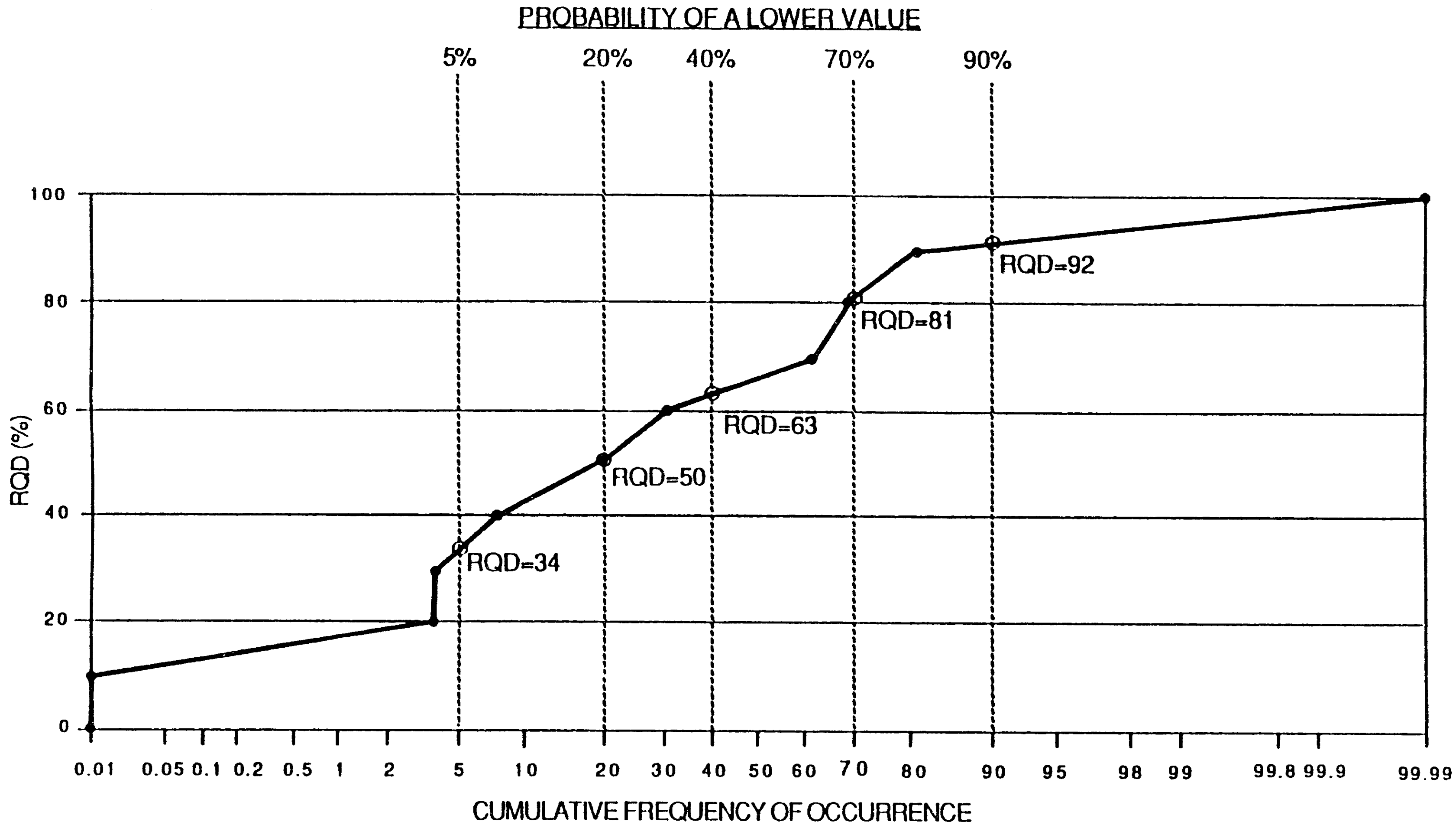


Figure 5-2. Rock Quality Designation Versus Cumulative Probability of Occurrence for TCw Unit

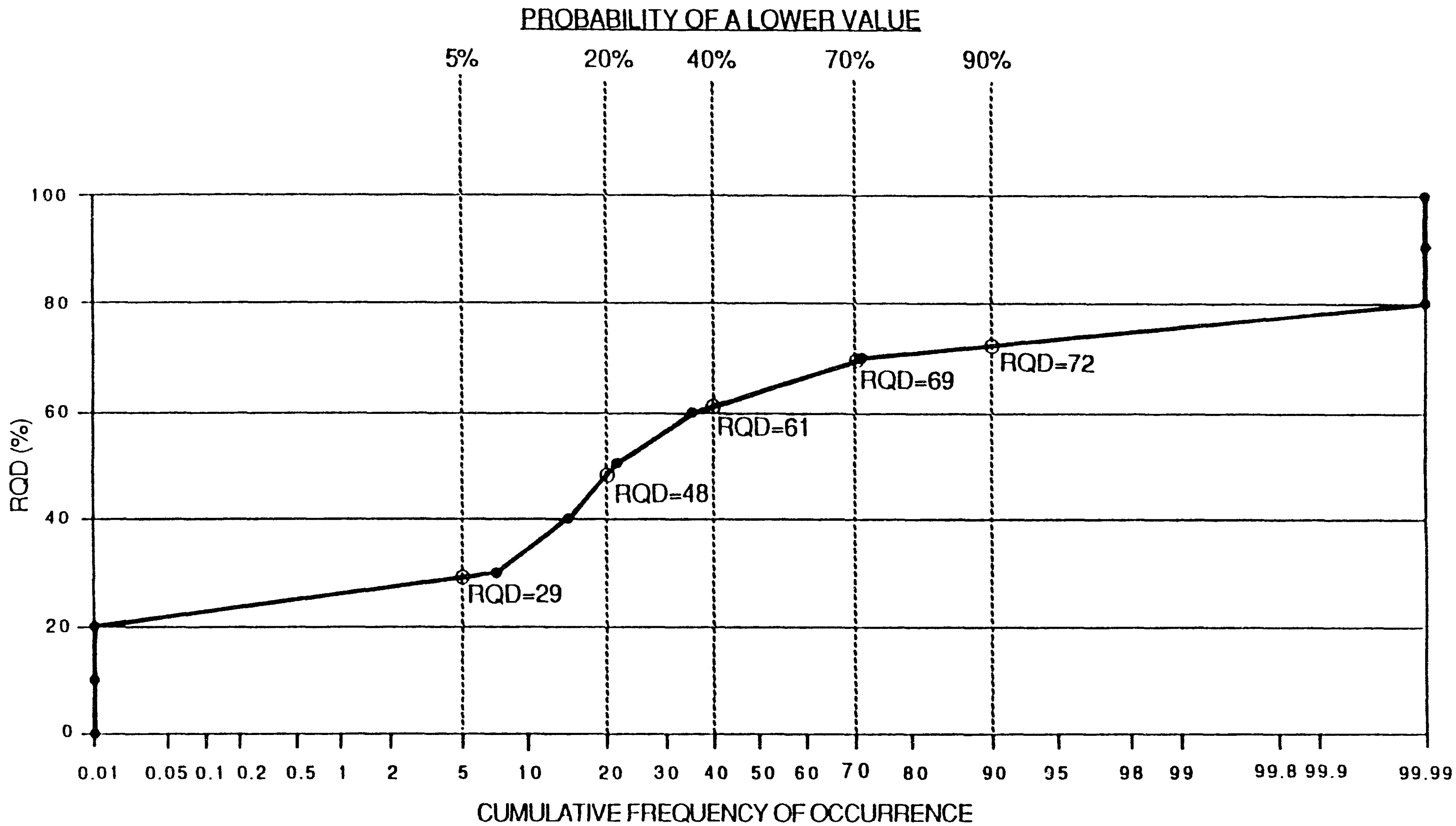


Figure 5-3. Rock Quality Designation Versus Cumulative Probability of Occurrence for PTn Unit

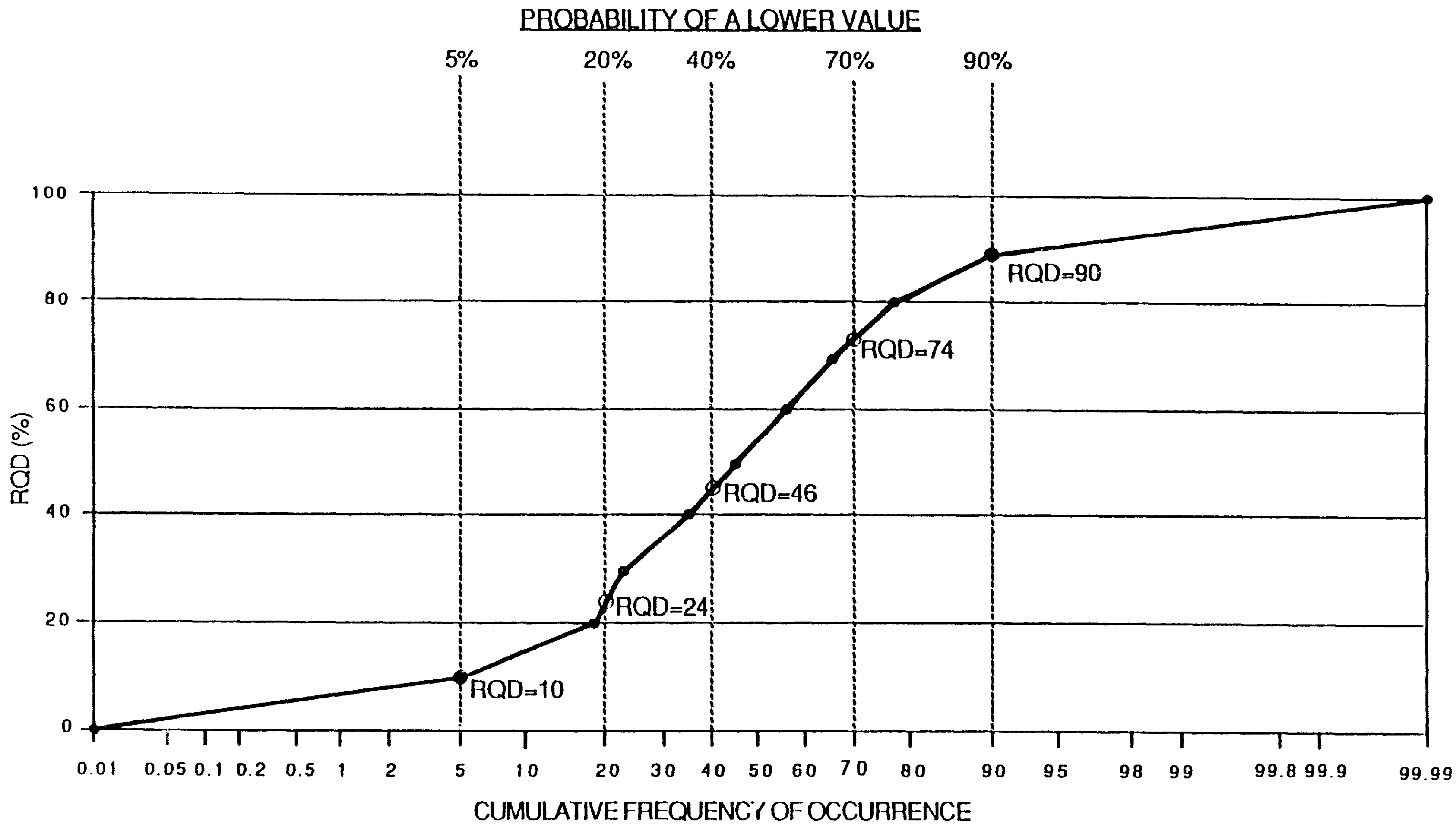


Figure 5-4. Rock Quality Designation Versus Cumulative Probability of Occurrence for TSw1 Unit

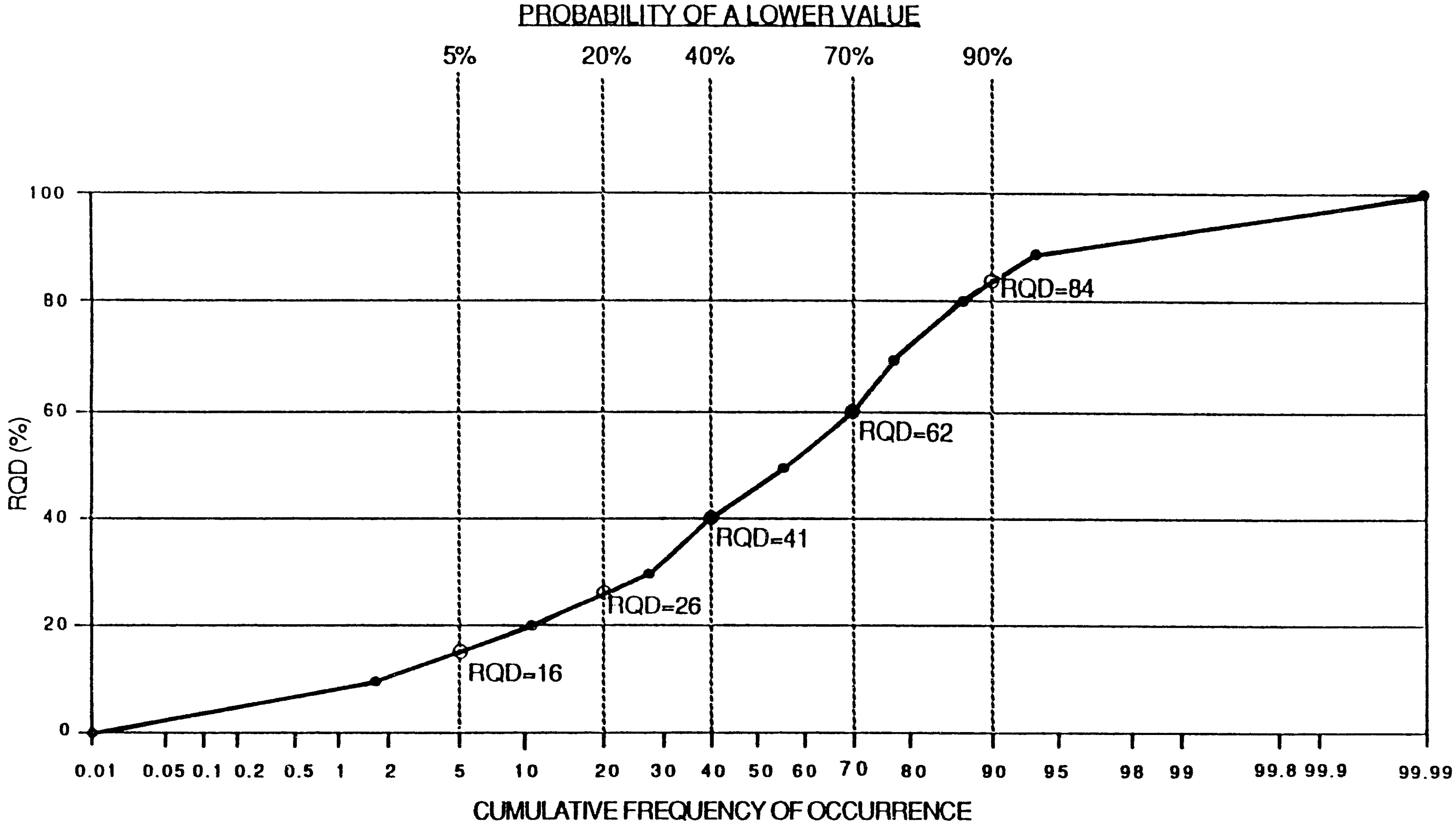


Figure 5-5. Rock Quality Designation Versus Cumulative Probability of Occurrence for TSw2 Unit

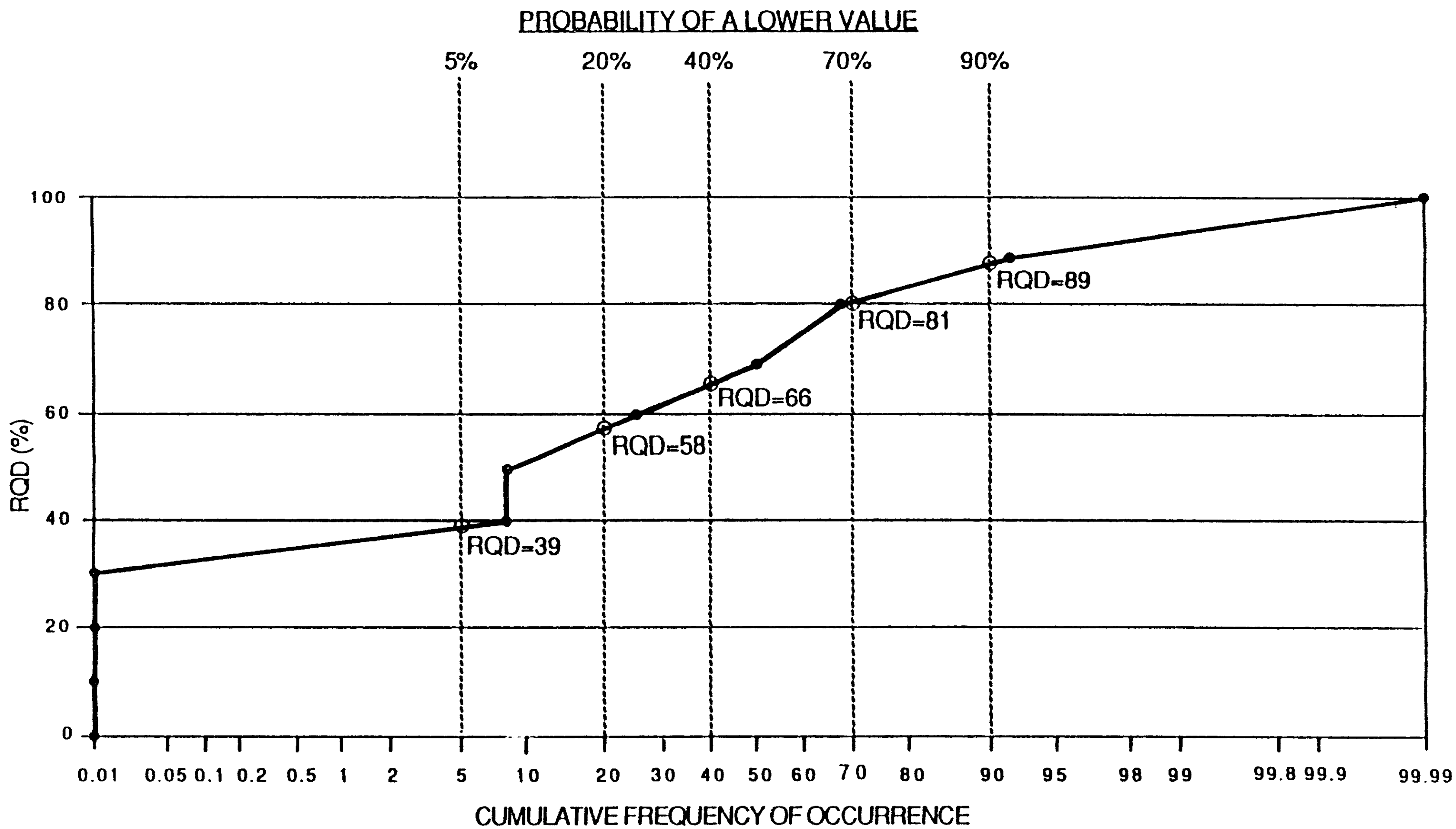


Figure 5-6. Rock Quality Designation Versus Cumulative Probability of Occurrence for TSw3 Unit

