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WM-11
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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET
Complete Only Applicable Items

1. QA: QA

2. ☒ Analysis — Check all that apply	3. ☐ Model — Check all that apply
Type of Analysis: ☐ Engineering ☐ Performance Assessment ☒ Scientific	Type of Model: ☐ Conceptual Model ☐ Abstraction Model ☐ Mathematical Model ☐ System Model ☐ Process Model
Intended Use of Analysis: ☐ Input to Calculation ☒ Input to another Analysis or Model ☐ Input to Technical Document	Intended Use of Model: ☐ Input to Calculation ☐ Input to another Model or Analysis ☐ Input to Technical Document
Describe use: Provides representive estimates of fracture and matrix properties for use in the Calibrated Properties Model and numerical grid development.	Describe use:

4. Title:
Analysis of Hydrologic Properties Data

5. Document Identifier (including Rev. No. and Change No., if applicable):
ANL-NBS-HS-000002 REV00

6. Total Attachments:

7. Attachment Numbers - No. of Pages in Each:
I-36, II-8, III-4, IV-~~9~~ 70 4/19/00

	Printed Name	Signature	Date
8. Originator	H.H. Liu		3/12/00
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12. Remarks:

Block 8: Prepared by H.H. Liu with C.F. Ahlers preparing Section 6.2 and 6.4 and M.A. Cushey preparing Section 6.1.
Editorial corrections to page 3, Table of Contents JEH 4/28/00
Editorial corrections to page 7, Tables JEH 4/28/00
Editorial corrections to page 71, Attachments JEH 4/28/00
Editorial correction - added "N/A" to "Change" box throughout Attachment I JEH 4/28/00
Editorial correction to Attachment IV - pagination throughout JEH 4/28/00
Obliterations in Attachment II do not affect technical content JEH 4/28/00

Enclosure 2

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OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL REVISION RECORD

Complete Only Applicable Items

2. Analysis or Model Title:

Analysis of Hydrologic Properties Data

3. Document Identifier (including Rev. No. and Change No., if applicable):

ANL-NBS-HS-000002 REV00

4. Revision/Change No.	5. Description of Revision/Change
00	Initial issue

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ACRONYMS

ACC	Accession Number
AMR	Analysis/Model Report
AP	Administrative Procedure (DOE)
CFu	Crater Flat Undifferentiated Hydrogeologic Unit
CHn	Calico Hills Nonwelded Hydrogeologic Unit
CRWMS	Civilian Radioactive Waste Management System
DOE	Department of Energy
DSL	Detailed Line Survey
DST	Drift Scale Test
DTN	Data Tracking Number
ECM	Effective Continuum Method
ECRB	Enhanced Characterization of Repository Block
ESF	Exploratory Studies Facility
FY	Fiscal Year
GFM	Geologic Framework Model
HGU	Hydrogeologic Unit
ISM	Integrated Site Model
ITN	Input Tracking Number
LBNL	Lawrence Berkeley National Laboratory
M&O	Management and Operating Contractor
NSP	Nevada State Planar
OCRWM	Office of Civilian Radioactive Waste Management
PA	Performance Assessment
PTn	Paintbrush nonwelded hydrogeologic unit
QAP	Administrative Procedure (M&O)
QARD	Quality Assurance Requirements and Description
QIP	Quality Implementing Procedure
RIB	Reference Information Base
RIS	Records Information System

ACRONYMS (CONTINUED)

SHT	Single Heater Test
TBV	To Be Verified
TCw	Tiva Canyon welded hydrogeologic unit
TDMS	Technical Data Management System
TSw	Topopah Spring welded hydrogeologic unit
USGS	United States Geological Survey
UZ	Unsaturated Zone
YMP	Yucca Mountain Site Characterization Project

1. PURPOSE

The purpose of this Analysis/Model Report (AMR) is to describe the methods used to determine hydrologic properties based on the available field data from the unsaturated zone at Yucca Mountain, Nevada. This is in accordance with the *AMR Development Plan (DP) for U0090 Analysis of Hydrologic Properties Data* (CRWMS M&O 1999c). Fracture and matrix properties are developed by compiling and analyzing available survey data from the Exploratory Studies Facility (ESF), Cross Drift of Enhanced Characterization of Repository Block (ECRB), and/or boreholes; air injection testing data from surface boreholes and from boreholes in the ESF; in-situ measurements of water potential; and data from laboratory testing of core samples.

The primary objective of this work activity is to provide representative estimates of fracture and matrix properties for use in the inversion process in the AMR documenting the calibrated properties model and fracture spacing for generating dual-permeability grids as documented in an AMR describing development of numerical grids for unsaturated zone (UZ) flow and transport modeling. The resulting calibrated property sets and numerical grids from these other AMRs will be used directly in the Unsaturated Zone Flow and Transport Process Model (UZ Model).

The fracture and matrix properties developed in this AMR include:

- Fracture properties (frequency, permeability, van Genuchten α and m parameters, aperture, porosity, and interface area) for each UZ Model layer
- Matrix properties (porosity, permeability, and van Genuchten α and m parameters) for each UZ Model layer
- Thermal properties (grain density, wet and dry thermal conductivity, grain specific heat, and tortuosity coefficients) for each UZ Model layer
- Fault properties for each major hydrogeologic unit.

These properties incorporate the available measurement data, as applicable, to determine base estimates of fracture and matrix properties. Another objective is to use field data from liquid release testing in the ESF and other relevant data to confirm these properties and provide bounds on property values.

Caveats, constraints, and limitations are that the fracture permeability, van Genuchten fracture α and m, matrix permeability, and van Genuchten matrix α and m reported here are uncalibrated and serve only as initial estimates for the calibration process. These values should not be used directly in the UZ or other models. Also, these properties as well as the other properties are intended for use in the UZ Model and, thus, were developed to be applicable to the conceptual model assumptions and scale of the UZ Model. These properties are also limited by the available site data as discussed in this AMR and in the documentation accompanying the data submittal to the Technical Data Management System (TDMS).

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2. QUALITY ASSURANCE

This AMR was developed in accordance with AP-3.10Q, *Analyses and Models*. Other applicable Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM) Administrative Procedures (APs) and YMP-LBNL Quality Implementing Procedures (QIPs) are identified in the *AMR Development Plan for U0090 Analysis of Hydrologic Properties Data, Rev 00* (CRWMS M&O 1999c).

The activities documented in this AMR were evaluated with other related activities in accordance with QAP-2-0, Conduct of Activities, and were determined to be subject to the requirements of the U.S. DOE Office of Civilian Radioactive Waste Management (OCRWM) Quality Assurance Requirements and Description (QARD) (DOE 1998). This evaluation is documented in CRWMS M&O (1999a, 1999b) and Wemheuer (1999) (Activity Evaluation for Work Package WP 1401213UM1).

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3. COMPUTER SOFTWARE AND MODEL USAGE

All software used for this work activity is either a routine or standard spreadsheet program. These routines have been qualified per AP-SI.1Q, Rev.1, ICN 0, *Software Management*. Table 1 lists the routines and the accession numbers (ACC) documenting their qualification.

Table 1. Software Routines Used

Routine	ACC
Read_TDB, Version 1.0	MOL. 19990903.0031 MOL. 20000104.0304
frac_calc, Version 1.1	MOL. 19990903.0032
CAPFIT, Version 1.0	MOL. 19990903.0033

The documentation for these routines have been submitted to the Records Processing Center (RPC) and are also included as Attachment IV. Standard spreadsheet programs (Excel 97 SR-1) were also used but are not subject to software quality assurance requirements. The use of these routines is documented in the corresponding scientific notebooks. No models are used in this analysis.

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4. INPUTS

Fracture properties are developed by compiling and analyzing available fracture survey data from the ESF, ECRB Cross Drift, and boreholes and from air injection testing data within vertical boreholes and ESF alcoves. Matrix properties are determined by combining core and small-scale measurements with in-situ water potential data. These properties are assigned to UZ Model layers using the delineation of lithostratigraphic units developed in the AMR *Development of Numerical Grid for UZ Flow and Transport Modeling* (CRWMS M&O 1999d). Effective properties are determined by computing geometric means, standard deviations, and standard errors for each UZ Model layer for each property. Fracture porosities are determined based on the analyses of drift-scale gas tracer data from the ESF. When no data for a specific layer are available, analogs are identified and used to assign properties. Field testing data from the ESF are used to confirm the magnitude of parameters by establishing appropriate bounds for values.

4.1 DATA AND PARAMETERS

The key input data used in the property set development include the following:

- Detailed Line Survey (DLS) fracture data from the ESF North and South Ramps, Main Drift, and ECRB Cross Drift that provide spatially varying frequency, length, and fracture dips and strikes
- Fracture frequency data from boreholes
- Air-injection testing data from vertical boreholes that provide fracture permeability estimates
- Air-injection and gas tracer data from the Upper Tiva Canyon, Bow Ridge fault, and Upper Paintbrush Contact Alcoves, the Single Heater Test (SHT) area, and the Drift Scale Test (DST) area that provide fracture permeability and porosity estimates
- Liquid release and air-injection data from the ESF niches that provide fracture permeability and porosity estimates
- Measured properties from core samples including effective porosity, bulk density, porosity, particle density, volumetric water content, saturation, water potential, saturated hydraulic conductivity, matrix van Genuchten α and m values, and residual saturation
- In-situ water potentials from instrumented boreholes
- Thermal properties by lithostratigraphic unit developed from small-scale measurements

Specific input data sets and the associated Data Tracking Numbers (DTNs) are provided in Table 2. Reports documenting past work related to UZ fracture and matrix properties for the Project are listed in Section 8.5, as a supporting bibliography. This bibliography is for information only, and this AMR does not directly rely on any of the listed documents.

Table 2. Data Tracking Numbers for Input Data Used

DTN	Data Description
GS000399991221.004	Matrix saturation, water potential and hydrologic property data
GS950208312232.003 GS951108312232.008 GS960308312232.001 GS960808312232.004 GS970108312232.002 GS970808312232.005 GS971108312232.007 GS980408312232.001	In-situ water potential data for boreholes USW NRG-6, USW NRG-7a, USW SD-12, UE-25 UZ#4, & USW UZ-7a
GS960908312232.012 GS960908312232.013	Air permeability data from vertical boreholes
GS970183122410.001	Air permeability data from Alcoves 1,2,3
LB960500834244.001	Air injection and permeability data - SHT area
LB970600123142.001 LB980120123142.004 LB980120123142.005	Air injection and permeability data - DST area
LB980001233124.002	Pre-excavation air permeability data from Niches 1 and 2
LB980901233124.001	Pre-excavation air permeability data from Niches 3 and 4
LB980912332245.002	Air-injection , tracer test and fracture porosity data
GS971108314224.020	Fracture type (location, strike, dip, length) Sta. 0+60 to 4+00
GS971108314224.021	Fracture type (location, strike, dip, length) Sta. 4+00 to 8+00
GS971108314224.022	Fracture type (location, strike, dip, length) Sta. 8+00 to 10+00
GS971108314224.023	Fracture type (location, strike, dip, length) Sta. 10+00 to 18+00
GS971108314224.024	Fracture type (location, strike, dip, length) Sta. 18+00 to 26+00
GS971108314224.025	Fracture type (location, strike, dip, length) Sta. 26+00 to 30+00
GS960708314224.008	Fracture type (location, strike, dip, length) Sta. 30+00 to 35+00
GS960808314224.011	Fracture type (location, strike, dip, length) Sta. 35+00 to 40+00
GS960708314224.010	Fracture type (location, strike, dip, length) Sta. 40+00 to 45+00

Table 2. Data Tracking Numbers for Input Data Used (Cont.)

DTN	Data Description
GS971108314224.026	Fracture type (location, strike, dip, length) Sta. 45+00 to 50+00
GS960908314224.014	Fracture type (location, strike, dip, length) Sta. 50+00 to 55+00
GS971108314224.028	Fracture type (location, strike, dip, length) Sta. 55+00 to 60+00
GS970208314224.003	Fracture type (location, strike, dip, length) Sta. 60+00 to 65+00
GS970808314224.008	Fracture type (location, strike, dip, length) Sta. 65+00 to 70+00
GS970808314224.010	Fracture type (location, strike, dip, length) Sta. 70+00 to 75+00
GS970808314224.012	Fracture type (location, strike, dip, length) Sta. 75+00 to 78+77
GS960908314224.020	Fracture type (location, strike, dip, length) Sta. 4+00 to 28+00, Alcoves 3 & 4
GS960908314224.018	Fracture type (location, strike, dip, length) Alcove 5
GS970808314224.014	Fracture type (location, strike, dip, length) Alcove 6
GS990408314224.001 GS990408314224.002 GS981108314224.005	Fracture type (location, strike, dip, length) and lithostratigraphic contacts for ECRB Cross Drift
GS970408314222.003	Fracture Frequency data of 15 model units from 14 borehole locations in the Yucca Mountain vicinity
GS970308314222.001	Fracture Type data from outcrop survey of Calico Hills Formation
GS930608312332.001 GS930608312332.002	Fracture Type data on line surveys in the Bullfrog Member of the Crater Flat Tuff from (1) Raven Canyon and (2) east side of Little Skull Mountain in Yucca Mountain Area
TM000000SD12RS.012	Fracture frequency - SD-12
SNF29041993002.084	Fracture frequency – NRG-7a
SNT05071897001.012	Thermal conductivity, grain specific heat
LB980901233124.003	ESF seepage test data
MO9901MWDGFM31.000	Geologic Framework Model
GS990883122410.002	Ghost Dance fault permeability

4.2 CRITERIA

At this time, no specific criteria (e.g., System Description Documents) have been identified as applying to this analysis activity in project requirements documents. However, this AMR provides information required in specific subparts of the proposed U.S. Nuclear Regulatory Commission rule 10 CFR 63 (see Federal Register for February 22, 1999, 64 FR 8640). It supports the site characterization of Yucca Mountain (Subpart B, Section 15), the compilation of

information regarding the hydrology of the site in support of the License Application (Subpart B, Section 21(c)(1) (ii)), and the definition of hydrologic parameters used in performance assessment (Subpart E, Section 114(1)).

The DOE interim guidance (Dyer 1999), requiring the use of specified subparts of the proposed NRC high-level waste rule, 10 CFR Part 63 (64 FR 8640), was released after completion of the work documented in this AMR; it has no impact on this work activity.

4.3 CODES AND STANDARDS

No specific formally established standards have been identified as applying to this analysis activity.

5. ASSUMPTIONS

This section documents the major assumptions made to determine hydrologic properties based on data available from the unsaturated zone of Yucca Mountain.

1. The subsurface heterogeneity of the unsaturated zone of Yucca Mountain is adequately represented by a number of model layers, each of which is assumed to have uniform hydrologic properties. This is based on the following considerations. First, the overall behavior of flow and transport processes in the unsaturated zone of Yucca Mountain is mainly determined by relatively large-scale heterogeneities introduced by stratification of the tuffs. Second, the complexity of a heterogeneity model needs to be consistent with the data availability. More complicated models generally introduce larger degrees of uncertainty in rock property estimations when data are limited. This is because more complicated models correspond to larger numbers of variables. Third, this layered approach is supported by field observations, such as matrix water saturation distributions. For a given geologic unit, measured matrix saturation distributions are very similar from different boreholes (Flint 1998, pp. 24-30, Figures 5-9), indicating that matrix flow behavior and effective hydraulic properties should be similar within the unit. A further discussion on this assumption is provided in an AMR describing conceptual and numerical models for UZ flow and transport. Based on the above reasoning, no confirmation is needed for this assumption.

2. Another major assumption is that van Genuchten (1980, pp. 892-898) relationships, originally developed for porous media, can be used as constitutive relations for the active fracture continuum. Not all connected fractures are active in conducting liquid water in the unsaturated zone of Yucca Mountain (Liu et al. 1998, pp. 2638-2641). The active fracture continuum consists of fractures that actively conduct liquid water. The use of van Genuchten relations is based on a conceptual model that flow in fractures can be described using porous medium equivalence. A further discussion on this conceptual model is provided in an AMR describing conceptual and numerical models for UZ flow and transport. No confirmation is needed for this assumption.

3. Since a systematic approach for upscaling properties directly from small-scale measurements is still lacking for unsaturated fractured rocks, simple averaging schemes are assumed to be appropriate in most cases for the upscaling purpose in the analyses to be reported in this study. The relation of Paleologos et al. (1996, p. 1336), originally developed for porous media, is assumed to be appropriate for upscaling matrix permeability when an upper limit of 1.5 orders of magnitude is used for the amount of upscaling. Hydrologic property data have been determined on scales that are generally much smaller than the scales characterizing the subsurface heterogeneity (e.g., characteristic sizes for model layers). While considerable progress has been made in developing upscaling schemes for porous media, the scale-dependent behavior of a hydrologic property for fractured rocks can be very different from that for porous media. For example, the existence of fractures in a fractured rock, which may act as a capillary barrier, can increase tortuosity of liquid water in the matrix, and therefore reduce large-scale matrix permeability compared with the case without fractures. It is necessary to make this assumption to determine the rock properties using small-scale

measurements. Note that the rock properties to be reported in this report are mainly used as initial estimates for use in the inversion process documented in an AMR describing calibrated properties model. The upscaling issue is further considered in the inversion process which results in the large-scale properties by matching the large-scale simulation results with grid block-scale observations averaged from small-scale data. Based on the above reasoning, no confirmation is needed for this assumption.

4. It is assumed that a van Genuchten fracture m value, estimated from the middle nonlithophysal zone of the Topopah Spring welded unit (UZ Model layer tsw34), can be used as a representative estimate for all of UZ Model layers. This is based on the following considerations. First, for other model layers, there are limited data for determining the m values. Second, the m value determined in this report is only used as an initial guess for use in the inversion process documented in an AMR describing calibrated properties model. The inversion process results in more accurate m values for the model layers because it adjusts rock properties to make model simulation results match the relevant observations. Based on these considerations, no confirmation is needed for this assumption.

6. ANALYSES/MODEL

In this section, the methodologies and data used to determine representative estimates of the fracture and matrix properties for the UZ Model layers are discussed. Table 3 shows the relationships between the lithostratigraphy of the Geologic Framework Model (GFM3.1) and the UZ Model layers, as documented in an AMR describing development of numerical grids for UZ flow and transport modeling (CRWMS M&O 1999d, Table 10). Most of these property estimates are used as the prior information and initial estimates in the inversion modeling studies documented in the AMR describing calibrated properties model.

Table 3. GFM3.1 Lithostratigraphy, UZ Model Layer, and Hydrogeologic Unit Correlation (CRWMS M&O 1999d, Table 10)

Major Unit	GFM3.1 Lithostratigraphic Nomenclature*	FY 99 UZ Model Layer	Hydrogeologic Unit
Tiva Canyon welded (TCw)	Tiva_Rainier	tcw11	CCR, CUC
	Tpcp	tcw12	CUL, CW
	TpcLD		
	Tpcpv3	tcw13	CMW
	Tpcpv2		
Paintbrush nonwelded (PTn)	Tpcpv1	ptn21	CNW
	Tpbt4	ptn22	BT4
	Tpy (Yucca)		
		ptn23	TPY
		ptn24	BT3
	Tpbt3		
	Tpp (Pah)	ptn25	TPP
	Tpbt2	ptn26	BT2
	Tptrv3		
	Tptrv2		
Topopah Spring welded (TSw)	Tptrv1	tsw31	TC
	Tptrn		
		tsw32	TR
	Tptrl, Tptf	tsw33	TUL
	Tptpul		
	Tptpmn	tsw34	TMN
	Tptpll	tsw35	TLL
	Tptpln	tsw36	TM2 (upper 2/3 of Tptpln)
		tsw37	TM1 (lower 1/3 of Tptpln)
	Tptpv3	tsw38	PV3
	Tptpv2	tsw39	PV2

NOTE: * GFM 3.1 is the Geologic Framework Model, Version 3.1.

Table 3. GFM3.1 Lithostratigraphy, UZ Model Layer, and Hydrogeologic Unit Correlation (CRWMS M&O 1999d, Table 10) (Cont.)

Major Unit	GFM3.1 Lithostratigraphic Nomenclature*	FY 99 UZ Model Layer	Hydrogeologic Unit
Calico Hills nonwelded (CHn)	Tptpv1	ch1 (vit, zeo)	BT1 or BT1a (altered)
	Tpbt1		
	Tac (Calico)	ch2 (vit, zeo)	CHV (vitric) or CHZ (zeolitic)
		ch3 (vit, zeo)	
		ch4 (vit, zeo)	
		ch5 (vit, zeo)	
	Tacbt (Calicobt)	ch6 (vit, zeo)	BT
	Tcpuv (Prowuv)	pp4	PP4 (zeolitic)
	Tcpuc (Prowuc)	pp3	PP3 (devitrified)
	Tcpm (Prowmd)	pp2	PP2 (devitrified)
	Tcplc (Prowlc)		
	Tcplv (Prowlv)	pp1	PP1 (zeolitic)
	Tcpbt (Prowbt)		
	Tcbuv (Bullfroguv)		
Crater Flat undifferentiated (CFu)	Tcbuc (Bullfroguc)	bf3	BF3 (welded)
	Tcbm (Bullfrogmd)		
	Tcblc (Bullfroglc)		
	Tcblv (Bullfroglv)	bf2	BF2 (nonwelded)
	Tcbbt (Bullfrogbt)		
	Tctuv (Tramuv)		
	Tctuc (Tramuc)	tr3	Not Available
	Tctm (Trammd)		
	Tctlc (Tramlc)		
	Tctlv (Tramlv)	tr2	Not Available
	Tctbt (Trambt)		

NOTE: * GFM 3.1 is the Geologic Framework Model, Version 3.1.

The key scientific notebooks (with relevant page numbers) used for this analysis are listed in Table 4.

Table 4. Scientific Notebooks

Scientific Notebook ID No.	Pages	ACC
YMP-LBNL-GSB-1.1.2 (SN-LBNL-SCI-003-V1)	70-73; 81-85, 91-94, 117-127 and 145-146	MOL.20000302.0391
YMP-LBNL-GSB-1.9 (SN-LBNL-SCI-053-V1)	104-107	MOL.20000301.1097
YMP-LBNL-GSB-LHH-2 (SN-LBNL-SCI-098-V1)	64-66	MOL.20000302.0390

Table 4. Scientific Notebooks (Cont.)

Scientific Notebook ID No.	Pages	ACC
YMP-LBNL-GSB-MC-1 (SN-LBNL-SCI-079-V1)	126, 134, 152-153	MOL.19990908.0228
YMP-LBNL-GSB-MC-1.1 (SN-LBNL-SCI-080-V1)	54-55	MOL.19990908.0229
YMP-LBNL-GSB-MC-1.2 (SN-LBNL-SCI-047-V1)	9-47, 51	MOL.19990902.0135
YMP-LBNL-YSW-WZ-1 (SN-LBNL-SCI-115-V1)	57-64	MOL.20000302.0392

The following subsections present the methods used to determine fracture properties, matrix properties, thermal properties, and fault properties followed by an analysis confirming specific fracture properties utilizing field data.

6.1 FRACTURE PROPERTIES

The following subsection discusses the determination of fracture properties from field data for the UZ Model. These properties include fracture frequency, fracture aperture, fracture porosity, fracture interface area, uncalibrated van Genuchten fracture α and m, uncalibrated fracture permeability. The fracture frequency, aperture, porosity, and interface area are for use in developing numerical grids for the UZ Model. The uncalibrated van Genuchten fracture α and m and uncalibrated fracture permeability are for use as prior information and the initial estimates for the calibrated property sets documented in an AMR describing calibrated properties model.

6.1.1 Fracture Permeability

The fracture permeabilities calculated here for the UZ Model layers are based on air permeabilities inferred from air injection tests performed in vertical boreholes and in ESF alcoves. Permeabilities inferred from air-injection tests in boreholes are believed to be representative of fracture absolute permeabilities. These permeabilities were determined based on pneumatic pressure data and are calculated using a modified version of Hvorslev (1951, p. 30, case 8) solution for steady-state elliptic flow (LeCain 1995, p. 10). The values are combined here to determine effective fracture permeabilities for the UZ Model layers. Geometric means of these fracture permeabilities are assumed to reflect upscaling of these permeabilities for use as single values representative for each model layer. Note that permeability is an intrinsic property for a test medium and theoretically independent of test fluids, as long as the test medium can be viewed as a continuum. Thus, fracture permeabilities derived from air injection tests are considered to be applicable for describing liquid water flow in fractures.

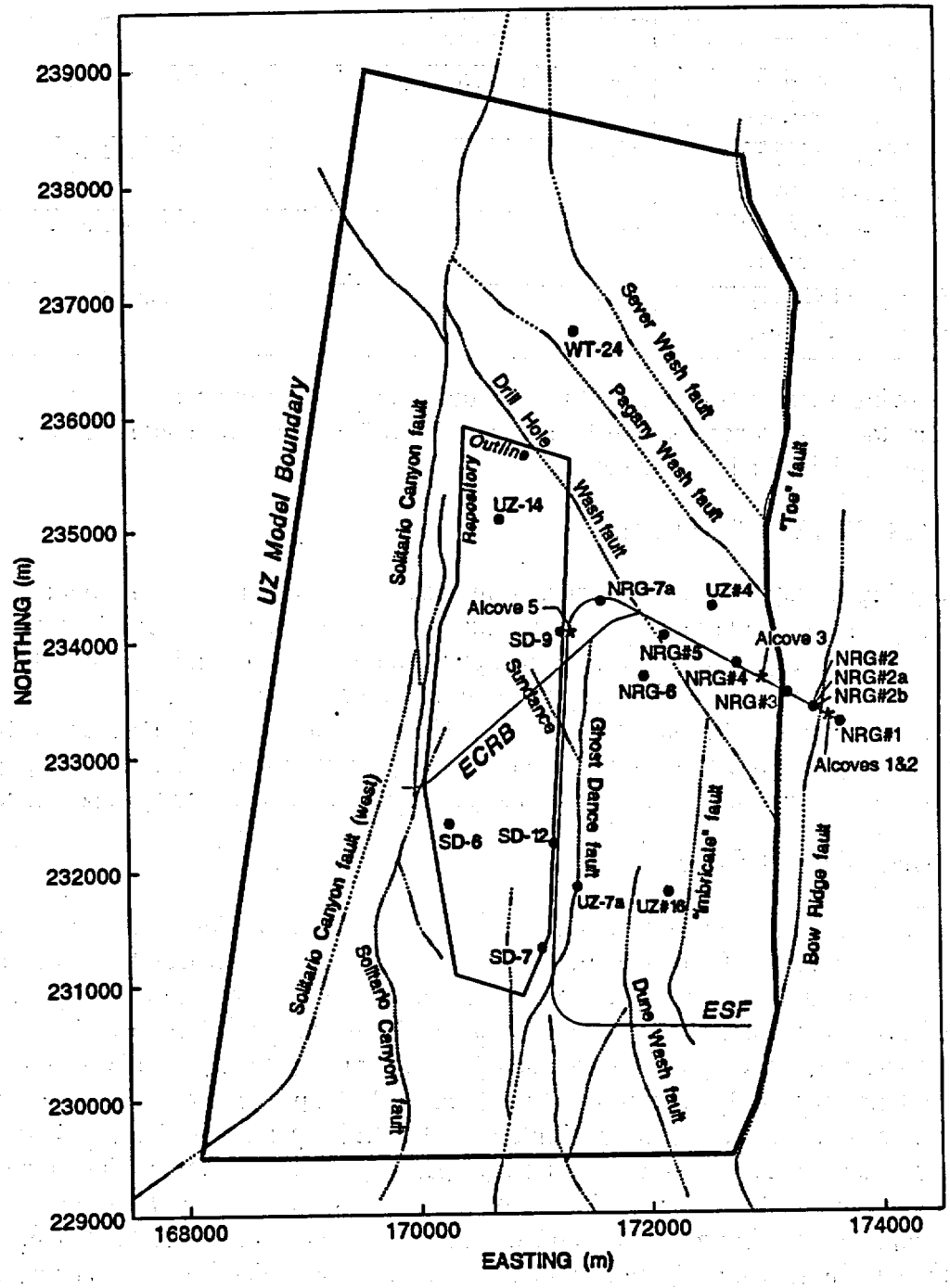


Figure 1. Schematic showing locations of selected boreholes and alcoves.