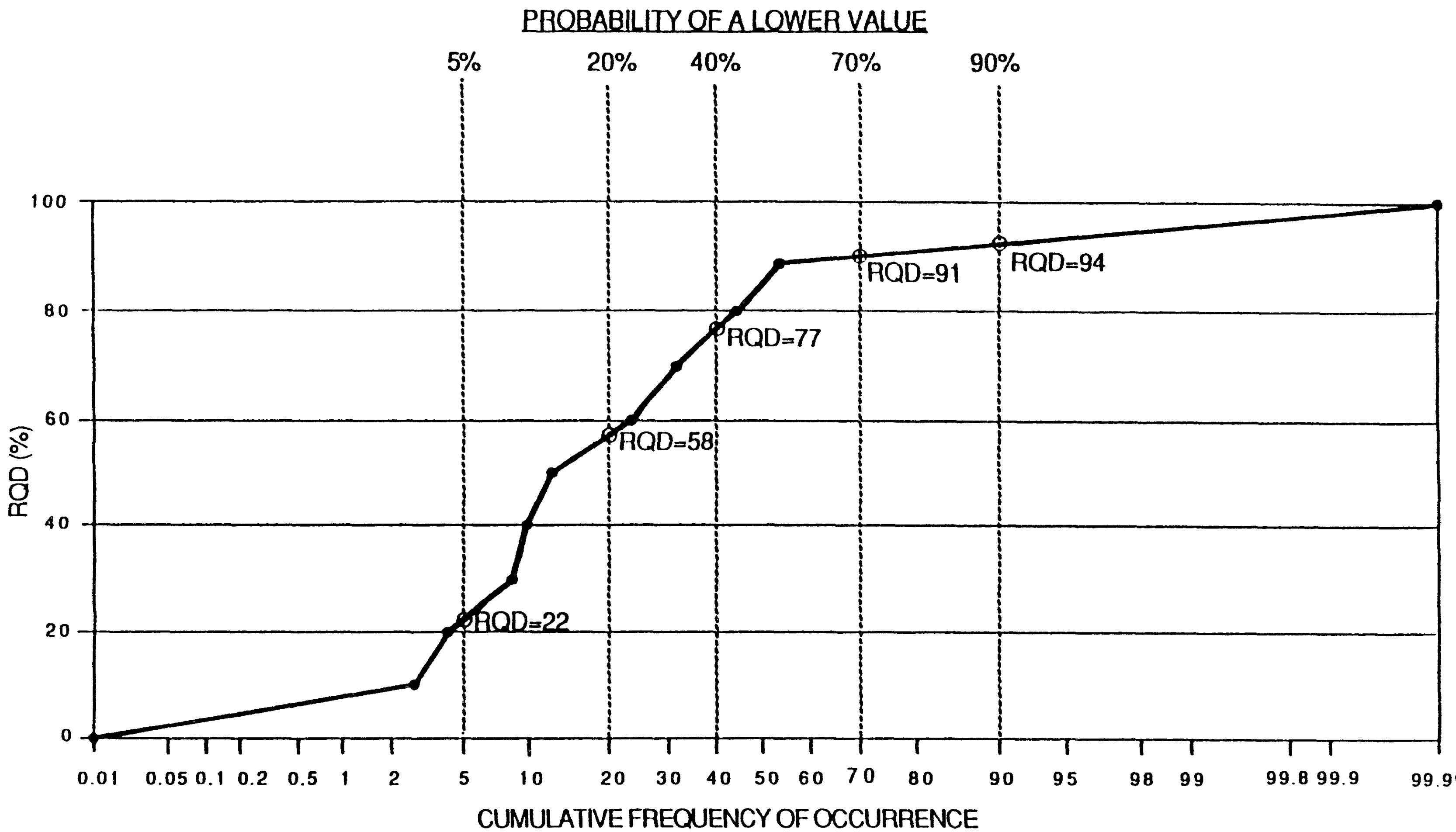


Figure 5-7. Rock Quality Designation Versus Cumulative Probability of Occurrence for CHn1 Unit

TABLE 5-9. ROCK QUALITY DESIGNATIONS FOR THE FIVE ROCK QUALITY CATEGORIES

	Rock Quality Category				
Unit	**1**	**2**	**3**	**4**	**5**
TCw	34	50	63	81	92
PTn	29	48	61	69	72
TSw1	10	24	46	74	90
TSw2	16	26	41	62	84
TSw3	39	58	66	81	89
CHn1	22	58	77	91	94

6.0 DISCUSSION OF RESULTS

Available data on fractures and their characteristics have been studied and analyzed, and estimates of the range in rock quality based on RQD were made for the thermomechanical units to be encountered in excavations in the ESF at Yucca Mountain. These results, summarized in Appendix D, are recommended for inclusion in the RIB.

A total of 3966 fractures were identified in the four drill holes for the six thermomechanical units; 95% of these fractures occur in the densely welded units. Generally, a near-vertical dip was observed for most fractures in all the thermomechanical units. The abundance of fractures was quantified by calculating the linear fracture frequency along the drill hole axis, correcting the linear fracture frequency in 10° inclination angle intervals, and then estimating the nondirectional volumetric fracture frequency for each unit. Fracture frequency was found to generally increase with the degree of welding. However, within the densely welded Topopah Spring Member, the lithophysae-rich units commonly were associated with a slight decrease in fracture frequency. This observation was consistent with work by Scott and Castellanos (1984) and Spengler and Chornack (1984).

Available information on the fracture roughness was not sufficient to define a distinct roughness value for each thermomechanical unit, therefore, ranges of the expected value of the roughness for the rock fractures were based upon the subdivision of welded and nonwelded tuff. Fracture fillings were generally reported to be thin and, therefore, were not expected to impact the fracture shear strength.

The RQD has been estimated from the logged data on number of joints and the CI number. The average RQD and RQDs for five rock quality categories based on the actual statistical distribution of the RQD data were also estimated. These rock quality ranges will provide an important part of the basis for estimating rock mass mechanical properties.

Apparent inconsistency in the reporting of CI and the number of joints in the CI logs presented a problem in obtaining an accurate RQD. Modification of CI numbers for certain intervals might have caused the inconsistency. In order to calculate the correct RQD for these intervals, the evaluation of RQD directly from the core would be necessary.

The results obtained for spatial abundance and distribution of fractures in the rock units at Yucca Mountain were based mainly on data from drill cores. However, because the cores were only vertical line samples through three-dimensional fracture networks and because of the limited number of core holes in or near the proposed repository site, the results are certainly incomplete and, therefore, should be considered preliminary. Ongoing and planned studies of fractures on surface outcrops and in underground testing facilities will enhance knowledge of orientation and spatial abundance of fractures.

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APPENDIX A

Core Evaluation to Determine Contacts Between Thermomechanical Units TSw1 and TSw2–By the Sample Overview Committee

Science Applications International Corporation

WBS #1.2.3
QA: N/A

May 15, 1991

David C. Dobson, YMP, NV
J. Russell Dyer, YMP, NV

CORE EVALUATION TO DETERMINE CONTACTS BETWEEN THERMAL-MECHANICAL UNITS TSw1 AND TSw2

Reference: (1) Letter, Gertz to TPOs, dtd. 4/23/91
(2) Letter, Clanton to SOC Members, dtd. 4/29/91

The evaluation of core was undertaken as part of the regularly scheduled Sample Overview Committee Meeting held at the Sample Management Facility on May 7, 1991. The criteria under which the evaluation was performed are shown in Enclosure 1.

The following people served as core evaluators: Chris Rautman, Sandia National Laboratories (SNL); David Vaniman, Los Alamos National Laboratory (LANL); Rick Spengler, U.S. Geological Survey (USGS); Uel S. Clanton, Department of Energy, Yucca Mountain Site Characterization Project (DOE/YMP); and John Peck, Technical and Management Support Services/Science Applications International Corporation (T&MSS/SAIC). The following people served as observers during the evaluation:

Stephen Bolivar, LANL
Albert C. Williams, DOE-Quality Assurance
W. Arch Girdley, DOE/YMP
Donna Sinks, T&MSS/SAIC
Jim McCormick, Raytheon Services Nevada
John Davis, T&MSS/SAIC
Robert Saunders, T&MSS/Westinghouse
Chris Lewis, T&MSS/Harza
Wunan Lin, Lawrence Livermore National Laboratory
John A. Hartley, T&MSS/Harza
Chris Weiss, T&MSS/SAIC

Core from the following boreholes was examined during the evaluation: UE25-a#1, UE25-a#7, USW G-4, USW GU-3, and USW G-1. Core which spanned the contact intervals previously designated by SNL (Ortiz et al., 1985) for units TSw1 and TSw2 was examined as well as contacts defined by the USGS (numerous reports) between the upper lithophysal and middle non-lithophysal units of the Topopah Spring Member of the Paintbrush Tuff. The evaluation showed

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clearly that contacts chosen by Ortiz et al. (1985) from interpretation of borehole logs in two boreholes (USW G-1 and UE25-a#1) were not stratigraphically consistent with contacts chosen in other boreholes or in outcrop. The evaluation further determined that the contact between the upper lithophysal and middle non-lithophysal units of the Topopah Spring Member is readily recognizable in all the boreholes examined and is coincident with the contact between the TSw1 and TSw2 units chosen by Ortiz et al. except for those two holes mentioned previously.

The evaluators were asked to independently choose the contact depth in all five boreholes for the contact between the upper lithophysal and middle non-lithophysal units. This contact is recommended by the evaluation team to be recognized as the contact between thermal-mechanical units TSw1 and TSw2. The tabulation below gives the depth and elevation of the contact in each borehole established by consensus of the evaluators.

BOREHOLE	DEPTH	ELEVATION
UE25-a#1	650 ft	3314 ft
UE25-a#7	775 ft*	3308 ft**
USW G-4	680 ft	3487 ft
USW GU3	720 ft***	4137 ft
	690 ft***	4167 ft
USW G-1	715 ft	3634 ft

*depth in borehole not corrected for true vertical depth (borehole drilled at 26 degree angle from vertical)

**true elevation corrected for 26 degree angle

***two contacts chosen to envelope a 30-ft transition zone (both values to be used to check model sensitivity)

Elevations were derived by subtracting the depth from ground elevations recorded in Fenix and Scisson, Inc. report DOE/NV/10322-24, 1987 for the five boreholes from which core was examined.

The evaluation team concluded that the contact of the TSw1/TSw2 units is a consistent lithologic contact. It is easily recognized in the core samples, is correlatable across the repository block from north to south and from west to east, and corresponds to the lithologic contact recognized by the USGS as the base of the upper lithophysal unit of the Topopah Spring Member. It meets the criteria used for the evaluation.

We recommend that the elevations of the contact determined by the evaluation team be used by SNL as revised input to its three-dimensional model of reference thermal-mechanical stratigraphy at Yucca Mountain.

This evaluation was carried out under BTP-RSE-001. The disclaimer in Enclosure 1 needs to be made a part of the record wherever the data resulting from this evaluation are used.

John H. Peck, Responsible Staff Member

Uel S. Clanton, Evaluator

Chris Rautman, Evaluator

Rick Spengler, Evaluator

JHP-BP-L91-9642

David Vaniman, Evaluator

CORE EVALUATION MEETING
MAY 7, 1989

CRITERIA FOR EVALUATION

1. PURPOSE

THE PURPOSE OF THIS EVALUATION IS TO REACH CONCENSUS ON THE PLACEMENT OF THE CONTACT BETWEEN THERMAL-MECHANICAL UNITS TSw1 and TSw2 IN FOUR BOREHOLES WHICH HAVE CORE AVAILABLE TO OBSERVE IN THE STRATIGRAPHIC INTERVAL IN QUESTION

2. APPROACH

A SHORT PRESENTATION WILL BE GIVEN BY THE SANDIA REPRESENTATIVE REGARDING THE DEFINITION OF THERMAL-MECHANICAL UNITS OF THE TOPOPAH SPRINGS STRATIGRAPHIC UNIT AS BACKGROUND INFORMATION.

A SHORT PRESENTATION WILL BE GIVEN BY A USGS REPRESENTATIVE REGARDING THE STRATIGRAPHIC SUBDIVISIONS OF THE TOPOPAH SPRINGS BASED ON USGS STUDIES AND THE RECOGNITION OF CONTACTS AMONG THOSE UNITS

A ROUNDTABLE DISCUSSION WILL SERVE TO CLARIFY THE DIFFERENCES, IF ANY, BETWEEN DEFINITION OF CONTACTS CHOSEN BY THE USGS FOR STRATIGRAPHIC PURPOSES AND CONTACTS CHOSEN BY SANDIA FOR MODELING AND ENGINEERING PURPOSES

CORE FROM THE FOUR BOREHOLES WILL BE EXAMINED BY THE EVALUATORS TO VERIFY CONTACTS CHOSEN PREVIOUSLY AND REACH CONSENSUS ON THE PLACEMENT OF THE CONTACT BETWEEN UNITS TSw1 AND TSw2 USING THE BACKGROUND INFORMATION AS BASIS FOR THE CHOICE OF CONTACT.

3. CRITERIA

THE CONTACT CHOSEN MUST BE CONSISTENT WITH CRITERIA USED PREVIOUSLY BY SANDIA FOR CHOSING CONTACTS

THE CONTACT CHOSEN MUST HAVE A CONSISTENT AND RECOGNIZABLE STRATIGRAPHIC RELATIONSHIP TO UNIT CONTACTS DEFINED BY THE USGS

THE CONTACT CHOSEN MUST BE ABLE TO BE DEFINED CONSISTENTLY AMONG THE FOUR BOREHOLES ON VISUALLY IDENTIFIABLE FEATURES READILY APPARENT TO ALL EVALUATORS

MINERALOGICAL FEATURES, MICROSTRUCTURE, OR OTHER CHARACTERISTICS IDENTIFIABLE ONLY THROUGH LABORATORY ANALYSIS SHALL NOT BE USED IN THE ESTABLISHMENT OF THE CONTACT CHOSEN

QUALITATIVE ESTIMATES OF ROCK PROPERTIES SUCH AS COMPETENCE, DEGREE OF FRACTURING, DENSITY, HARDNESS, RELATIVE ABUNDANCE OF VOID SPACE, ETC. MAY BE USED AS SUPPORTIVE EVIDENCE TO LOCATE THE CONTACT, BUT THE CONTACT PLACEMENT SHALL BE MADE USING SPECIFIC VISUAL FEATURES WHICH CAN BE CORRELATED FROM CORE TO CORE

4. RESULTS OF EVALUATION

THE CONTACT EVALUATION SHOULD RESULT IN A CONSENSUS CONCERNING THE LOCATION OF THE CONTACT BETWEEN TSw1 AND TSw2. THE POSITION OF THE POTENTIAL REPOSITORY HORIZON WITHIN THE TWs2 UNIT WILL BE REEVALUATED BY SANDIA BASED ON THE RESULTS OF THE EVALUATION. THE RESULTS WILL BE DOCUMENTED AND SENT TO SANDIA AS INPUT FOR RECOMMENDING A POTENTIAL REPOSITORY HORIZON.

NOTE: IT IS RECOGNIZED THAT THE CORE BEING EXAMINED IS NOT QUALIFIED FOR USE IN A LICENSING PROCESS. HOWEVER, THE RESULTS OF CORE EXAMINATION SHALL BE DEEMED AS CORROBRATIVE EVIDENCE WHICH MAY BE USED IN DEFINING PRELIMINARY RECOMMENDATIONS SUBJECT TO LATER VERIFICATION. ALL ELEVATIONS OF CONTACTS DETERMINED BY THIS EVALUATION SHOULD BE CONSIDERED APPROXIMATE ONLY, PROBABLY WITHIN A RANGE OF PLUS OR MINUS 10 FEET.

APPENDIX B

Statistical Generation of the Fracture Network

The disaggregate characterization approach was applied to generate the assemblage of geometric fracture characteristics by applying statistical procedures to characterize the fracture trace length, the location, the spacing, and the orientation of each fracture in the assemblage. This approach is based upon substantial literature on the appropriate stochastic representation for each geometric fracture characteristic (e.g., Call et al., 1976; Hudson and Priest, 1979; Dershowitz and Einstein, 1988; and Kulatilake, 1988). Based on these literatures, the negative exponential distribution was selected as the stochastic representation for both the trace length and joint spacing, and the uniform distribution was selected for fracture orientation in this study. Monte Carlo simulation techniques were then used to generate a group of fracture networks.

Both two- and three-dimensional simulations of the joint spatial arrangements were investigated. For the two-dimensional simulation, fractures were assumed to be planes with infinite area, perpendicular to the two-dimensional projection plane. A three-dimensional picture was also constructed by assuming joint set strikes and dips based on the limited oriented core data from core hole USW G-4. The two-dimensional models were constructed to allow numerical experiments to check the validity of Terzaghi's (1965) correction factors. The three-dimensional models were used to judge the adequacy of the two-dimensional representation. The two-dimensional models were found to be sufficient for checking the Terzaghi correction.

For two dimensions, the generation process was started with inputting the mean fracture frequencies and mean trace length required for the negative exponential distribution, assuming all joints had the same continuity. The fractures were then generated for nine 10° dip angle intervals beginning with the 0° to 10° set. A reference line which was perpendicular to the mid-angle of the interval and passing through the centroid of the survey area was created as the base line for the random spacing generation. Fracture spacing and trace length were generated by the Monte Carlo simulation technique and are based on the input mean values and negative exponential distribution. Fracture dip was determined assuming a uniform distribution within the 10° intervals by the same simulation technique. Once the spacing, trace length, orientation, and continuity of fractures were determined, coordinates of these fractures were calculated based on trigonometry.

Discontinuity along the length of the fracture was also considered by adopting the concept of joint continuity, where continuity is expressed as a percentage along the joint trace length in the window. Figures B-1 to B-3 show the two-dimensional simulated fracture networks for three cases with different joint continuities. These fractures were generated using the calculated true linear frequencies for each 10° interval of dip from drill hole USW G-4 (Section 3.2.2) as the mean frequency for negative exponential distribution. The mean value for trace lengths, 0.1 m, was calculated based on the data presented in Barton and Hsieh (1989) from the mapping of surface pavements.

To evaluate the validity of the Terzaghi correction factor, 19 scanlines were placed in a 20 m by 20 m area to count the number of fractures in each 10° dip angle interval. By dividing the total number of fractures observed in each 10° inclination angle interval by the total length of the scanlines, the uncorrected fracture frequencies were obtained. The correction factors for this experiment were then calculated by dividing the uncorrected fracture frequency by the mean frequency. Table B-1 presents the uncorrected fracture frequency, calculated correction factors, and the Terzaghi correction factors.

Close agreement was found between the results of the 100% continuity case and the Terzaghi correction factors (Figure B-4), which was based on the assumption of an infinitely long trace length for each fracture. The results shown in Table B-1 indicate the Terzaghi correction was less accurate as the joint continuity decreased. For the 50% continuity case, the calculated correction factor is approximately twice the values of the Terzaghi correction factors, and that those for the 80% continuity case are approximately 1.25 times the Terzaghi correction factor.

The joint patterns shown in Figures B-1, B-2, and B-3 were not what would be observed in a wall exposure because of the assumption that the strike of all joints was perpendicular to the plane of the mapped window. The true fracture network was dependent on the strike of the fractures. Two fractures that were inclined within the 10° interval might have a 90° difference

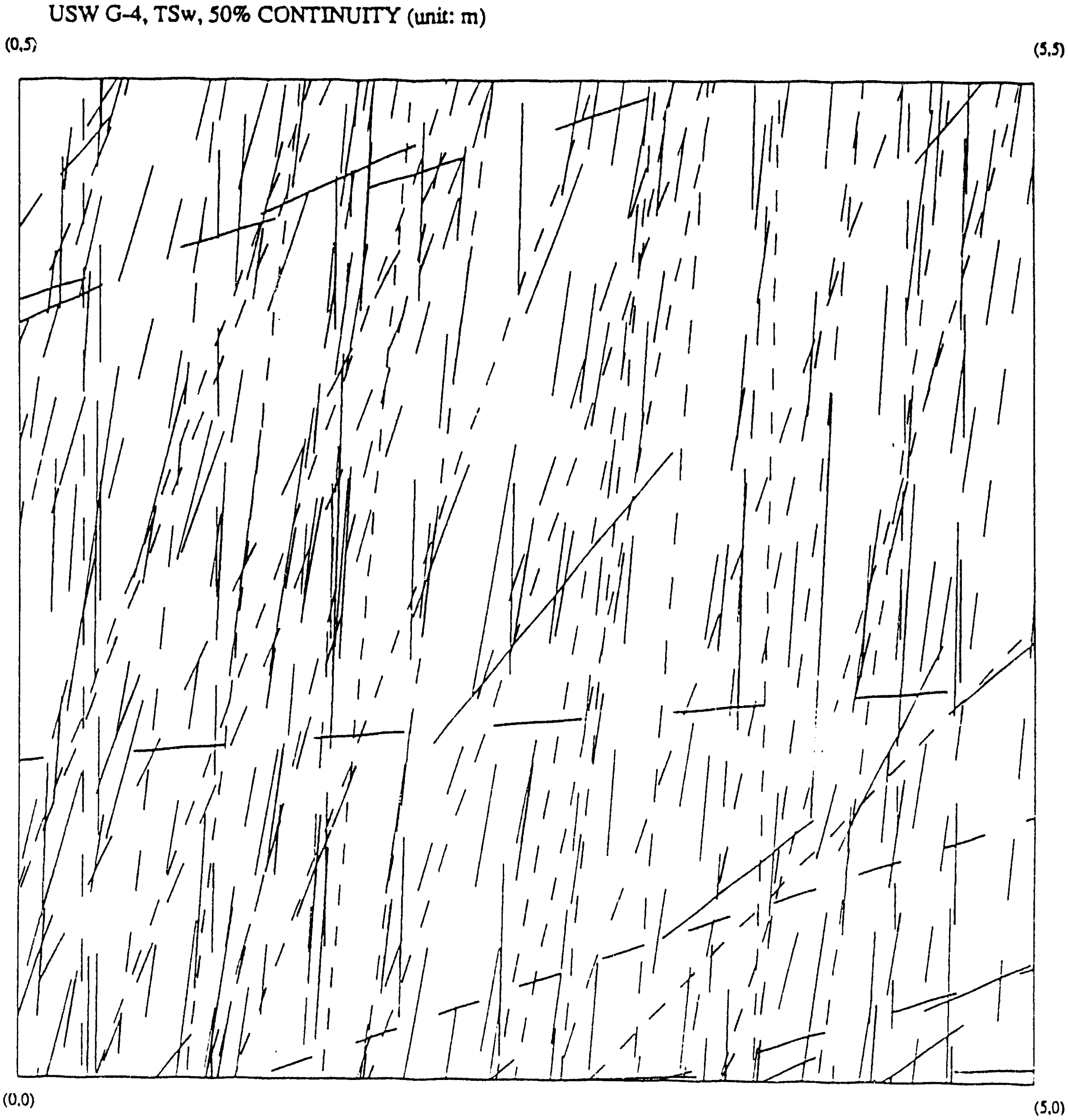


Figure B-1. Generated Fracture Network for 50% Continuity Using Two-Dimensional Approach Based on Data from USW G-4 (unit=m)

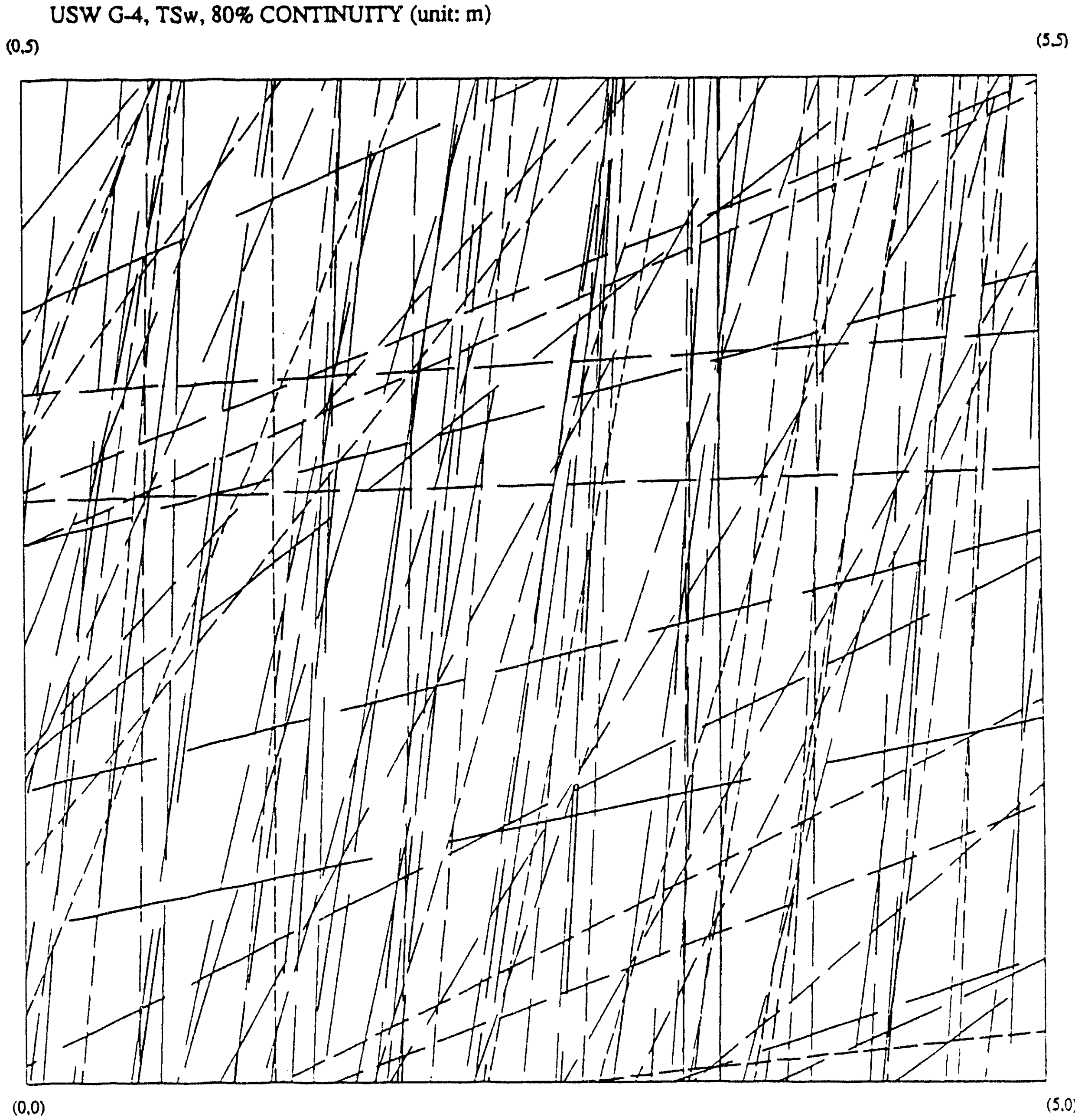


Figure B-2. Generated Fracture Network for 80% Continuity Using Two-Dimensional Approach Based on Data from USW G-4 (unit=m)

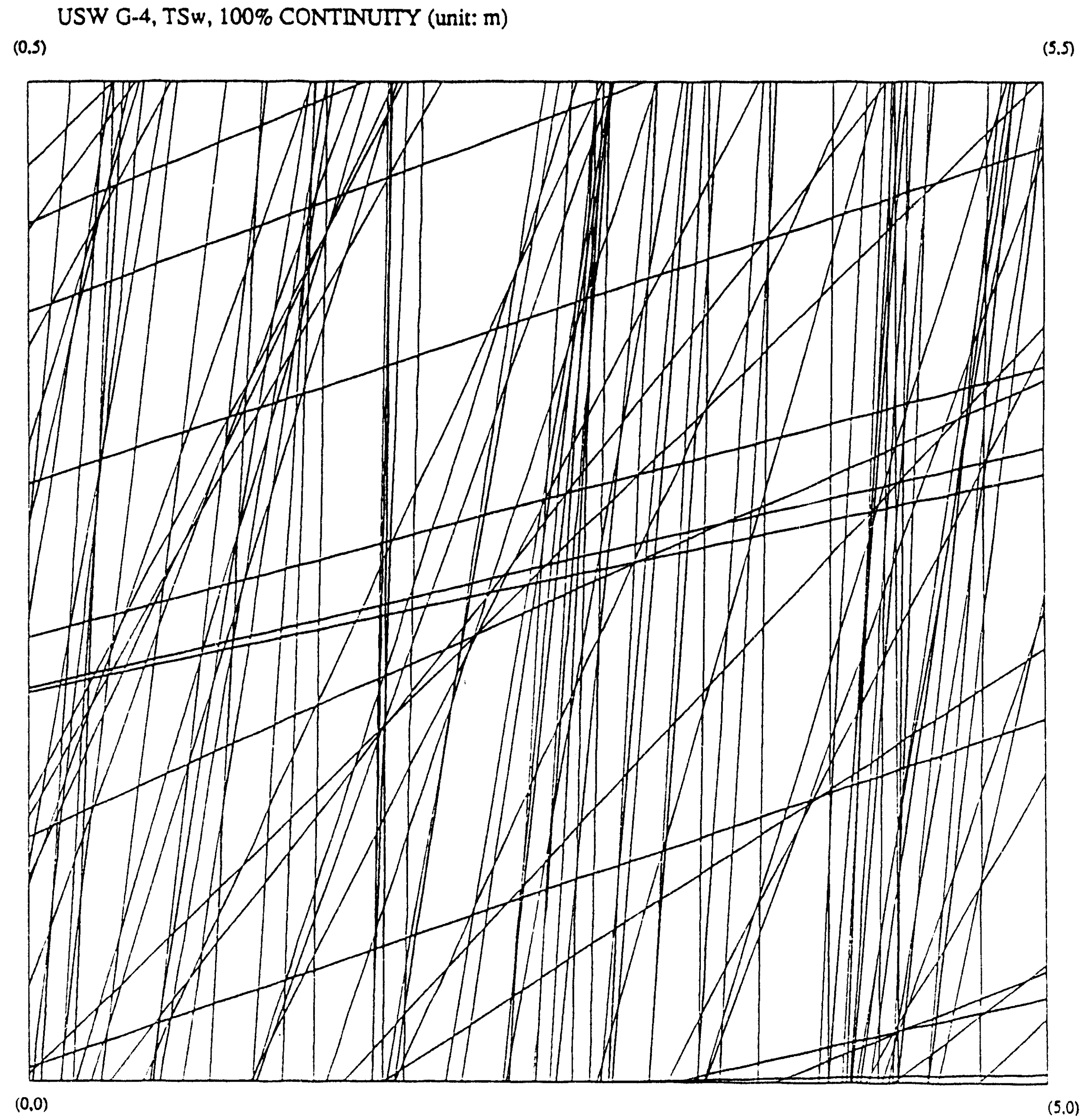


Figure B-3. Generated Fracture Network for 100% Continuity Using Two-Dimensional Approach Based on Data from USW G-4 (unit=m)

TABLE B-1. OBSERVED JOINT FREQUENCY AND CALCULATED CORRECTION FACTORS FROM THE STATISTICALLY GENERATED FRACTURE NETWORK (Data Based on USW G-4)

Inclination Angle (deg)	Mean Joint Frequency (m^{-1})	Continuity 50% Joint Frequency (m^{-1})	Correction Factors	Continuity 80% Joint Frequency (m^{-1})	Correction Factors	Continuity 100% Joint Frequency (m^{-1})	Correction Factors	Terzaghi Correction Factors
5.00	0.50	0.21	2.42	0.38	1.30	0.50	1.00	1.00
15.00	0.60	0.23	2.61	0.61	0.99	0.42	1.45	1.04
25.00	0.50	0.18	2.72	0.42	1.20	0.42	1.20	1.10
35.00	0.30	0.23	1.30	0.03	9.38	0.21	1.45	1.22
45.00	0.40	0.09	4.35	0.16	2.50	0.17	2.41	1.41
55.00	0.50	0.23	2.17	0.13	3.91	0.33	1.51	1.74
65.00	0.70	0.18	3.80	0.10	7.29	0.33	2.11	2.37
75.00	2.20	0.32	6.83	0.42	5.29	0.50	4.42	3.86
85.00	12.50	0.58	21.74	0.80	15.63	1.16	10.76	11.47