For the Tiva Canyon welded hydrogeologic unit (TCw), fracture permeabilities were based on air-injection tests performed in vertical boreholes NRG-7a, NRG-6, SD-12 and UZ#16 and the Upper Tiva Canyon, Bow Ridge fault, and Upper Paintbrush Contact Alcoves (Alcoves 1, 2 and 3, respectively). For the Paintbrush nonwelded hydrogeologic unit (PTn), the permeability data

are from vertical borehole NRG-7a and Upper Paintbrush Contact Alcove (Alcove 3). For the Topopah Spring welded hydrogeologic unit (TSw), the permeability data are from vertical boreholes NRG-7a, NRG-6, SD-12 and UZ#16 and the Single Heater and Drift Scale Test Areas in Alcove 5. For the Calico Hills nonwelded hydrogeologic unit (CHn), permeability data are only available from a single sampled interval in vertical borehole UZ#16. The locations of the boreholes and alcoves are given in Figure 1. These permeabilities are listed in Table II-1 in Attachment II. No air-injection data are available for the Prow Pass (pp), Bullfrog (bf), and Tram (tr) units. For model layers where no data are available, analogs to other units are used based on those designated for matrix properties (Flint 1998, p. 46), the degree of zeolitic alteration, and degree of welding. These fracture permeabilities are used as prior information and initial estimates for an AMR describing the calibrated properties model.

Table 5 lists the geometric means of the fracture permeabilities for the UZ Model layers. The lithostratigraphic units were assigned to the UZ Model layers as listed in Table 3. The fracture permeabilities were treated as isotropic, and the data from vertical boreholes and the horizontal and inclined boreholes in the ESF alcoves were combined. The scales of these measurements are similar, as discussed in Section 6.1.1.1.

Table 5. Uncalibrated Fracture Permeabilities for the UZ Model Layers

UZ Model Layer	Fracture permeability (m^2)				
	Basis[a]	k_G[b]	$\log(k_G)$	$\sigma_{\log(k_G)}$[c]	N[d]
tcw11	BRFA	3.0E-11	-10.521	-	2
tcw12	UTCA UPCA NRG-6 NRG-7a SD-12 UZ#16	5.3E-12	-11.279	0.778	80
tcw13	UPCA NRG-7a	4.5E-12	-11.344	1.147	3

NOTE: Submitted under DTN: LB990501233129.001. Source DTNs are included in Table II-1 in Attachment II and Table 2 in Section 4.

[a]Identifies the corresponding air-injection borehole(s) and/or alcove(s) or analog to another model layer(s). UTCA-Upper Tiva Canyon Alcove, BRFA-Bow Ridge fault Alcove, UPCA-Upper Paintbrush Contact Alcove, SHT-Single Heater Test Area, DST-Drift Scale Test Area, and NRG-6, NRG-7a, SD-12, and UZ#16 are vertical boreholes.

[b]Geometric mean

[c]Standard deviation

[d]Number of sampled intervals

Table 5. Uncalibrated Fracture Permeabilities for the UZ Model Layers (Cont.)

UZ Model Layer	Fracture permeability (m^2)				
	Basis[a]	k_G[b]	$\log(k_G)$	$\sigma_{\log(k_G)}$[c]	N[d]
ptn21	UPCA NRG-7a	3.2E-12	-11.491	0.885	12
ptn22	NRG-7a	3.0E-13	-12.524	0.202	4
ptn23	NRG-7a	3.0E-13	-12.524	0.202	4
ptn24	NRG-7a	3.0E-12	-11.527	-	1
ptn25	NRG-7a	1.6E-13	-12.784	0.101	7
ptn26	NRG-7a	2.2E-13	-12.661	-	1
tsw31	Average TSW	6.4E-13	-12.195	-	-
tsw32	NRG-6 NRG-7a SD-12 UZ#16	7.1E-13	-12.146	0.658	31
tsw33	NRG-6 NRG-7a SD-12 UZ#16	7.7E-13	-12.112	0.612	27
tsw34	SHT DST NRG-6 NRG-7a SD-12 UZ#16	3.4E-13	-12.474	0.546	180

NOTE: Submitted under DTN: LB990501233129.001. Source DTNs are included in Table II-1 in Attachment II and Table 2 in Section 4.

[a]Identifies the corresponding air-injection borehole(s) and/or alcove(s) or analog to another model layer(s). UTCA-Upper Tiva Canyon Alcove, BRFA-Bow Ridge fault Alcove, UPCA-Upper Paintbrush Contact Alcove, SHT-Single Heater Test Area, DST-Drift Scale Test Area, and NRG-6, NRG-7a, SD-12, and UZ#16 are vertical boreholes.

[b]Geometric mean

[c]Standard deviation

[d]Number of sampled intervals

Table 5. Uncalibrated Fracture Permeabilities for the UZ Model Layers (Cont.)

UZ Model Layer	Fracture permeability (m^2)				
	Basis[a]	k_G[b]	$\log(k_G)$	$\sigma_{\log(k_G)}$[c]	N[d]
alternate tsw34	SHT DST NRG-6 NRG-7a SD-12 UZ#16	1.6E-13	-12.805	-	180
tsw35	NRG-7a UZ#16	9.0E-13	-12.044	0.544	31
tsw3[67]	SD-12 UZ#16	1.4E-12	-11.868	0.285	19
tsw38	Average TSW	6.4E-13	-12.195	-	-
tsw39	Average TSW	6.4E-13	-12.195	-	-
ch1Ze	ch2Ze	2.5E-14	-13.606	-	-
ch1VI	ptn26	2.2E-13	-12.661	-	-
ch[2345]VI	ptn26	2.2E-13	-12.661	-	-
ch[2345]Ze	UZ#16	2.5E-14	-13.606	-	1
ch6	ch2Ze	2.5E-14	-13.606	-	-
pp4	ch2Ze	2.5E-14	-13.606	-	-
pp3	ptn26	2.2E-13	-12.661	-	-
pp2	ptn26	2.2E-13	-12.661	-	-
pp1	ch2Ze	2.5E-14	-13.606	-	-
bf3	ptn26	2.2E-13	-12.661	-	-
bf2	ch2Ze	2.5E-14	-13.606	-	-
tr3	ptn26	2.2E-13	-12.661	-	-

NOTE: Submitted under DTN: LB990501233129.001. Source DTNs are included in Table II-1 in Attachment II and Table 2 in Section 4.

[a]Identifies the corresponding air-injection borehole(s) and/or alcove(s) or analog to another model layer(s). UTCA-Upper Tiva Canyon Alcove, BRFA-Bow Ridge fault Alcove, UPCA-Upper Paintbrush Contact Alcove, SHT-Single Heater Test Area, DST-Drift Scale Test Area, and NRG-6, NRG-7a, SD-12, and UZ#16 are vertical boreholes.

[b]Geometric mean

[c]Standard deviation

[d]Number of sampled intervals

Table 5. Uncalibrated Fracture Permeabilities for the UZ Model Layers (Cont.)

UZ Model Layer	Fracture permeability (m^2)				
	Basis[a]	k_G[b]	$\log(k_G)$	$\sigma_{\log(k_G)}$[c]	N[d]
tr2	ch2Ze	2.5E-14	-13.606	-	-

NOTE: Submitted under DTN: LB990501233129.001. Source DTNs are included in Table II-1 in Attachment II and Table 2 in Section 4.

[a]Identifies the corresponding air-injection borehole(s) and/or alcove(s) or analog to another model layer(s). UTCA-Upper Tiva Canyon Alcove, BRFA-Bow Ridge fault Alcove, UPCA-Upper Paintbrush Contact Alcove, SHT-Single Heater Test Area, DST-Drift Scale Test Area, and NRG-6, NRG-7a, SD-12, and UZ#16 are vertical boreholes.

[b]Geometric mean

[c]Standard deviation

[d]Number of sampled intervals

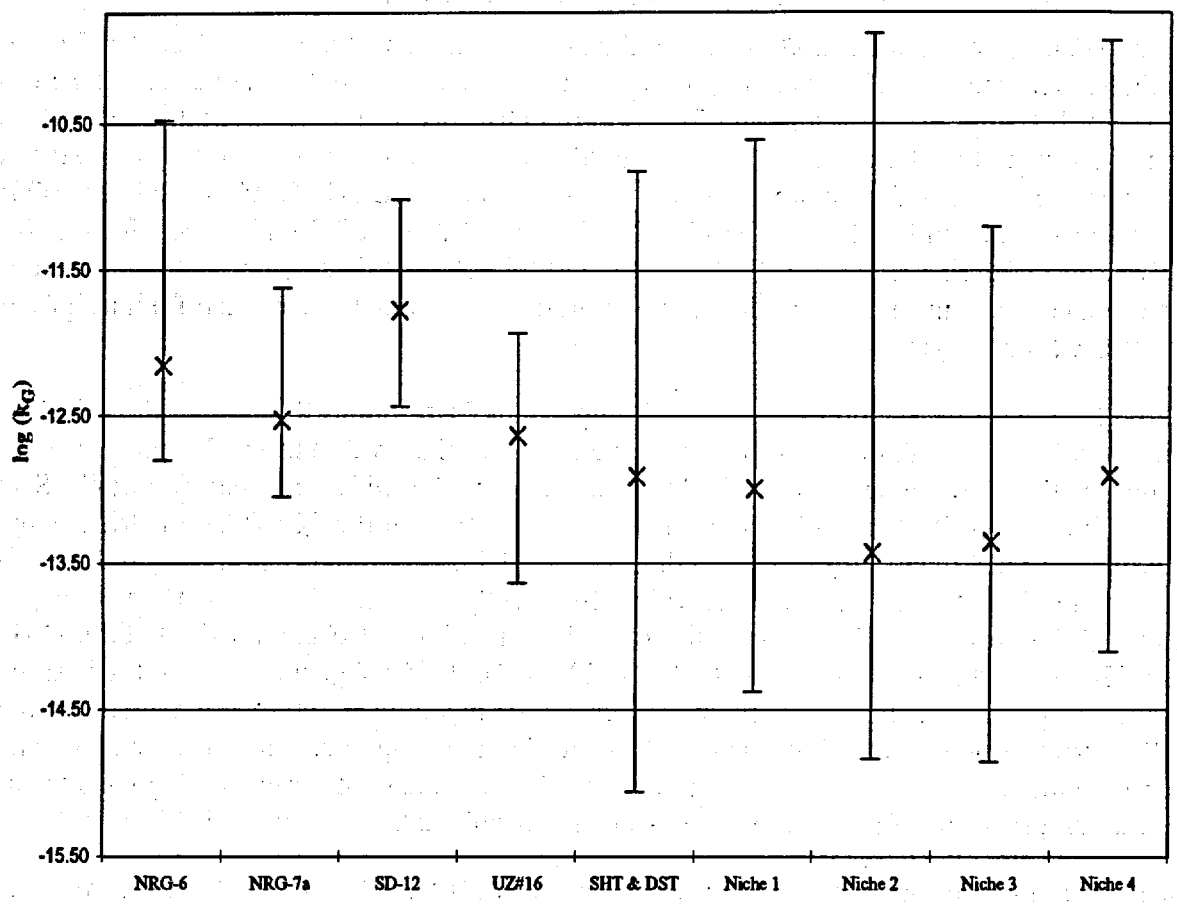
The mean fracture permeabilities range from 2.5 x 10^{-14} m^2 to 3 x 10^{-11} m^2. The Tiva Canyon welded unit (TCw) has the highest fracture permeabilities. The Topopah Spring welded unit (TSw) fracture permeabilities are, in general, higher than those for the nonwelded Paintbrush (PTn) and Calico Hills (CHn) units. Two fracture permeabilities are shown for the Topopah Spring middle nonlithophysal unit (tsw34). These represent two different approaches to weighting the available air injection data. For tsw34, there were 143 sampled intervals in the Alcove 5 heater test areas compared to 37 sampled intervals in the four vertical borehole injection tests. For the first case, the data from Alcove 5 were weighted with those from the vertical borehole tests ($k = 0.8\ k_{G,\text{vertical boreholes}} + 0.2\ k_{G,\ \text{Alcove 5}}$). In the alternate tsw34 case, each sampled interval is weighted equally.

The uncertainty and variability of fracture permeabilities for the UZ Model layers are reflected by the standard deviations reported in Table 5. These standard deviations would result in 95% confidence intervals covering three orders of magnitude even for the units that had a large number of sampled intervals. The data indicate that fracture permeabilities are highly variable.

6.1.1.1 Scaling Issues

As noted previously, the permeabilities measured in the vertical boreholes and alcoves were combined to determine the fracture permeability for each UZ Model layer. The packer lengths were approximately 4 meters for vertical boreholes, 1 to 3 meters for Alcoves 1, 2 and 3, and 5 to 12 meters in the SHT and DST areas (Alcove 5). These data were all considered to be on the same relative scale and representative of the fracture permeability on the scale of the UZ Model after upscaling using geometric means. Additional air permeability data on a scale of one-foot intervals are also available from air injection testing in niches in the ESF in the Topopah Spring middle nonlithophysal unit (tsw34). The air-injection data from the niche studies are not used here for determining mean fracture permeabilities for the model layers since these data are on a smaller

scale and may not be representative of a larger scale effective permeability. Figure 2 compares the geometric means and range of data for the model layer tsw34. The data shown for the niche studies are inferred from pre-excavation air injection testing. The ranges of the data overlap, but the geometric means for the measurements from the niche studies are generally lower than the other values. This would be expected because the mean permeability decreases as the scale of the measurement decreases (Neuman 1994, pp. 349-352).



DTN: GS960908312232.012, GS960908312232.013, LB960500834244.001, LB970600123142.001, LB980120123142.004, LB980001233124.001, LB980001233124.002

Figure 2. Fracture Permeabilties for Topopah Spring Middle Nonlithophysal Unit. Ranges for Inferred Permeabilties from Air Injection Data. (X are the geometric means)

6.1.2 Fracture Frequency, Intensity, Fracture Interface Area, Aperture, and van Genuchten Parameters

The following subsections present the field data analyzed, the equations utilized, and the steps for determining these fracture properties.

6.1.2.1 Field Data Used for Calculating Fracture Properties

Fracture data are available from three general types of locations – the ESF and ECRB Cross Drift, boreholes, and surveys of surface exposures and outcrops. The entire length of the ESF Main Drift, North Ramp, South Ramp, and ECRB Cross Drift, as well as Alcoves 3, 4, 5, and 6 have been surveyed to characterize subsurface fracturing. Over 21,000 fractures have been characterized. Qualified fracture data from borehole cores (DTN: GS970408314222.003) are available for fourteen boreholes – NRG-1, NRG-2, NRG-2a, NRG-2b, NRG-3, NRG-4, NRG-5, NRG-6, NRG-7a, SD-7, SD-9, SD-12, UZ-14, and UZ#16. The discussion here is focused on the fracture data relevant to the UZ Model and applying these data to determine fracture properties for the UZ Model layers.

The DLS in the ESF (including the North Ramp, Main Drift, South Ramp) and the ECRB Cross Drift include data for all of the TCw model layers, four of the six PTn model layers, and seven out of nine of the TSw model layers. Geologic intervals of the ESF, described in CRWMS M&O (1998, Table 2, pp. 20-22) and DTN: GS981108314224.005 for the ECRB Cross Drift, were used to assign the DLS data to the corresponding UZ Model layers. These are listed in Table II-2 in Attachment II. Fracture data were downloaded directly from the Technical Data Management System (TDMS) for calculating fracture properties and were listed previously in Table 2 (DTN: GS971108314224.020 to DTN: GS990408314224.002). Borehole data were used for estimating fracture properties for model layers only when no, or incomplete, data were available from the DLS. Surface fracture mapping was used to scale fracture properties when utilizing an analog to determine the fracture properties for a model layer. Only data used for estimating the statistics of the fracture properties for the UZ Model layers are discussed here and listed in Table 2.

Fracture orientations are not used directly in this analysis. CRWMS M&O (1998, Figure 5 and Attachment II) provides fracture orientation rosettes along the ESF. These rosettes suggest that fracture orientations and site stratigraphy are correlated (CRWMS M&O 1998, p.35)

6.1.2.2 Equations Used for Calculating Fracture Properties

For calculating fracture frequencies using the DLS in the ESF and ECRB Cross Drift, the mean fracture frequency is given by the inverse of the mean spacing. The mean spacing $\bar{s}$ is calculated by:

$$\bar{s} = \frac{1}{nf-1}\sum_{2}^{nf}(D_i - D_{i-1}) \qquad \text{(Eq.1)}$$

where D_i is the distance or station along the ESF where fracture i intersects the DLS and nf is the number of fractures. This is the *apparent* spacing. It is not the normal distance between the center of fractures and is therefore a rough estimate of the *true* spacing. These values were not corrected for any possible bias in orientation in the DLS. The mean fracture frequency f is given by the inverse of the mean apparent spacing:

$$\bar{f} = \frac{1}{\bar{s}} \qquad \text{(Eq.2)}$$

Directional bias is inherent in the DLS in that only those fractures that intersect the survey line are included. Fractures that are parallel or subparallel to the ESF tunnel azimuth as well as horizontal or subhorizontal dipping fractures are underrepresented in the survey. Corrections for this directional bias were not made in this analysis. To assess the impact of not correcting for directional bias, the apparent fracture frequency of hydrogeologic units that are intersected by both the ESF Main Drift and the ECRB Cross Drift were compared. These two tunnels intersect these units in different directions. The hydrogeologic units compared include the Topopah Spring upper lithophysal, middle nonlithophysal and lower lithophysal, which correspond with UZ Model layers tsw33, tsw34 and tsw35, respectively. The fracturing, as represented by the DLS data, was found to be similar for these units (YMP-LBNL-GSB-MC-1.2, p. 51). For the other units, the analysis in CRWMS M&O (1998, p.34) was used to assess the impact of directional bias. The analysis in CRWMS M&O (1998, p.34), similarly, did not correct for directional bias in the selection and analysis of joint sets using the DLS data. For that analysis, a visual inspection of the full periphery geologic maps (these include the entire surface of the exposed tunnel) was conducted to assess the impact of the directional bias (CRWMS M&O 1998, p. 34). This inspection found that fracturing along the ceiling and the walls of the tunnels in the ESF North Ramp, Main Drift, and South Ramp did not vary significantly and that, in general, the line survey provided conservative results (i.e., indicated more fracturing). This suggests that the impact of the directional bias in the DLS data is minimal.

For calculating fracture frequency from borehole data, the data are corrected by normalizing for core recovery, correcting for bias in orientation, and scaling to represent larger length fracture. To correct for orientation bias, the dip distributions are used as follows (modified from Lin et al. 1993, p. 24):

$$f_{cb} = \frac{\sum_i f_{i,0-19^\circ dip}}{\cos(10^\circ)} + \frac{\sum_i f_{i,20-39^\circ dip}}{\cos(30^\circ)} + \frac{\sum_i f_{i,40-59^\circ dip}}{\cos(50^\circ)} + \frac{\sum_i f_{i,60-90^\circ dip}}{\cos(75^\circ)} \qquad \text{(Eq.3)}$$

where f_{cb} is the fracture frequency corrected for orientation bias and f_i is the fracture frequency corresponding to the range of dip distribution. Lastly, these values are corrected to represent larger length fractures on the scale of those characterized in the ESF. A simple correction ratio is

used based on comparisons of ESF data with corresponding vertical boreholes for that model layer:

$$\bar{f} = f_{corrected} = f_{cb}R$$
$$R = \left(\frac{f_{ESF}}{f_{borehole}}\right)_{average} \qquad \text{(Eq.4)}$$

Two correction factors R were calculated, one for welded units using data for the Topopah Springs middle nonlithophysal hydrogeologic unit (tsw34) and one for non-welded units using data for the Pah Canyon Tuff in the Paintbrush hydrogeologic unit (ptn25). These units were selected because both ESF and borehole data are available and these were assumed to be representative of the other units.

The fracture intensity is calculated by dividing the trace length of the fracture by the area surveyed. The area surveyed was 3 meters above and below the traceline times the length along the tunnel considered for that interval. The average fracture intensity I (m/m^2) is given by:

$$I = \frac{\sum_{i=1}^{nf} t_i}{\text{area}} = \frac{\sum_{i=1}^{nf} t_i}{(6\text{ m})(\text{interval length in meters})} \qquad \text{(Eq.5)}$$

where t is trace length in meters for fracture i.

The fracture interface area is calculated by dividing the fracture area by the volume of the interval surveyed. The volume for the interval is estimated by multiplying the interval length surveyed times the square of the geometric mean of the trace lengths of fractures surveyed. The average fracture interface area per volume a_f (m^2/m^3) is given by:

$$a_f = \frac{\sum_{i=1}^{nf} \pi r_i^2}{\text{volume}} = \frac{\sum_{i=1}^{nf} \pi r_i^2}{(\text{interval length})(\text{geometric mean of trace lengths})^2} \qquad \text{(Eq.6)}$$

where r is radius of fracture i, or one-half of the trace length of fracture i.

Fracture apertures are calculated assuming that the velocity within a fracture is given by the cubic law and the fractures characterized are fully connected. The fracture aperture b is then given by (Bear et al. 1993, p. 15):

$$b = \left(\frac{12k}{\bar{f}}\right)^{1/3} \qquad \text{(Eq.7)}$$

where k is the fracture permeability. Note that the fracture aperture determined in this way is an effective "hydraulic" aperture, not a "physical" aperture.

Fitted parameters are required to utilize the van Genuchten equation relating the effective saturation S_e and capillary pressure P_c (van Genuchten 1980, p. 892-895):

$$P_c = \frac{1}{\alpha}\left(S_e^{-1/m} - 1\right)^{1/1-m} \qquad \text{(Eq.8)}$$

where α and m are the van Genuchten parameters. A simplified form of the Young-LaPlace equation is assumed, to directly calculate the van Genuchten fracture α (α_f) from b. Note that the subscript f refers to fractures. The resulting relationship is:

$$\alpha_f = \frac{b}{2\tau\cos\theta} \qquad \text{(Eq.9)}$$

where τ is the surface tension of pure water at 20 °C (0.072 N/m) and θ is the contact angle. Essentially, Equation 9 assumes that van Genuchten α can be estimated as the inverse of the air entry value, which is often used in the soil science literature (Wang and Narasimhan, 1993, p.374). The contact angle θ is assumed to be zero, since the rock is expected to be water wetting and no other specific data are available.

The van Genuchten fracture m parameter (m_f) is determined by fitting an analytical solution to the fracture saturation-capillary pressure curve given in Equation 8.

6.1.2.3 Steps for Determining the Fracture Properties for the UZ Model Layers

The DLS data from the ESF are limited in that from station 37+80 to the end of the tunnel, only fractures one meter or longer are characterized. For the first part of the ESF (station 0+00 to 37+80), fractures that were 30 cm or longer were characterized. Excluding fractures less than 1 meter in length may underestimate the effective fracture properties for the UZ Model layer because it would exclude smaller fractures. No method of assessing the exact portion of fractures hydraulically connected or the relationship between hydraulic-connectivity and fracture length is available. As such, an approach was developed to estimate fracture properties believed to be reasonably representative of the geometrically connected fractures on the mountain-scale for use in the UZ Model. Utilization of 80% of the fractures larger than 30 cm in length was selected as a reasonable means to estimate fractures that may be hydraulically connected. Note that not all these connected fractures are active in conducting liquid water under unsaturated conditions due to fingering flow at different scales (Liu et al. 1998, p. 2641). An active fracture model (Liu et al. 1998, pp. 2633-2646), in which only a small portion of the connected fractures are assumed to be actively conducting liquid water in the UZ, is used to deal with this issue, as documented in an AMR describing calibrated property model.

To utilize this approach, the first part of the ESF had to be used to determine the distribution of fracture trace lengths and then these ratios were applied to the remainder of the ESF data.

The following steps were followed for computing fracture frequencies, fracture interface area, and fracture intensity for model layers tcw11, tcw12, tcw13, ptn21, ptn24, ptn25, ptn26, tsw31, tsw32, tsw33, and tsw34:

1. Compile all the data from the DLS in the ESF and ECRB Cross Drift. The software routine Read_TDB, Version 1.0, was used to read and combine text files from the TDMS for the DTN: GS971108314224.020 through DTN: GS990408314224.002 in Table 2. The output file includes the location, strike, dip, and trace lengths above and below the traceline for each fracture in the DLS. All types of fractures were included and only entries for contacts recorded in the DLS or entries with incomplete survey data were excluded (see YMP-LBNL-GSB-MC-1.1 pp. 54-55 and YMP-LBNL-GSB-MC-1.2, pp. 9-10). In addition, entries for fractures at 4 locations in the ESF were not used because the values were misentered (YMP-LBNL-GSB-MC-1, pp. 126, 134, and 152–153 and YMP-LBNL-GSB-MC-1.2, pp. 46–47).

2. Using only the first part of the ESF data (up to Station 37+80), determine the minimum fracture length cutoff for each unit that corresponds to 80% of the fractures that are 30 cm or longer. Data from the first part of the ESF are available for model layers tcw11, tcw12, tcw13, ptn21, ptn24, ptn25, ptn26, tsw31, tsw32, tsw33, and tsw34. The following minimum fracture length cutoffs were determined (see YMP-LBNL-GSB-MC-1.2, pp. 17-18):

UZ Model Layer	Cutoff length (m)
tcw11	0.95
tcw12	0.57
tcw13	0.5
ptn21	1.1
ptn24	1.0
ptn25	1.5
ptn26	0.7
tsw31	0.5
tsw32	0.8
tsw33	0.54
tsw34	0.51

   As expected, the welded units had a larger proportion of fractures with smaller trace lengths than the nonwelded units.