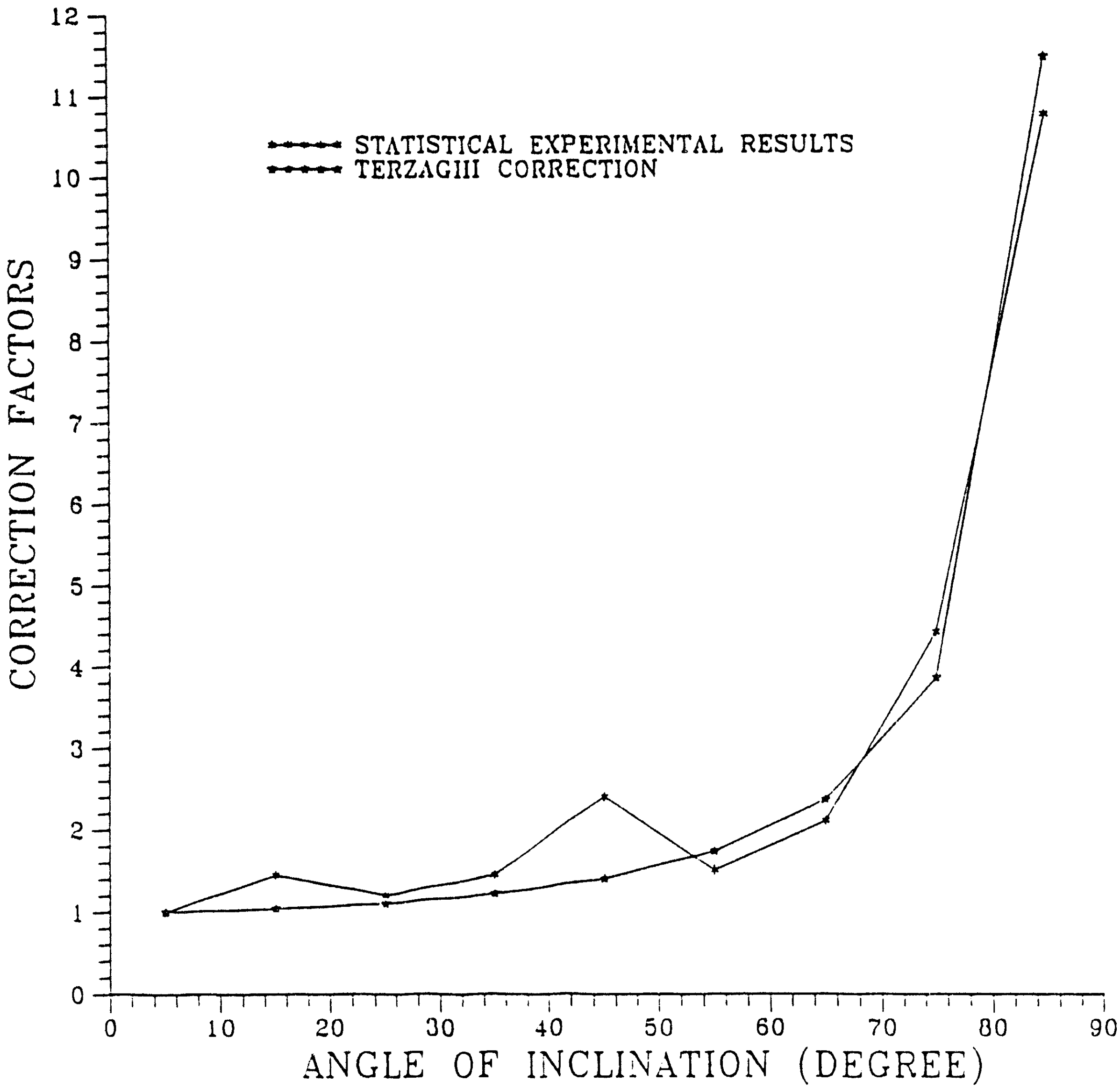
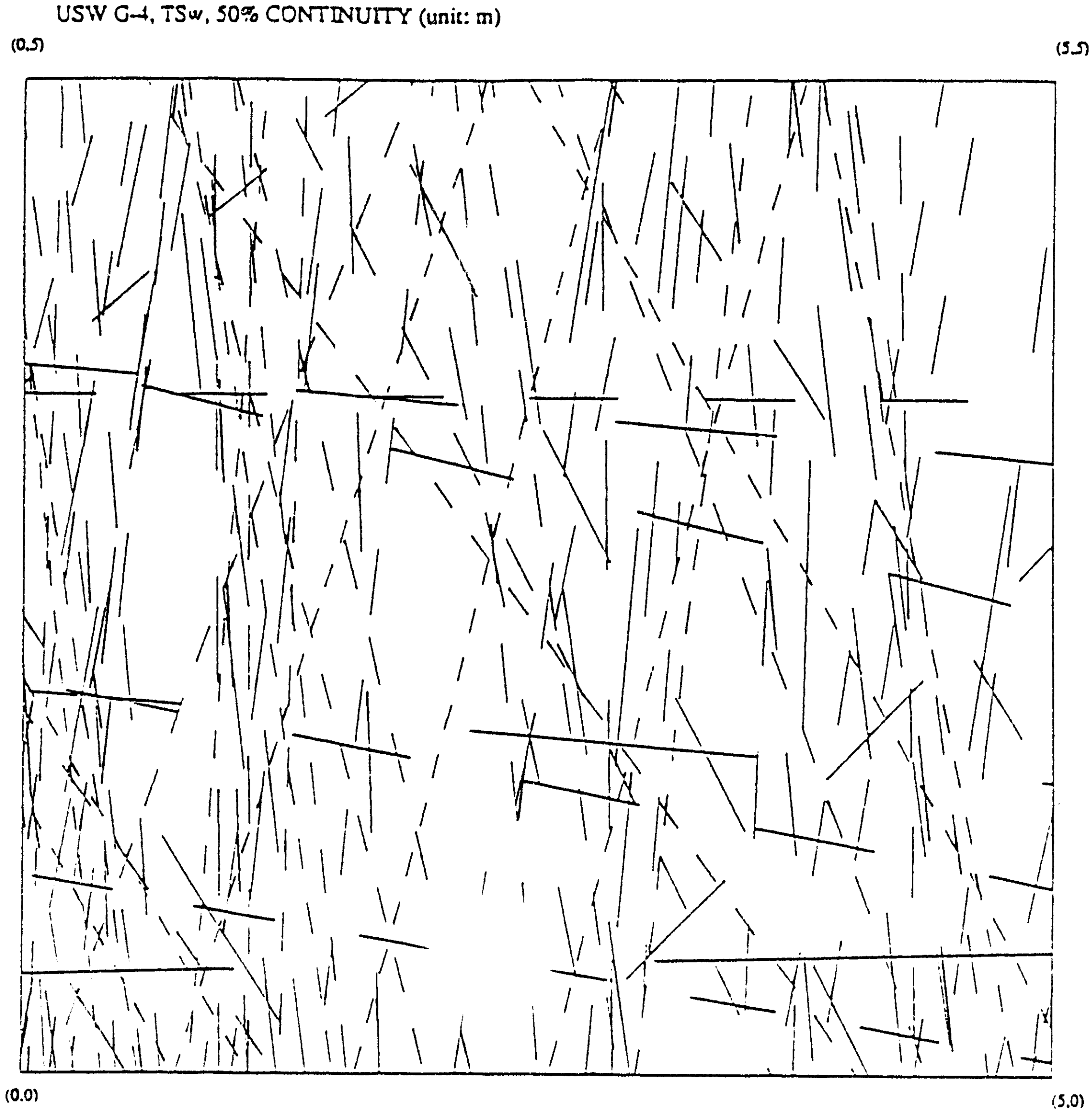


Figure B-4. Comparison of the Correction Factors from Terzaghi and the Statistical Experiment Assuming 100% Continuity between their strike directions. These two fractures, which were counted as the same set in the two-dimensional approach, actually might belong to two different joint sets in three-dimensional space. Figures B-5 and B-6 were generated to illustrate this effect with the consideration of three-dimensional joint planes projected to two planes perpendicular to each other. The lower hemisphere diagram for the Topopah Spring Member from drill hole USW G-4 (see Figure 3-2) was used to obtain the three-dimensional distribution of fracture planes projected in these two figures. The fracture spacings projected in Figures B-5 and B-6 are apparently larger than those of Figure B-1.

Knowledge of the continuity and orientation (in three-dimensional space) of the fractures at the Yucca Mountain site was limited at this stage. Overestimation of the true frequencies using the two-dimensional approach in a three-dimensional rock mass might well be compensated for by assuming 100% continuity fractures in the frequency calculation. The two-dimensional approach with 100% fracture continuity was, therefore, still applied in this study.

Clearly, the rock mass was not intersected by infinitely long fractures or joints. Estimates of continuity were made from photographs of pit walls excavated in the TSw2 unit near the Yucca Mountain site. A joint continuity of 0.518 was reported from nine vertical fractures, and 0.415 from five horizontal fractures (Hardy and Bauer, 1991). The rock mass might look like that shown in Figures B-5 or B-6, but the representation of discrete joint planes as discontinuous joints with repeated sections of joint and intact material appears to be too simplistic. The concept of joint spacing is also too simplistic in the real world of discontinuous joints and complex joint patterns. However, Terzaghi's method does an adequate job given the data set at hand and the assumptions made.



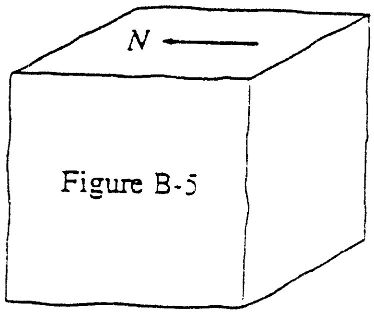
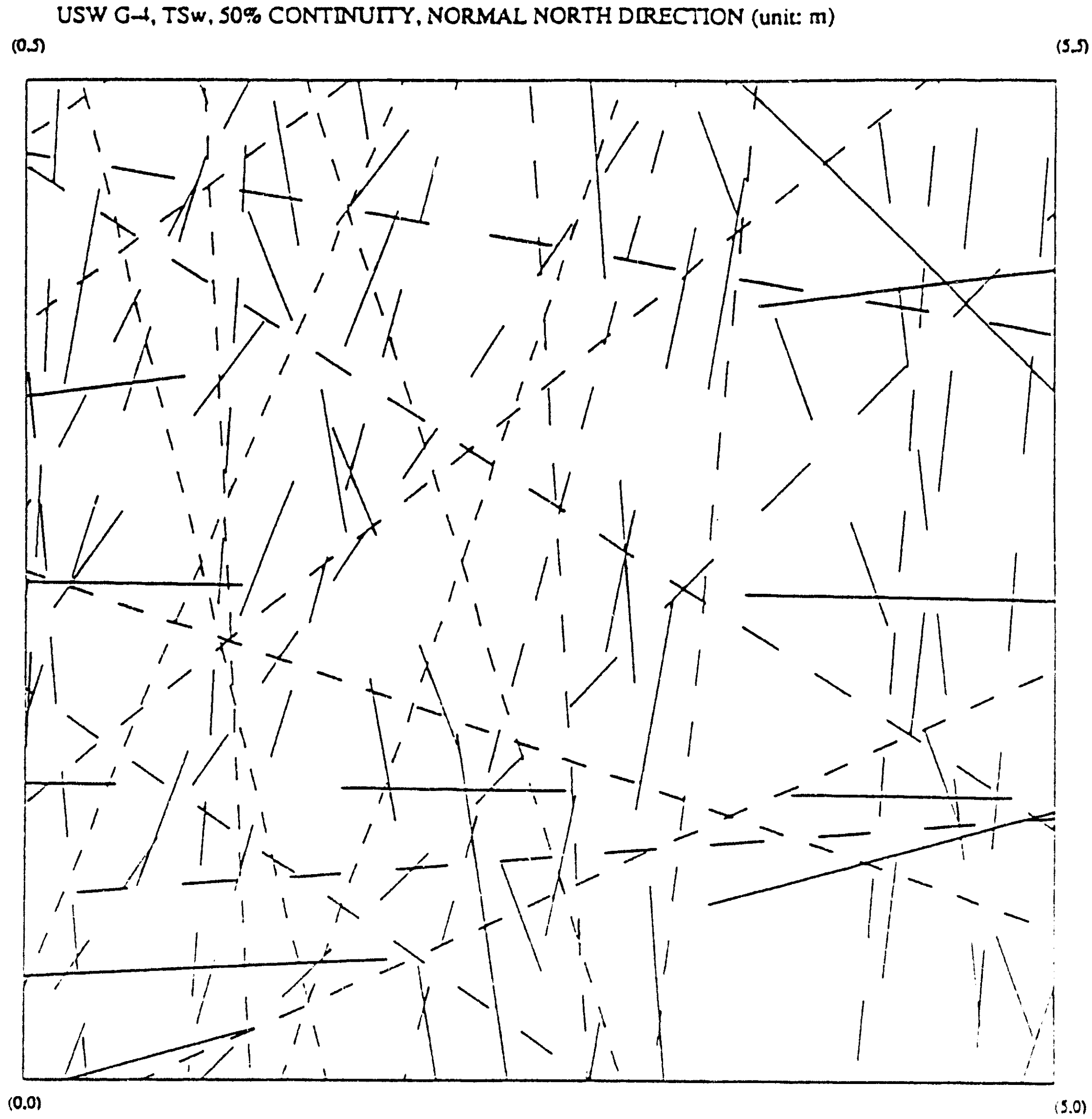


Figure B-5. Projected Three-Dimensional Fracture Network in Plane that has Pole Directs Toward the East Based on USW G-4 Data



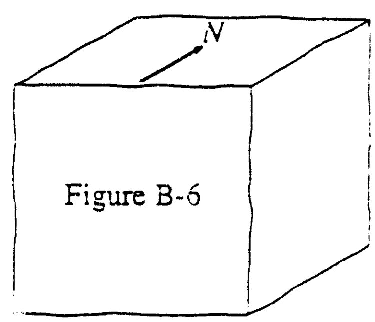


Figure B-6. Projected Three-Dimensional Fracture Network in Plane that has Pole Directs Toward the North Based on USW G-4 Data

APPENDIX C

Calculated Rock Quality Designation for the Four Drill Holes

TABLE C-1. RQD FOR CORE HOLE USW G-1

Unit	Depth (ft)			Joint* No.	Core Index	Drilled Interval	RQD (Modified)
TSw1	290	-	300	5	20	10	97
	300	-	310	6.5	60	10	62
	310	-	320	0	70	10	30
	320	-	330	2	30	10	77
	330	-	340	1	85	10	18
	340	-	350	0	85	10	15
	350	-	360	0	54	10	46
	360	-	365	0	40	5	60
	365	-	370	0	27	5	73
	370	-	375	1	27	5	76
	375	-	380	1	12	5	91
	380	-	385	0	12	5	88
	385	-	395	0	14	10	86
	395	-	405	0	18	10	82
	405	-	410	0	20	5	80
	410	-	415	2	20	5	87
	415	-	420	2	26	5	81
	420	-	425	5	26	5	91
	425	-	430	5	31	5	86
	430	-	435	2	31	5	76
	435	-	440	2	63	5	44
	440	-	445	0	63	5	37
	445	-	455	0	53	10	47
	455	-	460	0	100	5	0
	460	-	470	1	35	10	68
	470	-	480	0	100	10	0
	480	-	490	1	100	10	3
	490	-	500	0	12	10	88
	500	-	510	0	20	10	80
	510	-	520	0	25	10	75
	520	-	530	2	20	10	87
	530	-	540	2	86	10	21
	540	-	545	3	66	5	44
	545	-	550	3	42	5	68
	550	-	555	0	42	5	58
	555	-	560	0	47	5	53
	560	-	570	2	100	10	7
	570	-	575	2	35	5	72
	575	-	585	2	46	10	61
	585	-	595	2	36	10	71
	595	-	600	2	100	5	7
	600	-	610	1	100	10	3
	610	-	615	0	100	5	0
	615	-	625	0	30	10	70
	625	-	630	0	40	5	60
	630	-	632.5	1	40	2.5	63
	632.5	-	635	1	80	2.5	23
	635	-	640	1	33	5	70
	640	-	642.5	3	33	2.5	77
	642.5	-	650	3	39	7.5	71
	650	-	652.5	1	39	2.5	64

TABLE C-1. RQD FOR CORE HOLE USW G-1 (Cont'd)

Unit	Depth (ft)			Joint* No.	Core Index	Drilled Interval	RQD (Modified)
	652.5	-	660	1	31	7.5	72
	660	-	662.5	4	31	2.5	82
	662.5	-	670	4	78	7.5	35
	670	-	672.5	1	78	2.5	25
	672.5	-	680	1	68	7.5	35
	680	-	682.5	6	68	2.5	52
	682.5	-	690	6	100	7.5	20
	690	-	700	0	100	10	0
	700	-	702.5	1	100	2.5	3
	702.5	-	710	1	50	7.5	53
TSw2	710	-	712.5	5	50	2.5	67
	712.5	-	717.5	5	30	5	87
	717.5	-	720	5	67	2.5	50
	720	-	722.5	8	67	2.5	60
	722.5	-	730	8	48	7.5	79
	730	-	735	12	88	5	52
	735	-	740	12	86	5	54
	740	-	745	7	86	5	37
	745	-	750	7	52	5	71
	750	-	760	11	100	10	37
	760	-	770	2	100	10	7
	770	-	777.5	0	65	7.5	35
	777.5	-	780	0	85	2.5	15
	780	-	787.5	4	85	7.5	28
	787.5	-	790	4	20	2.5	93
	790	-	797.5	2	20	7.5	87
	797.5	-	800	2	18	2.5	89
	800	-	807.5	8	18	7.5	100
	807.5	-	810	8	55	2.5	72
	810	-	817.5	1	55	7.5	48
	817.5	-	822.5	1	48	5	55
	822.5	-	827.5	1	92	5	11
	827.5	-	830	1	72	2.5	31
	830	-	832.5	0	72	2.5	28
	832.5	-	840	0	74	7.5	26
	840	-	842.5	2	74	2.5	33
	842.5	-	850	2	100	7.5	7
	850	-	877.5	0	100	27.5	0
	877.5	-	880	0	44	2.5	56
	880	-	882.5	1	44	2.5	59
	882.5	-	887.5	1	92	5	11
	887.5	-	890	1	45	2.5	58
	890	-	892.5	3	45	2.5	65
	892.5	-	900	3	100	7.5	10
	900	-	902.5	2	100	2.5	7
	902.5	-	905	2	80	2.5	27
	905	-	910	2	70	5	37
	910	-	912.5	3	70	2.5	40
	912.5	-	920	3	100	7.5	10
	920	-	922.5	0	92	2.5	8
	922.5	-	927.5	0	83	5	17

TABLE C-1. RQD FOR CORE HOLE USW G-1 (Cont'd)

Unit	Depth (ft)		Joint* No.	Core Index	Drilled Interval	RQD (Modified)
	927.5 -	930	0	80	2.5	20
	930 -	932.5	2	80	2.5	27
	932.5 -	935	2	87	2.5	20
	935 -	940	2	74	5	33
	940 -	945	0	85	5	15
	945 -	947.5	0	100	2.5	0
	947.5 -	950	0	71	2.5	29
	950 -	952.5	3	71	2.5	39
	952.5 -	957.5	3	100	5	10
	957.5 -	960	3	71	2.5	39
	960 -	965	1	41	5	62
	965 -	970	1	100	5	3
	970 -	995	0	100	25	0
	995 -	1015	0	NA	20	NA
	1015 -	1025	0	80	10	20
	1025 -	1035	0	85	10	15
	1035 -	1040	0	80	5	20
	1040 -	1045	3	80	5	30
	1045 -	1050	3	62	5	48
	1050 -	1055	1	62	5	41
	1055 -	1060	1	90	5	13
	1060 -	1065	1	65	5	38
	1065 -	1067.5	1	95	2.5	8
	1067.5 -	1070	1	90	2.5	13
	1070 -	1075	2	87	5	20
	1075 -	1080	2	78	5	29
	1080 -	1085	0	78	5	22
	1085 -	1090	0	100	5	0
	1090 -	1100	0	74	10	26
	1100 -	1105	2	74	5	33
	1105 -	1110	2	28	5	79
	1110 -	1115	0	28	5	72
	1115 -	1120	0	90	5	10
	1120 -	1125	1	90	5	13
	1125 -	1130	1	85	5	18
	1130 -	1140	1	70	10	33
	1140 -	1150	4	65	10	48
	1150 -	1160	1	35	10	68
	1160 -	1170	5	45	10	72
	1170 -	1180	4	37	10	76
	1180 -	1190	0	30	10	70
	1190 -	1200	5	54	10	63
	1200 -	1205	10	38	5	95
	1205 -	1210	10	30	5	100
	1210 -	1215	7	30	5	93
	1215 -	1220	7	35	5	88
	1220 -	1230	10	40	10	93
	1230 -	1240	4	100	10	13
	1240 -	1245	4	85	5	28
	1245 -	1250	4	90	5	23
	1250 -	1255	0	90	5	10

TABLE C-1. RQD FOR CORE HOLE USW G-1 (Concl'd)

Unit	Depth (ft)			Joint* No.	Core Index	Drilled Interval	RQD (Modified)
	1255	-	1260	0	75	5	25
	1260	-	1270	1	96	10	7
	1290	-	1295	5	34	5	83
	1295	-	1300	5	58	5	59
	1300	-	1310	0.5	40	10	62
	1310	-	1320	5	40	10	77
	1320	-	1330	14	30	10	100
	1330	-	1340	17	40	10	100
CHn1	1340	-	1350	8	57	10	70
	1350	-	1360	1	48	10	55
	1360	-	1370	0	60	10	40
	1370	-	1390	0	35	20	65
	1390	-	1400	0	35	10	65
	1400	-	1410	2	24	10	83
	1410	-	1420	0	20	10	80
	1420	-	1430	0	59	10	41
	1430	-	1440	1	22	10	81
	1440	-	1450	0	37	10	63
	1450	-	1460	0	10	10	90
	1460	-	1470	0	0	10	100
	1470	-	1480	0	9	10	91
	1480	-	1490	0	0	10	100
	1490	-	1500	0	4	10	96
	1500	-	1520	0	0	20	100
	1520	-	1530	0	4	10	96
	1530	-	1540	0	29	10	71
	1540	-	1547.5	0	0	7.5	100
	1547.5	-	1557.5	0	20	10	80
	1557.5	-	1560	0	23	2.5	77
	1560	-	1567.5	0	19	7.5	81
	1567.5	-	1577.5	0	27	10	73
	1577.5	-	1590	0	48	12.5	52
	1590	-	1600	0	55	10	45
	1600	-	1610	0	13	10	87
	1610	-	1630	0	35	20	65
	1630	-	1640	0	55	10	45
	1640	-	1650	0	20	10	80
	1650	-	1660	0	40	10	60
	1660	-	1670	0	10	10	90
	1670	-	1680	0	14	10	86
	1680	-	1690	0	4	10	96
	1690	-	1700	0	10	10	90
	1700	-	1710	0	13	10	87
	1710	-	1720	0	17	10	83
	1720	-	1740	0	4	20	96

* *Joint numbers are the values for 10-ft interval*

TABLE C-2. RQD FOR CORE HOLE USW G-4

Unit	Depth (ft)		Joint* No.	Core Index	Drilled Interval (ft)	RQD (Modified)
TCw	40 -	45	22	100	5	73
	45 -	50	22	49	5	100
	50 -	55	16	38	5	100
	55 -	57.5	16	66	2.5	87
	57.5 -	60	16	52	2.5	100
	60 -	62.5	38	52	2.5	100
	62.5 -	70	38	92	7.5	100
	70 -	77.5	37	100	7.5	100
	77.5 -	80	37	67	2.5	100
	80 -	82.5	15	67	2.5	83
	82.5 -	90	15	39	7.5	100
	90 -	92.5	17	39	2.5	100
	92.5 -	100	17	60	7.5	97
	100 -	102.5	20	60	2.5	100
	102.5 -	107.5	20	50	5	100
	107.5 -	110	20	100	2.5	67
	110 -	112.5	42	57	2.5	100
	112.5 -	115	42	86	2.5	100
	115 -	117.5	42	63	2.5	100
	117.5 -	120	42	100	2.5	100
PTn	120 -	127.5	28	90	7.5	100
	127.5 -	130	28	72	2.5	100
	130 -	137.5	6	72	7.5	48
	137.5 -	140	6	93	2.5	27
	140 -	147.5	0	93	7.5	7
	147.5 -	150	0	55	2.5	45
	150 -	157.5	1	55	7.5	48
	157.5 -	160	1	68	2.5	35
	160 -	167.5	0	68	7.5	32
	167.5 -	177.5	0	44	10	56
	177.5 -	187.5	0	90	10	10
	187.5 -	195	0	80	7.5	20
	195 -	205	0	35	10	65
	205 -	215	0	30	10	70
	215 -	225	0	55	10	45
	225 -	230	0	0	5	100
	230 -	235	3	0	5	100
	235 -	240	3	90	5	20
TSw1	240 -	245	69	90	5	100
	245 -	250	69	100	5	100
	250 -	260	52	95	10	100
	260 -	265	51	100	5	100
	265 -	270	51	44	5	100
	270 -	275	43	44	5	100
	275 -	280	43	90	5	100
	280 -	285	12	100	5	40
	285 -	290	12	31	5	100
	290 -	295	20	31	5	100
	295 -	300	20	33	5	100
	300 -	305	9	33	5	97

TABLE C-2. RQD FOR CORE HOLE USW G-4 (Cont'd)

Unit	Depth (ft)		Joint* No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	305 -	310	9	26	5	100
	310 -	315	12	26	5	100
	315 -	320	12	29	5	100
	320 -	325	10	29	5	100
	325 -	330	10	12	5	100
	330 -	335	12	12	5	100
	335 -	340	12	53	5	87
	340 -	345	10	53	5	80
	345 -	350	10	34	5	99
	350 -	355	14	34	5	100
	355 -	365	14	50	10	97
	365 -	370	14	41	5	100
	370 -	375	6	41	5	79
	375 -	380	6	79	5	41
	380 -	385	20	79	5	88
	385 -	390	20	75	5	92
	390 -	395	11	75	5	62
	395 -		11	61	5	76
	400 -	402.5	7	61	2.5	62
	402.5 -	405	7	57	2.5	66
	405 -	410	7	34	5	89
	410 -	415	10	34	5	99
	415 -	420	10	23	5	100
	420 -	425	11	23	5	100
	425 -	430	11	95	5	42
	430 -	432.5	12	95	2.5	45
	432.5 -	[illegible]	12	100	2.5	40
	435 -		12	74	5	66
	440 -	[illegible]	16	74	2.5	79
	442.5 -	445	16	100	2.5	53
	445 -	447.5	16	46	2.5	100
	447.5 -	450	16	100	2.5	53
	450 -	470	NA	NA	20	NA
	470 -	480	1	100	10	3
	480 -	485	4	100	5	13
	485 -	490	4	91	5	22
	490 -	495	3	91	5	19
	495 -	500	3	100	5	10
	500 -	510	1	100	10	3
	510 -	515	3	100	5	10
	515 -	517.5	3	84	2.5	26
	517.5 -	520	3	54	2.5	56
	520 -	525	1	54	5	49
	525 -	527.5	1	90	2.5	13
	527.5 -	540	1	100	12.5	3
	540 -	547.5	5	100	7.5	17
	547.5 -	550	5	90	2.5	27
	550 -	557.5	1	90	7.5	13
	557.5 -	560	1	68	2.5	35
	560 -	567.5	3	68	7.5	42

TABLE C-2. RQD FOR CORE HOLE USW G-4 (Cont'd)

Unit	Depth (ft)		Joint* No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	567.5 -	570	3	63	2.5	47
	570 -	577.5	4	63	7.5	50
	577.5 -	580	4	83	2.5	30
	580 -	587.5	12	83	7.5	57
	587.5 -	590	12	80	2.5	60
	590 -	597.5	4	80	7.5	33
	597.5 -	600	4	49	2.5	64
	600 -	607.5	6	49	7.5	71
	607.5 -	610	6	75	2.5	45
	610 -	617.5	16	69	7.5	84
	617.5 -	620	16	100	2.5	53
	620 -	630	12	100	10	40
	630 -	632.5	6	100	2.5	20
	632.5 -	635	6	75	2.5	45
	635 -	637.5	6	100	2.5	20
	637.5 -	640	6	94	2.5	26
	640 -	642.5	9	100	2.5	30
	642.5 -	645	9	50	2.5	80
	645 -	650	9	100	5	30
	650 -	655	33	100	5	100
	655 -	660	33	96	5	100
	660 -	662.5	15	96	2.5	54
	662.5 -	665	15	100	2.5	50
	665 -	670	15	85	5	65
TSw2	670 -	680	15	50	10	100
	680 -	682.5	25	50	2.5	100
	682.5 -	690	25	80	7.5	100
	690 -	692.5	32	80	2.5	100
	692.5 -	700	32	90	7.5	100
	700 -	702.5	20	90	2.5	77
	702.5 -	710	20	95	7.5	72
	710 -	712.5	0	95	2.5	5
	712.5 -	720	0	100	7.5	0
	720 -	722.5	8	82	2.5	45
	722.5 -	730	8	100	7.5	27
	730 -	732.5	23	100	2.5	77
	732.5 -	740	23	50	7.5	100
	740 -	745	13	50	5	93
	745 -	750	13	74	5	69
	750 -	757.5	20	74	7.5	93
	757.5 -	760	20	85	2.5	82
	760 -	765	31	85	5	100
	765 -	770	31	100	5	100
	770 -	772.5	28	100	2.5	93
	772.5 -	780	28	90	7.5	100
	780 -	785	11	78	5	59
	785 -	790	11	83	5	54
	790 -	792.5	11	90	2.5	47
	792.5 -	800	11	100	7.5	37
	800 -	810	9	100	10	30

TABLE C-2. RQD FOR CORE HOLE USW G-4 (Cont'd)

Unit	Depth (ft)		Joint* No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	810 -	815	22	100	5	73
	815 -	820	22	90	5	83
	820 -	825	12	100	5	40
	825 -	830	12	90	5	50
	830 -	835	15	90	5	60
	835 -	840	15	100	5	50
	840 -	842.5	11	100	2.5	37
	842.5 -	847.5	11	95	5	42
	847.5 -	850	11	100	2.5	37
	850 -	860	12	100	10	40
	860 -	870	4	100	10	13
	870 -	880	17	100	10	57
	880 -	882.5	12	100	2.5	40
	882.5 -	890	12	70	7.5	70
	890 -	910	6	100	20	20
	910 -	920	5	100	10	17
	920 -	927.5	9	81	7.5	49
	927.5 -	930	9	100	2.5	30
	930 -	935	13	100	5	43
	935 -	940	13	94	5	49
	940 -	942.5	8	94	2.5	33
	942.5 -	950	8	75	7.5	52
	950 -	957.5	9	74	7.5	56
	957.5 -	960	9	89	2.5	41
	960 -	967.5	15	89	7.5	61
	967.5 -	970	15	75	2.5	75
	970 -	977.5	12	75	7.5	65
	977.5 -	980	12	100	2.5	40
	980 -	985	9	100	5	30
	985 -	990	9	78	5	52
	990 -	992.5	8	78	2.5	49
	992.5 -	1000	8	89	7.5	38
	1000 -	1002.5	18	NA	2.5	NA
	1002.5 -	1010	18	100	7.5	60
	1010 -	1012.5	8	100	2.5	27
	1012.5 -	1017.5	8	93	5	34
	1017.5 -	1020	8	84	2.5	43
	1020 -	1022.5	7	50	2.5	73
	1022.5 -	1030	7	88	7.5	35
	1030 -	1032.5	4	88	2.5	25
	1032.5 -	1040	4	92	7.5	21
	1040 -	1050	2	100	10	7
	1050 -	1060	8	100	10	27
	1060 -	1070	4	100	10	13
	1070 -	1080	11	58	10	79
	1080 -	1090	6	84	10	36
	1090 -	1100	11	100	10	37
	1100 -	1110	13	84	10	59
	1110 -	1120	10	93	10	40
	1120 -	1130	8	95	10	32

TABLE C-2. RQD FOR CORE HOLE USW G-4 (Cont'd)

Unit	Depth (ft)		Joint* No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	1130 -	1140	16	88	10	65
	1140 -	1155	17	100	15	57
	1155 -	1165	17	74	10	83
	1165 -	1170	17	57	5	100
	1170 -	1172.5	11	57	2.5	80
	1172.5 -	1180	11	40	7.5	97
	1180 -	1182.5	9	40	2.5	90
	1182.5 -	1190	9	75	7.5	55
	1190 -	1200	11	80	10	57
	1200 -	1210	13	100	10	43
	1210 -	1215	14	100	5	47
	1215 -	1220	14	87	5	60
	1220 -	1222.5	22	87	2.5	86
	1222.5 -	1232.5	22	98	10	75
	1232.5 -	1240	22	90	7.5	83
	1240 -	1242.5	20	90	2.5	77
	1242.5 -	1250	20	85	7.5	82
	1250 -	1257.5	24	90	7.5	90
	1257.5 -	1260	24	37	2.5	100
	1260 -	1265	10	37	5	96
	1265 -	1270	10	100	5	33
	1270 -	1280	5	100	10	17
	1280 -	1290	1	100	10	3
	1290 -	1300	6	100	10	20
TSw3	1300 -	1310	11	78	10	59
	1310 -	1320	14	68	10	79
	1320 -	1330	13	100	10	43
	1330 -	1340	8	100	10	27
CHn1	1340 -	1350	1	93	10	10
	1350 -	1360	0	100	10	0
	1360 -	1370	1	5	10	98
	1370 -	1380	1	4	10	99
	1380 -	1390	1	40	10	63
	1390 -	1395	0	40	5	60
	1395 -	1405	0	5	10	95
	1405 -	1415	0	8	10	92
	1415 -	1435	0	1	20	99
	1435 -	1455	0	5	20	95
	1455 -	1475	0	2	20	98
	1475 -	1495	0	1	20	99
	1495 -	1500	0	0	5	100
	1500 -	1505	1	6	5	97
	1505 -	1510	1	0	5	100
	1510 -	1515	0	0	5	100
	1515 -	1525	0	6	10	94
	1525 -	1535	0	3	10	97
	1535 -	1540	0	0	5	100
	1540 -	1542.5	1	0	2.5	100
	1542.5 -	1547.5	1	3	5	100
	1547.5 -	1550	1	1	2.5	100

TABLE C-2. RQD FOR CORE HOLE USW G-4 (Concl'd)

Unit	Depth (ft)		Joint* No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	1550 -	1552.5	0	1	2.5	99
	1552.5 -	1560	0	8	7.5	92
	1560 -	1562.5	2	8	2.5	99
	1562.5 -	1570	2	13	7.5	94
	1570 -	1572.5	0	13	2.5	87
	1572.5 -	1580	0	0	7.5	100
	1580 -	1590	1	0	10	100
	1590 -	1602.5	0	0	12.5	100
	1602.5 -	1612.5	0	10	10	90
	1612.5 -	1620	0	22	7.5	78
	1620 -	1630	4	13	10	100
	1630 -	1640	0	22	10	78
	1640 -	1650	2	5	10	100
	1650 -	1670	1	7	20	96
	1670 -	1680	2	10	10	97
	1680 -	1690	1	4	10	99
	1690 -	1700	2	0	10	100
	1700 -	1710	4	0	10	100

* *Joint numbers are the values for 10-ft interval*

TABLE C-3. RQD FOR CORE HOLE USW GU-3

Unit	Depth (ft)		Joint* No.	Core Index	Drilled Interval (ft)	RQD (Modified)
TCw	40 -	47.5	9	31	7.5	78
	47.5 -	50	9	26	2.5	83
	50 -	55	15	26	5	89
	55 -	60	15	16	5	99
	60 -	62.5	16	16	2.5	100
	62.5 -	70	16	41	7.5	75
	70 -	72.5	5	65	2.5	40
	72.5 -	75	5	50	2.5	55
	75 -	80	5	5	5	100
	80 -	90	12	40	10	72
	90 -	95	6.5	40	5	67
	95 -	97.5	6.5	30	2.5	77
	97.5 -	100	6.5	40	2.5	67
	100 -	102.5	10	40	2.5	70
	102.5 -	105	10	100	2.5	10
	105 -	110	10	56	5	54
	110 -	112.5	5	56	2.5	49
	112.5 -	120	5	20	7.5	85
	120 -	122.5	10	20	2.5	90
	122.5 -	130	10	50	7.5	60
	130 -	140	15	50	10	65
	140 -	142.5	20	50	2.5	70
	142.5 -	150	20	55	7.5	65
	150 -	152.5	11	55	2.5	56
	152.5 -	160	11	80	7.5	31
	160 -	162.5	15	80	2.5	35
	162.5 -	170	15	60	7.5	55
	170 -	172.5	17	60	2.5	57
	172.5 -	175	17	100	2.5	17
	175 -	180	17	65	5	52
	180 -	182.5	11	65	2.5	46
	182.5 -	187.5	11	75	5	36
	187.5 -	190	11	65	2.5	46
	190 -	192.5	18	65	2.5	53
	192.5 -	197.5	18	55	5	63
	197.5 -	200	18	100	2.5	18
	200 -	205	18	70	5	48
	205 -	210	18	30	5	88
	210 -	212.5	6	30	2.5	76
	212.5 -	220	6	40	7.5	66
	220 -	225	6	55	5	51
	225 -	240	6	45	15	61
	240 -	250	10	30	10	80
	250 -	260	5	10	10	95
	260 -	270	11	35	10	76
	270 -	280	12	55	10	57
	280 -	285	21	70	5	51
	285 -	290	21	100	5	21
	290 -	295	12	100	5	12
	295 -	297.5	12	75	2.5	37