3. Use the software routine frac_calc, Version 1.1, to compute the fracture frequency, fracture intensity, and fracture interface area using these cutoff lengths and a one-meter cutoff length (see YMP-LBNL-GSB-MC-1.2, p. 19). The software routine frac_calc, Version 1.1, performs the calculations specified in Equations 1, 2, 5, 6, 7 and 9.

4. Compute ratios between these values using the specified cutoff length and the one-meter cutoff length (see YMP-LBNL-GSB-MC-1.2, p. 20).

5. Using all of the ESF and ECRB Cross Drift data, compute the fracture frequency, fracture intensity, and fracture interface area using a cutoff length of one-meter (see YMP-LBNL-GSB-MC-1.2, p. 21). These values are given in Table II-3 in Attachment II.

6. Use the ratios determined under step 4 to correct these values to represent 80% of the fractures with trace lengths longer than 30 cm. The corrected values for fracture frequency and fracture interface area are listed in Table 6 with a basis of either ESF or ESF/ECRB.

For model layers tsw35-tsw39, ch1Ze, ch1Vl, ch[2-5]Ze, and ch[2-5]Vl, borehole data were used. For tsw35-tsw37, data from the ESF and ECRB Cross Drift were available but these could not be corrected to the 80% representation, because these units are not present in the first portion of the ESF (see step 2 above) where surveys included fractures as small as 30 cm in length. For model layers tsw35-tsw38, the summary of borehole fracture data compiled in DTN: GS970408314222.003[1] were used, which are already normalized for core recovery. These data were used directly as input into Equation 3 to correct for bias in orientation (see Table II-4 in Attachment II). Equation 4 was used to scale the frequency to represent larger fracture lengths using R of 0.21 for welded units. The correction factor R for welded units was computed using the fracture frequency from the ESF for tsw34 given in Table 6 and the fracture frequency computed using borehole data (see Table II-4 in Attachment II).

For ch1Ze, data are available from only one borehole, SD-12 (DTN: TM000000SD12RS.012) and for tsw39, ch1Vl, ch[2-5]Ze, and ch[2-5]Vl data from two boreholes, SD-12 and NRG-7a available (DTN: TM000000SD12RS.012 and SNF29041993002.084). The data were corrected by normalizing for core recovery, correcting for bias in orientation (Equation 3), and scaled to represent larger length fracture (Equation 4). Averages for each model layer were weighted using the length of the cores analyzed. For the welded unit (tsw39), a correction factor R of 0.21 was used in Equation 4. For the non-welded units, a correction factor R of 0.09 was used. The correction factor R for nonwelded units was computed using the fracture frequency from the ESF for ptn25 given in Table 6 and the fracture frequency computed using borehole data (see Table II-4 in Attachment II). For ch[2-5]Ze and ch[2-5]Vl, all of the data for the Calico Hills hydrogeologic units were combined to give a single average value because there were little data available for these individual units. The resulting fracture frequencies for tsw39, ch1Ze, ch1Vl, ch[2-5]Ze, and ch[2-5]Vl are listed in Table 6. The details of these calculations are documented in YMP-LBNL-GSB-MC-1.2, pp. 24-27.

For the remaining model layers, analogs to other model layers were used. These analogs are listed in Table 6 under basis. For ptn22, the analog ptn24 was used because both are non-welded and both represent a portion of the Yucca Mountain Tuff and the data for ptn24 are from the DLS in the ESF. For ch6, the analog ch1Ze was used because both are part of the Calico Hills hydrogeologic unit, include bedded tuffs, and have zeolitic alteration. For the Prow Pass and

1. Fracture frequencies were developed for 1997 model layers, which were defined differently than the current UZ Model layers.

Bullfrog hydrogeologic units, nonwelded units (pp4, pp1, bf2, and tr2) were assigned the fracture frequencies of the Calico Hills (ch2-5Ze, ch2-5Vl). The partially welded units (pp3, pp2, bf3, and tr3) were assigned an adjusted value. This value was adjusted using a ratio of surface mapping data for the Bullfrog hydrogeologic unit (DTN: GS930608312332.001 and GS930608312332.002 – using a minimum fracture cutoff length of 0.7 m to characterize 80% of the fractures gives a fracture frequency of 1.23 m^{-1}) to surface mapping data for the Calico Hills pyroclastic units (unit L1 of DTN: GS970308314222.001 – using a minimum fracture cutoff length of 1.23 m gives a fracture frequency of 0.87 m^{-1}). The resulting fracture frequency for these units is 0.2 m^{-1} as listed in Table 6 (see YMP-LBNL-GSB-MC-1.2, pp. 28-30). The surface mapping data were not used directly because fracturing of these exposures may not be representative of subsurface fracturing.

The estimated mean fracture frequencies for the model layers, as listed in Table 6, range from 0.04 to 4.4 fractures/meter. The TCw has fracturing on the order of 1 to 3 fractures/meter. The PTn is less fractured, with frequencies less than 1 fracture/meter. The TSw has the most fracturing, on the order of 1 to 4.4 fractures/meter. The remaining units are much less fractured, with frequencies less than 0.25 fractures/meter.

The estimated fracture interface areas listed in Table 6 range from approximately 0.1 to 14 m^2/m^3 with values typically ranging from 1 to 4 m^2/m^3. The model layers tsw34 and tcw12 had the highest fracture interface areas. For the units where borehole data were used to compute fracture frequency, a correlation between fracture frequency and fracture interface area was used. The data from the ESF indicated that the relationship between the fracture interface area and frequency is linear and has a slope of 3.06 (with zero intercept) for the data analyzed here. This factor was used to estimate the fracture interface area for the remaining model layers.

Fracture aperture and fracture van Genuchten alpha (α_f) are calculated using fracture frequency and fracture permeability estimates as detailed in Equations 7 and 9. The estimated mean apertures are approximately 100 to 400 μm except for the model layer tcw11, which had a relatively high fracture permeability resulting in a higher estimated fracture aperture. The fracture van Genuchten alpha parameters (α_f) are on the order of 10^{-3} Pa^{-1}. There are relatively large uncertainties in these values for the Calico Hills formation and lower units because little or no fracture permeability and fracture frequency data are available.

The van Genuchten fracture m parameter (m_f) is determined by fitting an analytical solution resulting from the aperture size distribution to the fracture saturation-capillary pressure (Pcap) curve given in Equation 8. A non-linear least-squares fit to this curve was performed using the software routine, CAPFIT, Version 1.0, giving fitted values of $m_f = 0.633$ and $\alpha_f = 1.3 \times 10^{-3}$ for tsw34 (see YMP-LBNL-GSB-1.9, pp. 104-107). Figure 3 compares the analytical solution with the fitted curve. A fitted value for m of 0.633 was used for all of the model layers. This is because

for other model layers, the data used to determine the aperture size distributions are relatively limited compared with tsw34.

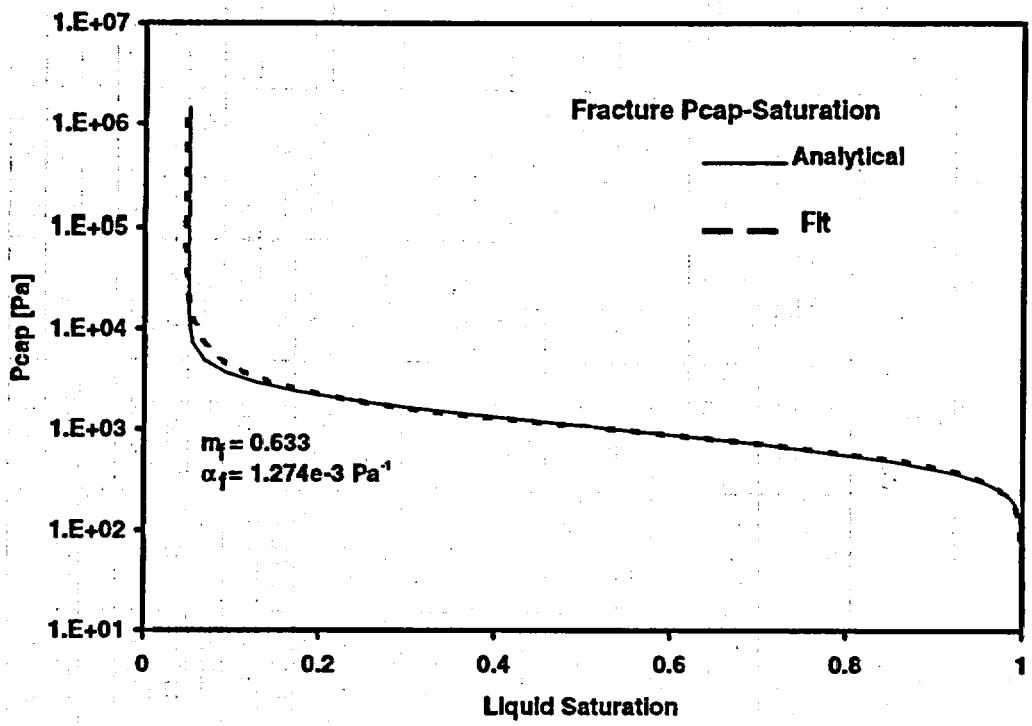


Figure 3. Analytical and Fitted Curves for Fracture Capillary Pressure (Pcap) and Liquid Saturation

Table 6: Fracture Properties for the UZ Model Layers

UZ Model Layer	Basis[a]	Fracture Frequency (m^{-1})			Fracture Intensity (m/m^2)	Aperture (m)	Fracture Porosity (-)	van Genuchten Parameters			Basis[c]	Fracture Interface area (m^2/m^3)
		f^0	σ_f	N				α (Pa^{-1})	log(α_f)	m_f (-)		
tcw11	ESF	0.92	0.94	76	0.48	7.3E-4	2.8E-2	5.1E-3	-2.294	0.633	ESF	1.56
tcw12	ESF	1.91	2.09	1241	0.77	3.2E-4	2.0E-2	2.2E-3	-2.652	0.633	ESF	13.39
tcw13	ESF	2.79	1.43	60	0.69	2.7E-4	1.5E-2	1.9E-3	-2.728	0.633	ESF	3.77
ptn21	ESF	0.67	0.92	76	0.34	3.9E-4	1.1E-2	2.7E-3	-2.571	0.633	ESF	1
ptn22	ptn24	0.46	-	-	-	2.0E-4	1.2E-2	1.4E-3	-2.861	0.633	Frequency	1.41
ptn23	Borehole	0.57	-	63	-	1.8E-4	2.5E-3	1.3E-3	-2.892	0.633	Frequency	1.75
ptn24	ESF	0.46	0.45	18	0.34	4.3E-4	1.2E-2	3.0E-3	-2.529	0.633	ESF	0.34
ptn25	ESF	0.52	0.6	72	0.49	1.6E-4	6.2E-3	1.1E-3	-2.965	0.633	ESF	1.09
ptn26	ESF	0.97	0.84	114	0.32	1.4E-4	3.6E-3	9.7E-4	-3.015	0.633	ESF	3.56
tsw31	ESF	2.17	2.37	140	0.45	1.5E-4	5.5E-3	1.1E-3	-2.976	0.633	ESF	3.86
tsw32	ESF	1.12	1.09	842	0.60	2.0E-4	9.5E-3	1.4E-3	-2.864	0.633	ESF	3.21
tsw33	ESF/ECRB	0.81	1.03	1329	0.36	2.3E-4	6.6E-3	1.6E-3	-2.806	0.633	ESF/ECRB	4.44
tsw34	ESF/ECRB	4.32	3.42	10646	1.26	9.8E-5	1.0E-2	6.8E-4	-3.169	0.633	ESF/ECRB	13.54
tsw35	borehole	3.16	-	595	-	1.5E-4	1.1E-2	1.0E-3	-2.980	0.633	Frequency	9.68
tsw3[67]	borehole	4.02	-	526	-	1.6E-4	1.5E-2	1.1E-3	-2.956	0.633	Frequency	12.31
tsw38	borehole	4.36	-	37	-	1.2E-4	1.2E-2	8.4E-4	-3.077	0.633	Frequency	13.34
tsw39	borehole	0.96	-	46	-	2.0E-4	4.6E-3	1.4E-3	-2.858	0.633	Frequency	2.95
ch1Ze	borehole	0.04	-	3	-	2.0E-4	1.7E-4	1.4E-3	-2.852	0.633	Frequency	0.11
ch1VI	borehole	0.10	-	11	-	3.0E-4	6.9E-4	2.1E-3	-2.680	0.633	Frequency	0.3

Table 6: Fracture Properties for the UZ Model Layers (Continued)

UZ Model Layer	Basis[a]	Fracture Frequency (m^{-1})			Fracture Intensity (m/m^2)	Aperture (m)	Fracture Porosity (-)	van Genuchten Parameters			Basis[c]	Fracture Interface area (m^2/m^3)
		f^b	σ_f	N				α (Pa^{-1})	$\log(\alpha_f)$	m_f (-)		
ch[2345]VI	borehole	0.14	-	25	-	2.6E-4	8.9E-4	1.8E-3	-2.736	0.633	Frequency	0.43
ch[2345]Ze	borehole	0.14	-	25	-	1.3E-4	4.3E-4	8.9E-4	-3.051	0.633	Frequency	0.43
ch6	ch1Ze	0.04	-	-	-	2.0E-4	1.7E-4	1.4E-3	-2.852	0.633	Frequency	0.11
pp4	ch2VI/Ze	0.14	-	-	-	1.3E-4	4.3E-4	8.9E-4	-3.051	0.633	Frequency	0.43
pp3	Adjusted ch2VI/Ze	0.20	-	-	-	2.4E-4	1.1E-3	1.6E-3	-2.786	0.633	Frequency	0.61
pp2	Adjusted ch2VI/Ze	0.20	-	-	-	2.4E-4	1.1E-3	1.6E-3	-2.786	0.633	Frequency	0.61
pp1	ch2VI/Ze	0.14	-	-	-	1.3E-4	4.3E-4	8.9E-4	-3.051	0.633	Frequency	0.43
bf3	Adjusted ch2VI/Ze	0.20	-	-	-	2.4E-4	1.1E-3	1.6E-3	-2.786	0.633	Frequency	0.61
bf2	ch2VI/Ze	0.14	-	-	-	1.3E-4	4.3E-4	8.9E-4	-3.051	0.633	Frequency	0.43
tr3	Adjusted ch2VI/Ze	0.20	-	-	-	2.4E-4	1.1E-3	1.6E-3	-2.786	0.633	Frequency	0.61
tr2	ch2VI/Ze	0.14	-	-	-	1.3E-4	4.3E-4	8.9E-4	-3.051	0.633	Frequency	0.43

NOTE: DTN: LB990501233129.001
[a]Indicates whether based on ESF data, borehole data or analog to model layer
[b]mean fracture frequency
[c]Indicates whether based on ESF data or estimated based on the fracture frequency for the model layer

6.1.3 Fracture Porosity

Fracture porosity herein is defined as the effective porosity of fractures in which fluid flow and solute transport take place. In this study, a combination of porosity data derived from gas tracer tests in the ESF, and porosity estimates based on the geometry of fracture networks, are used to develop representative fracture porosities for the UZ Model layers. The calculation of the fracture porosity is documented in the Scientific Notebooks YMP-LBNL-GSB-1.1.2 (pp. 85-86; 112-114) and YMP-LBNL-MC-1.2 (pp. 9-38).

Gas tracer tests were performed in the ESF to obtain estimates of the effective fracture porosity for the Topopah Spring middle nonlithophysal welded tuff, corresponding to the tsw34 model layer (DTN: LB980912332245.002). Since gas tracer travel times through the fractured rocks are directly related to the storage of the corresponding fracture networks, analyses of tracer data can provide reliable estimates of fracture porosity if the matrix diffusion is negligible. The porosities, estimated from the tracer tests, are reported in DTN: LB980912332245.002, and range from 0.006 to 0.02. These values are also consistent with those estimated from the ESF seepage test results (Section 6.5). Based on these results, an approximate average value of 0.01 is considered to be a reasonable, order of magnitude, estimate for fracture porosity for the model layer tsw34.

Gas tracer test data are not available for model layers other than tsw34. Alternative approaches are available to estimate fracture porosity based on the geometry of fracturing observed in the ESF. These geometric representations of porosity are used to apply the tsw34 value to the other units. A so-called 2-D porosity for a model layer can be estimated using the aperture and the total fracture length per unit area (fracture intensity). The fracture intensity is based on tracer lengths given by the DLS in the ESF and the area enclosing the traces (see Equation 5). The equation used to calculate the 2-D porosity is given below:

$$\phi_{2-D} = bI \qquad \text{(Eq.10)}$$

where I is the fracture intensity (m/m^2). When no intensity data are available (in cases where the unit does not intersect any portion of the ESF or ECRB Cross-Drift), the so-called 1-D porosity can be estimated by assuming all fractures are continuous. The 1-D porosity is calculated by:

$$\phi_{1-D} = b\overline{f} \qquad \text{(Eq.11)}$$

It is important to note that a large degree of uncertainty exists in the estimates based on Equations 10 and 11 for the following two reasons. First, the estimated apertures are "hydraulic" apertures, and may be very different from the average geometric apertures, since they are estimated based on the air permeability data. Second, Equations 10 and 11 only consider 2-D or 1-D geometric features while actual fracture networks are three-dimensional. Therefore, the estimates directly from these equations may not be reliable. However, it is reasonable to consider these estimates to provide more reliable relative ratios of the fracture porosity for different stratigraphic units. Based on these considerations, a fracture porosity is determined by using the corresponding estimate from these equations to determine a ratio of fracture porosity between units. Because the porosity,

based on analyses of the gas tracer tests, is available for the tsw34 (0.01), this value was used with these ratios to estimate fracture porosity for the other units:

$$\phi_{\text{model layer x}} = \phi_{tsw34} \frac{\phi_{\text{2-D, model layer x}}}{\phi_{\text{2-D, tsw34}}} \quad \text{or} \quad \phi_{\text{model layer x}} = \phi_{tsw34} \frac{\phi_{\text{1-D, model layer x}}}{\phi_{\text{1-D, tsw34}}} \qquad \text{(Eq.12)}$$

where ϕ_{tsw34} is 0.01 and $\phi_{2\text{-D}}$ and $\phi_{1\text{-D}}$ refer to values calculated using Equations 10 and 11, respectively. The developed fracture porosity values for the UZ Model layers are given in Table 6. All of these values are on the order of 1%, the value measured for tsw34. An alternative approach would have been to use 1% for all units. Use of this scaling scheme for estimating fracture porosities is to approximately determine the spatially variability of the porosity among the model layers, while more rigorous approaches are not available at this point. The estimates need to be updated when gas tracer data are available for more model layers.

6.1.4 Further Discussion of the Determination of Fracture Porosity

To clarify the defensibility and usefulness of the approach reported in Section 6.1.3, in this section, the currently available approaches to estimate fracture porosity are briefly reviewed, the reasoning for selecting the approach used is further discussed, and supporting evidence of validity of the fracture porosity estimates is presented.

As discussed in Section 6.1.3, two general approaches are available for estimating fracture porosities in the literature. The first approach is based on field tracer transport data. Since tracer travel times through fracture rocks are directly related to the storage of the fracture networks, analyses of these field data are expected to provide reliable estimates for fracture porosity if the matrix diffusion is negligible. Researchers outside the Yucca Mountain Project have also used similar approaches. For example, inverse modeling was used to analyze a radially convergence flow tracer test in a fractured chalk formation, resulting in a calibrated fracture porosity of 0.3 % (National Research Council 1996, pp. 292-293). This porosity value is close to the estimates reported in Table 6.

The second general approach is based on the geometry of a fracture network. This approach assumes that all the fractures under consideration are connected and fracture apertures can be exactly determined. Although, as indicated in Section 6.1.3, a large degree of uncertainty exists in fracture porosity values estimated from this approach for several reasons, this approach has often been used when field tracer test data are not available. For example, in their review of numerical approaches for modeling multiphase flow in fractured petroleum reservoirs, Kazemi and Gilman (1993, pp. 270-271 and 312-313) discuss the determination of fracture porosity based on fracture geometry data.

Considering that gas tracer test data are only available for one model layer (tsw34) and a large degree of uncertainty exists when the second approach is used, the only use of one of the two approaches can not provide reasonable estimates for fracture porosity in the whole UZ. Therefore, in order to make the best use of the relevant data, including both gas tracer data and the fracture mapping data, a combination of the above two approaches was used to determine fracture porosities for the UZ (See Section 6.1.3).

The validity of the approach used and porosity estimates given in Table 6 are supported by the following observations and studies:

- The average fracture porosity estimate in the highly fractured welded units is higher than that in the nonwelded units.
- The average fracture porosity estimate of the TCw unit is higher than that of the TSw unit, and average fracture porosity estimate of the PTn unit is higher than that of the CHn unit. This is consistent with a reasoning that the fracture porosity decreases with the depth because of the stress effects.
- The calibrated fracture porosity based on the Alcove 1 infiltration test data is about 3%, which is close to the average estimate for the TCw unit (about 2%). The calibration based on Alcove 1 test data is reported in an AMR describing UZ flow model and submodels.
- The estimated fracture porosity for model layer tsw34 is similar to the value independently estimated from water release tests performed in the same model layer, as reported in Section 6.5 of this AMR.
- The approach is a combination of the two approaches, both of which have been used by scientists outside the Yucca Mountain Project.

Based on the above discussions, the approach used to determine fracture porosity is considered to be reasonable and defensible given the currently available data.

6.2 MATRIX PROPERTIES

Matrix properties include matrix permeability and van Genuchten (1980, pp. 892-898) parameters used to describe water retention and relative permeability relations. They were determined from laboratory measurements made on core samples from 33 boreholes at Yucca Mountain and from in-situ measurements made in 4 boreholes at Yucca Mountain. Twenty-three of the boreholes from which core samples came are shallow, variously penetrating the TCw, PTn, and top portions of the TSw. There are eight deep boreholes from which core samples have been collected and analyzed for the entire depth: NRG-6, NRG-7a, SD-7, SD-9, SD-12, UZ-7a, UZ-14, and UZ#16. Six of these penetrate into the Calico Hills Formation, five penetrate into the Prow Pass Tuff, and one, SD-7, penetrates the Bullfrog and Tram Tuffs. Core samples have also been collected from portions of two other deep boreholes: SD-6 and WT#24. In-situ measurements of water potential from boreholes NRG-6, NRG-7a, SD-12, and UZ#4 are used in addition to the desaturation measurements made on cores to better characterize the relationship of saturation to water potential.

The sample collection and laboratory measurement methodologies as well as estimates of uncertainty for core are described by Flint (1998, pp. 11-19) and Rousseau et al. (1999, pp. 125-153). The in-situ water potential measurement methodology is described by Rousseau et al. (1999, pp 143-150).

Core samples are grouped and analyzed according to the hydrogeologic units characterized by Flint (1998, pp. 19-46). Table 3 shows these hydrogeologic units in relation to the lithostratigraphy of GFM3.1 and the UZ Model layers.

The calculation of matrix properties is described in Scientific Notebook YMP-LBNL-GSB-1.1.2 on pp. 70-73, 81-85 and 91-94. The calculated matrix properties are given in Table 7.

Table 7. Matrix Properties Developed From Core Data (Note that permeability for layer CUL is not upscaled, and this layer is not used in the UZ Model)

Geologic Layer (Flint 1998)	UZ Model Layer	Permeability (m^2) k	log(k)	σ_{log}	N	N non-detect	Porosity (-) ϕ	σ_ϕ	N	van Genuchten Parameters α (Pa^{-1})	log(α)	m (-)	SE_m	S_r (-)	S_s
CUL	tcw11	4.7E-15	-14.328	0.471	3	0	0.233	0.060	101	3.77E-5	-4.424	0.485	0.068	0.07	1.0
CUL	-	1.9E-15	-14.894	-	1	0	0.184	0.062	98	3.78E-5	-4.425	0.849	0.116	0.23	1.0
CHV	tcw12	2.0E-16	-15.579	1.459	39	29	0.082	0.030	899	2.90E-6	-5.096	0.253	0.028	0.19	1.0
CMW	tcw13	1.8E-16	-16.737	2.360	6	1	0.203	0.065	90	3.72E-6	-5.430	0.418	0.094	0.31	1.0
CMV	ptn21	8.0E-14	-13.097	2.047	19	5	0.287	0.070	101	1.81E-4	-3.770	0.202	0.043	0.29	1.0
BT4	ptn22	1.9E-12	-11.720	2.379	4	0	0.439	0.125	33	2.52E-5	-4.599	0.299	0.041	0.16	1.0
TPY	ptn23	1.0E-12	-12.023	1.552	5	0	0.251	0.063	43	3.46E-6	-5.243	0.405	0.078	0.05	1.0
BT3	ptn24	1.1E-13	-12.950	1.041	18	1	0.411	0.060	85	8.72E-6	-4.059	0.197	0.029	0.14	1.0
TPP	ptn25	1.1E-13	-12.964	0.369	11	0	0.489	0.041	154	9.93E-6	-4.406	0.293	0.067	0.08	1.0
BT2	ptn26	6.7E-13	-12.174	1.116	21	0	0.492	0.098	170	4.01E-4	-3.397	0.216	0.037	0.05	1.0
TC	tsw31	2.9E-17	-16.535	3.377	10	5	0.083	0.036	91	9.41E-6	-4.918	0.278	0.034	0.21	1.0
TR	tsw32	3.2E-16	-15.495	0.925	47	0	0.157	0.030	439	6.35E-5	-4.197	0.269	0.032	0.07	1.0
TIK	tsw33	2.3E-17	-16.631	1.911	51	14	0.154	0.031	455	1.81E-5	-4.743	0.250	0.022	0.12	1.0
TMN	tsw34	7.5E-19	-18.124	1.966	39	28	0.110	0.020	266	3.69E-6	-5.433	0.325	0.036	0.19	1.0
TLL	tsw35	3.1E-17	-16.510	1.073	63	21	0.131	0.030	451	1.41E-6	-5.193	0.342	0.034	0.11	1.0
TM2	tsw36	3.9E-19	-18.408	3.564	48	32	0.112	0.031	226	2.23E-6	-5.652	0.416	0.027	0.18	1.0
TM1	tsw37	2.9E-19	-18.538	1.285	22	15	0.094	0.019	102	1.01E-6	-5.996	0.400	0.052	0.25	1.0
PV3	tsw38	3.8E-19	-17.419	1.707	16	2	0.037	0.039	88	4.90E-7	-6.310	0.319	0.048	0.44	1.0
PV2	tsw39	5.4E-17	-16.355	1.499	9	0	0.175	0.107	39	1.60E-6	-6.797	0.560	0.106	0.29	1.0
BT1a	ch1Za	1.7E-19	-18.778	0.641	5	1	0.288	0.073	58	4.08E-7	-6.391	0.535	0.071	0.32	1.0
BT1	ch1Vl	2.6E-14	-13.584	1.076	16	0	0.273	0.066	43	2.91E-5	-4.535	0.357	0.095	0.03	1.0
CHV	ch[2345]Vl	8.6E-14	-13.065	1.438	24	0	0.345	0.038	89	7.40E-6	-5.143	0.270	0.057	0.07	1.0
CHZ	ch[2345]Za	5.4E-18	-17.269	0.890	125	17	0.331	0.039	293	8.12E-6	-5.090	0.348	0.026	0.29	1.0
BT	ch4	1.0E-18	-17.993	1.505	14	8	0.268	0.041	89	3.30E-7	-6.473	0.502	0.036	0.27	1.0
PP4	pp4	4.4E-17	-16.356	2.275	10	2	0.325	0.046	47	1.80E-7	-6.744	0.684	0.042	0.28	1.0
PP3	pp3	6.6E-15	-14.179	0.940	83	0	0.307	0.044	166	7.69E-6	-5.199	0.337	0.039	0.19	1.0
PP2	pp2	5.7E-17	-16.286	0.920	25	0	0.263	0.073	140	3.39E-6	-5.470	0.376	0.032	0.18	1.0
PP1	pp1	4.2E-17	-16.378	1.454	49	4	0.288	0.053	243	3.22E-6	-5.493	0.451	0.059	0.30	1.0
BF3	bf3	3.9E-15	-14.414	1.815	5	1	0.115	0.041	99	1.69E-6	-5.771	0.416	0.062	0.11	1.0
BF2	bf2	3.9E-17	-16.410	2.089	5	3	0.239	0.085	83	2.49E-7	-6.603	0.582	0.046	0.16	1.0

DTN: LB990501233129.001, LB991091233129.005

6.2.1 Matrix Permeability

Matrix permeability has been measured on 750 core samples from 8 boreholes (including SD-6 and WT#24) at Yucca Mountain. Measurements are available for layers from the CUC down to the BF2 (Table 7). Two different permeameters were used to measure permeability. The detection limit of the first is higher than the second. Most of the samples were tested using the first permeameter. The second was used to test some new samples and retest some old samples tested using the first permeameter, including some with permeabilities too low to measure (non-detect results). When the same sample was tested on both permeameters, the permeability measured on the one with the lower detection limit is used. This is because the permeameter with the lower detection limit is expected to result in a more reliable measurement.