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1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910

301/587-8202

Centimeter

Inches

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TABLE C-3. RQD FOR CORE HOLE USW GU-3 (Cont'd)

Unit	Depth (ft)		Joint* No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	297.5 -	300	12	60	2.5	52
	300 -	307.5	14	60	7.5	54
	307.5 -	310	14	100	2.5	14
	310 -	320	5	30	10	75
	320 -	325	16	70	5	46
	325 -	330	16	60	5	56
	330 -	340	11	45	10	66
PTn	340 -	345	9	70	5	39
	345 -	347.5	9	100	2.5	9
	347.5 -	350	9	35	2.5	74
	350 -	355	11	35	5	76
	355 -	360	11	50	5	61
	360 -	362.5	6	50	2.5	56
	362.5 -	370	6	45	7.5	61
	370 -	377.5	1.5	5	7.5	97
	377.5 -	380	1.5	50	2.5	52
	380 -	387.5	1	50	7.5	51
	387.5 -	390	1	5	2.5	96
	390 -	397.5	0	5	7.5	95
	397.5 -	407.5	0	55	10	45
	407.5 -	410	0	30	2.5	70
	410 -	420	2	30	10	72
	420 -	430	10	30	10	80
TSw1	430 -	437.5	6	30	7.5	76
	437.5 -	447.5	6	40	10	66
	447.5 -	450	6	50	2.5	56
	450 -	457.5	3	50	7.5	53
	457.5 -	460	3	15	2.5	88
	460 -	467.5	2	15	7.5	87
	467.5 -	470	2	50	2.5	52
	470 -	477.5	9	50	7.5	59
	477.5 -	487.5	9	25	10	84
	487.5 -	490	9	5	2.5	100
	490 -	497.5	2	5	7.5	97
	497.5 -	507.5	2	25	10	77
	507.5 -	510	2	95	2.5	7
	510 -	512.5	0	95	2.5	5
	512.5 -	517.5	0	100	5	0
	517.5 -	520	0	0	2.5	100
	520 -	530	7	40	10	67
	530 -	532.5	1	40	2.5	61
	532.5 -	540	1	15	7.5	86
	540 -	542.5	14	15	2.5	99
	542.5 -	547.5	14	90	5	24
	547.5 -	550	14	55	2.5	59
	550 -	557.5	12	55	7.5	57
	557.5 -	560	12	90	2.5	22
	560 -	565	5	90	5	15
	565 -	570	5	85	5	20
	570 -	575	0	100	5	0

TABLE C-3. RQD FOR CORE HOLE USW GU-3 (Cont'd)

Unit	Depth (ft)		Joint* No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	575 -	580	0	70	5	30
	580 -	585	1	80	5	21
	585 -	590	1	10	5	91
	590 -	600	1	25	10	76
	600 -	610	4	25	10	79
	610 -	620	3	65	10	38
	620 -	625	3	50	5	53
	625 -	630	3	65	5	38
	630 -	640	3	15	10	88
	640 -	650	2	0	10	100
	650 -	660	2	15	10	87
	660 -	667.5	0	45	7.5	55
	667.5 -	670	0	10	2.5	90
	670 -	677.5	3	10	7.5	93
	677.5 -	680	3	25	2.5	78
	680 -	685	5	25	5	80
	685 -	690	5	5	5	100
TSw2	690 -	700	12	25	10	87
	700 -	705	14	25	5	89
	705 -	710	14	20	5	94
	710 -	712.5	28	20	2.5	100
	712.5 -	720	28	45	7.5	83
	720 -	730	25	75	10	50
	730 -	740	14	85	10	29
	740 -	742.5	7	100	2.5	7
	742.5 -	750	7	90	7.5	17
	750 -	752.5	2	90	2.5	12
	752.5 -	760	2	10	7.5	92
	760 -	762.5	5	10	2.5	95
	762.5 -	770	5	45	7.5	60
	770 -	772.5	7	45	2.5	62
	772.5 -	777.5	7	65	5	42
	777.5 -	780	7	80	2.5	27
	780 -	782.5	18	80	2.5	38
	782.5 -	790	18	100	7.5	18
	790 -	800	21	100	10	21
	800 -	810	13	100	10	13
	810 -	817.5	25	100	7.5	25
	817.5 -	820	25	95	2.5	30
	820 -	822.5	30	95	2.5	35
	822.5 -	827.5	30	100	5	30
	827.5 -	830	30	60	2.5	70
	830 -	832.5	31	60	2.5	71
	832.5 -	837.5	31	80	5	51
	837.5 -	840	31	100	2.5	31
	840 -	847.5	30	100	7.5	30
	847.5 -	850	30	85	2.5	45
	850 -	855	15	85	5	30
	855 -	857.5	15	55	2.5	60
	857.5 -	860	15	100	2.5	15

TABLE C-3. RQD FOR CORE HOLE USW GU-3 (Cont'd)

Unit	Depth (ft)	Joint* No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	860 - 870	20	100	10	20
	870 - 875	14	25	5	89
	875 - 880	14	80	5	34
	880 - 885	12	40	5	72
	885 - 890	12	70	5	42
	890 - 892.5	10	45	2.5	65
	892.5 - 900	10	80	7.5	30
	900 - 902.5	17	65	2.5	52
	902.5 - 910	17	40	7.5	77
	910 - 915	27	30	5	97
	915 - 917.5	27	100	2.5	27
	917.5 - 920	27	0	2.5	100
	920 - 925	5	0	5	100
	925 - 930	5	15	5	90
	930 - 935	14	15	5	99
	935 - 940	14	0	5	100
	940 - 942.5	5	0	2.5	100
	942.5 - 950	5	15	7.5	90
	950 - 952.5	1	15	2.5	86
	952.5 - 962.5	1	5	10	96
	962.5 - 967.5	17	35	5	82
	967.5 - 970	17	40	2.5	77
	970 - 972.5	17	40	2.5	77
	972.5 - 980	17	100	7.5	17
	980 - 982.5	18	100	2.5	18
	982.5 - 987.5	18	75	5	43
	987.5 - 990	18	100	2.5	18
	990 - [illegible]	10	100	10	10
	1000 - [illegible]	14	75	5	39
	1005 - 1010	14	100	5	14
	1010 - 1015	29	75	5	54
	1015 - 1017.5	29	100	2.5	29
	1017.5 - 1020	29	80	2.5	49
	1020 - 1025	23	100	5	23
	1025 - 1027.5	23	60	2.5	63
	1027.5 - 1030	23	100	2.5	23
	1030 - 1032.5	8	85	2.5	23
	1032.5 - 1040	8	100	7.5	8
	1040 - 1042.5	19	100	2.5	19
	1042.5 - 1050	19	65	7.5	54
	1050 - 1052.5	18	65	2.5	53
	1052.5 - 1055	18	85	2.5	33
	1055 - 1060	18	100	5	18
	1060 - 1067.5	25	60	7.5	65
	1067.5 - 1070	25	90	2.5	35
	1070 - 1072.5	14	90	2.5	24
	1072.5 - 1080	14	60	7.5	54
	1080 - 1082.5	17	35	2.5	82
	1082.5 - 1085	17	45	2.5	72
	1085 - 1087.5	17	80	2.5	37

TABLE C-3. RQD FOR CORE HOLE USW GU-3 (Cont'd)

Unit	Depth (ft)		Joint* No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	1087.5 -	1090	17	75	2.5	42
	1090 -	1097.5	25	75	7.5	50
	1097.5 -	1100	25	80	2.5	45
	1100 -	1107.5	20	80	7.5	40
	1107.5 -	1110	20	60	2.5	60
	1110 -	1115	23	60	5	63
	1115 -	1117.5	23	65	2.5	58
	1117.5 -	1120	23	35	2.5	88
	1120 -	1127.5	25	35	7.5	90
	1127.5 -	1130	25	90	2.5	35
	1130 -	1132.5	21	90	2.5	31
	1132.5 -	1137.5	21	65	5	56
	1137.5 -	1140	21	55	2.5	66
	1140 -	1142.5	11	55	2.5	56
	1142.5 -	1150	11	20	7.5	91
	1150 -	1160	15	20	10	95
	1160 -	1167.5	26	50	7.5	76
	1167.5 -	1170	26	100	2.5	26
	1170 -	1180	21	25	10	96
	1180 -	1190	22	25	10	97
TSw3	1190 -	1197.5	11	25	7.5	86
	1197.5 -	1200	11	30	2.5	81
	1200 -	1210	6.5	30	10	77
	1210 -	1215	7	30	5	77
	1215 -	1220	7	25	5	82
	1220 -	1225	4	25	5	79
	1225 -	1230	4	20	5	84
	1230 -	1235	3	20	5	83
	1235 -	1240	3	15	5	88
	1240 -	1250	1	15	10	86
	1250 -	1260	0	50	10	50
	1260 -	1270	10	50	10	60
CHn1	1270 -	1277.5	7	86	7.5	21
	1277.5 -	1280	7	15	2.5	92
	1280 -	1290	4	15	10	89
	1290 -	1300	9	15	10	94
	1300 -	1310	8	15	10	93
	1310 -	1317.5	1	10	7.5	91
	1317.5 -	1320	1	15	2.5	86
	1320 -	1330	2	15	10	87
	1330 -	1340	2	50	10	52
	1340 -	1350	0	100	10	0
	1350 -	1360	0	70	10	30
	1360 -	1370	0	55	10	45
	1370 -	1390	0	81	20	19
	1390 -	1400	0	20	10	80
	1400 -	1410	0	81	10	19
	1410 -	1420	0	90	10	10
	1420 -	1430	0	70	10	30
	1430 -	1440	0	10	10	90

TABLE C-3. RQD FOR CORE HOLE USW GU-3 (Concl'd)

Unit	Depth (ft)		Joint* No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	1440 -	1460	0	100	20	0
	1460 -	1480	0	95	20	5
	1480 -	1500	1	50	20	51
	1500 -	1510	0	10	10	90

* *Joint numbers are the values for 10-ft interval*

TABLE C-4. RQD FOR CORE HOLE UE25a#1

Unit	Depth (ft)		Joint No.	Core Index	Drilled Interval (ft)	RQD (Modified)
TCw	60 -	65	2	74	5	33
	65 -	70	2	65	5	42
	70 -	77.5	10	95	7.5	38
	77.5 -	82.5	10	81	5	52
	82.5 -	87.5	10	84	5	49
	87.5 -	97.5	10	27	10	100
	97.5 -	100	10	19	2.5	100
	100 -	102.5	2	19	2.5	88
	102.5 -	105	2	99	2.5	8
	105 -	110	2	97	5	10
	110 -	120	17	10	10	100
	120 -	130	26	65	10	100
	130 -	137.5	49	76	7.5	100
	137.5 -	140	49	98	2.5	100
	140 -	150	5	76	10	41
	150 -	155	3	19	5	91
	155 -	160	3	15	5	95
	160 -	170	1	25	10	78
	170 -	175	2	50	5	57
	175 -	180	2	60	5	47
	180 -	185	0	99	5	1
	185 -	190	0	82	5	18
	190 -	200	1	82	10	21
PTn	200 -	207.5	1	39	7.5	64
	207.5 -	210	1	28	2.5	75
	210 -	217.5	0	28	7.5	72
	217.5 -	227.5	0	47	10	53
	227.5 -	230	0	35	2.5	65
	230 -	235	1	35	5	68
	235 -	240	1	45	5	58
	240 -	242.5	0	45	2.5	55
	242.5 -	250	0	22	7.5	78
	250 -	260	5	42	10	75
	260 -	270	0	61	10	39
	270 -	280	3	48	10	62
TSw1	280 -	287.5	8	100	7.5	27
	287.5 -	290	8	80	2.5	47
	290 -	295	8	100	5	27
	295 -	300	8	90	5	37
	300 -	305	0	100	5	0
	305 -	307.5	0	86	2.5	14
	307.5 -	317.5	0	100	10	0
	317.5 -	320	0	86	2.5	14
	320 -	330	4	92	10	21
	330 -	335	8	86	5	41
	335 -	337.5	8	15	2.5	100
	337.5 -	340	8	26	2.5	100
	340 -	347.5	4	26	7.5	57
	347.5 -	350	4	61	2.5	52
	350 -	357.5	0	61	7.5	39

TABLE C-4. RQD FOR CORE HOLE UE25a#1 (Cont'd)

Unit	Depth (ft)			Joint No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	357.5	-	360	0	20	2.5	80
	360	-	367.5	4	20	7.5	93
	367.5	-	370	4	55	2.5	58
	370	-	375	1	55	5	48
	375	-	377.5	1	100	2.5	3
	377.5	-	380	1	40	2.5	63
	380	-	387.5	0	40	7.5	60
	387.5	-	392.5	0	45	5	55
	392.5	-	400	0	55	7.5	45
	400	-	402.5	3	86	2.5	24
	402.5	-	405	3	50	2.5	60
	405	-	410	3	99	5	11
	410	-	415	0	99	5	1
	415	-	417.5	0	75	2.5	25
	417.5	-	420	0	86	2.5	14
	420	-	425	1	99	5	4
	425	-	430	1	55	5	48
	430	-	435	0.5	99	5	3
	435	-	437.5	0.5	88	2.5	14
	437.5	-	440	0.5	99	2.5	3
	440	-	445	2	99	5	8
	445	-	447.5	2	88	2.5	19
	447.5	-	450	2	65	2.5	42
	450	-	460	0.5	20	10	82
	460	-	470	0	18	10	82
	470	-	477.5	0	72	7.5	28
	477.5	-	480	0	75	2.5	25
	480	-	485	1	75	5	28
	485	-	490	1	99	5	4
	490	-	502.5	0	99	12.5	1
	502.5	-	507.5	0	86	5	14
	507.5	-	512.5	0	91	5	9
	512.5	-	515	0	85	2.5	15
	515	-	525	0	99	10	1
	525	-	530	0	81	5	19
	530	-	535	0	99	5	1
	535	-	545	0	54	10	46
	545	-	560	0	99	15	1
	560	-	567.5	0	85	7.5	15
	567.5	-	577.5	0	60	10	40
	577.5	-	580	0	50	2.5	50
	580	-	587.5	0.5	50	7.5	52
	587.5	-	590	0.5	55	2.5	47
	590	-	597.5	0	55	7.5	45
	597.5	-	600	0	99	2.5	1
	600	-	607.5	0	66	7.5	34
	607.5	-	610	0	100	2.5	0
	610	-	615	0	95	5	5
TSw2	615	-	630	0	74	15	26
	630	-	632.5	2	74	2.5	33

TABLE C-4. RQD FOR CORE HOLE UE25a#1 (Cont'd)

Unit	Depth (ft)		Joint No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	632.5 -	640	2	68	7.5	39
	640 -	645	5	58	5	59
	645 -	650	5	90	5	27
	650 -	655	6	93	5	27
	655 -	660	6	86	5	34
	660 -	665	0.5	86	5	16
	665 -	670	0.5	50	5	52
	670 -	672.5	10	50	2.5	83
	672.5 -	677.5	10	98	5	35
	677.5 -	680	10	76	2.5	57
	680 -	682.5	14	76	2.5	71
	682.5 -	690	14	68	7.5	79
	690 -	700	10	82	10	51
	700 -	707.5	10	69	7.5	64
	707.5 -	710	10	90	2.5	43
	710 -	717.5	4	90	7.5	23
	717.5 -	720	4	100	2.5	13
	720 -	722.5	10	100	2.5	33
	722.5 -	730	10	38	7.5	95
	730 -	732.5	15	38	2.5	100
	732.5 -	740	15	79	7.5	71
	740 -	742.5	0	79	2.5	21
	742.5 -	750	0	66	7.5	34
	750 -	760	2	59	10	48
	760 -	767.5	10	77	7.5	56
	767.5 -	770	10	73	2.5	60
	770 -	775	5	73	5	44
	775 -	780	5	69	5	48
	780 -	785	3	69	5	41
	785 -	795	3	55	10	55
	795 -	810	3	90	15	20
	810 -	820	1	100	10	3
	820 -	827.5	11	88	7.5	49
	827.5 -	830	11	69	2.5	68
	830 -	837.5	8	69	7.5	58
	837.5 -	847.5	8	44	10	83
	847.5 -	850	8	22	2.5	100
	850 -	852.5	5	22	2.5	95
	852.5 -	860	5	31	7.5	86
	860 -	870	9	32	10	98
	870 -	877.5	2	42	7.5	65
	877.5 -	880	2	59	2.5	48
	880 -	887.5	8	16	7.5	100
	887.5 -	890	8	80	2.5	47
	890 -	895	2	80	5	27
	895 -	900	2	26	5	81
	900 -	905	1	26	5	77
	905 -	910	1	62	5	41
	910 -	912.5	3	62	2.5	48
	912.5 -	915	3	41	2.5	69

TABLE C-4. RQD FOR CORE HOLE UE25a#1 (Cont'd)