The measured data are presented in terms of saturated hydraulic conductivity (m/s), K, which is converted to permeability (m^2), k, by the following relationship

$$k = \frac{K\mu_w}{g\rho_w} \qquad \text{(Eq.13)}$$

where μ_w is the viscosity of water (0.001 N s/m^2), g is the acceleration of gravity (9.81 m/s^2), and ρ_w is the density of water (998 kg/m^3).

Permeability is considered to be a log normally distributed quantity. Therefore the geometric mean is used to represent the average permeability of each model layer. The standard deviation of the log transformed permeabilities, log(k), is used as the basis for uncertainty, which is detailed below. Where there are no non-detect measurements in the data set for a layer, the calculation of the average and standard deviation of the data is simple. When there are non-detect measurements present, it is important to take them into account because they may represent important information about the extent of the lognormal distribution below the detection limit. They are taken into account as follows:

1. All data points, including non-detects, are ranked and assigned a percentile.
2. Those data points that the first permeameter could measure are fit to a lognormal distribution based on their percentile ranking. The fitting parameters are k_g, the geometric mean of the permeability data, and $\sigma_{log(k)}$, the standard deviation of the log transformed permeability data.
3. Data points, that could be measured with the second permeameter, but not the first one, are re-ranked to fall as close to the lognormal distribution as possible.
4. All data points, except non-detects, are fit to a lognormal distribution as in step 2.
5. Steps 3 and 4 are repeated if necessary.

While steps 3 and 4 are somewhat circular from a logical standpoint, this method allows all valued data points to contribute fully to the calculation of the mean and standard deviation.

The geometric mean permeabilities calculated above represent the average behavior of the core-scale samples. For a given model layer, this averaged permeability can be very different from the effective matrix permeability used to represent large-scale water flow and solute transport due to the scale effects (e.g., Paleologos et al. 1996, Figure 4, p. 1337). While many upscaling schemes are available in the literature, a scheme for highly heterogeneous porous media is described by the following expression (Paleologos et al. 1996, p. 1336)

$$k_e = k_g \exp[\sigma_{\ln(k)}^2 (1/2 - D)] \qquad \text{(Eq.14)}$$

where k_e is the effective permeability, k_g is the geometric mean of small (core) scale permeability, $\sigma_{ln(k)}^2$ is the variance of the natural log transformed permeability, and D is a function of spatial dimensions (e.g. 2-D and 3-D) and the correlation scale of $ln(k)$. Note that the geometric mean permeability is not the same as the effective permeability in a general case. For a 3-D isotropic problem, $D = 1/6$ when the characteristic size of a flow domain under consideration (say, a model layer) is much larger than the correlation length (Paleologos et al. 1996, p. 1336). For a site-scale model layer, these conditions are approximately satisfied. In this case, Equation 14 can be rewritten as

$$\log(k_e) = \log(k_g) + 0.38\sigma_{\log(k)}^2 \qquad \text{(Eq. 15)}$$

where $\sigma_{\log(k)}^2$ is the variance of the log transformed permeability.

In these layers, the amount of upscaling predicted by Equation 15 is as large as five orders of magnitude while the average predicted upscaling for all layers is 1.2 orders of magnitude. An upper limit of 1.5 orders of magnitude upscaling is imposed on layers CMW, CNW, BT4, TC, TM2, PP4 and BF2. For all other layers, the amount of upscaling predicted by Equation 15 is less than 1.5 orders of magnitude. Use of this limiting scheme is mainly based on the following consideration. Equation 15 was developed for a porous medium (single continuum), and can only be considered as an approximation for a dual-continua system. For example, the existence of fractures, which may act as a capillary barrier, can increase tortuosity of liquid water flow in the matrix, and therefore reduce the effective permeability compared with the case without fractures. This situation is not considered in Equation 15. A rigorous upscaling scheme for the matrix has not been developed yet for the unsaturated fractured rocks.

6.2.2 Porosity

Matrix porosity has been measured on 4888 core samples from boreholes (not including SD-6 and WT#24) at Yucca Mountain. Porosity is determined after drying samples in a 105 °C oven for at least 48 hours in order to obtain a standard dry weight (Flint 1998, p. 17). Porosity is considered to be a normally distributed quantity, so the arithmetic mean of core measurements and standard deviation are used to characterize the porosity for a model layer.

6.2.3 Matrix van Genuchten Parameters

The relationships described by van Genuchten (1980, pp. 892-893) are used to characterize unsaturated flow in the matrix of Yucca Mountain. Use of the water potential vs. saturation relationship allows the prediction of the relative permeability relationship. This technique is used to describe the unsaturated flow at Yucca Mountain. Preliminary evidence from Yucca Mountain core suggests that this approach is valid; those data will be addressed in a future revision of this document.

van Genuchten parameters are S_s (satiated saturation), S_r (residual saturation), α, and m. Satiated Saturation is assumed to be 1.0, i.e. it is assumed that there is no residual gas saturation. Residual saturation is calculated based on two porosity measurements as described below. With satiated and residual saturation fixed, α and m are varied to fit water potential and saturation data.

6.2.3.1 Residual Saturation

Residual saturation is determined from relative humidity (RH) porosity and total porosity. RH porosity is measured after drying a sample for 48 hours in a 60 °C and 65% relative humidity oven. This process is designed to remove water from the pores that contributes to flow leaving only bound water and water in the smallest pores (Flint 1998, p. 17). Layer average values for RH porosity are calculated in the same manner as total porosity (see Section 6.2.2). The layer average values of RH porosity are subtracted from the layer average values of total porosity to provide an estimate of residual water content or the amount of water left in the pores and bound to the minerals after relative permeability has been reduced to zero. Residual saturation is calculated by dividing the residual water content by total porosity.

6.2.3.2 Matrix α and m

Desaturation data, water potential and saturation measured at several times while a core sample is drying, from seventy-five samples, at least one for each layer, are used to calculate the α and m fitting parameters for each layer. The best-fit parameters are obtained by minimizing the sum of the squared saturation residuals,

$$\sum_{i=1}^{n} r_i^2 = \sum_{i=1}^{n} (S_i - S(\Psi_i))^2 \qquad \text{(Eq. 16)}$$

where r_i is a saturation residual, n is the number of saturation and water potential data pairs for a layer, S_i is a saturation data point, and $S(\Psi_i)$ is the saturation predicted by the van Genuchten relationship for a water potential, Ψ_i.

The uncertainty or standard error of α and m is given by the diagonal terms of the covariance matrix,

$$\mathbf{C} = s_0^2 \left(\mathbf{J}^T \mathbf{J}\right)^{-1} \qquad \text{(Eq.17)}$$

where C is the covariance matrix, s_0^2 is the error variance, and J is the jacobian matrix. It should be noted that standard error, SE, can be related to the standard deviation, σ, which is given for other properties, by

$$SE = \sigma / \sqrt{n} \qquad \text{(Eq.18)}$$

Because the data used to estimate α and m are from laboratory desaturation experiments, the estimate of α represents a lower bound of the average wetting and drying behavior. A better estimate of this average behavior can be obtained by forcing the water potential curve through saturation and water potential data representing field conditions. In-situ measurements of water potential are available from several boreholes. Field saturation conditions are adequately represented by saturation measurements from core.

In-situ water potentials are averaged for 15 layers from measurements in four boreholes, NRG-6, NRG-7a, SD-12, and UZ#4. In-situ measurements from UZ#5 are not included because this borehole is sited next to UZ#4 and using data from both boreholes would bias the layer averages. Measurements from UZ-7a are not used because this borehole is sited in the Ghost Dance fault where water potential is influenced by water and gas flow in the fault.

Saturation measurements on core from five deep boreholes, SD-7, SD-9, SD-12, UZ-14, and UZ#16, are averaged for the same 15 layers. Saturation measurements from NRG-6 and NRG-7a are not used because the samples were not properly handled (Rousseau et al. 1999, p. 139). Measurements from UZ-7a were not used because of its siting in the Ghost Dance fault.

The m value estimated from the desaturation data is not changed, while α is re-estimated based solely on the field condition data. For the layers with no field condition data, an analogously modified parameter, α', is calculated by

$$\alpha' = \alpha_d' c \qquad \text{(Eq.19)}$$

where α_d' is the estimate of α for that layer from desaturation data and c is a modification factor given by

$$c = \left(\prod_{i=1}^{n} \frac{\alpha_{I,i}}{\alpha_{d,i}} \right)^{1/n} \qquad \text{(Eq.20)}$$

where n is either the number of welded or non-welded units with field condition data, $\alpha_{I,i}$ is the estimate of α from field condition data for unit i, and , $\alpha_{d,i}$ is the estimate of α from desaturation data for unit i. These calculations are carried out separately for welded and non-welded units.The welded units are CUC, CUL, CW, CMW, TC, TR, TUL, TMN, TLL, TM2, TM1, PV3, PV2, PP3, PP2, and BF2 (Table 3). The non-welded units are CNW, BT4, TPY, BT3, TPP, BT2, BT1a, BT1, CHV, CHZ, BT, PP4, PP1, and BF3. For the non-welded units $c = 2.14$, and for the welded units $c = 4.74$.

6.3 THERMAL PROPERTIES

Thermal properties include rock grain density, dry and wet rock thermal conductivities, rock grain specific heat, and tortuosity coefficient. These properties are basic inputs into model studies involving heat flow. The approaches to determine the thermal properties are documented in Francis (1997). For completeness, these approaches are briefly reviewed herein.

The wet and dry thermal conductivities for a lithostratigraphic unit were calculated by averaging the conductivity measurements made within the unit. If existing experimental data for the conductivity were found to be incomplete for a unit, a multiple linear regression analysis was used to estimate the conductivity value. Special considerations were also given to the lithophysal units. The grain density was determined from the core measurements and the grain specific heat was generally calculated from the measured thermal capacitance data. Due to the lack of experimental data for the tortuous diffusion coefficient in the rock of Yucca Mountain, a representative value of 0.7 for the tortuosity coefficient, obtained from the literature, was assumed to be applicable for all the units (Francis 1997, p.5). The developed thermal property data for all the lithostratigraphic units based on these approaches are given in DTN: SNT05071897001.012.

The thermal properties for the UZ Model layers are developed from the thermal property data (DTN: SNT05071897001.012) by correlating the geological units with each model layer (Table 3). When a UZ Model layer is composed of two or more adjacent lithostratigraphic units, the averaging technique of Francis (1997, pp. 5-7) is used for estimating the properties while assuming an equal thickness for all the relevant units. This technique was developed based on an assumption that heat flow is one-dimensional and in a direction normal to interfaces between the units under consideration. This is appropriate because heat flow in the ambient system and in the disturbed system (during repository heating) at Yucca Mountain is dominantly vertical. With this assumption, the corresponding equivalent thermal conductivity ($\lambda_{\text{wet or dry, eq}}$), grain density ($\rho_{g,eq}$), and heat capacity ($C_{p,eq}$) are calculated using the following equations (Francis 1997, pp. 5-7):

$$\lambda_{k,eq} = \frac{n\prod_{i=1}^{n}\lambda_{k,i}}{\sum_{j=1}^{n}\left(\prod_{i=1,i\neq j}^{n}\lambda_i\right)} \quad \text{(k = wet or dry)} \qquad \text{(Eq.21)}$$

$$\rho_{g,eq} = \frac{\sum_{i=1}^{n}\rho_{g,i}}{n} \qquad \text{(Eq.22)}$$

$$C_{p,eq} = \frac{\sum_{i=1}^{n}C_{p,i}\rho_{g,i}}{n\rho_{g,eq}} \qquad \text{(Eq.23)}$$

where n is the total number of the involved lithostratigraphic units, and $\lambda_{g,i}$, $\rho_{g,i}$ and $C_{p,i}$ are heat conductivity, grain density and heat capacity, respectively, for a lithostratigraphic unit i. Note that these equations are derived from those of Francis (1997, pp. 5-7) by assuming an equal thickness for all the relevant units within a model layer. The determined thermal properties for the UZ Model layers are given in Table 8. The determination of the properties is described in Scientific Notebook YMP-LBNL-YSW-WZ-1 on pages 57-64.

Table 8. Thermal Properties and Tortuosity Factor for the UZ Model Layers

Model Layer	Grain Density (kg/m^3)	Specific Heat (J/kg K)	Dry Conductivity (W/m K)	Wet Conductivity (W/m K)	Tortuosity (-)
tcw11	2550	823	1.60	2.00	0.7
tcw12	2510	851	1.24	1.81	0.7
tcw12	2470	857	0.54	0.98	0.7
ptn21	2380	1040	0.50	1.07	0.7
ptn22	2340	1080	0.35	0.50	0.7
ptn23	2400	849	0.44	0.97	0.7
ptn24	2370	1020	0.46	1.02	0.7
ptn25	2260	1330	0.35	0.82	0.7
ptn26	2370	1220	0.23	0.67	0.7
tsw31	2510	834	0.37	1.00	0.7
tsw32	2550	866	1.06	1.62	0.7
tsw33	2510	882	0.79	1.68	0.7
tsw34	2530	948	1.56	2.33	0.7
tsw35	2540	900	1.20	2.02	0.7
tsw36	2560	865	1.42	1.84	0.7
tsw37	2560	865	1.42	1.84	0.7
tsw38	2360	984	1.69	2.08	0.7
tsw39	2360	984	1.69	2.08	0.7
ch1Ze	2310	1060	0.70	1.31	0.7
ch1Vl	2310	1060	0.70	1.31	0.7
ch[2-5]Ve	2240	1200	0.58	1.17	0.7
ch[2-5]Ze	2350	1150	0.61	1.20	0.7
ch6	2440	1170	0.73	1.35	0.7
pp4	2410	577	0.62	1.21	0.7
pp3	2580	841	0.66	1.26	0.7
pp2	2580	841	0.66	1.26	0.7
pp1	2470	635	0.72	1.33	0.7
bf3	2570	763	1.41	1.83	0.7
bf2	2410	633	0.74	1.36	0.7

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6.4 FAULT PROPERTIES

The UZ Model represents faults as having four layers that are defined by the major hydrogeologic units (HGU), TCw, PTn, TSw, and CHn/CFu. The constituent sub-layers of these HGUs are shown in Table 3. Fault properties are calculated for these four layers. In other words, we assumed that each HGU has the uniform properties within faults to reduce the number of fault properties. This is mainly because data to characterize faults are very limited.

Direct measurements of fault specific properties are limited to air injection tests performed in alcoves 2, 6 and 7, the Bow Ridge fault Alcove, North Ghost Dance fault Access Drift, and South Ghost Dance fault Access Drift, respectively. Analysis of cross-hole tests run in the Bow Ridge fault Alcove (LeCain 1998, p. 21) and the North Ghost Dance fault Access Drift (DTN: GS990883122410.002) give the best estimates of fracture permeability in the TCw and TSw fault layers, respectively.

All other fault properties are calculated directly as averages of non-fault layer properties or using these averages. Some layers are much thicker than others and therefore the properties of those layers should be weighted more heavily when calculating the fault properties. Properties are weighted by their respective average layer thickness. Some properties are arithmetically averaged (e.g. porosity),

$$p_a = \frac{\sum_{i=1}^{n} p_i L_i}{\sum_{i=1}^{n} L_i} \qquad \text{(Eq.24)}$$

where p_a is the weighted arithmetic average property, n is the number of layers being averaged, p_i is the property for layer i, and L_i is the thickness of layer i. Other properties are more appropriately harmonically averaged (e.g. permeability),

$$p_h = \frac{\sum_{i=1}^{n} L_i}{\sum_{i=1}^{n} \frac{L_i}{p_i}} \qquad \text{(Eq.25)}$$

where p_h is the weighted harmonic average property.

Layer thickness is estimated as the average (arithmetic) layer thickness over the GFM3.1 model (DTN: MO990LMWDGFM31.000) area. The GFM3.1 model area is slightly larger than the UZ Model area but will provide a reasonable approximation of the average layer thickness over the UZ Model area.

It should be indicated that a more rigorous way to estimate the fault properties is to correlate them with geologic information specific to each fault being modeled and to individual locations within each fault, such as amount of fault offset, width of the disturbed zone, and presence of contacts

with significant property changes. This alternative approach, however, requires the development of relationships between hydraulic properties and geologic information that can not be reliably estimated for the given limited data regarding fault properties.

The calculation of fault properties is described in Scientific Notebook YMP-LBNL-GSB-1.1.2 on pages 117-127 and 145-146. The calculated fault matrix and fracture properties are given in Tables 9 and 10, respectively.

6.4.1 Matrix properties

Because flow is generally perpendicular to the bedding at Yucca Mountain, it is appropriate to use the harmonic mean to calculate the effective permeability. Calculation of the weighted harmonic mean is as shown in Equation 25. Effective matrix porosity is calculated using a weighted arithmetic average (Equation 24).

The most accurate way to calculate the matrix van Genuchten parameters for faults would be to recalculate them using the composite data sets for each of the major HGUs and the process used for the matrix van Genuchten parameters in Section 6.2.4. However this process would be complicated (but still possible) by the necessity to weight the data by the respective layer thickness. A much simpler way that still provides a good approximation of this process is to take the weighted average of each individual parameter.

Equivalent satiated and residual saturation and m are calculated using a weighted arithmetic average (Equation 24). The van Genuchten parameter α is approximately the inverse of an air entry pressure. The equivalent air entry pressure would be calculated using the weighted arithmetic mean. It can be shown that the weighted arithmetic mean of $1/p_i$ is equal to the harmonic mean of p_i, so the weighted harmonic mean of α is used to calculate the equivalent α for the faults.

Table 9. Calculated Fault Matrix Properties

Model Layer	Permeability (m^2)	Porosity (-)	van Genuchten α (Pa^{-1})	van Genuchten m (-)	Residual saturation S_r (-)	Satiated saturation S_s (-)
tcwf	2.7E-19	0.086	8.35E-6	0.260	0.20	1.00
ptnf	1.2E-13	0.446	3.68E-5	0.255	0.10	1.00
tswf	1.8E-18	0.127	3.18E-6	0.296	0.16	1.00
chnf	4.0E-18	0.259	9.79E-7	0.386	0.23	1.00

DTN: LB990501233129.001

6.4.2 Fracture Properties

Fracture permeability for the TCw and TSw fault layers is given by the cross-hole air injection tests described above. Permeability for the PTn and CHn/CFu fault layers is calculated by scaling the weighted average bulk rock fracture permeability. As with the matrix permeability, equivalent

fracture permeability is calculated for all four fault layers using the weighted harmonic mean of permeabilities for the corresponding non-fault model layers. The average (geometric mean) ratio of the measured permeability to the calculated equivalent permeability for layers TCw and TSw is calculated. This factor multiplies the calculated equivalent permeability of the PTn and CHn/CFu layers to scale them up. This process is equivalent to the process used to scale bulk rock matrix α, which is explained in Section 6.2.

Equivalent fracture spacing, equal to the inverse of fracture frequency, can be calculated using the weighted arithmetic mean. Again, it can be shown that the weighted arithmetic mean of $1/p_i$ is equal to the harmonic mean of p_i, so the weighted harmonic mean of frequency is used to calculate the equivalent frequency for the faults.

Fracture aperture is calculated as in Section 6.1 (using Equation 7) based on the cubic law and the fault permeabilities and frequencies.

Fracture porosity is determined by scaling the weighted arithmetic mean of bulk rock fracture porosity. The scaling factor is the ratio of fault fracture aperture to mean bulk rock fracture aperture. The mean bulk rock fracture aperture is calculated as the weighted arithmetic average of fracture aperture.

The fracture van Genuchten m (m_f) is assumed to be 0.633 as for all other fractures (see Section 6.1). The fracture van Genuchten α (α_f) is calculated based on the fracture aperture using Equation 9 as documented in Section 6.1.

The fracture to matrix connection area for the faults is approximated as the weighted arithmetic mean of bulk rock fracture to matrix connection area.

Table 10. Calculated Fault Fracture Properties

Model Layer	Permeability (m^2)	Porosity (-)	Aperture (m)	Frequency (m^{-1})	α_f (Pa^{-1})	m_f (-)	Interface area (m^2/m^3)
tcwf	2.7E-11	4.4E-2	5.5E-4	1.90	3.8E-3	0.633	1.3E+1
ptnf	3.0E-12	1.6E-2	4.0E-4	0.54	2.8E-3	0.633	1.3E+0
tswf	1.5E-11	3.6E-2	4.7E-4	1.70	3.2E-3	0.633	8.6E+0
chnf	3.6E-13	1.6E-3	3.3E-4	0.13	2.3E-3	0.633	4.7E-1

DTN: LB990501233129.001

6.4.3 Thermal Properties

Thermal conductivity, both wet and dry, are calculated as the weighted harmonic mean of bulk rock thermal conductivity (Francis 1997, p. 6). This is appropriate because heat flow in the ambient system and in the disturbed system (during repository heating) at Yucca Mountain is dominantly vertical. The tortuosity factor is assumed to be the same as non-fault model layers. Grain density is calculated as the weighted arithmetic mean (Francis 1997, p. 7).

Equivalent grain heat capacity, $C_{p,eq}$, for the fault layers is calculated by (Francis 1997, p. 7):

$$C_{p,eq} = \frac{\sum_{i=1}^{n} L_i C_{p,i} \rho_{g,i}}{\sum_{i=1}^{n} L_i \rho_{g,i}} \qquad \text{(Eq.26)}$$

where $C_{p,i}$ is the grain heat capacity of layer i, and $\rho_{g,i}$ is the grain density of layer i. The developed thermal properties are given in the bottom portion of Table 11.

Table 11. Calculated Fault Thermal Properties and Tortuosity Factor

Model Layer	Grain Density (kg/m^3)	Specific Heat (J/kg K)	Dry Conductivity (W/m K)	Wet Conductivity (W/m K)	Tortuosity (-)
tcwf	2508	851	1.18	1.75	0.7
ptnf	2330	1156	0.36	0.81	0.7
tswf	2519	901	1.12	1.88	0.7
chnf	2455	870	0.75	1.35	0.7

Submitted with this AMR under DTN: LB991091233129.006

6.5 CONFIRMATION OF FRACTURE PROPERTIES

Uncertainties generally exist in the estimated rock properties due to the data availability and limitations of the estimation procedures used. This is particularly true for the fracture properties, since these properties, such as fracture van Genuchten parameters and porosity, are not directly measured, but indirectly estimated from other property measurements. In addition to model calibration, it is useful to confirm the appropriateness of the estimated properties based on independent methods and the relevant data. In this subsection, the ESF seepage test results are used to determine fracture van Genuchten α and porosity for the confirmation purpose. The determination procedures are very different from those used in Section 6.1 of this report. The calculation is documented in a Scientific Notebook YMP-LBNL-GSB-LHH-2 (pp. 64-66).

6.5.1 ESF Seepage Tests

After Niche 3650 (Niche 2) in the ESF was excavated, a series of seepage tests were performed by pumping water into boreholes labeled UL, UM and UR that were located above the niche. Water was released into a number of intervals in these boreholes. Tracers were also introduced during the seepage tests. As test observations, water entering the niche was captured, and the water arrival times were recorded during the tests. Based on water seepage rates and the corresponding water release fluxes for a given test interval, a seepage threshold flux could be determined (DTN: LB980901233124.003). The threshold flux is defined as the water-release flux within a test interval at which seepage into the niche no longer occurred. The threshold water flux and water

arrival time data are the primary data used for determining van Genuchten fracture α (α_f) and porosity. The test sites were located at the fractured middle nonlithophysal zone of the Topopah Spring welded unit, corresponding to the UZ Model layer tsw34.

6.5.2 Approaches

The approach to determine van Genuchten fracture α from the seepage test results is based on the theory of Philip et al. (1989). They developed analytical solutions of water exclusion from, or entry into, cavities from downward seepage through an unsaturated porous media. The underlying assumptions they used are as follows (Philip et al. 1989, pp.16-23):

First, liquid water flow is downward and steady, and the concerned porous medium is isotropic and homogeneous. To be consistent with this assumption, in our analyses we only used the results for the seepage tests associated with fracture networks. This is because a fracture network may be conceptualized as a continuum such that the solutions developed for porous media can be approximately applied. Data in DTN: LB980901233124.003 indicated that the tests were associated with either connected fracture networks or individual vertical fractures (or small groups of vertical fractures). Studies documented in an AMR describing seepage calibrated model and seepage testing data also support the use of the continuum approach for dealing with seepage at the same scale.

Second, Philip et al. (1989, pp. 16-18) assumed that the flow domain is infinite in extent and flow velocity in the upstream is spatially uniform. It is important to note that in the seepage tests, the flow patterns between the test intervals in the boreholes above Niche 3650 (Niche 2) and the niche were localized in extent, as will be documented in an AMR describing in-situ field testing of processes. However, liquid water flow in a fracture continuum is largely dominated by gravity and the capillary dispersion effects are weak. Therefore, it is not unreasonable to use the theory of Philip et al. (1989) for analyzing the localized tests for fracture networks.

Third, Philip et al (1989, p.18) assumed that there exists a functional relation between unsaturated hydraulic conductivity, $K(\Psi)$ (m/s), and moisture potential, Ψ (m), that is exponential in nature.

$$K(\Psi) = K_0 e^{\alpha'(\Psi-\Psi_0)} \qquad \text{(Eq.27)}$$

where K_0 (m/s) is the hydraulic conductivity at a referential water potential Ψ_0 (m), and α' (m^{-1}) is the sorptive number. In this study, we treat K_0 as the saturated hydraulic conductivity, and therefore $\Psi_0 = 0$ by definition. The sorptive number is a constant for a homogeneous porous medium, and usefully characterizes the capillary properties of the medium in unsaturated flow (Philip et al. 1989, p.18). This number can be used to determine van Genuchten alpha, which will be discussed later on.

According to Philip et al. (1989, p.19; p.23), the threshold water flux, K_{0*} (m/s), can be related to the saturated hydraulic conductivity K_0 as

$$K_{0^*} = K_0[\vartheta_{max}(s)]^{-1} \qquad \text{(Eq.28)}$$

with $s = (1/2)\alpha^1 l$, where l (m) is the radius for a circular cylindrical cavity. For the ESF seepage tests, it is the radius of the niche. Under a condition that s is large (or capillary effects are weak), ϑ_{max} can be expressed as (Philip et al. 1989, p.23)

$$\vartheta_{max}(s) = 2s + 2 - \frac{1}{s} + \frac{1}{s^2} - \ldots \qquad \text{(Eq.29)}$$

Based on Equations 28 and 29 a sorptive number, α', can be estimated from known saturated conductivity and threshold flux values for a given seepage test. The sorptive number values estimated are given in the data set (DTN: LB980901233124.003).

The sorptive number can be related to van Genuchten fracture α (α_f) by the following curve fitting procedure. Based on the definition of relative permeability, Equation 27 leads to a relative permeability (k) relation

$$\ln(k) = \frac{\alpha' p}{\rho g} \qquad \text{(Eq.30)}$$

where P (Pa) is the capillary pressure, g (m/s^2) is the gravitational acceleration, and ρ (kg/m^3) is the liquid water density. van Genuchten (1980) relations result in

$$\ln(k) = -\frac{m}{2}\ln[(p^*)^n + 1] + 2\ln[1 - (1 - \frac{1}{1 + (p^*)^n})^m] \qquad \text{(Eq.31)}$$

where n and m=1-1/n are van Genuchten parameters, and p* is a dimensionless capillary pressure defined by

$$p^* = \alpha_f |p| \qquad \text{(Eq.32)}$$

In terms of p^*, Equation 30 can be rewritten as

$$\ln(k) = -\frac{\alpha'}{\rho g \alpha_f} p^* \qquad \text{(Eq.33)}$$

For a given fracture m (m_f) value and a range of p^* values, $\alpha'/(\rho g \alpha_f)$ can be estimated by fitting Equation 33 through a number of data points calculated from Equation 31. Since α' is known, the corresponding α_f (Pa^{-1}) can be easily estimated.

In addition to determining the van Genuchten fracture α, the seepage test results can be used to estimate volumetric water content of the fracture continuum. The estimated saturated water contents provide useful information for confirming fracture priorities estimated in Section 6.1 of the report.

Under conditions that water flow is one-dimensional and the wetting front has a constant velocity, the depth of the wetting front can be determined as

$$z_p = \frac{q_s t}{(\theta_{av} - \theta_r)} \qquad \text{(Eq.34)}$$

where z_p (m) is the depth from the water supply source to the wetting front, t (s) is the arrival time of the front at depth z_p, q_s is the constant flux of water supplied at the source, and θ_r is the residual water content, and θ_{av} is the average volumetric water content between the source and the wetting front. For the seepage tests, z_p and t can be considered as the distance between the source and the ceiling of the niche, and the wetting front arrival time at the ceiling, respectively. Assuming $\theta_r = 0$, θ_{av} can be estimated for each seepage test. The estimated (θ_{av} - θ_r) values are reported in DTN: LB980901233124.003. Note that the conditions for Equation 34 to hold are approximately satisfied when the capillary effects are weak, which is the case for water flow in fractures.

Finally, it should be indicated that in the above discussions, the matrix imbibition was ignored. This is because for the given temporal and spatial scales of the seepage tests, the matrix imbibition is expected to be insignificant compared with the amount of water flowing through fractures.

6.5.3 Results and Discussion

The van Genuchten fracture α values estimated from the seepage test results are given in Table 12. To estimate these values, we applied the curve fitting procedure for $p^* \leq 5$ based on the following considerations. First, van Genuchten fracture α is closely related to the air entry pressure, which is mainly characterized by capillarity and relative permeability data at large saturations (or small capillary pressures). Therefore, it is appropriate to perform the curve fitting for a range of p^*, corresponding to relatively small capillary pressure values, in order to estimate the van Genuchten fracture α. Second, assuming a unit hydraulic head gradient condition, the water release flux at the source for a given seepage test can be considered as the unsaturated hydraulic conductivity. In this case, the ratio of the water release flux to the saturated hydraulic conductivity is an approximation of the relative permeability. The natural logs of the calculated ratio for the relevant seepage tests based on the data in DTN: LB980901233124.003 are larger than –5. In this case, $p^* \leq 5$ results in relative permeability values that are adequate to cover this range (Figure 4). We also used $m_f = 0.633$ for the curve fitting. The determination of this m value was given in Section 6.1 of this report. The curve fitting results are shown in Figure 4.

Table 12. Log Values of van Genuchten Fracture α Estimated from the ESF Seepage Tests (Niche 3650)

Borehole (Depth(m))[a]	Log(α_f)[b]
UL (7.01-7.32)	-3.31
UM (4.27-4.57)	-2.73
UM (5.49-5.79)	-2.90

Table 12. Log Values of van Genuchten Fracture α Estimated from the ESF Seepage Tests (Niche 3650)

(Cont.)

Borehole (Depth(m))[a]	Log(α_f)[b]
UR (4.27-4.57)	-3.10
UR (4.88-5.18)	-2.69
UR (5.49-5.79)	-4.23
average	-3.16

NOTES: [a]UL – upper left; UM – upper middle; UR – upper right.
[b]Log(α_f) is calculated using α' data (DTN: LB980901233124.003).

Table 12 shows that the estimated fracture alpha value varies for different test locations due to the heterogeneities. However, the average log(α_f) value is –3.16, which is very close to the log(α_f) value of -3.17, determined from air permeability data for UZ Model layer tsw34. As indicated before, the test sites are located in zones represented by the model layer tsw34. It is encouraging that independent approaches used to estimate the fracture α based on different data sets lead to similar fracture α values. This indicates that the approach used to estimate fracture α based on the air permeability data and the resultant fracture α values, reported in Section 6.1 of this report, are reasonable.

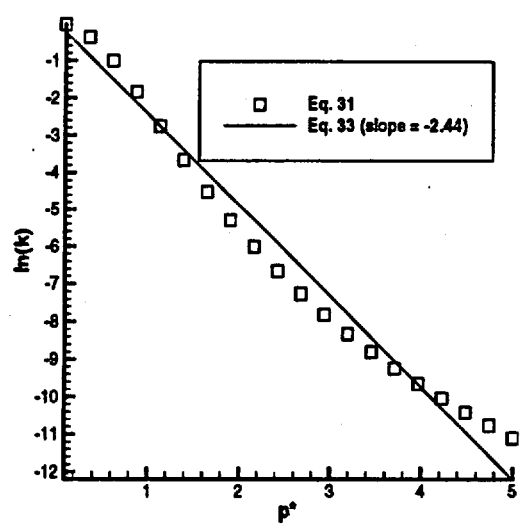

Figure 4. Graph of fitting of Equation 33 to Equation 31 using a number of data points for $p^* < 5$

The data from DTN: LB980901233124.003 include values of the fracture water content change for the seepage tests. As discussed before, this change is equal to the average volumetric water content when assuming zero residual water content. Herein, we are interested in the water content values under the saturated condition or when the liquid water release flux at the source is close to the saturated hydraulic conductivity. In these cases, the fracture networks are or should be nearly saturated, and therefore, the water content values are good approximations of the corresponding fracture porosities. Three water content values of this kind were given in DTN: LB980901233124.003. They are 0.0242, 0.0124 and 0.0024, respectively, and the average value is 0.013. The fracture porosity for the model layer tsw34, determined in Section 6.1, is 0.01 and close to this average value. Again, this confirms that the fracture porosity values developed in Section 6.1 are reasonable.

7. CONCLUSIONS

Methodologies have been described for providing representative estimates of fracture and matrix properties for UZ Model layers based on the relevant data. The fracture and matrix properties developed here were submitted to the Technical Data Management System (TDMS) under DTN: LB990501233129.001 and DTN: LB991091233129.005. The thermal properties developed here were submitted to the TDMS under DTN: LB991091233129.006. The estimated properties are also documented in this report for use as the prior information and initial estimates in the inversion processes in an AMR documenting calibrated properties model. The resultant fracture spacing is an important input for the development of the UZ Model grids. The independent determination of fracture properties based on ESF seepage test results confirms the appropriateness of the estimated fracture properties and the procedures used for the estimation.

Like many field-scale problems, data availability and limitations of approaches for upscaling flow parameters, directly from small-scale measurements, are major sources of uncertainties in the estimated hydraulic properties. It is particularly true for the unsaturated fractured rocks due to the complexity of the flow processes involved. To reduce the uncertainties, model calibrations are generally needed. The calibration is discussed in an AMR describing calibrated properties model. Therefore, it should be emphasized that flow parameter estimates reported herein are only developed as inputs into model calibrations, and should not be directly used for modeling UZ flow and transport processes without careful evaluations.

This document may be affected by technical product input information that requires confirmation. Any changes to the document that may occur as a result of completeing the confirmation activities will be reflected in subsequent revisions. The status of the input information quality may be confirmed by review of the DIRS database. The impact of modifications or inability to verify these data may be minimal, because the results of this AMR are primarily used as prior information (input) to the calibration process and changes in these inputs as a result of the verification process are not expected to be substantial. Therefore, changes in property values will not result in substantial changes in the final calibrated values. The data that support the properties that are not calibrated (fracture porosity, fracture frequency and thermal properties) may have a greater impact because these properties represent final values used for flow and transport simulations.

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8. REFERENCES

8.1 DOCUMENTS CITED

Bear, J.; Tsang, C.F.; and de Marsily, G. eds. 1993. *Flow and Contaminant Transport in Fractured Rock.* San Diego, California: Academic Press. TIC: 226388.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. *Geology of the Exploratory Studies Facility Topopah Spring Loop*, Rev. 1. BAB000000-01717-0200-00002. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980415.0283.

CRWMS M&O 1999a. *M&O Site Investigations.* Activity Evaluation. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990317.0330.

CRWMS M&O 1999b. *M&O Site Investigations.* Activity Evaluation. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990928.0224.

CRWMS M&O 1999c. *Analysis & Modeling Development Plan (DP) for U0090 Analysis of Hydrologic Properties Data, Rev 00.* TDP-NBS-HS-000003. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990826.0105.

CRWMS M&O 1999d. *Development of Numerical Grids for UZ Flow and Transport Modeling.* ANL-NBS-HS-000015. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990721.0517.

Dyer, J.R. 1999. "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada." Letter from J.R. Dyer (DOE) to D.R. Wilkins (CRWMS M&O), September 9, 1999, OL&RC: SB-1714, with enclosure, "Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01)." ACC: MOL.19990910.0079.

Flint, L.E. 1998. *Characterization of Hydrogeologic Units Using Matrix Properties, Yucca Mountain, Nevada.* Water-Resources Investigations Report 97-4243. Denver, Colorado: U.S. Geological Survey. TIC: 236515.

Francis, N.D. 1997. "The Base-Case Thermal Properties for TSPA-VA Modeling." Memorandum from N.D. Francis (SNL) to Distribution, April 16, 1997. Albuquerque, New Mexico: Sandia National Laboratories. ACC: MOL.19980518.0229.

Hvorslev, M.J. 1951. "Time Lag and Soil Permeability in Ground-Water Observations." *U.S. Army Corps of Engineers Bulletin*, 36. Vicksburg, Mississippi: U.S. Army Corps of Engineers. TIC: 238956.

Kazemi, H. and J.R. Gilman. 1993. "Multiphase Flow in fractured Petroleum Reservoirs" in J. Bear; C.-F. Tsang; and G. de Marsily (eds.) *Flow and Contaminant Transport in Fractured Rock.* San Diego, California: Academic Press. TIC: 226388.

LeCain, G. D. 1995. *Pneumatic Testing in 45-Degree-Inclined Boreholes in Ash-Flow Tuff near Superior, Arizona.* Water-Resources Investigations Report 95-4073. Denver, Colorado: U.S. Geological Survey. TIC: 221220.

LeCain, G.D. 1997. *Air-Injection Testing in Vertical Boreholes in Welded and Nonwelded Tuff, Yucca Mountain, Nevada.* Water-Resources Investigations Report 96-4262. Denver, Colorado: U.S. Geological Survey. TIC: 233455.

LeCain, G.D. 1998. *Results from Air-Injection and Tracer Testing in the Upper Tiva Canyon, Bow Ridge Fault, and Upper Paintbrush Contact Alcoves of the Exploratory Facility, August 1994 through July 1996, Yucca Mountain, Nevada.* Water-Resources Investigations Report 98-4058. Denver, Colorado: U.S. Geological Survey. TIC: 237249.

Lin, M.; Hardy, M.P.; and Bauer, S.J. 1993. *Fracture Analysis and Rock Quality Designation Estimation for the Yucca Mountain Site Characterization Project.* Report SAND92-0449. Albuquerque, New Mexico: Sandia National Laboratories. ACC: NNA.19921204.0012.

Liu, H.H.; Doughty, C.; and Bodvarsson, G.S. 1998. "An Active Fracture Model for Unsaturated Flow and Transport in Fractured Rocks." *Water Resources Research*, 34 (10), 2633-2646. Washington, D.C.: American Geophysical Union. TIC: 243012.

National Research Council. 1996. *Rock Fractures and Fluid Flow, Contemporary Understanding and Applications.* Washington, D.C.: National Academy Press. TIC: 235913.

Neuman, S.P. 1994. "Generalized Scaling of Permeabilities: Validation and Effect of Support Scale." *Geophysical Research Letters*, 30 (21), 349-352. Washington, D.C.: American Geophysical Union. TIC: 240142.

Paleologos, E.K.; Neuman, S.P.; and Tatakovsky, D. 1996. "Effective Hydraulic Conductivity of Bounded, Strongly Heterogeneous Porous Media" *Water Resources Research*, 32, 1333-1341. Washington, D.C.: American Geophysical Union. TIC: 224599.

Philip, J.R.; Knight, J.H.; and Waechter, R.T. 1989. "Unsaturated Seepage and Subterranean Holes: Conspectus, and Exclusion Problem for Cylindrical Cavities." *Water Resources Research*, 25 (1), 16-28. Washington, D.C.: American Geophysical Union. TIC: 239117.

Rautman, R.A. and Engstrom, D.A. 1996. *Geology of the USW SD-12 Drill Hole, Yucca Mountain, Nevada.* Letter Report SAND96-1368, UC-814. Albuquerque, New Mexico: Sandia National Laboratories. ACC: MOL.19961219.0271.

Rousseau, J.P.; Kwicklis, E.M.; and Gillies, D.C., eds. 1999. *Hydrogeology of the Unsaturated Zone, North Ramp Area of the Exploratory Studies Facility, Yucca Mountain, Nevada.* Water-Resources Investigations Report 98-4050. Denver, Colorado: U.S. Geological Survey. TIC: 243099.

van Genuchten, M. 1980. "A Closed-Form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils." *Soil Science Society of America Journal*, 44 (5), 892-898. Madison, Wisconsin: Soil Science Society of America. TIC: 217327.

Wang J.S.Y. and Narasimhan T.N. 1993. "Unsaturated Flow in Fractured Porous Media." Chapter 7 of *Flow and Contaminant Transport in Fractured Rocks*. Bear, J.; Tsang, C-H; and de Marsily, G., eds. San Diego, California: Academic Press. TIC: 235461.

Wemheuer, R.F. 1999. "First Issue of FY00 NEPO QAP-2-0 Activity Evaluations." Interoffice correspondence from R.F. Wemheuer (CRWMS M&O) to R.A. Morgan (CRWMS M&O), October 1, 1999, LV.NEPO.RTPS.TAG.10/99-155, with attachments, Activity Evaluation for Work Package #1401213UM1. ACC: MOL.19991028.0162.

8.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

64 FR (Federal Register) 8640. Disposal of High-Level Radioactive Waste in a Proposed Geologic Repository at Yucca Mountain. Proposed rule 10 CFR (Code of Federal Regulations) 63. Readily available.

AP-3.10Q, Rev. 1, ICN 0. Analyses and Models. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19990702.0314.

AP-3.14Q, Rev. 0. Transmittal of Input. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19990701.0621.

AP-SI.1Q, Rev. 1, ICN 0. Software Management. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19990630.0395.

DOE (U.S. Department of Energy) 1998. Quality Assurance Requirements and Description. DOE/RW-0333P, REV 8. Washington D.C.: DOE OCRWM. ACC: MOL.19980601.0022.

QAP-2-0, Rev. 5. Conduct of Activities. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980826.0209.

8.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

GS930608312332.001. Outcrop-Fractures Orientation and Geometry in the Area of Raven Canyon. Submittal date: 06/30/1993.

GS930608312332.002. Outcrop Fractures Orientation, Description and Geometry in the Area East of Little Skull Mountain, Nevada . Submittal date: 10/30/1993.

GS950208312232.003. Data, Including Water Potential, Pressure and Temperature, Collected from Boreholes USW NRG-6 and USW NRG -7A from Instrumentation through March 31, 1995. Submittal date: 02/13/95.

GS951108312232.008. Data, Including Water Potential, Pressure and Temperature, Collected from Boreholes UE-25 UZ#4 & UZ#5 from Instrumentation through September 30, 1995, and from USW NRG-6 & NRG-7A from April 1 through September 30, 1995. Submittal date: 11/21/ 1995.

GS960308312232.001. Deep Unsaturated Zone Surface-Based Borehole Instrumentation Program Data from Boreholes USW NRG-7A, USW NRG-6, UE-25 UZ#4, UE-25 UZ#5, USW UZ-7A, and USW SD-12 FOR the Time Period 10/01/95 through 3/31/96. Submittal date: 04/04/1996.

GS960708314224.008. Provisional Results: Geotechnical Data for Station 30+00 to Station 35+00, Main Drift of the ESF. Submittal date: 08/05/1996.

GS960708314224.010. Provisional results: Geotechnical Data for Station 40+00 to Station 45+00, Main Drift of the ESF. Submittal date: 08/05/1996.

GS960808312232.004. Deep Unsaturated Zone Surface-Based Borehole Instrumentation Program Data for Boreholes USW NRG-7A, USW N RG-6, UE-25 UZ#4, UE-25 UZ#5, USW UZ-7A and USW SD-12 for the Time Period 4/1/96 through 8/15/96. Submittal date: 08/30/1996.

GS960808314224.011. Provisional results: Geotechnical Data for Station 35+00 to Station 40+00, Main Drift of the ESF. Submittal date: 08/29/1996.

GS960908312232.012. Comparison of Air-Injection Permeability Values to Laboratory Permeability Values. Submittal date: 09/26/1996.

GS960908312232.013. Air-Injection Testing in Vertical Boreholes in Welded and Non-Welded Tuff, Yucca Mountain, Nevada. Submittal date: 09/26/1996.

GS960908314224.014. Provisional Results¾ESF Main Drift, Station 50+00 to Station 55+00. Submittal date: 09/09/1996.

GS960908314224.018. Provisional Results: Geotechnical Data for Alcove 5 (DWFA), Main Drift of the ESF. Submittal date: 09/09/1996.

GS960908314224.020. Analysis Report: Geology of the North Ramp - Stations 4+00 to 28+00 and Data: Detailed Line Survey and Full-Periphery Geotechnical Map - Alcoves 3 (UPCA) and 4 (LPCA), and Comparative Geologic Cross Section - Stations 0+60 to 28+00. Submittal date: 09/09/1996.

GS970108312232.002. Deep Unsaturated Zone, Surface-Based Borehole Instrumentation Program-Raw Data Submittal for Boreholes USW NRG-7A, USW NRG-6, UE-25 UZ#4, UE-25 UZ#5, USW UZ-7A, and USW SD-12, for the Period 8/16/96 through 12/31/96. Submittal date: 01/22/97.

GS970183122410.001. Results from Air-Injection and Tracer Testing in the Upper Tiva Canyon, Bowridge Fault, and Upper Paintbrush Contact Alcoves of the Exploratory Studies Facility, August 1994 through July 1996, Yucca Mountain, Nevada. Submittal date: 02/03/1997.

GS970208314224.003. Geotechnical Data for Station 60+00 to Station 65+00, South Ramp of the ESF. Submittal date: 12/12/1997.

GS970308314222.001. Fracture Data from Natural Outcrops of the Calico Hills Formation and the Topopah Spring Tuff at 10 Locations in the Vicinity of Prow Pass, at the Head of Yucca Wash, North of Yucca Mtn, and 2 Locations at the NE End of Busted Butte, SE of Yucca Mtn. Submittal date: 03/26/1997.

GS970408314222.003. Integrated Fracture Data in Support of Process Models, Yucca Mountain, Nevada. Submittal date: 04/21/1997.

GS970808312232.005. Deep Unsaturated Zone Surface-Based Borehole Instrumentation Program Data from Boreholes USW NRG-7A, UE-2 5 UZ#4, UE-25 UZ#5, USW UZ-7A and USW SD-12 for the Time Period 1/1/97 - 6/30/97. Submittal date: 08/28/97.

GS970808314224.008. Provisional Results: Geotechnical Data for Station 65+00 to Station 70+00, South Ramp of the ESF. Submittal date: 08/18/1997.

GS970808314224.010. Provisional Results: Geotechnical Data for Station 70+00 to Station 75+00, South Ramp of the ESF. Submittal date: 08/25/1997.

GS970808314224.012. Provisional Results: Geotechnical Data for Station 75+00 to Station 78+77, South Ramp of the ESF. Submittal date: Submittal date: 08/25/1997.

GS970808314224.014. Provisional Results: Geotechnical Data for Alcove 6 and Alcove 6 Drill Alcove, Main Drift of the ESF. Submittal date: 08/25/1997.

GS971108312232.007. Provisional Results: Geotechnical Data for Alcove 6 and Alcove 6 Drill Alcove, Main Drift of the ESF. Submittal date: 11/18/1997.

GS971108314224.020. Revision 1 of Detailed Line Survey Data, Station 0+60 to Station 4+00, North Ramp Starter Tunnel, Exploratory Studies Facility. Submittal date: 12/03/1997.

GS971108314224.021. Revision 1 of Detailed Line Survey Data, Station 4+00 to Station 8+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/3/97.

GS971108314224.022. Revision 1 of Detailed Line Survey Data, Station 8+00 to Station 10+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/3/97.

GS971108314224.023. Revision 1 of Detailed Line Survey Data, Station 10+00 to Station 18+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/3/97.

GS971108314224.024. Revision 1 of Detailed Line Survey Data, Station 18+00 to Station 26+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/3/97.

GS971108314224.025. Revision 1 of Detailed Line Survey Data, Station 26+00 to Station 30+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/3/97.

GS971108314224.026. Revision 1 of Detailed Line Survey Data, Station 45+00 to Station 50+00, Main Drift, Exploratory Studies Facility. Submittal date: 12/03/1997.

GS971108314224.028. Revision 1 of Detailed Line Survey Data, Station 55+00 to Station 60+00, Main Drift and South Ramp, Exploratory Studies Facility. Submittal Date: 12/03/1997.

GS980408312232.001. Deep Unsaturated Zone Surface-Based Borehole Instrumentation Program Data from Boreholes USW NRG-7A, UE-2 5 UZ #4, USW NRG-6, UE-25 UZ #5, USW UZ-7A and USW SD-12 for the Time Period 10/01/97 - 03/31/98. Submittal date: 04/16/1998.

GS981108314224.005. Locations of Lithostratigraphic Contacts in the ECRB Cross Drift. Submittal date: 11/30/1998.

GS990408314224.001. Detailed Line Survey Data for Stations 00+00.89 to 14+95.18, ECRB Cross Drift. Submittal Date: 09/09/1999.

GS990408314224.002. Detailed Line Survey Data for Stations 15+00.85 TO 26+63.8, ECRB Cross Drift. Submittal Date: 09/09/1999.

GS9908813122410.002. Qualified Data in "Results From Geothermal Logging, Air and Core-Water Chemistry Sampling, Air-Injection Testing and Tracer Testing in the Northern Ghost Dance Fault, November, 1996 - August, 1998." Submittal date: 08/16/1999.

GS000399991221.004. Preliminary Developed Matrix Properties. Submittal dates: 3/10/2000.

LB960500834244.001. Hydrological Characterization of the Single Heater Test Area in ESF. Submittal date: 08/23/1996.

LB970600123142.001. Ambient Characterization of the ESF Drift Scale Test Area by Field Air Permeability Measurements. Submittal date: 06/13/1997.

LB980001233124.001. Water Potential Measurements in Niches 3566 and 3650. Submittal date: 04/23/1998.

LB980001233124.002. Air Permeability Testing in Niches 3566 and 3650. Submittal date: 04/23/1998.

LB980120123142.004. Air Injections in Boreholes 57 through 61, 74 through 78, 185 and 186 in the Drift Scale Test Area. Submittal date: 01/20/1998.

LB980120123142.005. Hydrological Characterization by Air Injections Tests in Boreholes in Heated Drift in DST. Submittal date: 01/20/1998.

LB980901233124.001. Pneumatic Pressure and Air Permeability Data from Niches 3107 and 4788 in the ESF from Chapter 2 of Report SP33PBM4: Fracture Flow and Seepage Testing in the ESF, FY98. Submittal date: 09/14/1998.

LB980901233124.002. Laboratory Imbibition, Tracer, and Seepage Tests in Niches 3566, 3650, 3107, and 4788 in the ESF. Submittal date: 09/14/1998.

LB980901233124.003. Liquid Release and Tracer Tests in Niches 3566, 3650, 3107, and 4788 in the ESF. Submittal date: 09/14/1998.

LB980912332245.002. Gas Tracer Data from Niche 3107 of the ESF. Submittal date: 09/30/1998.

LB991091233129.005. Hydrologic Properties Data - Number of Matrix Permeability Non Detects for AMR U0090, "Analysis of Hydrologic Properties Data." These Data are also Associated with AMR U0035, "Calibrated Properties Model." Submittal date: 10/22/1999.