Unit	Depth (ft)		Joint No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	915 -	920	3	91	5	19
	920 -	925	16	91	5	62
	925 -	927.5	16	58	2.5	95
	927.5 -	930	16	27	2.5	100
	930 -	932.5	1	27	2.5	76
	932.5 -	937.5	1	58	5	45
	937.5 -	940	1	74	2.5	29
	940 -	950	2	74	10	33
	950 -	952.5	0	74	2.5	26
	952.5 -	955	0	79	2.5	21
	955 -	960	0	100	5	0
	960 -	970	2	100	10	7
	970 -	975	2	44	5	63
	975 -	980	2	79	5	28
	980 -	982.5	4	79	2.5	34
	982.5 -	987.5	4	78	5	35
	987.5 -	990	4	77	2.5	36
	990 -	992.5	1	77	2.5	26
	992.5 -	1000	1	39	7.5	64
	1000 -	1002.5	2	39	2.5	68
	1002.5 -	1010	2	66	7.5	41
	1010 -	1017.5	3	44	7.5	66
	1017.5 -	1020	3	79	2.5	31
	1020 -	1025	4	79	5	34
	1025 -	1030	4	56	5	57
	1030 -	1035	0.5	54	5	48
	1035 -	1040	0.5	59	5	43
	1040 -	1042.5	6	59	2.5	61
	1042.5 -	1052.5	6	100	10	20
	1052.5 -	1060	6	50	7.5	70
	1060 -	1062.5	0.5	100	2.5	2
	1062.5 -	1067.5	0.5	56	5	46
	1067.5 -	1070	0.5	59	2.5	43
	1070 -	1080	4	98	10	15
	1080 -	1082.5	5	46	2.5	71
	1082.5 -	1090	5	75	7.5	42
	1090 -	1097.5	6	75	7.5	45
	1097.5 -	1100	6	55	2.5	65
	1100 -	1107.5	3	55	7.5	55
	1107.5 -	1110	3	84	2.5	26
	1110 -	1115	5	84	5	33
	1115 -	1117.5	5	100	2.5	17
	1117.5 -	1120	5	79	2.5	38
	1120 -	1122.5	1	79	2.5	24
	1122.5 -	1125	1	93	2.5	10
	1125 -	1130	1	89	5	14
	1130 -	1132.5	7	89	2.5	34
	1132.5 -	1137.5	7	93	5	30
	1137.5 -	1140	7	100	2.5	23
	1140 -	1147.5	1	100	7.5	3

TABLE C-4. RQD FOR CORE HOLE UE25a#1 (Cont'd)

Unit	Depth (ft)		Joint No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	1147.5 -	1150	1	65	2.5	38
	1150 -	1155	4	65	5	48
	1155 -	1160	4	100	5	13
	1160 -	1165	5	100	.5	17
	1165 -	1170	5	87	5	30
	1170 -	1175	8	82	5	45
	1175 -	1180	8	39	5	88
	1180 -	1182.5	12	39	2.5	100
	1182.5 -	1187.5	12	90	5	50
	1187.5 -	1190	12	100	2.5	40
	1190 -	1192.5	11	100	2.5	37
	1192.5 -	1200	11	83	7.5	54
	1200 -	1210	1	100	10	3
	1210 -	1215	2	100	5	7
	1215 -	1220	2	70	5	37
	1220 -	1225	7	70	5	53
	1225 -	1230	7	83	5	40
	1230 -	1232.5	18	83	2.5	77
	1232.5 -	1240	18	77	7.5	83
	1240 -	1250	12	40	10	100
	1250 -	1260	6	41	10	79
TSw3	1260 -	1265	1	27	5	76
	1265 -	1270	1	56	5	47
	1270 -	1275	15	56	5	94
	1275 -	1280	15	100	5	50
	1280 -	1282.5	5	45	2.5	72
	1282.5 -	1285	5	100	2.5	17
	1285 -	1290	5	32	5	85
	1290 -	1297.5	3	32	7.5	78
	1297.5 -	1300	3	13	2.5	97
	1300 -	1310	7	13	10	100
	1310 -	1320	2	72	10	35
CHn1	1320 -	1330	3	40	10	70
	1330 -	1340	4	55	10	58
	1340 -	1350	0	60	10	40
	1350 -	1360	0	25	10	75
	1360 -	1370	0	4	10	96
	1370 -	1380	1	15	10	88
	1380 -	1390	3	3	10	100
	1390 -	1400	1	16	10	87
	1400 -	1410	1	66	10	37
	1410 -	1420	3	37	10	73
	1420 -	1430	1	12	10	91
	1430 -	1440	1	37	10	66
	1440 -	1450	0	93	10	7
	1450 -	1460	1	11	10	92
	1460 -	1470	0.5	0	10	100
	1470 -	1480	0	1	10	99
	1480 -	1490	0	0	10	100
	1490 -	1500	1	0	10	100

TABLE C-4. RQD FOR CORE HOLE UE25a#1 (Concl'd)

Unit	Depth (ft)		Joint No.	Core Index	Drilled Interval (ft)	RQD (Modified)
	1500 -	1510	1	90	10	13
	1510 -	1530	0	3	20	97
	1530 -	1540	0	2	10	98
	1540 -	1550	0	4	10	96
	1550 -	1560	0	1	10	99
	1560 -	1570	0	8	10	92
	1570 -	1580	0	1	10	99
	1580 -	1590	0.5	11	10	91
	1590 -	1600	0	6	10	94
	1600 -	1610	0	0	10	100
	1610 -	1620	0	6	10	94
	1620 -	1630	0	0	10	100
	1630 -	1640	1	1	10	100
	1640 -	1650	2	8	10	99
	1650 -	1660	1	44	10	59
	1660 -	1680	0	0	20	100
	1680 -	1690	2	12	10	95
	1690 -	1700	0	41	10	59
	1700 -	1710	0	58	10	42
	1710 -	1720	0	8	10	92
	1720 -	1730	0	4	10	96
	1730 -	1750	0	0	20	100
	1750 -	1760	0	4	10	96
	1760 -	1770	0	0	10	100
	1770 -	1780	0	93	10	7
	1780 -	1790	0	6	10	94

* *Joint numbers are the values for 10-ft interval*

TABLE C-5. AVERAGE RQD FOR 20-FT INTERVALS OF TCw UNIT

Depth (ft)	RQD
USW GU-3	
40 - 60	87
60 - 80	78
80 - 100	71
100 - 120	62
120 - 140	66
140 - 160	52
160 - 180	47
180 - 200	45
200 - 220	68
220 - 240	59
240 - 260	88
260 - 280	67
280 - 300	32
300 - 320	60
320 - 340	59
USW G-4	
40 - 60	92
60 - 80	100
80 - 100	97
100 - 120	96
UE-25a#1	
60 - 80	40
80 - 100	81
100 - 120	65
120 - 140	100
140 - 160	67
160 - 180	65
180 - 200	15

TABLE C-6. AVERAGE RQD FOR 20-FT INTERVALS OF PTn UNIT

Depth (ft)	RQD
USW GU-3	
340 - 360	54
360 - 380	73
380 - 400	72
400 - 420	62
USW G-4	
120 - 140	71
140 - 160	31
160 - 180	41
180 - 200	28
200 - 220	63
220 - 240	66
UE-25a#1	
200 - 220	67
220 - 240	60
240 - 260	74
260 - 280	51

TABLE C-7. AVERAGE RQD FOR 20-FT INTERVALS OF TSw1 UNIT

Depth (ft)	RQD
USW G-1	
290 - 310	80
310 - 330	54
330 - 350	17
350 - 370	56
370 - 390	85
390 - 410	83
410 - 430	86
430 - 450	51
450 - 470	46
470 - 490	2
490 - 510	84
510 - 530	81
530 - 550	39
550 - 570	31
570 - 590	66
590 - 610	21
610 - 630	50
630 - 650	65
650 - 670	58
670 - 690	30
690 - 710	20
USW GU-3	
430 - 450	69
450 - 470	70
470 - 490	77
490 - 510	76
510 - 530	47
530 - 550	66
550 - 570	33
570 - 590	36
590 - 610	77
610 - 630	42
630 - 650	94
650 - 670	75
670 - 690	90
USW G-4	
240 - 260	100
260 - 280	100
280 - 300	85
300 - 320	99
320 - 340	97
340 - 360	94
360 - 380	79
380 - 400	80
400 - 420	88
420 - 440	63
440 - 480	NA
480 - 500	16
500 - 520	14
520 - 540	16
540 - 560	19
560 - 580	44
580 - 600	49
600 - 620	70
620 - 640	34
640 - 660	71
UE-25a#1	
280 - 300	32
300 - 320	4
320 - 340	46
340 - 360	64
360 - 380	62
380 - 400	53
400 - 420	18
420 - 440	16
440 - 460	51
460 - 480	55
480 - 500	9
500 - 520	8
520 - 540	17
540 - 560	12
560 - 580	32
580 - 600	42
600 - 620	21

TABLE C-8. AVERAGE RQD FOR 20-FT INTERVALS OF TSw2 UNIT

Depth (ft)	RQD
USW G-1	
710 - 730	74
730 - 750	54
750 - 770	22
770 - 790	37
790 - 810	90
810 - 830	38
830 - 850	20
850 - 870	0
870 - 890	24
890 - 910	25
910 - 930	17
930 - 950	22
950 - 970	29
970 - 990	0
990 - 1020	NA
1020 - 1040	18
1040 - 1060	32
1060 - 1080	24
1080 - 1100	19
1100 - 1120	49
1120 - 1140	24
1140 - 1160	58
1160 - 1180	74
1180 - 1200	67
1200 - 1220	94
1220 - 1240	53
1240 - 1260	22
1260 - 1280	31
USW GU-3	
690 - 710	89
710 - 730	69
730 - 750	22
750 - 770	70
770 - 790	33
790 - 810	17
810 - 830	34
830 - 850	42
850 - 870	27
870 - 890	59
890 - 910	55
910 - 930	88
930 - 950	96
950 - 970	89
970 - 990	31
990 - 1010	18
1010 - 1030	40
1030 - 1050	29
1050 - 1070	44
1070 - 1090	52
1090 - 1110	47
1110 - 1130	72
1130 - 1150	67
1150 - 1170	79
1170 - 1190	97
USW G-4	
670 - 690	100
690 - 710	87
710 - 730	16
730 - 750	88
750 - 770	95
770 - 790	77
790 - 810	35
810 - 830	62
830 - 850	47
850 - 870	27
870 - 890	60
890 - 910	20
910 - 930	31
930 - 950	47
950 - 970	58
970 - 990	50
990 - 1010	43
1010 - 1030	40
1030 - 1050	15
1050 - 1070	20
1070 - 1090	58
1090 - 1110	48
1110 - 1130	36
1130 - 1150	61
1150 - 1170	81
1170 - 1190	78
1190 - 1210	50
1210 - 1230	66
1230 - 1250	81
1250 - 1270	79
1270 - 1290	10
UE-25a#1	
620 - 640	32
640 - 660	37
620 - 640	32
640 - 660	37
660 - 680	43
680 - 700	64
700 - 720	40
720 - 740	79
740 - 760	39
760 - 780	52
780 - 800	43
800 - 820	12
820 - 840	59
840 - 860	88
860 - 880	79

TABLE C-8. AVERAGE RQD FOR 20-FT INTERVALS OF TSw2 UNIT (Concl'd)

Depth (ft)	RQD
880 - 900	70
900 - 920	49
920 - 940	64
940 - 960	22
960 - 980	26
980 - 1000	45
1000 - 1020	53
1020 - 1040	46
1040 - 1060	44
1060 - 1080	25
1080 - 1100	50
1100 - 1120	39
1120 - 1140	22
1140 - 1160	21
1160 - 1180	45
1180 - 1200	55
1200 - 1220	13
1220 - 1240	64
1240 - 1260	90

TABLE C-9. AVERAGE RQD FOR 20-FT INTERVALS OF TSw3 UNIT

Depth (ft)			RQD
USW G-1			
1280	-	1300	59
1300	-	1320	70
1320	-	1340	100
USW GU-3			
1190	-	1210	81
1210	-	1230	81
1230	-	1250	86
1250	-	1270	55
USW G-4			
1300	-	1320	69
1320	-	1340	35
UE-25a#1			
1260	-	1280	67
1280	-	1300	74
1300	-	1320	68

TABLE C-10. AVERAGE RQD FOR 20-FT INTERVALS OF CHn1 UNIT

Depth (ft)	RQD
USW G-1	
1340 - 1360	63
1360 - 1380	53
1380 - 1400	65
1400 - 1420	82
1420 - 1440	61
1440 - 1460	77
1460 - 1480	96
1480 - 1500	98
1500 - 1520	100
1520 - 1540	84
1540 - 1560	87
1560 - 1580	73
1580 - 1600	49
1600 - 1620	76
1620 - 1640	55
1640 - 1660	70
1660 - 1680	88
1680 - 1700	93
1700 - 1720	85
1720 - 1740	96
USW GU-3	
1270 - 1290	64
1290 - 1310	94
1310 - 1330	88
1330 - 1350	26
1350 - 1370	38
1370 - 1390	19
1390 - 1410	50
1410 - 1430	20
1430 - 1450	45
1450 - 1470	3
1470 - 1490	28
1490 - 1510	71
USW G-4	
1340 - 1360	5
1360 - 1380	99
1380 - 1400	70
1400 - 1420	95
1420 - 1440	98
1440 - 1460	96
1460 - 1480	98
1480 - 1500	99
1500 - 1520	98
1520 - 1540	97
1540 - 1560	97
1560 - 1580	96
1580 - 1600	100
1600 - 1620	87
1620 - 1640	92
1640 - 1660	98
1660 - 1680	97
1680 - 1700	100
UE-25a#1	
1320 - 1340	64
1340 - 1360	58
1360 - 1380	92
1380 - 1400	94
1400 - 1420	55
1420 - 1440	79
1440 - 1460	50
1460 - 1480	100
1480 - 1500	100
1500 - 1520	55
1520 - 1540	98
1540 - 1560	98
1560 - 1580	96
1580 - 1600	93
1600 - 1620	97
1620 - 1640	100
1640 - 1660	79
1660 - 1680	100
1680 - 1700	77
1700 - 1720	67
1720 - 1740	98
1740 - 1760	98
1760 - 1780	54

APPENDIX D

Tables Recommended for Reference Information Base

The results of this study are summarized in this appendix and are recommended for inclusion in the RIB. No data from this study is considered for entry into the Site and Engineering Properties Database (SEPDB).

TABLE D-1. FRACTURE ORIENTATIONS AS ESTIMATED FOR ORIENTED CORE AND BOREHOLE TELEVISION SURVEYS

	USW GU-3		USW G-4	
Geologic Member	Strike	Dip	Strike	Dip
Tiva Canyon Member	N18°W-N36°E	85°-90°SW/NE	N-N22°E	65°-90°NW
	N50°W	12°NE	---	---
	---	---	E-W	70°-90°N/S
	---	---	N50°W	70°-90°NE/SW
Topopah Spring Member	N10°W	75°-90°NE/SW	N°12W	80°-90°NE/SW
	N25°E	10°SE	---	---
	N45°E	80°-90°SE/NW	N-N40°E	*NM*

NM *Not measured by borehole television system.*
--- *No corresponding joint observed.*

Note: See Section 3.1.1 for explanation. No subsurface data available for the nonwelded tuff units.

TABLE D-2. PERCENTAGE OF MAPPED FRACTURES IN EACH 10° INCLINATION ANGLE

Units	Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
Tiva Canyon Member	USW G-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
	USW G-4	12	21	12	10	5	6	10	7	17
	USW GU-3*	6	8	6	4	6	8	17	21	24
	UE-25a#1	4	10	14	19	10	10	13	13	7
Pah Canyon Member	USW G-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
	USW G-4	17	18	11	4	10	7	11	5	17
	USW GU-3*	NA	NA	NA	NA	NA	NA	NA	NA	NA
	UE-25a#1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Topopah Spring Member	USW G-1	6	12	7	4	4	4	9	24	30
	USW G-4	12	14	10	6	6	6	9	12	25
	USW GU-3*	7	7	5	5	4	3	5	27	37
	UE-25a#1	3	3	8	8	8	6	12	21	30
Tuffaceous Beds of Calico Hills	USW G-1	20	20	0	0	0	0	20	20	20
	USW G-4	0	0	0	0	6	19	14	44	17
	USW GU-3*	12	12	11	10	9	7	7	6	26
	UE-25a#1	3	8	5	0	3	14	12	20	35

* *The percentage data presented in the rose diagram of Scott and Castellanos (1984) are the corrected data through Terzaghi's (1965) procedure. The data presented in this table have been converted to the original percentage data.*

NA *Data not available.*

Note: Interval percentages were adjusted based on engineering judgment to total 100%. Same as Table 3-2, see Section 3.1.2 for explanation.

TABLE D-3. CORRECTED LINEAR FRACTURE FREQUENCY FOR TCw UNIT (m^{-1})

Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
USW G-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
USW G-4	0.93	1.68	1.02	0.94	0.55	0.81	1.83	2.09	15.05
USW GU-3	0.23	0.31	0.25	0.18	0.32	0.53	1.52	3.06	10.37
UE-25a#1	0.11	0.28	0.42	0.64	0.39	0.48	0.84	1.38	2.20
Mean	0.42	0.76	0.57	0.59	0.42	0.60	1.40	2.17	9.21
Upper range	0.93	1.68	1.02	0.94	0.55	0.81	1.83	3.06	15.05
Lower range	0.11	0.28	0.25	0.18	0.32	0.48	0.84	1.38	2.20

NA—*Data not available.*

Note: Same as Table 3-6, see Section 3.2.2 for explanation.

TABLE D-4. CORRECTED LINEAR FREQUENCY FOR PTn UNIT (m^{-1})

Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
USW G-1	NA	NA	NA	NA	NA	NA	NA	NA	NA
USW G-4	0.17	0.19	0.12	0.05	0.14	0.12	0.26	0.19	1.94
USW GU-3	NA	NA	NA	NA	NA	NA	NA	NA	NA
UE-25a#1	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mean	NA	NA	NA	NA	NA	NA	NA	NA	NA
Upper range	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lower range	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA—*Data not available.*

Note: Same as Table 3-7, see Section 3.2.2 for explanation.

TABLE D-5. CORRECTED LINEAR FRACTURE FREQUENCY FOR TSw1 UNIT (m^{-1})

Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
USW G-1	0.05	0.06	0.05	0.05	0.05	0.05	0.10	0.43	1.61
USW G-4	0.52	0.62	0.48	0.32	0.37	0.45	0.92	2.00	12.35
USW GU-3	0.09	0.10	0.07	0.08	0.07	0.07	0.16	1.38	5.62
UE-25a#1	0.05	0.05	0.05	0.05	0.05	0.05	0.12	0.35	1.55
Mean	0.18	0.21	0.16	0.12	0.14	0.15	0.32	1.04	5.28
Upper range	0.52	0.62	0.48	0.32	0.37	0.45	0.92	2.00	12.35
Lower range	0.05	0.05	0.05	0.05	0.05	0.05	0.10	0.35	1.55

Note: Same as Table 3-8, see Section 3.2.2 for explanation.