MO9901MWDGFM31.000. Geologic Framework Model. Submittal date: 01/06/1999.

SNF29041993002.084. Yucca Mountain Site Characterization Project Core Hole Rock Structural Data Summaries for Boreholes UE25 NRG-1, -2, -2A, -2B, -3, -4, -5; and USW NRG-6 and 7/7A, Revision 2. Submittal date: 07/09/1996.

SNT05071897001.012. Source Data for Base Case Thermal Property Data for TSPA-VA (Total System Performance Assessment-Viability Assessment) (VA supporting data). Submittal date: 05/25/1999.

TM000000SD12RS.012. USW SD-12 Composite Borehole Log (0.0' - 1435.3') and Weight Logs (1,438.8 - 2,151.7'). Submittal date: 09/08/1995.

8.4 OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

LB990501233129.001. Fracture Properties for the UZ Model Grids and Uncalibrated Fracture and Matrix Properties for the UZ Model Layers for AMR U0090, "Analysis of Hydrologic Properties Data." Submittal date: 08/25/1999.

LB991091233129.006. Thermal Properties and Tortuosity Factor for the UZ Model Layers. Submittal date: 10/15/1999.

8.5 SUPPORTING BIBLIOGRAPHY

Altman, S.J.; Arnold, B.W.; Barnard, R.W.; Barr, G.E.; Ho, C.K.; McKenna, S.A.; and Eaton, R.R. 1996. *Flow Calculations for Yucca Mountain Groundwater Travel Time (GWTT-95).* SAND96-0819. Albuquerque, New Mexico: Sandia National Laboratories. ACC: MOL.19961106.0109.

Cook, P.J.; Trautz, R.C.; and Wang, J.S.Y. 1998. "Compilation of Borehole Permeability Values from the Pre- and Post-Excavation Air Injection Tests." Chapter 3 of *Drift Seepage and Niche Moisture Study: Phase 1 Report on Flux Threshold Determination, Air Permeability Distribution, and Water Potential Measurement, Version 1.0.* Wang, J.S.Y. ed. Milestone Report SPC315M4. Berkeley, California: Lawrence Berkeley National Laboratory. ACC: MOL.19980806.0713.

Sonnenthal, E.L.; Ahlers, C.F.; and Bodvarsson, G.S. 1997. "Fracture and Fault Properties for the UZ Site-Scale Flow Model." Chapter 7 of *The Site-scale Unsaturated Zone Model of Yucca Mountain, Nevada, for the Viability Assessment.* Bodvarsson, G.S.; Bandurraga, T.M.; and Wu.

Y.S., eds. Report LBNL-40376. Berkeley, California: Lawrence Berkeley National Laboratory. ACC: MOL.19971014.0232.

Sweetkind, D.S. and Williams-Stroud, S.C. 1996. *Characteristics of Fractures at Yucca Mountain, Nevada.* Milestone Report 3GGF205M. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19961213.0181.

Sweetkind, D.S.; Barr, D.; Polacsek, D.; and Anna, L. 1997. *Administrative Report: Integrated Fracture Data in Support of Process Models.* Milestone Report SPG32M3. Denver, Colorado: U.S. Geological Survey. ACC: MOL.19971017.0726.

Tsang Y. W.; Wang, J.; Freifeld, B.; Cook, P.; Suarez-Rivera, R.; and Tokunaga, T. 1996. Letter Report on Hydrological Characterization of the Single Heater Test Area in the ESF. Milestone Report OS327322D1. Berkeley, California: Lawrence Berkeley National Laboratory. ACC: MOL.19971119.0549.

Tsang, Y.W. and Cook, P. 1997. *Ambient Characterization of the ESF Drift Scale Test Area by Field Air Permeability Measurements.* Milestone Report SP9512M4. Berkeley, California: Lawrence Berkeley National Laboratory. ACC: MOL.19971201.0829.

Tsang, Y.W. and Freifeld, B. 1998a. "Hydrological Baseline Measurements." Chapter 2 of *ESF Drift Scale Test As-Built Data and Baseline Measurements (Hydrological, Radar, and Microseismic). Milestone Report SPY193M4.* Berkeley, California: Lawrence Berkeley National Laboratory. ACC: MOL.19980527.0252.

Tsang, Y.W. and Freifeld, B. 1998b. "Hydrological Characterization Data." Chapter 3 of *ESF Drift Scale Test As-Built Data and Baseline Measurements (Hydrological, Radar, and Microseismic). Milestone Report SPY193M4.* Berkeley, California: Lawrence Berkeley National Laboratory. ACC: MOL.19980527.0252.

9. ATTACHMENTS

Attachment I - Document Reference Input Sheet

Attachment II - Supporting Data for the Calcutaions of Fracture Properties

Attachment III - Technical Data Information Form

Attachment IV - Software Routines

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ATTACHMENT I - DOCUMENT INPUT REFERENCE SYSTEM

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

1. Document Identifier No./Rev.: ANL-NBS-HS-000002/Rev.00			Change:	Title: Analysis of Hydrologic Properties Data					
Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
2a									
1.	DTN: GS000399991221.004. Preliminary Developed Matrix Properties. Submittal date: 3/10/2000.	Entire	N/A-Qualified-Verification Level 2	6.2	Matrix property and saturation	N/A	N/A	N/A	N/A
2.	DTN: GS930608312332.001. Outcrop-Fractures Orientation and Geometry in the Area of Raven Canyon. Submittal date: 06/30/1993. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data	N/A	N/A	N/A	N/A
3.	DTN: GS930608312332.002. Outcrop Fractures Orientation, Description and Geometry in the Area East of Little Skull Mountain, Nevada. Submittal date: 10/30/1993. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data	N/A	N/A	N/A	N/A

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	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
4.	DTN: GS950208312232.003. Data, Including Water Potential, Pressure and Temperature, Collected from Boreholes USW NRG-6 and USW NRG-7A from Instrumentation through March 31, 1995. Submittal date: 02/13/1995.	Water potential	N/A-Qualified-Verification Level 2	6.2	Calculation of in-situ water potentials for model layers	N/A	N/A	N/A	N/A
5.	DTN: GS951108312232.008. Data, Including Water Potential, Pressure and Temperature, Collected from Boreholes UE-25 UZ#4 & UZ#5 from Instrumentation through September 30, 1995, and from USW NRG-6 & NRG-7A from April 1 through September 30, 1995. Submittal date: 11/21/1995.	Water potential	N/A-Qualified-Verification Level 2	6.2	Calculation of In-situ water potentials for model layers	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
6.	DTN: GS960308312232.001. Deep Unsaturated Zone Surface-Based Borehole Instrumentation Program Data from Boreholes USW NRG-7A, USW NRG-6, UE-25 UZ#4, UE-25 UZ#5, USW UZ-7A, and USW SD-12 FOR the Time Period 10/01/95 through 3/31/96. Submittal date: 04/04/1996.	Water potential	N/A-Qualified-Verification Level 2	6.2	Calculation of in-situ water potentials for model layers	N/A	N/A	N/A	N/A
7.	DTN: GS960708314224.008. Provisional Results: Geotechnical Data for Station 30+00 to Station 35+00, Main Drift of the ESF. Submittal date: 08/05/1996.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
8.	DTN: GS960708314224.010. Provisional results: Geotechnical Data for Station 40+00 to Station 45+00, Main Drift of the ESF. Submittal date: 08/05/1996.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A
9.	DTN: GS960808312232.004. Deep Unsaturated Zone Surface-Based Borehole Instrumentation Program Data for Boreholes USW NRG-7A, USW N RG-6, UE-25 UZ#4, UE-25 UZ#5, USW UZ-7A and USW SD-12 for the Time Period 4/1/96 through 8/15/96. Submittal date: 08/30/1996.	Water potential	N/A-Qualified-Verification Level 2	6.2	Calculation of in-situ water potentials for model layers	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
10.	DTN: GS960808314224.011. Provisional results: Geotechnical Data for Station 35+00 to Station 40+00, Main Drift of the ESF. Submittal date: 08/29/1996.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A
11.	DTN: GS960908312232.012. Comparison of Air-Injection Permeability Values to Laboratory Permeability Values. Submittal date: 09/26/1996.	Column of Permeability data	TBV-3533	6.1	Air permeability	1	✓	N/A	N/A
12.	DTN: GS960908312232.013. Air-Injection Testing in Vertical Boreholes in Welded and Non-Welded Tuff, Yucca Mountain, Nevada. Submittal date: 09/26/1996.	Entire	N/A-Qualified-Verification Level 2	6.1	Air permeability	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
13.	DTN: GS960908314224.014. Provisional Results—ESF Main Drift, Station 50+00 to Station 55+00. Submittal date: 09/09/1996.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A
14.	DTN: GS960908314224.018. Provisional Results: Geotechnical Data for Alcove 5 (DWFA), Main Drift of the ESF. Submittal date: 09/09/1996. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
15.	DTN: GS960908314224.020. Analysis Report: Geology of the North Ramp - Stations 4+00 to 28+00 and Data: Detailed Line Survey and Full-Periphery Geotechnical Map - Alcoves 3 (UPCA) and 4 (LPCA), and Comparative Geologic Cross Section - Stations 0+60 to 28+00. Submittal date: 09/09/1996.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
16.	DTN: GS970108312232.002. Deep Unsaturated Zone, Surface-Based Borehole Instrumentation Program—Raw Data Submittal for Boreholes USW NRG-7A, USW NRG-6, UE-25 UZ#4, UE-25 UZ#5, USW UZ-7A, and USW SD-12, for the Period 8/16/96 through 12/31/96. Submittal date: 01/22/1997.	Water potential	N/A-Qualified-Verification Level 2	6.2	Calculation of in-situ water potentials for model layers	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
17.	DTN: GS970183122410.001. Results from Air-Injection and Tracer Testing in the Upper Tiva Canyon, Bowridge Fault, and Upper Paintbrush Contact Alcoves of the Exploratory Studies Facility, August 1994 through July 1996, Yucca Mountain, Nevada. Submittal date: 02/03/1997. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1 6.4	Air permeability	N/A	N/A	N/A	N/A
18.	DTN: GS970208314224.003. Geotechnical Data for Station 60+00 to Station 65+00, South Ramp of the ESF. Submittal date: 02/12/1997.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
19.	DTN: GS970308314222.001. Fracture Data from Natural Outcrops of the Calico Hills Formation and the Topopah Spring Tuff at 10 Locations in the Vicinity of Prow Pass, at the Head of Yucca Wash, North of Yucca Mtn, and 2 Locations at the NE End of Busted Butte, SE of Yucca Mtn. Submittal date: 03/26/1997. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	fracture data	N/A	N/A	N/A	N/A
20.	DTN: GS970408314222.003. Integrated Fracture Data in Support of Process Models, Yucca Mountain, Nevada. Submittal date: 04/21/1997. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture properties	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
21.	DTN: GS970808312232.005. Deep Unsaturated Zone Surface-Based Borehole Instrumentation Program Data from Boreholes USW NRG-7A, UE-2 5 UZ#4, UE-25 UZ#5, USW UZ-7A and USW SD-12 for the Time Period 1/1/97 - 6/30/97. Submittal date: 08/28/1997.	Water potential	N/A-Qualified-Verification Level 2	6.2	Calculation of in-situ water potentials for model layers	N/A	N/A	N/A	N/A
22.	DTN: GS970808314224.008. Provisional Results: Geotechnical Data for Station 65+00 to Station 70+00, South Ramp of the ESF. Submittal date: 08/18/1997.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
23.	DTN: GS970808314224.010. Provisional Results: Geotechnical Data for Station 70+00 to Station 75+00, South Ramp of the ESF. Submittal date: 08/25/1997.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A
24.	DTN: GS970808314224.012. Provisional Results: Geotechnical Data for Station 75+00 to Station 78+77, South Ramp of the ESF. Submittal date: 08/25/1997.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A
25.	DTN: GS970808314224.014. Provisional Results: Geotechnical Data for Alcove 6 and Alcove 6 Drill Alcove, Main Drift of the ESF. Submittal date: 08/25/1997. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	Calculation of fracture properties	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
26.	DTN: GS971108312232.007. Provisional Results: Geotechnical Data for Alcove 6 and Alcove 6 Drill Alcove, Main Drift of the ESF. Submittal date: 11/18/1997.	Water potential	N/A-Qualified-Verification Level 2	6.2	Calculation of in-situ water potentials for model layers	N/A	N/A	N/A	N/A
27.	DTN: GS971108314224.020. Revision 1 of Detailed Line Survey Data, Station 0+60 to Station 4+00, North Ramp Starter Tunnel, Exploratory Studies Facility. Submittal date: 12/03/1997.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A
28.	DTN: GS971108314224.021. Revision 1 of Detailed Line Survey Data, Station 4+00 to Station 8+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/03/1997.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
29.	DTN: GS971108314224.022. Revision 1 of Detailed Line Survey Data, Station 8+00 to Station 10+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/03/1997.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A
30.	DTN: GS971108314224.023. Revision 1 of Detailed Line Survey Data, Station 10+00 to Station 18+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/03/1997.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A
31.	DTN: GS971108314224.024. Revision 1 of Detailed Line Survey Data, Station 18+00 to Station 26+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/03/1997.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
32.	DTN: GS971108314224.025. Revision 1 of Detailed Line Survey Data, Station 26+00 to Station 30+00, North Ramp, Exploratory Studies Facility. Submittal date: 12/03/1997.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A
33.	DTN: GS971108314224.026. Revision 1 of Detailed Line Survey Data, Station 45+00 to Station 50+00, Main Drift, Exploratory Studies Facility. Submittal date: 12/03/1997.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
34.	DTN: GS971108314224.028. Revision 1 of Detailed Line Survey Data, Station 55+00 to Station 60+00, Main Drift and South Ramp, Exploratory Studies Facility. Submittal date: 12/03/1997.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data (location, length, strike, dip)	N/A	N/A	N/A	N/A
35.	DTN: GS980408312232.001. Deep Unsaturated Zone Surface-Based Borehole Instrumentation Program Data from Boreholes USW NRG-7A, UE-2 5 UZ #4, USW NRG-6, UE-25 UZ #5, USW UZ-7A and USW SD-12 for the Time Period 10/01/97 - 03/31/98. Submittal date: 04/16/1998.	Water potential	N/A-Qualified-Verification Level 2	6.2	Calculation of water potentials for model layers	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
36.	DTN: GS981108314224.005. Locations of Lithostratigraphic Contacts in the ECRB Cross Drift. Submittal date: 11/30/1998.	Entire	N/A - Qualified/Confirmed/Controlled	6.1.2	Lithostratigraphic contacts in the ESF	N/A	N/A	N/A	N/A
37.	DTN: GS990408314224.001. Detailed Line Survey Data for Stations 00+00.89 to 14+95.18, ECRB Cross Drift. Submittal Date: 09/09/1999.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture Data	N/A	N/A	N/A	N/A
38.	DTN: GS990408314224.002. Detailed Line Survey Data for Stations 15+00.85 TO 26+63.8, ECRB Cross Drift. Submittal Date: 09/09/1999.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture Data	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
39.	DTN: GS9908813122410.002. Qualified Data in "Results From Geothermal Logging, Air and Core-Water Chemistry Sampling, Air-Injection Testing and Tracer Testing in the Northern Ghost Dance Fault, November, 1996 - August, 1998." Submittal date: 08/16/1999.	Entire	N/A-Qualified-Verification Level 2	6.4	Fault fracture permeability	N/A	N/A	N/A	N/A
40.	DTN: LB960500834244.001. Hydrological Characterization of the Single Heater Test Area in ESF. Submittal date: 08/23/1996. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	Air permeability	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
41.	DTN: LB970600123142.001. Ambient Characterization of the ESF Drift Scale Test Area by Field Air Permeability Measurements. Submittal date: 06/13/1997. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	Air permeability	N/A	N/A	N/A	N/A
42.	DTN: LB980001233124.001. Water Potential Measurements in Niches 3566 and 3650. Submittal date: 04/23/1998.	Entire	N/A-Qualified-Verification Level 2	6.1	Air permeability	N/A	N/A	N/A	N/A
43.	DTN: LB980001233124.002. Air Permeability Testing in Niches 3566 and 3650. Submittal date: 04/23/1998	Entire	N/A-Qualified-Verification Level 2	6.1	Air permeability	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
44.	DTN: LB980120123142.004. Air Injections in Boreholes 57 through 61, 74 through 78, 185 and 186 in the Drift Scale Test Area. Submittal date: 01/20/1998. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	Air permeability	N/A	N/A	N/A	N/A
45.	DTN: LB980120123142.005. Hydrological Characterization by Air Injections Tests in Boreholes in Heated Drift in DST. Submittal date: 01/20/1998. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	Air permeability	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
46.	DTN: LB980901233124.001. Pneumatic Pressure and Air Permeability Data from Niches 3107 and 4788 in the ESF from Chapter 2 of Report SP33PBM4: Fracture Flow and Seepage Testing in the ESF, FY98. Submittal date: 09/14/1998. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	Air Permeability	N/A	N/A	N/A	N/A
47.	DTN: LB980901233124.002. Laboratory Imbibition, Tracer, and Seepage Tests in Niches 3566, 3650, 3107, and 4788 in the ESF. Submittal date: 09/14/1998. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	Air Permeability	N/A	N/A	N/A	N/A
48.	DTN: LB980901233124.003. Liquid Release and Tracer Tests in Niches 3566, 3650, 3107, and 4788 in the ESF. Submittal date: 09/14/1998. Initial use.	Characteristics and water content data	N/A-Qualified-Verification Level 2	6.5	Confirmation of fracture alpha & porosity	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
49.	DTN: LB980912332245.002. Gas Tracer Data from Niche 3107 of the ESF. Submittal date: 09/30/1998. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	fracture & porosity	N/A	N/A	N/A	N/A
50.	DTN: LB991091233129.005. Hydrologic Properties Data—Number of Matrix Permeability Non Detects. Submittal date: 10/22/1999. Initial Use.	Entire	N/A-Qualified-Verification Level 2	6.2	Calculation of matrix properties	N/A	N/A	N/A	N/A
51.	DTN: MO9901MWDGFM31.000. Geologic Framework Model. Submittal date: 01/06/1999.	Entire	TBV-3005 TBV-3582	6.2	Lithostratigraphy	1	✓	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
52.	DTN: SNF29041993002.084. Yucca Mountain Site Characterization Project Core Hole Rock Structural Data Summaries for Boreholes UE25 NRG-1, -2, -2A, -2B, -3, -4, -5; and USW NRG-6 and 7/7A, Revision 2. Submittal date: 07/09/1996. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data	N/A	N/A	N/A	N/A
53.	DTN: SNT05071897001.012. Source Data for Base Case Thermal Property Data for TSPA-VA (Total System Performance Assessment-Viability Assessment) (VA supporting data). Submittal date: 05/25/1999. Initial use.	Entire	TBV-3260	6.3	Calculation of thermal properties	1	✓	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
54.	DTN: TM000000SD12RS.012. USW SD-12 Composite Borehole Log (0.0' - 1435.3') and Weight Logs (1,438.8 - 2,151.7'). Submittal date: 09/08/1995. Initial use.	Entire	N/A-Qualified-Verification Level 2	6.1	Fracture data	N/A	N/A	N/A	N/A
55.	Bear, J.; Tsang, C.F.; and de Marsily, G. eds. 1993. *Flow and Contaminant Transport in Fractured Rock*. San Diego, California: Academic Press. TIC: 226388.	p.15	N/A-Reference only	6.1.2.2	Determination of fracture aperture	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
56.	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1998. *Geology of the Exploratory Studies Facility Topopah Spring Loop, Rev. 1.* BAB000000-01717-0200-00002. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19980415.0283.	Table 2, pp. 20-22 34-35 Fig. 5 Att. II	TBV	6.1.2.1 6.1.2.2	Lithostratigraphic contacts in the ESF	1	N/A	✓	N/A
57.	CRWMS M&O 1999a. *M&O Site Investigations.* Activity Evaluation. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990317.0330.	Entire	N/A-Reference only	2	Activity Evaluation	N/A	N/A	N/A	N/A
58.	CRWMS M&O 1999b. *M&O Site Investigations.* Activity Evaluation. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990928.0224.	Entire	N/A-Reference only	2	Activity Evaluation	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From -Uncontrolled Source	Un-confirmed
59.	CRWMS M&O 1999c. *Analysis & Modeling Development Plan (DP) for U0090 Analysis of Hydrologic Properties Data, Rev 00.* TDP-NBS-HS-000003. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990826.0105.	Entire	N/A - Reference only	2	Plan	N/A	N/A	N/A	N/A
60.	CRWMS M&O 1999d. *Development of Numerical Grids for UZ Flow and Transport Modeling.* ANL-NBS-HS-000015. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990721.0517.	Table 10	N/A – Reference only	6	FY99 UZ Model Layers	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
61.	Dyer, J.R. 1999. "Revised Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01, July 22, 1999), for Yucca Mountain, Nevada." Letter from J.R. Dyer (DOE) to D.R. Wilkins (CRWMS M&O), September 9, 1999, OL&RC: SB-1714, with enclosure, "Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations (Revision 01)." ACC: MOL.19990910.0079.	Entire	N/A-Reference only	4.2	Interim Guidance	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
62.	Flint, L.E. 1998. *Characterization of Hydrogeologic Units Using Matrix Properties, Yucca Mountain, Nevada.* Water-Resources Investigations Report 97-4243. Denver, Colorado: U.S. Geological Survey. TIC: 236515.	pp. 11-46	N/A - Reference only	6.2	Geologic layers	N/A	N/A	N/A	N/A
63.	Francis, N.D. 1997. "The Base-Case Thermal Properties for TSPA-VA Modeling." Memorandum from N.D. Francis (SNL) to Distribution, April 16, 1997. Albuquerque, New Mexico: Sandia National Laboratories. ACC: MOL.19980518.0229.	pp. 5-7	N/A - Reference only	6.3, 6.4.	Thermal Properties	N/A	N/A	N/A	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
64.	Hvorslev, M.J. 1951. "Time Lag and Soil Permeability in Ground-Water Observations." *U.S. Army Corps of Engineers Bulletin, 36.* Vicksburg, Mississippi: U.S. Army Corps of Engineers. TIC: 238956.	p.30	N/A - Reference only	6.1	Equation for permeability	N/A	N/A	N/A	N/A
65.	Kazemi, H. and J.R. Gilman. 1993. "Multiphase Flow in Fractured Petroleum Reservoirs" in J. Bear; C-F. Tsang; and G. de Marsily (eds.) *Flow and Contaminant Transport in Fractured Rock.* San Diego, California; Academic Press. TIC: 226388.	pp.270-271, 312-313	N/A – Reference only	6.1.4	Fracture porosity	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
66.	LeCain, G. D. 1995. *Pneumatic Testing in 45-Degree-Inclined Boreholes in Ash-Flow Tuff near Superior, Arizona.* Water-Resources Investigations Report 95-4073. Denver, Colorado: U.S. Geological Survey. TIC: 221220.	p.10	N/A - Reference only	6.1	Equation for permeability	N/A	N/A	N/A	N/A
67.	LeCain, G.D. 1997. *Air-Injection Testing in Vertical Boreholes in Welded and Nonwelded Tuff, Yucca Mountain, Nevada.* Water-Resources Investigations Report 96-4262. Denver, Colorado: U.S. Geological Survey. TIC: 233455.	2	N/A - Reference only	6.1.1	Fracture permeability	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
68.	LeCain, G.D. 1998. *Results from Air-Injection and Tracer Testing in the Upper Tiva Canyon, Bow Ridge Fault, and Upper Paintbrush Contact Alcoves of the Exploratory Facility, August 1994 through July 1996, Yucca Mountain, Nevada.* Water-Resources Investigations Report 98-4058. Denver, Colorado: U.S. Geological Survey. TIC: 237249.	p. 5 p. 21	N/A - Reference only	6.1.1 6.4	Air permeability	N/A	N/A	N/A	N/A
69.	Lin, M.; Hardy, M.P.; and Bauer, S.J. 1993. *Fracture Analysis and Rock Quality Designation Estimation for the Yucca Mountain Site Characterization Project.* Report SAND92-0449. Albuquerque, New Mexico: Sandia National Laboratories. ACC: NNA.19921204.0012.	p.24	N/A – Reference only	6.1.2.2	Correction of borehole observations	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
70.	Liu, H.H.; Doughty, C.; and Bodvarsson, G.S. 1998. "An Active Fracture Model for Unsaturated Flow and Transport in Fractured Rocks." *Water Resources Research, 34* (10), 2633–2646. Washington, D.C.: American Geophysical Union. TIC: 243012.	pp. 2633-2646	N/A - Reference only	5	Active Fracture Model	N/A	N/A	N/A	N/A
71.	National Research Council. 1996. *Rock Fractures and Fluid Flow, Contemporary Understanding and Applications.* Washington, D.C.: National Academy Press. TIC: 235913	pp. 292-293	N/A – Reference only	6.1.4	Fracture porosity	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
72.	Neuman, S.P. 1994. "Generalized Scaling of Permeabilities: Validation and Effect of Support Scale." *Geophysical Research Letters, 30* (21), 349–352. Washington, D.C.: American Geophysical Union. TIC: 240142.	pp. 349-352.	N/A - Reference only	6.1	Scale-dependent behavior of permeability	N/A	N/A	N/A	N/A
73.	Paleologos, E.K.; Neuman, S.P.; and Tatakovsky, D. 1996. "Effective Hydraulic Conductivity of Bounded, Strongly Heterogeneous Porous Media" *Water Resources Research, 32*, 1333–1341. Washington, D.C.: American Geophysical Union. TIC: 224599.	Fig. 4, p. 1337; p. 1336	N/A - Reference only	6.2	Upscaling of permeability.	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
74.	Philip, J.R.; Knight, J.H.; and Waechter, R.T. 1989. "Unsaturated Seepage and Subterranean Holes: Conspectus, and Exclusion Problem for Cylindrical Cavities." *Water Resources Research 25* (1), 16–28. Washington, D.C.: American Geophysical Union. TIC: 239117.	pp. 16-18, 23	N/A - Reference only	6.5.2	Theory of unsaturated seepage	N/A	N/A	N/A	N/A
75.	Rautman, R.A. and Engstrom, D.A. 1996. *Geology of the USW SD-12 Drill Hole, Yucca Mountain, Nevada.* Letter Report SAND96-1368, UC-814. Albuquerque, New Mexico: Sandia National Laboratories. ACC: MOL.19961219.0271.	N/A	N/A-Reference only	N/A	N/A	N/A	N/A	N/A	N/A

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2. Technical Product Input Source Title and Identifier(s) with Version		3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
76.	Rousseau, J.P.; Kwicklis, E.M.; and Gillies, D.C., eds. 1999. *Hydrogeology of the Unsaturated Zone, North Ramp Area of the Exploratory Studies Facility, Yucca Mountain, Nevada.* Water-Resources Investigations Report 98-4050. Denver, Colorado: U.S. Geological Survey. TIC: 243099.	pp. 125-153	N/A - Reference only	6.2	In-situ water potential measurement.	N/A	N/A	N/A	N/A
77.	van Genuchten, M. 1980. "A Closed-Form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils." *Soil Science Society of America Journal, 44* (5), 892–898. Madison, Wisconsin: Soil Science Society of America. TIC: 217327.	Pp. 892-893	N/A - Reference only	5.	van Genuchten relations and parameters	N/A	N/A	N/A	N/A

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78.	Wang J.S.Y. and Narasimhan T.N. 1993. "Unsaturated Flow in Fractured Porous Media." Chapter 7 of *Flow and Contaminant Transport in Fractured Rocks*. Bear, J.; Tsang, C-H; and de Marsily, G., eds. San Diego, California: Academic Press. TIC: 235461.	p. 374	N/A-Reference only	6.1	Van Genuchten α	N/A	N/A	N/A	N/A
79.	Wemheuer, R.F. 1999. "First Issue of FY00 NEPO QAP-2-0 Activity Evaluations." Interoffice correspondence from R.F. Wemheuer (CRWMS M&O) to R.A. Morgan (CRWMS M&O), October 1, 1999, LV.NEPO.RTPS.TAG.10/99-155, with attachments, Activity Evaluation for Work Package #1401213UM1. ACC: MOL.19991028.0162.	Work Package #1401213UM1.	N/A-Reference only	N/A	N/A	N/A	N/A	N/A	N/A

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ATTACHMENT II - DATA USEDIN THE CALCULATIONS OF FRACTURE PROPERTIES

The following tables provide data for the calculation of fracture properties discussed in Section 6.1.

Table II-1: Air Permeability Data from Air Injection Testing

Vertical Boreholes LeCain, 1997 DTN: GS960908312232.012 DTN: GS960908312232.013			UPCA Upper PTn Contact Alcove (Alcove 3) LeCain, 1998 DTN: GS970183122410.001			SHT Observation Drift DTN: LB970600123142.001
Borehole	Unit	k (m^2)	Borehole	Unit	k (m^2)	k (m^2)
uz-16	Tac	2.48E-14	RBT #1	Tpcpinc	1.6E-12	4.5E-13
nrg-7a	Tpcpv1	1.20E-13	RBT #1	Tpcpinc	2E-13	9E-14
nrg-7a	Tpcpv1	2.87E-13	RBT #4	Tpcpinc	2E-12	4.7E-13
nrg-7a	Tpy	2.12E-13	RBT #4	Tpcpinc	2E-14	3.4E-13
nrg-7a	Tpy	2.40E-13	RBT #4	Tpcpinc	6E-14	4.1E-14
nrg-7a	Tpy	2.65E-13	RBT #4	Tpcpinc	4E-13	2E-12
nrg-7a	Tpy	5.92E-13	RBT #4	Tpcpinh	4E-13	4.8E-13
nrg-7a	Tpbt3	2.97E-12	RBT #4	Tpcpinh	4.7E-12	1.4E-13
nrg-7a	Tpp	1.24E-13	RBT #4	Tpcpinh	1.7E-12	4.9E-13
nrg-7a	Tpp	1.37E-13	RBT #4	Tpcpinh	1E-13	4.2E-13
nrg-7a	Tpp	1.40E-13	RBT #4	Tpcpinh	6.2E-12	1E-13
nrg-7a	Tpp	1.50E-13	RBT #4	Tpcpinh	3.1E-12	3E-13
nrg-7a	Tpp	2.01E-13	RBT #4	Tpcpinh	1.2E-11	7.8E-14
nrg-7a	Tpp	2.10E-13	RBT #4	Tpcpinh	6.2E-12	2.4E-14
nrg-7a	Tpp	2.19E-13	RBT #4	Tpcpinh	1E-12	6.2E-15
nrg-7a	Tpp-Tpbt2-Tptrv3	2.18E-13	RBT #4	Tpcpinh	2.3E-12	4.4E-13
nrg-6	Tpcpinc	2.78E-13	RBT #4	Tpcpinh	2.9E-12	3.5E-14
nrg-6	Tpcpinc	2.29E-12	RBT #1	Tpcpv2	9.3E-12	4.4E-13
nrg-6	Tpcpll	1.40E-11	RBT #1	Tpcpv2	4.11E-11	1.2E-13
nrg-6	Tpcpll-Tpcpinh	2.82E-11	RBT #1	Tpcpv1	5.7E-11	1.3E-12
nrg-7a	Tpcpinc	1.09E-11	RBT #1	Tpcpv1	3.39E-11	3.4E-14
nrg-7a	Tpcpinc	4.06E-11	RBT #1	Tpcpv1	1.5E-11	6.1E-14
nrg-7a	Tpcpinh-Tpcpinc	5.39E-11	RBT #1	Tpcpv1	4E-13	9.5E-15
sd-12	Tpcpinc	7.71E-13	RBT #1	Tpcpv1	1.3E-11	4.5E-14
sd-12	Tpcpll-Tpcpinh	9.16E-13	RBT #1	Tpcpv1	1.1E-12	6.8E-15
sd-12	Tpcpll	9.23E-13	RBT #1	Tpcpv1	7.7E-12	1.4E-13
sd-12	Tpcpinh	1.66E-12	RBT #1	Tpcpv1	9E-13	1.1E-14
sd-12	Tpcpinc	2.10E-12	RBT #1	Tpcpv1	1.9E-12	5.8E-14
sd-12	Tpcpinc-Tpcpv2	3.16E-12	RBT #1	Tpcpv1	1.7E-11	4.1E-15
sd-12	Tpcpinc	5.86E-12	UTCA Upper Tiva Canyon Alcove (Alcove 1) LeCain, 1998 DTN: GS970183122410.001			6.1E-14
sd-12	Tpcpinh-Tpcpinc	5.97E-12				2.4E-14
sd-12	Tpcpinc-Tpcpv2	6.77E-12				8.8E-16
sd-12	Tpcpinh-Tpcpinc	1.10E-11				1E-13
sd-12	Tpcpll	3.83E-11				1.1E-13
uz-16	Tpcpll/Tpcpinh	1.50E-12	Borehole	Unit	k (m^2)	1.9E-15
uz-16	Tpcpll	5.48E-12	RBT #1	Tpcpul	5.5E-12	2.7E-13
uz-16	Tpcpinc	1.50E-11	RBT #1	Tpcpul	1.13E-11	2.1E-13
uz-16	Tpcpinh/Tpcpinc	2.74E-11	RBT #1	Tpcpul	3.4E-12	1.9E-14
nrg-7a	Tpcpinc-Tpcpv2	2.42E-13	RBT #1	Tpcpul	2.3E-12	6.6E-14
nrg-6	Tptrn	8.15E-14	RBT #1	Tpcpul	2.4E-11	4.9E-13
nrg-6	Tptrn	1.30E-13	RBT #1	Tpcpul	2.7E-11	5.5E-14
nrg-6	Tptrn	1.68E-13	RBT #1	Tpcpul	3.2E-12	
nrg-6	Tptrn	1.87E-13	RBT #2	Tpcpul	4.7E-11	

Table II-1 (cont.)

nrg-6	Tptrn	3.23E-13
nrg-6	Tptrn	4.32E-13
nrg-6	Tptrn	4.60E-13
nrg-6	Tptrn	6.44E-13
nrg-6	Tptrn	6.50E-13
nrg-6	Tptrn	6.74E-13
nrg-6	Tptrn	6.78E-13
nrg-6	Tptrn	9.19E-13
nrg-6	Tptrn	9.43E-13
nrg-6	Tptrn	1.06E-12
nrg-6	Tptrn	1.06E-12
nrg-6	Tptrn	2.21E-12
nrg-6	Tptrn	2.56E-12
nrg-6	Tptrn	3.04E-12
nrg-6	Tptrn	3.70E-12
nrg-6	Tptrn	2.37E-11
nrg-7a	Tptrn	3.47E-14
nrg-7a	Tptrn	2.58E-13
nrg-7a	Tptrn	4.00E-13
sd-12	Tptrn	1.20E-13
sd-12	Tptrn	1.85E-13
sd-12	Tptrn	5.45E-13
sd-12	Tptrn	6.40E-13
sd-12	Tptrn	1.02E-12
sd-12	Tptrn	8.95E-12
sd-12	Tptrn	2.92E-11
uz-16	Tptrn	6.45E-13
nrg-6	Tptpul	2.39E-13
nrg-6	Tptrl	2.49E-13
nrg-6	Tptpul	1.91E-12
nrg-6	Tptpul	2.08E-12
nrg-6	Tptpul	3.61E-12
nrg-6	Tptpul	1.25E-11
nrg-7a	Tptrl	6.09E-14
nrg-7a	Tptrl	1.54E-13
nrg-7a	Tptpul	1.67E-13
nrg-7a	Tptpul	1.90E-13
nrg-7a	Tptrl	2.47E-13
nrg-7a	Tptpul	2.77E-13
nrg-7a	Tptpul	2.79E-13
nrg-7a	Tptpul	3.00E-13
nrg-7a	Tptpul	3.18E-13
nrg-7a	Tptpul	4.24E-13
nrg-7a	Tptpul	4.50E-13
nrg-7a	Tptpul	4.71E-13
sd-12	Tptpul	7.23E-13
sd-12	Tptpul	1.10E-12
sd-12	Tptpul	2.71E-12
sd-12	Tptpul	4.18E-12
sd-12	Tptpul	1.84E-11
uz-16	Tptpul	1.36E-12
uz-16	Tptpul	1.68E-12
uz-16	Tptpul	2.12E-12
uz-16	Tptpul	2.19E-12
nrg-6	Tptpmn	1.58E-13
nrg-6	Tptpmn	2.58E-13
nrg-6	Tptpmn	4.67E-13

RBT #2	Tpcpul	3E-11
RBT #2	Tpcpul	2.9E-11
RBT #2	Tpcpul	2.6E-11
RBT #2	Tpcpul	2.6E-11
RBT #2	Tpcpul	4.9E-11
RBT #2	Tpcpul	7.6E-11
RBT #2	Tpcpul	8E-13
RBT #2	Tpcpul	2.8E-11
RBT #2	Tpcpul	8.1E-11
RBT #2	Tpcpul	6.6E-11
RBT #2	Tpcpul	3E-11
RBT #2	Tpcpul	1.17E-11
RBT #3	Tpcpul	1.5E-11
RBT #3	Tpcpul	2.8E-11
RBT #3	Tpcpul	2.7E-11
RBT #3	Tpcpul	8.5E-11
RBT #3	Tpcpul	2E-13
RBT #3	Tpcpul	2.3E-11
RBT #3	Tpcpul	1.65E-11

BRFA

Bow Ridge Fault Alcove (Alcove 2)

LeCain, 1998

DTN: GS970183122410.001

Borehole	Unit	k (m²)
HPF #1	Tpcpmn	8.1E-12
HPF #1	Tpcpmn	1.37E-11
HPF #1	Tpcpmn	2.1E-11
HPF #1	Tpcpmn	2.16E-11
HPF #1	Tpcpmn	2.64E-11
HPF #1	Tpcpmn	8E-12
HPF #1	Tpcpmn	6.1E-12
HPF #1	Tpcpmn	6E-12
HPF #1	Tpcpmn-ll	1.1E-12
HPF #1	Tpcpll	9E-13
HPF #1	Tpcpll	6E-13
HPF #1	Tpcpll	2E-12
HPF #1	Tpcpll	1.7E-12
HPF #1	Tpcpll	1.5E-12
HPF #1	Tmbtl	4.13E-11
HPF #1	Tmbtl	2.2E-11

DST

Heated Drift Boreholes

DTN:LB980120123142.005

k (m²)
7.01E-15
1.12E-13
2.33E-13
1.26E-11
2.89E-12
5.22E-13
2.79E-13
3.32E-14
5.29E-14
3.59E-13
3.76E-13
3.44E-13
8.63E-14
1.17E-13
3.72E-13
8.02E-14
3.1E-13
1.02E-14
1.79E-14
7.05E-13
4.61E-13
7.36E-13
1.03E-12
8.26E-13
1.26E-12
1.51E-11
2.26E-12

DST

Hydrology Boreholes

DTN: LB980120123142.004

k (m²)
1.46E-13
2.26E-13
1.58E-15
4.37E-13
1.74E-13
2.15E-13
8.45E-13
1.27E-13
1.45E-13
4.04E-13
3.11E-13
9.69E-13
3.62E-13
2.13E-13
4.98E-13
1.35E-14
9.85E-15
2.04E-13

Table II-1 (cont.)

nrg-6	Tptpmn	9.16E-13		2.61E-13
nrg-6	Tptpmn	9.25E-13		8.99E-13
nrg-6	Tptpmn	1.55E-12		4.68E-14
nrg-6	Tptpmn	3.11E-12		8.23E-14
nrg-7a	Tptpmn	9.00E-14		2.65E-13
nrg-7a	Tptpmn	1.89E-13		6.12E-14
nrg-7a	Tptpmn	2.26E-13		1.44E-13
nrg-7a	Tptpmn	2.60E-13		1.21E-13
nrg-7a	Tptpmn	2.70E-13		2.95E-13
nrg-7a	Tptpmn	2.39E-12		1.46E-13
sd-12	Tptpmn	3.67E-13		1.53E-13
sd-12	Tptpmn	8.65E-13		7.24E-13
sd-12	Tptpmn	1.24E-12		2.64E-13
sd-12	Tptpmn	2.01E-12		1.29E-13
sd-12	Tptpmn	2.04E-12		6.76E-14
sd-12	Tptpmn	2.51E-12		8.62E-14
sd-12	Tptpmn	9.64E-12		1.4E-13
uz-16	Tptpmn	2.34E-14		3.57E-13
uz-16	Tptpmn	4.63E-14		3.91E-13
uz-16	Tptpmn	8.59E-14		4.21E-14
uz-16	Tptpmn	1.37E-13		2.56E-14
uz-16	Tptpmn	1.40E-13		2.74E-14
uz-16	Tptpmn	1.42E-13		2.75E-14
uz-16	Tptpmn	1.50E-13		3.94E-13
uz-16	Tptpmn	1.90E-13		2.02E-13
uz-16	Tptpmn	2.29E-13		4.64E-14
uz-16	Tptpmn	2.31E-13		5.49E-14
uz-16	Tptpmn	2.92E-13		1.09E-13
uz-16	Tptpmn	3.10E-13		3.46E-13
uz-16	Tptpmn	5.89E-13		2.07E-13
uz-16	Tptpmn	6.11E-13		9.26E-14
uz-16	Tptpmn	9.52E-13		3.8E-13
uz-16	Tptpmn	1.04E-12		2.01E-13
uz-16	Tptpmn	1.18E-12		2.71E-14
nrg-7a	Tptpll	1.49E-13		7.34E-15
nrg-7a	Tptpll	1.65E-13		8.68E-15
nrg-7a	Tptpll	1.74E-13		Single Heater
nrg-7a	Tptpll	1.80E-13		DTN: LB960500834244.001
nrg-7a	Tptpll	1.86E-13		k (m^2)
nrg-7a	Tptpll	2.02E-13		1.6E-13*
nrg-7a	Tptpll	2.22E-13		7.2E-14
nrg-7a	Tptpll	4.12E-13		1.8E-13
nrg-7a	Tptpll	4.31E-13		9.2E-15
nrg-7a	Tptpll	4.41E-13		3.7E-14*
nrg-7a	Tptpll	4.86E-13		2.3E-12*
nrg-7a	Tptpll	5.19E-13		1.2E-14
nrg-7a	Tptpll	6.26E-13		5.2E-12
nrg-7a	Tptpll	6.43E-13		2.1E-13
nrg-7a	Tptpll	1.20E-12		6.6E-14
uz-16	Tptpll	4.14E-13		1.4E-14
uz-16	Tptpll	4.97E-13		8.3E-15
uz-16	Tptpll	6.68E-13		2.8E-12
uz-16	Tptpll	1.35E-12		8.8E-14
uz-16	Tptpll	2.20E-12		1.6E-13
uz-16	Tptpll	2.22E-12		9.9E-15
uz-16	Tptpll	2.31E-12		
uz-16	Tptpll	2.42E-12		

* Average of measurements from same borehole

Table II-1 (cont.)

uz-16	Tptpll	3.04E-12		5E-15
uz-16	Tptpll	3.06E-12		1.2E-14
uz-16	Tptpll	3.11E-12		4.6E-13
uz-16	Tptpll	3.19E-12		1.1E-12
uz-16	Tptpll	3.45E-12		5.1E-15
uz-16	Tptpll	5.31E-12		
uz-16	Tptpll	8.40E-12		
uz-16	Tptpll	9.50E-12		
sd-12	Tptpln	6.12E-13		
sd-12	Tptpln	1.01E-12		
sd-12	Tptpln	1.05E-12		
sd-12	Tptpln	1.58E-12		
sd-12	Tptpln	1.58E-12		
sd-12	Tptpln	1.94E-12		
uz-16	Tptpln	3.45E-13		
uz-16	Tptpln	6.44E-13		
uz-16	Tptpln	6.69E-13		
uz-16	Tptpln	1.12E-12		
uz-16	Tptpln	1.25E-12		
uz-16	Tptpln	1.31E-12		
uz-16	Tptpln	1.44E-12		
uz-16	Tptpln	1.45E-12		
uz-16	Tptpln	1.64E-12		
uz-16	Tptpln	2.00E-12		
uz-16	Tptpln	2.29E-12		
uz-16	Tptpln	4.14E-12		
uz-16	Tptpln	5.83E-12		

Table II-2: Corresponding UZ Model Layers Along the ESF and ECRB Cross-Drift, (see section 6.1.2.1)

Distance (m) along the ESF		
Unit	start	end
tcw12	61.7	198.6
tcw11	348.8	435.2
tcw12	441.9	776.5
tcw13	776.5	793.6
ptn21	793.6	869.3
ptn24	875.8	894.6
ptn25	894.6	1021
ptn26	1021	1075.7
tsw31	1075.7	1191
tsw32	1191	1716
tsw33	1716	2720
tsw34	2720	5729.2
tsw35	5729.2	5878.3
tsw34	5878.3	6308
tsw33	6308	6324.2
tsw33	6327.5	6507.7
tsw32	6507.7	6525.2
tsw32	6527.4	6632.8
tsw31	6632.8	6637.5
ptn26	6637.5	6680.7
ptn24	6680.7	6694
ptn21	6697.5	6718.5
tcw13	6718.5	6725.5
tcw12	6725.5	6761.4
tcw13	6761.4	6769.4
tcw12	6769.4	6787.5
tsw33	6791.8	6885
tsw32	6885	6990.3
tsw31	6990.3	6996.5
ptn26	6996.5	7057.4
tsw34	7057.4	7100
tsw34	7143	7167.5
tsw33	7167.5	7255
tsw33	7290	7341.5
tsw32	7341.5	7440
tsw31	7440	7451.9
ptn26	7451.9	7476.3
ptn25	7476.3	7481.3
ptn24	7481.3	7494
ptn21	7495.4	7507.8
tcw13	7507.8	7514.2
tcw12	7514.2	7875

Distance(m) Along Alcove 4		
unit	start	end
ptn26	0	22.2
ptn26	29.55	51.0

Distance(m) Along Alcove 5		
unit	start	end
tsw34	0	12.0
tsw34	0	15.0
tsw34	0	14.0

Distance(m) Along Alcove 6		
unit	start	end
tsw34	0	24.0
tsw34	0	175.0

Distance(m) Along ECRB Cross Drift		
unit	start	end
tsw33	0	1015
tsw34	1015	1444
tsw35	1444	2326
tsw36/37	2326	2583

Table II-3: Converting Fracture Data from ESF and ECRB Cross Drift, (see section 6.1.2.3)

Fracture Properties for Fractures > 1 m in Length (Based on DLS of ESF and ECRB Cross Drift)				Ratios for Converting Fracture Properties Data (Based on ESF Stations 0 to 37+80)		
Unit	Frequency (1/m)	Intensity (m/m^2)	Inter Area (m^2/m^3)	Ratio for Frequency (-)	Ratio for Intensity (-)	Ratio for Inter Area (-)
tcw11	0.89	0.474	1.478	1.03	1.01	1.05
tcw12	1.36	0.705	6.909	1.40	1.09	1.94
tcw13	1.70	0.585	1.695	1.64	1.18	2.22
ptn21	0.70	0.346	1.105	0.96	0.98	0.90
ptn24	0.46	0.338	1.558	1	1	0.22
ptn25	0.58	0.496	1.476	0.89	0.98	0.74
ptn26	0.69	0.292	2.002	1.41	1.09	1.78
tsw31	1.12	0.333	1.454	1.94	1.35	2.66
tsw32	1.01	0.576	2.504	1.11	1.04	1.28
tsw33	0.54	0.331	1.916	1.50	1.09	2.32
tsw34	2.49	1.056	5.147	1.74	1.19	2.63

Corrected Fracture Properties

Frequency (1/m)	Intensity (m/m^2)	Inter Area (m^2/m^3)
0.92	0.48	1.56
1.91	0.77	13.39
2.79	0.69	3.77
0.67	0.34	1.00
0.46	0.34	0.34
0.52	0.49	1.09
0.97	0.32	3.56
2.17	0.45	3.86
1.12	0.60	3.21
0.81	0.36	4.44
4.32	1.26	13.54

Table II-4: Fracture Data from Boreholesa Used for Model Layers tsw35-tsw38

UZ model layers	1997 model layers[b]	Fracture Frequency[c] # /10 ft	Fracture Frequency[d] 1/m	Dip Distribution[c] 0-19	20-39	40-59	60-90	Frequency Adjusted for Bias in Orientation[e] 1/m
ptn25	ptn24	6.6	2.17	17%	10%	27%	47%	5.50
tsw34	tsw34	22.5	7.38	13%	12%	15%	60%	20.97
tsw35	tsw35	15.6	5.12	14%	11%	8%	67%	15.35
tsw3[6,7]	tsw36	21.6	7.09	15%	18%	8%	58%	19.51
tsw38	tsw37	23.9	7.84	15%	19%	11%	55%	21.14

Notes:

[a]Only the data used for this AMR are listed here

[b]Model layers used in DTN: GS970408314222.003

[c]Fracture frequencies from DTN: GS970408314222.003 already normalized for core recovery

[d]Fracture frequency in meters (10 ft = 3.048 m)

[e]Using Equation 3

Table II-5: Fracture Data Used from Boreholes SD-12 and NRG-7a[a]
(DTN: TM000000SD12RS.012 and SNF29041992002.084

UZ model layers	SD-12 Interval Length[b] (m)	Fracture Frequency[c] (1/m)	NRG-7a Interval Length[d] (m)	Fracture Frequency[c] (1/m)	Fracture Frequency[e] (1/m)	Fracture Frequency[f] (1/m)
tsw39	12.19	4.20	9.14	5.29	4.67	0.96
ch1Ze	9.14	0.38	NA	NA	0.38	0.04
ch1V1	12.19	0.29	6.1	2.49	1.02	0.1
CH	28.955	0.27	9.15	5.46	1.5	0.14

Notes:

[a]Only the data used for this AMR is listed here
[b]From boring logs in Rautman and Engstrom (1996, Table 3 on pp. 10-11, Appendix B on pp.55-88)
[c]After normalizing for core recovery and correcting for bias in orientation
[d]From boring logs
[e]Average weighted by core length
[f]Corrected to represent larger fracture lengths

ATTACHMENT III - TECHNICAL DATA INFORMATION FORM

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TECHNICAL DATA INFORMATION FORM

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☐ ACQUIRED DATA DTN: LB990501233129.001

☒ DEVELOPED DATA Preliminary Data: ____

PART I Identification of Data

Title of Data: FRACTURE PROPERTIES FOR THE UZ MODEL GRIDS AND UNCALIBRATED FRACTURE AND MATRIX PROPERTIES FOR THE UZ MODEL LAYERS.

Description of Data: FRACTURE FREQUENCIES, APERTURES, FRACTURE POROSITIES, FRACTURE INTERFACE AREAS, UNCALIBRATED VAN GENUCHTEN FRACTURE ALPHAS AND M, AND UNCALIBRATED FRACTURE PERMEABILITIES FOR

Data Originator/Preparer: WU, Y S
Last Name First and Middle Initials

Data Originator/Preparer Organization: LAWRENCE BERKELEY NATIONAL LABORATORY

Qualification Status: ☒ Q ☐ Un-Q ☐ Accepted Governing Plan: SCP

SCP Activity Number(s): 8.3.1.2.2.9

WBS Number(s): 1.2.3.3.1.2.9

PART II Data Acquisition/Development Information

Method: COMPILATION AND ANALYSIS OF AVAILABLE SITE DATA.

Location(s): LBNL

Period(s): 3/29/1999 to 8/4/1999
From: MM/DD/YY To: MM/DD/YY

Sample ID Number(s): ____

PART III Source Data DTN(s)

GS930608312332.001	GS951108312232.008	GS960708314224.010
GS930608312332.002	GS960308312232.001	GS960808312232.004
GS950208312232.003	GS960708314224.008	GS960808314224.011

Comments

THIS PROPERTY SET INCLUDES BOTH FRACTURE AND MATRIX PROPERTIES. USED FOR DEVELOPMENT OF DUAL-K GRID (AMR U0000 DEVELOPMENT OF NUMERICAL GRIDS FOR UZ FLOW AND TRANSPORT MODELING) AND INITIAL ESTIMATES FOR

Checked by: Suzanne M. Link August 25, 1999
Signature Date

AP-SIII.3Q

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TECHNICAL DATA INFORMATION
CONTINUATION SHEET

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Description of Data (continued)

UZ MODEL LAYERS DETERMINED OR CALCULATED FROM SURVEY DATA FROM THE EXPLORATORY STUDIES FACILITY (ESF), EAST-WEST CROSS DRIFT, OR BOREHOLES AND AIR INJECTION TESTING IN BOREHOLES AND ESF. MATRIX POROSITY, MATRIX RESIDUAL AND SATIATED SATURATION, UNCALIBRATED MATRIX VAN GENUCHTEN PARAMETERS ALPHA AND M, AND UNCALIBRATED MATRIX PERMEABILITY DETERMINED OR CALCULATED FROM IN-SITU MEASUREMENTS OF WATER POTENTIAL AND LABORATORY TESTING CORE. FRACTURE PERMEABILITIES, FRACTURE VAN GENUCHTEN ALPHAS AND M ARE INITIAL ESTIMATES FOR CALIBRATION PROCEDURE AND SHOULD NOT BE USED DIRECTLY IN THE UZ MODEL OR ANY OTHER MODEL. DETAILS PROVIDED IN AMR U0090 ANALYSIS OF HYDROLOGIC PROPERTIES DATA.