TABLE D-6. CORRECTED LINEAR FRACTURE FREQUENCY FOR TSw2 UNIT (m^{-1})

Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
USW G-1	0.05	0.11	0.07	0.05	0.05	0.06	0.19	0.81	2.99
USW G-4	0.50	0.60	0.46	0.30	0.35	0.44	0.89	1.93	11.92
USW GU-3	0.40	0.41	0.31	0.35	0.32	0.30	0.67	5.92	24.07
UE-25a#1	0.05	0.05	0.15	0.17	0.20	0.18	0.49	1.40	6.14
Mean	0.25	0.29	0.25	0.22	0.23	0.24	0.56	2.51	11.28
Upper range	0.50	0.60	0.46	0.35	0.35	0.44	0.89	5.92	24.07
Lower range	0.05	0.05	0.07	0.05	0.05	0.06	0.19	0.81	2.99

Note: Same as Table 3-9, see Section 3.2.2 for explanation.

TABLE D-7. CORRECTED LINEAR FRACTURE FREQUENCY FOR TSw3 UNIT (m^{-1})

Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
USW G-1	0.15	0.31	0.19	0.12	0.14	0.17	0.53	2.29	8.49
USW G-4	0.40	0.49	0.37	0.25	0.28	0.35	0.71	1.55	9.61
USW GU-3	0.12	0.12	0.09	0.10	0.10	0.09	0.20	1.77	7.21
UE-25a#1	0.06	0.06	0.17	0.19	0.22	0.21	0.56	1.59	6.98
Mean	0.18	0.24	0.21	0.17	0.19	0.20	0.50	1.80	8.07
Upper range	0.40	0.49	0.37	0.25	0.28	0.35	0.71	2.29	9.61
Lower range	0.06	0.06	0.09	0.10	0.10	0.09	0.20	1.55	6.98

Note: Same as Table 3-10, see Section 3.2.2 for explanation.

TABLE D-8. CORRECTED LINEAR FRACTURE FREQUENCY FOR CHn1 UNIT (m^{-1})

Drill Holes	0-10 deg	10-20 deg	20-30 deg	30-40 deg	40-50 deg	50-60 deg	60-70 deg	70-80 deg	80-90 deg
USW G-1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.08	0.23
USW G-4	0.05	0.05	0.05	0.05	0.05	0.08	0.08	0.39	0.44
USW GU-3	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.11	1.44
UE-25a#1	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.15	0.78
Mean	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.18	0.72
Upper range	0.06	0.06	0.06	0.06	0.06	0.08	0.08	0.39	1.44
Lower range	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.08	0.23

Note: Same as Table 3-11, see Section 3.2.2 for explanation.

TABLE D-9. VOLUMETRIC FRACTURE FREQUENCY IN A UNIT VOLUME OF ROCK (m^{-3})

Drill Holes	TCw	PTn	TSw1	TSw2	TSw3	CHn1
USW G-1	NA	NA	3.04	5.41	15.36	0.81
USW G-4	30.87	3.95	22.35	21.56	17.39	1.53
USW GU-3	20.79	NA	9.48	40.61	12.16	2.46
UE-25a#1	8.36	NA	2.87	10.96	12.45	1.59
Mean	20.01	NA	9.44	19.64	14.34	1.60

NA *Data not available.*

Note: Same as Table 3-12, see Section 3.2.3 for explanation.

TABLE D-10. RECOMMENDED RANGE OF JOINT ROUGHNESS

	JRC		Narrative Description	
	Lower Bound	Upper Bound	Lower Bound	Upper Bound
TCw	3.0	9.6	Discontinuous	Smooth, undulating
PTn	2.0	8.0	Smooth, undulating	Smooth, planar
TSw1	3.0	9.6	Discontinuous	Smooth, undulating
TSw2	3.0	9.6	Discontinuous	Smooth, undulating
TSw3	3.0	9.6	Discontinuous	Smooth, undulating
CHn1	2.0	8.0	Smooth, undulating	Smooth, planar

Note: Same as Table 4-4, see Section 4.1 for explanation.

TABLE D-11. ROCK QUALITY DESIGNATIONS FOR THE FIVE ROCK QUALITY CATEGORIES

	Rock Quality Category				
Unit	1	2	3	4	5
TCw	34	50	63	81	92
PTn	29	48	61	69	72
TSw1	10	24	46	74	90
TSw2	16	26	41	62	84
TSw3	39	58	66	81	89
CHn1	22	58	77	91	94

Note: Same as Table 5-9, see Section 5.2 for explanation.

APPENDIX E

Candidate Information for the Site & Engineering Properties Data Base

This report contains no candidate information for the Site and Engineering Properties Data Base.

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

DISTRIBUTION LIST

1 J. W. Barlett (RW-1)
Director
OCRWM
US Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

1 F. G. Peters (RW-2)
Deputy Director
OCRWM
US Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

1 T. H. Isaacs (RW-4)
Office of Strategic Planning and International Programs
OCRWM
US Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

1 J. D. Saltzman (RW-5)
Office of External Relations
OCRWM
US Department of Energy
1000 Independence Av. ue SW
Washington, DC 20585

1 Samuel Rousso (RW-10)
Office of Program and Resource Mgt.
OCRWM
US Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

1 J. C. Bresee (RW-10)
OCRWM
US Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

1 C. P. Gertz (RW-20)
Office of Geologic Disposal
OCRWM
US Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

1 S. J. Brocoum (RW-22)
Analysis and Verification Division
OCRWM
US Department of Energy
1000 Independence Avenue SW
Washington, DC 2585

1 J. Roberts, Acting Associate Director (RW-30)
Office of Systems and Compliance
OCRWM
US Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

1 J. Roberts (RW-33)
Director, Regulatory Compliance Division
OCRWM
US Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

1 G. J. Parker (RW-332)
OCRWM
US Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

1 R. A. Milner (RW-40)
Office of Storage and Transporation
OCRWM
US Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

1 S. Rousso, Associate Director
(RW-50)
Office of Contract Business
Management
OCRWM
US Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

1 T. Wood (RW-52)
Director, M&O Management Division
OCRWM
US Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585

4 Victoria F. Reich, Librarian
Nuclear Waste Technical Review Board
1100 Wilson Blvd, Suite 910
Arlington, VA 22209

5 C.P. Gertz, Project Manager
Yucca Mountain Site
Characterization Project Office
US Department of Energy
P.O. Box 98608--MS 523
Las Vegas, NV 89193-8608

1 C. L. West, Director
Office of External Affairs
DOE Nevada Field Office
US Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

12 Technical Information Officer
DOE Nevada Field Office
US Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

1 P. K. Fitzsimmons, Technical Advisor
Office of Assistant Manager for
Environmental Safety and
Health
DOE Nevada Field Office
US Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

1 D. R. Elle, Director
Environmental Protection and Division
DOE Nevada Field Office
US Department of Energy
P.O. Box 98518
Las Vegas, NV 89193-8518

1 Repository Licensing & Quality
Assurance
Project Directorate
Division of Waste Management
US NRC
Washington, DC 20555

1 Senior Project Manager for Yucca
Mountain
Repository Project Branch
Division of Waste Management
US NRC
Washington, DC 20555

1 NRC Document Control Desk
Division of Waste Management
US NRC
Washington, DC 20555

1 Philip S. Justus
NRC Site Representive
301 E Stewart Avenue, Room 203
Las Vegas, NV 89101

1 E.P. Binnall
Field Systems Group Leader
Building 50B/4235
Lawrence Berkeley Laboratory
Berkeley, CA 94720

1 Center for Nuclear Waste
Regulatory Analyses
6220 Culebra Road
Drawer 28510
San Antonio, TX 78284

3 W. L. Clarke
Technical Project Officer - YMP
Attn: YMP/LRC
Lawrence Livermore National
Laboratory
P.O. Box 5514
Livermore, CA 94551

1 J. A. Blink
Deputy Project Leader
Lawrence Livermore National Laboratory
101 Convention Center Drive
Suite 820, MS 527
Las Vegas, NV 89109

4 J. A. Canepa
Technical Project Officer - YMP
N-5, Mail Stop J521
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos, NM 87545

1 H. N. Kalia
Exploratory Shaft Test Manager
Los Alamos National Laboratory
Mail Stop 527
101 Convention Center Dr., #820
Las Vegas, NV 89101

1 N. Z. Elkins
Deputy Technical Project Officer
Los Alamos National Laboratory
Mail Stop 527
101 Convention Center Dr., #820
Las Vegas, NV 89101

5 L. E. Shephard
Technical Project Officer - YMP
Sandia National Laboratories
Organization 6302
P.O. Box 5800
Albuquerque, NM 87185

1 J. F. Devine
Asst Director of Engineering Geology
US Geological Survey
106 National Center
12201 Sunrise Valley Drive
Reston, VA 22092

1 L. R. Hayes
Technical Project Officer
Yucca Mountain Project Branch
MS 425
US Geological Survey
P.O. Box 25046
Denver, CO 80225

1 V. R. Schneider
Asst. Chief Hydrologist--MS 414
Office of Program Coordination and Technical Support
US Geological Survey
12201 Sunrise Valley Drive
Reston, VA 22092

1 J. S. Stuckless
Geologic Division Coordinator
MS 913
Yucca Mountain Project
US Geological Survey
P.O. Box 25046
Denver, CO 80225

1 D. H. Appel, Chief
Hydrologic Investigations Program
MS 421
US Geological Survey
P.O. Box 25046
Denver, CO 80225

1 E. J. Helley
Branch of Western Regional Geology
MS 427
US Geological Survey
345 Middlefield Road
Menlo Park, CA 94025

1 R. W. Craig, Chief
Nevada Operations Office
US Geological Survey
101 Convention Center Drive
Suite 860, MS 509
Las Vegas, NV 89109

1 D. Zesiger
US Geological Survey
101 Conventional Center Drive
Suite 860, MS 509
Las Vegas, NV 89109

1 G. L. Ducret, Associate Chief
Yucca Mountain Project Division
US Geological Survey
P.O. Box 25046
421 Federal Center
Denver, CO 80225

1 A. L. Flint
US Geological Survey
MS 721
P.O. Box 327
Mercury, NV 89023

1 D. A. Beck
Water Resources Division, USGS
6770 S Paradise Road
Las Vegas, NV 89119

1 P. A. Glancy
US Geological Survey
Federal Building, Room 224
Carson City, NV 89701

1 Sherman S.C. Wu
Branch of Astrogeology
US Geological Survey
2255 N Gemini Drive
Flagstaff, AZ 86001

1 J. H. Sass - USGS
Branch of Tectonophysics
2255 N Gemini Drive
Flagstaff, AZ 86001

1 DeWayne Campbell
Technical Project Officer - YMP
US Bureau of Reclamation
Code D-3790
P.O. Box 25007
Denver, CO 80225

1 J. M. LaMonaca
Records Specialist
US Geological Survey
421 Federal Center
P.O. Box 25046
Denver, CO 80225

1 W. R. Keefer - USGS
913 Federal Center
P.O. Box 25046
Denver, CO 80225

1 M. D. Voegele
Technical Project Officer - YMP
SAIC
101 Convention Center Drive
Suite 407
Las Vegas, NV 89109

2 L. D. Foust
Nevada Site Manager
TRW Environmental Safety
Systems
101 Convention Center Drive
Suite 540, MS 423
Las Vegas, NV 89109

1 C. E. Ezra
YMP Support Office Manager
EG&G Energy Measurements Inc
MS V-02
P.O. Box 1912
Las Vegas, NV 89125

1 E. L. Snow, Program Manager
Roy F. Weston Inc
955 L'Enfant Plaza SW
Washington, DC 20024

1 Technical Information Center
Roy F. Weston Inc
955 L'Enfant Plaza SW
Washington, DC 20024

1 D. Hedges, Vice President, QA
Roy F. Weston Inc
4425 Spring Mountain Road
Suite 300
Las Vegas, NV 89102

1 D. L. Fraser, General Manager
Reynolds Electrical &
Engineering Co, Inc
MS 408
P.O. Box 98521
Las Vegas, NV 89193-8521

1 B. W. Colston, President and
General Manager
Las Vegas Branch
Raytheon Services Nevada
MS 416
P.O. Box 95487
Las Vegas, NV 89193-5487

1 R. L. Bullock
Technical Project Officer - YMP
Raytheon Services Nevada
Suite P-250, MS 403
101 Convention Center Drive
Las Vegas, NV 89109

1 Paul Eslinger, Manager
PASS Program
Pacific Northwest Laboratories
P.O. Box 999
Richland, WA 99352

1 A. T. Tamura
Science and Technology Division
OSTI
US Department of Energy
P.O. Box 62
Oak Ridge, TN 37831

1 Carlos G. Bell Jr
Professor of Civil Engineering
Civil and Mechanical Engineering Dept.
University of Nevada, Las Vegas
4505 S Maryland Parkway
Las Vegas, NV 89154

1 P. J. Weeden, Acting Director
Nuclear Radiation Assessment Div.
US EPA
Environmental Monitoring
Systems Lab
P.O. Box 93478
Las Vegas, NV 89193-3478

1 ONWI Library
Battelle Columbus Laboratory
Office of Nuclear Waste Isolation
505 King Avenue
Columbus, OH 43201

1 T. Hay, Executive Assistant
Office of the Governor
State of Nevada
Capitol Complex
Carson City, NV 89710

3 R. R. Loux
Executive Director
Agency for Nuclear Projects
State of Nevada
Evergreen Center, Suite 252
1802 N. Carson Street
Carson City, NV 89710

1 C. H. Johnson
Technical Program Manager
Agency for Nuclear Projects
State of Nevada
Evergreen Center, Suite 252
1802 N. Carson Street
Carson City, NV 89710

1 John Fordham
Water Resources Center
Desert Research Institute
P.O. Box 60220
Reno, NV 89506

1 David Rhode
Desert Research Institute
P.O. Box 60220
Reno, NV 89506

1 Eric Anderson
Mountain West Research-
Southwest Inc
2901 N Central Avenue #1000
Phoenix, AZ 85012-2730

1 The Honorable Cyril Schank
Chairman
Churchill County Board of
Commissioners
190 W First Street
Fallon, NV 89406

1 Dennis Bechtel, Coordinator
Nuclear Waste Division
Clark County Department of
Comprehensive Planning
301 E Clark Avenue, Suite 570
Las Vegas, NV 89101

1 Juanita D. Hayes
Nuclear Waste Repository
Oversight Program
Esmeralda County
P.O. Box 490
Goldfield, NV 89013

1 Yucca Mountain Information
Office
Eureka County
P.O. Box 714
Eureka, NV 89316

1 Brad Mettam
Inyo County Yucca Mountain Repository Assessment Office
Drawer L
Independence, CA 93526

1 The Honorable Gloria Derby
Chairman
Lander County Board of Commissioners
315 South Humbolt
Battle Mountain, NV 89820

1 The Honorable Edward E. Wright
Chairman
Lincoln County Board of Commissioners
P.O. Box 90
Pioche, NV 89043

1 Vernon E. Poe
Office of Nuclear Projects
Mineral County
P.O. Box 1026
Hawthorne, NV 89415

1 The Honorable Barbara J. Raper
Chairman
Nye County Board of Commissioners
P.O. Box 1240
Pahrump, NV 89041

1 Planning Department
Nye County
P.O. Box 153
Tonopah, NV 89049

1 Florindo Mariani
White Pine County Nuclear Waste Project Office
457 Fifth Street
Ely, NV 89301

5 Judy Foremaster
City of Caliente Nuclear Waste Project Office
P.O. Box 158
Caliente, NV 89008

1 Jason Pitts
Lincoln County Nuclear Waste Project Office
Lincoln County Courthouse
Pioche, NV 89043

1 Economic Development Dept.
City of Las Vegas
400 E. Stewart Avenue
Las Vegas, NV 89101

1 Commmunity Planning and Development
City of North Las Vegas
P.O. Box 4086
North Las Vegas, NV 89030

1 Community Development and Planning
City of Boulder City
P.O. Box 61350
Boulder City, NV 89006

1 Commission of the European Communities
200 Rue de la Loi
B-1049 Brussells
BELGIUM

2 M. J. Dorsey, Librarian
YMP Research and Study Center
Reynolds Electrical & Engineering Co Inc
MS 407
P.O. Box 98521
Las Vegas, NV 89193-8521

1 Amy Anderson
Argonne National Laboratory
Building 362
9700 S Cass AVenue
Argonne, IL 60439

1 Steve Bradhurst
P.O. Box 1510
Reno, NV 89505

1 Michael L. Baughman
35 Clark Road
Fiskdale, MA 01518

1 Glenn Van Roekel
Director of Community
Development
City of Caliente
P.O. Box 158
Caliente, NV 89008

1 Ray Williams, Jr
P.O. Box 10
Austin, NV 89310

1 R. F. Pritchett
Technical Project Officer - YMP
Reynolds Electrical &
Engineering Co Inc
MS 408
P.O. Box 98521
Las Vegas, NV 89193-8521

1 Charles Thistlethwaite, AICP
Associate Planner
Inyo County Planning Department
Drawer L
Independence, CA 93526

1 Les Bradshaw
Nye County District Attorney
P.O. Box 593
Tonopah, NV 89049

1 Dr. Moses Karakouzian
1751 E Reno #125
Las Vegas, NV 89119

6 M. Lin
Agapito & Associates, Inc
715 Horizon Drive, Suite 340
Grand Junction, CO 81506

6 Michael P. Hardy
Agapito & Associates, Inc
715 Horizon Drive, Suite 340
Grand Junction, CO 81506

1	6300	D.E. Miller
1	6302	L.E. Shephard
1	6304	J.T. Holmes
1	6312	F.W. Bingham
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