Source Data DTN(s) (continued)

GS960908312232.013
GS960908314224.014
GS960908314224.018
GS960908314224.020
GS970108312232.002
GS970183122410.001
GS970208314224.003
GS970308314222.001
GS970408314222.003
GS970808312232.005
GS970808314224.008
GS970808314224.010
GS970808314224.012
GS970808314224.014
GS971108312232.007
GS971108314224.020
GS971108314224.021
GS971108314224.022
GS971108314224.023
GS971108314224.024
GS971108314224.025
GS971108314224.026
GS971108314224.028
GS980408312232.001
GS980908312242.039
GS980908312242.041
LB960500834244.001
LB970600123142.001
LB980120123142.004
SNF29041993002.084
TM000000SD12RS.012

Comments (continued)

CALIBRATION OF HYDROLOGIC PARAMETERS FOR UZ MODEL SIMULATIONS (AMRU0035 CALIBRATED PROPERTIES MODEL). ADDITIONAL SOURCE DATA USED IN THIS PROPERTY SET: MOL.19971119.0549, MOL.19971201.0829, MOL.19980527.0252, AND MOL.19971017.0726. DATA SETS UNDER DTNS: GS990408314224.001 AND GS990408314224.002 WERE ALSO USED AS SOURCE DATA; ALTHOUGH THESE DTNS ARE NOT CURRENTLY IN THE SYSTEM, THE DATA HAVE BEEN REQUESTED OFFICIALLY THROUGH AP-3.15Q.

AP-SIII.3Q

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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT TECHNICAL DATA INFORMATION FORM

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☐ ACQUIRED DATA DTN: LB991091233129.006

☒ DEVELOPED DATA Preliminary Data: ____

PART I Identification of Data

Title of Data: THERMAL PROPERTIES AND TORTUOSITY FACTOR FOR THE UZ MODEL LAYERS FOR AMR U0090, "ANALYSIS OF HYDROLOGIC PROPERTIES DATA."

Description of Data: THERMAL PROPERTIES AND TORTUOSITY FACTOR FOR THE UZ MODEL LAYERS. AMR U0090. ANL-NBS-HS-000002, MOL.19990721.0519. SR/LA SUPPORTING DATA.

Data Originator/Preparer: WU, Y S (Last Name / First and Middle Initials)

Data Originator/Preparer Organization: LAWRENCE BERKELEY NATIONAL LABORATORY

Qualification Status: ☐ Q ☒ Un-Q ☐ Accepted Governing Plan: SCP

SCP Activity Number(s): 8.3.1.2.2.9

WBS Number(s): 1.2.3.3.1.2.9

PART II Data Acquisition/Development Information

Method: ANALYSIS AND SPREADSHEET CALCULATION OF SOURCE DATA USED TO DERIVE PROPERTIES FOR THE UZ MODEL LAYERS.

Location(s): LBNL

Period(s): 4/13/1999 to 9/1/1999 (From: MM/DD/YY To: MM/DD/YY)

Sample ID Number(s): ____

PART III Source Data DTN(s)

MO9901MWDGFM31.000

SNT05071897001.012

Comments

N/A

Checked by: Suzanne M. Link (Signature) October 20, 1999 (Date)

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CONTINUATION SHEET

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Title of Data (continued)

"CALIBRATED PROPERTIES MODEL."

Description of Data (continued)

ANL-NBS-HS-000002, MOL.19990721.0519 AND AMR U0035, MDL-NBS-HS-000003, MOL.19990721.0520. SR/LA SUPPORTING DATA.

Source Data DTN(s) (continued)

GS950608312231.006
GS950608312231.007
GS950608312231.008
GS951108312231.009
GS951108312231.010
GS951108312231.011
GS960808312231.001
GS960808312231.002
GS960808312231.003
GS960808312231.004
GS960808312231.005

Comments (continued)

LBL-USG-99247.T.

AP-SIII.3Q

CAPFIT v.1.0
Routine/Macro Documentation Form

The following information can be included in the scientific notebook. Attach and reference notebook pages and diskettes with files as needed when submitting routine/macro to records.

1. Name of routine/macro with version/OS/hardware environment:
   CAPFIT v.1.0 (routine) / UNIX Solaris /Sun workstation

   CAPFIT (CAPpillary pressure curve FITting for two-phase drainage and imbibition data), v1.0

2. Name of commercial software with version/OS/hardware used to develop routine/macro:
   FORTRAN compiler 77-03/UNIX SUNOS Solaris /Sun workstation

3. **Description and Test Plan.**

   - Explain whether this is a routine or macro and describe what it does:
     This routine is used in the development of Van Genuchten fracture parameters used in the flow and transport for the UZ. CAPFIT v1.0 fits a curve to water potential and saturation data points to obtain the Van Genuchten (1980) fitting parameters 'α' and 'n' with parameter m=1-1/n (see pp. 39-45 from S/N YMP-LBNL-GSB-MC-1.2).

   - Source code: (including equations or algorithms from software setup (LabView, Excel, etc.):
     The source code is attached to this form

   - Description of test(s) to be performed (be specific):
     pp. 39 from S/N YMP-LBNL-GSB-MC-1.2

   - Specify the range of input values to be used and why the range is valid
     The specific range of parameters tested is similar to the range of parameters found at Yucca Mountain. The two scenarios run in the test case use parameters that fully encompass any possible values. For the specific input range used see pp. 40 and 41, from S/N YMP-LBNL-GSB-MC-1.2.

4. **Test Results.**

   - Output from test (explain difference between input range used and possible input)
     pp. 42– 45 from S/N YMP-LBNL-GSB-MC-1.2

   - Description of how the testing shows that the results are correct for the specified input.
     pp. 44 – 45 from S/N YMP-LBNL-GSB-MC-1.2

   - List limitations or assumptions to this test case and code in general
     Values for Se and α must be appropriate for the hydrogeologic conditions at the site being modeled.

   - Electronic files identified by name and location (include disc if necessary)
     None

CAPFIT v.1.0
Routine/Macro Documentation Form

5. Supporting Information. Include background information, such as revision to a previous routine or macro, or explanation of the steps performed to run the software. Include listings of all electronic files and codes used. Attach Scientific Notebook pages with appropriate information annotated.

See attached pages for technical review forms, referenced scientific notebook pages and other supporting documentation.

Note: All relevant scientific notebook (SN) pages are included in this records package. In some instances, the included SN pages cross-reference other pages that are not included here because these were not essential to the documentation of this routine.

MAINTAIN NOTEBOOK PAGES IN THIS ORDER:
1) This 2-page Routine Documentation Form
2) pp. 39-45 from S/N YMP-LBNL-GSB-MC-1.2
3) 8 page print out of code

PROJECT NAME _____ NOTEBOOK NO. _____

mc 3/6/00 version 10 mc 3/6/00

Description: mc 3/6/00

study: Objective: routine Evaluation of macro "capfit" used in the development of fracture 'm' parameters used in the UZ flow and transport model. Capfit fits a curve to water potential and saturation data points to obtain the van Genuchten (1980) fitting parameters α and n. EMB 9/30/99 ~~for use~~ In the UZ model, α and n are provided as described in AMR U0035 for the matrix in the model layers. However, n for the fracture networks has not been measured. A process is devised to obtain a representative fracture n for use in model calibration with capfit ~~as described~~ EMB 9/30/99 in scientific Notebook YMP-LANL-GSB-1.9 pages 119 thru 125.

Test Case: mc 3/6/00

This check consists of developing two wat. pot. vs. sat curves using parameters similar to the range of parameters found @ Yucca Mtn. The synthetic curves are then evaluated with capfit to see if the correct van Genuchten fitting parameters are output by the macro.

SIGNATURE EMB DATE 9/30 19 99

READ AND UNDERSTOOD _____ DATE _____ 19 _____

PROJECT NAME _____ NOTEBOOK NO. _____

Pc=1/a*[(Se)**(-1/m)-1]**(1/n) m=1-1/n

Case1

alpha	n	m
10	2.50	0.6

Saturations and water potentials calculated from VG (1980) equation

Input range for test case 1

α = 10 bars
n = 2.5
m = 0.6

mc 3/6/00

Files located on page 41

Se = 0.1

$$P_c = \frac{1}{10}\left(0.1^{\left(\frac{1}{0.6}\right)} - 1\right)^{\left(\frac{1}{2.5}\right)}$$

= 4.6 E-01

checks

Se = m=.6, alpha=10

Se	Pc
0.001	1.0000E+01
0.002	6.2995E+00
0.003	4.8074E+00
0.004	3.9683E+00
0.005	3.4198E+00
0.006	3.0283E+00
0.007	2.7325E+00
0.008	2.4997E+00
0.009	2.3108E+00
0.01	2.1540E+00
0.02	1.3564E+00
0.03	1.0345E+00
0.04	8.5339E-01
0.05	7.3480E-01
0.06	6.5007E-01
0.07	5.8594E-01
0.08	5.3539E-01
0.09	4.9431E-01
0.1	4.6013E-01
0.11	4.3115E-01
0.12	4.0619E-01
0.13	3.8442E-01
0.14	3.6523E-01
0.15	3.4814E-01
0.16	3.3281E-01
0.17	3.1895E-01
0.18	3.0635E-01
0.19	2.9483E-01
0.2	2.8423E-01
0.21	2.7445E-01
0.22	2.6538E-01
0.23	2.5694E-01
0.24	2.4906E-01
0.25	2.4167E-01
0.26	2.3473E-01
0.27	2.2819E-01
0.28	2.2202E-01
0.29	2.1617E-01
0.3	2.1062E-01
0.31	2.0535E-01
0.32	2.0032E-01
0.33	1.9552E-01
0.34	1.9094E-01
0.35	1.8654E-01
0.36	1.8233E-01
0.37	1.7828E-01
0.38	1.7439E-01
0.39	1.7064E-01
0.4	1.6702E-01
0.41	1.6352E-01
0.42	1.6014E-01
0.43	1.5687E-01
0.44	1.5370E-01
0.45	1.5062E-01
0.46	1.4763E-01
0.47	1.4472E-01
0.48	1.4189E-01
0.49	1.3914E-01
0.5	1.3645E-01
0.51	1.3382E-01
0.52	1.3126E-01
0.53	1.2875E-01
0.54	1.2630E-01
0.55	1.2389E-01
0.56	1.2153E-01
0.57	1.1922E-01
0.58	1.1695E-01
0.59	1.1471E-01
0.6	1.1252E-01
0.61	1.1035E-01
0.62	1.0822E-01
0.63	1.0611E-01
0.64	1.0403E-01
0.65	1.0198E-01
0.66	9.9950E-02
0.67	9.7940E-02
0.68	9.5947E-02
0.69	9.3971E-02
0.7	9.2010E-02
0.71	9.0060E-02
0.72	8.8120E-02
0.73	8.6189E-02
0.74	8.4263E-02
0.75	8.2340E-02
0.76	8.0419E-02
0.77	7.8496E-02
0.78	7.6569E-02
0.79	7.4635E-02
0.8	7.2690E-02
0.81	7.0733E-02
0.82	6.8758E-02
0.83	6.6761E-02
0.84	6.4739E-02
0.85	6.2684E-02
0.86	6.0592E-02
0.87	5.8455E-02
0.88	5.6264E-02
0.89	5.4009E-02
0.9	5.1676E-02
0.91	4.9249E-02
0.92	4.6707E-02
0.93	4.4021E-02
0.94	4.1151E-02
0.95	3.8040E-02
0.96	3.4597E-02
0.97	3.0666E-02
0.98	2.5932E-02
0.982	2.4835E-02
0.984	2.3666E-02
0.986	2.2411E-02
0.988	2.1048E-02
0.99	1.9546E-02
0.992	1.7858E-02
0.994	1.5900E-02
0.996	1.3505E-02
0.998	1.0224E-02

SIGNATURE SMB DATE 9/30 19 99

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PROJECT NAME

NOTEBOOK NO.

saturations and water potentials calculated from van Genuchten 1980 equation shown above

Input range for test case 2

$\alpha = 0.1\ bar^{-1}$

MC 3/6/00

$n = 1.4286$

α dmb 9/30/99

$m = 1 - 1/n$

$= 0.3$

Location of files

Spreadsheet and files found in computer DOE # 6313734

MC 3/6/00

Spewang1 cil mark 1 capfitcheck Excel

Excel spreadsheet name: capfitchk.xls

capfit.f obtained and compiled on hydra/ tuxbaud / vgparams

Compiler: MC 3/6/00

compiled with: F77 - O3 capfit.f

Pc=1/a*[(Se)**(-1/m)-1]**(1/n) m=1-1/n

Caset 2 MC 3/6/00

alpha	n	m
0.1	1.4286	0.3

Se	m=.3, alpha=.1
0.001	1.0000E+08
0.002	1.9843E+07
0.003	7.7040E+06
0.004	3.9373E+06
0.005	2.3392E+06
0.006	1.5287E+06
0.007	1.0669E+06
0.008	7.8125E+05
0.009	5.9352E+05
0.01	4.6416E+05
0.02	9.2101E+04
0.03	3.5759E+04
0.04	1.8275E+04
0.05	1.0857E+04
0.06	7.0950E+03
0.07	4.9514E+03
0.08	3.6257E+03
0.09	2.7542E+03
0.1	2.1537E+03
0.11	1.7241E+03
0.12	1.4071E+03
0.13	1.1672E+03
0.14	9.8160E+02
0.15	8.3543E+02
0.16	7.1842E+02
0.17	6.2343E+02
0.18	5.4537E+02
0.19	4.8052E+02
0.2	4.2609E+02
0.21	3.8002E+02
0.22	3.4071E+02
0.23	3.0692E+02
0.24	2.7768E+02
0.25	2.5223E+02
0.26	2.2995E+02
0.27	2.1034E+02
0.28	1.9300E+02
0.29	1.7761E+02
0.3	1.6387E+02
0.31	1.5158E+02
0.32	1.4053E+02
0.33	1.3056E+02
0.34	1.2155E+02
0.35	1.1337E+02
0.36	1.0593E+02
0.37	9.9144E+01
0.38	9.2934E+01
0.39	8.7239E+01
0.4	8.2005E+01
0.41	7.7184E+01
0.42	7.2733E+01
0.43	6.8616E+01
0.44	6.4801E+01
0.45	6.1258E+01
0.46	5.7963E+01
0.47	5.4893E+01
0.48	5.2028E+01
0.49	4.9350E+01
0.5	4.6842E+01
0.51	4.4492E+01
0.52	4.2285E+01
0.53	4.0209E+01
0.54	3.8256E+01
0.55	3.6414E+01
0.56	3.4676E+01
0.57	3.3033E+01
0.58	3.1478E+01
0.59	3.0006E+01
0.6	2.8609E+01
0.61	2.7283E+01
0.62	2.6023E+01
0.63	2.4824E+01
0.64	2.3681E+01
0.65	2.2592E+01
0.66	2.1552E+01
0.67	2.0558E+01
0.68	1.9607E+01
0.69	1.8697E+01
0.7	1.7825E+01
0.71	1.6988E+01
0.72	1.6184E+01
0.73	1.5411E+01
0.74	1.4667E+01
0.75	1.3950E+01
0.76	1.3259E+01
0.77	1.2591E+01
0.78	1.1946E+01
0.79	1.1322E+01
0.8	1.0717E+01
0.81	1.0130E+01
0.82	9.5597E+00
0.83	9.0052E+00
0.84	8.4649E+00
0.85	7.9378E+00
0.86	7.4226E+00
0.87	6.9180E+00
0.88	6.4229E+00
0.89	5.9359E+00
0.9	5.4555E+00
0.91	4.9802E+00
0.92	4.5081E+00
0.93	4.0370E+00
0.94	3.5642E+00
0.95	3.0861E+00
0.96	2.5975E+00
0.97	2.0902E+00
0.98	1.5492E+00
0.982	1.4345E+00
0.984	1.3169E+00
0.986	1.1957E+00
0.988	1.0701E+00
0.99	9.3896E-01
0.992	8.0071E-01
0.994	6.5266E-01
0.996	4.8989E-01
0.998	3.0065E-01

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READ AND UNDERSTOOD DATE 19

Input

```
DATA FILE NAME: fracture.dat
CASE TITLE:      FRACT. PROPERTIES M=.6,a=10
INPUT PARAMETERS
================
PARAMETER TABLE OUTPUT OPTION (0=NO, 1=YES)
.......................................(MODE0) =  1
PARAMETER FITTING OPTION
(=0, BOTH ALPHA & BETA ARE VARYING)
(=1, BETA(DRYING)=BETA(WETTING)          (MODE1) =  1
NUMBER OF OBSERVATIONS....................(NOB) =116
NEW DATA READ INDEX(0=NO, 1=YES)........(NDATA) =  0
SATURATED FUID CONTENT ...................(WCS) = 1.0000

INITIAL PARAMETER VALUES
========================
ALPHA DRYING.....................................   8.0000
ALPHA WETTING....................................   8.0000
BETA DRYING......................................   2.5000
BETA WETTING.....................................   2.5000
RESIDUAL FLUID CONTENT...........................   0.0500
```

run for curve with α, m similar to fractures

- Estimates

output file fracture.out

ITERATION NO	SSQ	ALPHA	BETA	WCR
0	1.0886521	0.8000E+01	2.5000	0.0500
1	0.0251476	0.9473E+01	2.5832	0.0067
2	0.0003690	0.9940E+01	2.5091	0.0009
3	0.0000925	0.9995E+01	2.5009	0.0000
4	0.0000924	0.9996E+01	2.5007	0.0000
5	0.0000924	0.9996E+01	2.5007	0.0000
6	0.0000924	0.9996E+01	2.5007	0.0000

$n \simeq$

$m = 1 - \frac{1}{n}$

CORRELATION MATRIX

	1	2	3
1	1.0000		
2	-0.5498	1.0000	
3	0.0623	0.6557	1.0000

NON-LINEAR LEAST-SQUARES ANALYSIS: FINAL RESULTS

VARIABLE	VALUE	S.E.COEFF.	T-VALUE	95% CONFIDENCE LIMITS LOWER	UPPER
ALPHA	0.9996E+01	0.3900E-02	******	0.9988E+01	0.1000E+02
BETA	0.2501E+01	0.1423E-02	******	0.2498E+01	0.2503E+01

PROJECT NAME _____ NOTEBOOK NO. _____

Input

```
DATA FILE NAME: matrix.dat
CASE TITLE:      MATRIX PROPERTIES M=.3,a=.1
INPUT PARAMETERS
================
```

Run with curve similar to matrix

```
PARAMETER TABLE OUTPUT OPTION (0=NO, 1=YES)
.......................................(MODE0) =  1
PARAMETER FITTING OPTION
(=0, BOTH ALPHA & BETA ARE VARYING)
(=1, BETA(DRYING)=BETA(WETTING)          (MODE1) =  1
NUMBER OF OBSERVATIONS.....................(NOB) =116
NEW DATA READ INDEX(0=NO, 1=YES)........(NDATA) =  0
SATURATED FUID CONTENT ....................(WCS) = 1.0000
```

α, m

```
INITIAL PARAMETER VALUES
========================
```

– Estimates

```
ALPHA DRYING.....................................   0.0600
ALPHA WETTING....................................   0.0500
BETA DRYING......................................   1.8000
BETA WETTING.....................................   1.8000
RESIDUAL FLUID CONTENT...........................   0.0500
```

output file matrix.out

ITERATION NO	SSQ	ALPHA	BETA	WCR
0	0.3749536	0.6000E-01	1.8000	0.0500
1	0.1050593	0.6753E-01	1.5947	0.0571
2	0.0597970	0.8768E-01	1.4329	0.0157
3	0.0001782	0.9949E-01	1.4277	0.0001
4	0.0000447	0.9974E-01	1.4281	0.0001
5	0.0000112	0.9987E-01	1.4283	0.0000
6	0.0000028	0.9993E-01	1.4285	0.0000
7	0.0000007	0.9997E-01	1.4285	0.0000
8	0.0000000	0.1000E+00	1.4286	0.0000
9	0.0000000	0.1000E+00	1.4286	0.0000
10	0.0000000	0.1000E+00	1.4286	0.0000
11	0.0000000	0.1000E+00	n = 1.4286	0.0000

$m = 1 - \frac{1}{n}$

CORRELATION MATRIX
==========

	1	2	3
1	1.0000		
2	-0.8192	1.0000	
3	-0.3459	0.7194	1.0000

NON-LINEAR LEAST-SQUARES ANALYSIS: FINAL RESULTS
==========

VARIABLE	VALUE	S.E.COEFF.	T-VALUE	95% CONFIDENCE LIMITS LOWER	UPPER
ALPHA	0.1000E+00	0.2604E-06	******	0.1000E+00	0.1000E+00
n = BETA	0.1429E+01	0.8807E-06	******	0.1429E+01	0.1429E+01

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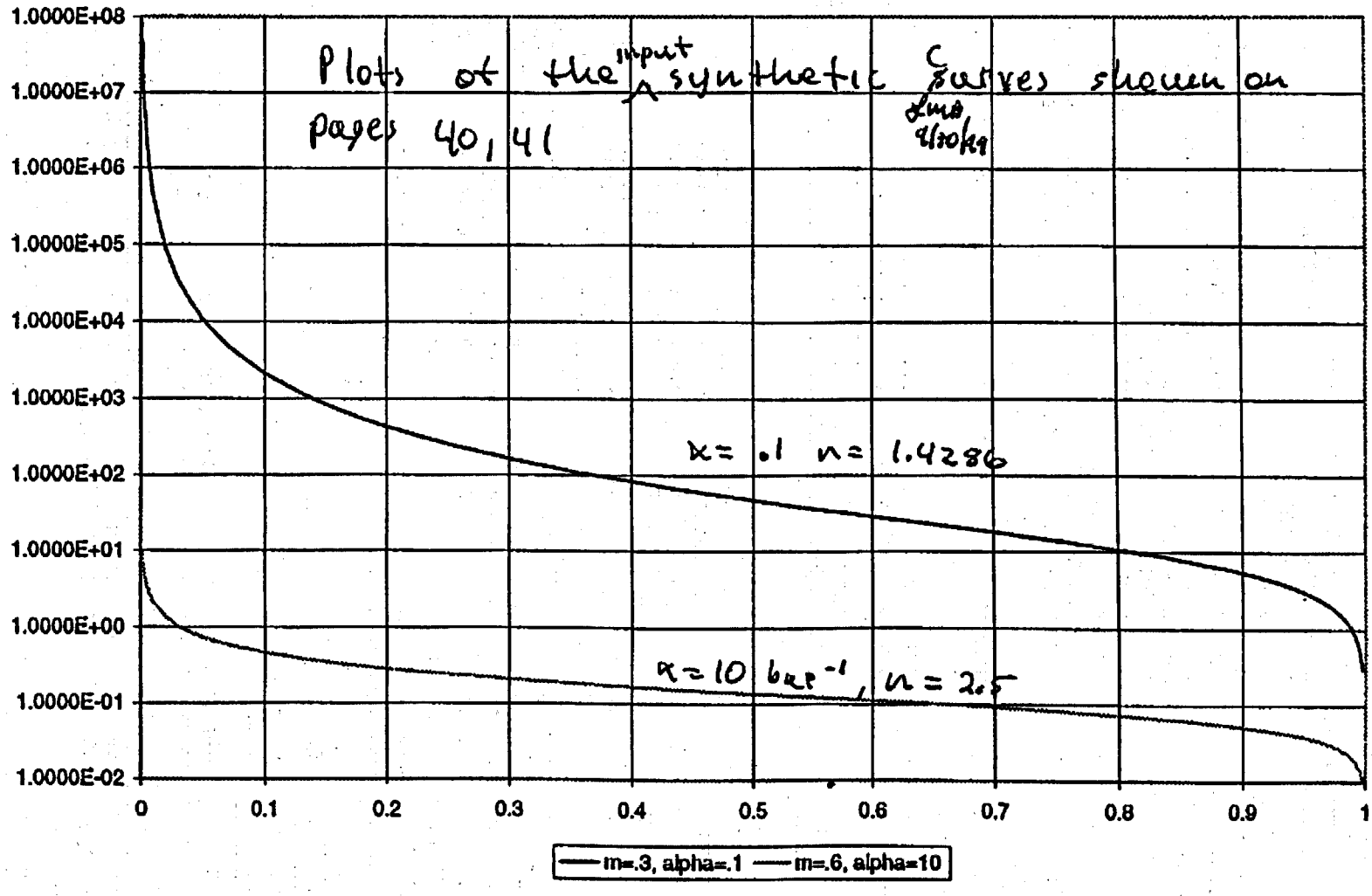
READ AND UNDERSTOOD _____ DATE _____ 19 _____

Cap. Pressure (bars) vs Eff. Saturation, vG formulation



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READ AND UNDERSTOOD _____ DATE _____ 19 ____

PROJECT NAME: NOTEBOOK NO.

Results	matrix.dat		fracture.dat	
	α	m	α	m
Input	0.100	0.3000	10.000	0.6000
Output	0.100	0.3000	9.996	0.6001

∴ Input values that generated data ≅ output values. Therefore, the macro is working correctly and provides correct results for the development of the fracture m parameter in the UZ model.

JMB 9/30/99

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```
c     ***************************************************************
c     *                                                             *
c     *       CAPFIT - CAPillary pressure curve-FITting             *
c     *                                                             *
c     *       VERSION 1.0 April 1993                                *
c     *                                                             *
c     *                                                             *
c     *       THE PROGRAM ESTIMATES PARAMETERS THAT DEFINE DRYING   *
c     *       AND WETTING RETENTION CURVES.                         *
c     *       DRYING AND WETTING CURVES ARE ASSUMED TO DIFFER ONLY  *
c     *       IN THEIR VALUES FOR PARAMETER ALPHA AND BETA RESIDUAL *
c     *       AND SATURATED FLUID CONTENT ARE THE SAME FOR DRYING   *
c     *       AND WETTING; THEY ARE DETERMINED BY SIMULTANEOUS      *
c     *       FITTING OF BOTH DRYING AND WETTING DATA.              *
c     *                                                             *
c     *                                                             *
c     *  BASED ON THE PROGRAM SOHYP BY M. TH. VAN GENUCHTEN (1980);  *
c     *  MODIFIED BY J.B. KOOL AND YU-SHU WU, 4/30/93               *
c     ***************************************************************
c
      implicit real*8 (A-H,O-Z)
      parameter(mxobs=100)
      CHARACTER TITLE*80,BI(8)*6,infil*30,outfil*30
      integer index(10)
      real*8 X(mxobs),Y(mxobs),R(mxobs),F(mxobs),DELZ(mxobs,5),B(10),
     1       E(5),P(5),PHI(5),Q(5),TB(10),A(5,5),D(5,5),TH(10),WT(mxobs)
      COMMON/SPR/ WCSW
      DATA STOPCR/.0005/,MIT/25/,MAXTRY/15/

c
c     ---- open files -----
c
      call get_files(infil,outfil)
      open(unit=5,file=infil,status='old')
      open(unit=6,file=outfil,status='unknown')
c     ----------------------------------------------------------------
c          NC IS NUMBER OF CASES (I5)
c
c          (FOLLOWING INPUTCARDS ARE REPEATED NC TIMES)
c
c     ----------------------------------------------------------------
      WRITE(6,1004)
      write(6,2002) infil
      READ(5,1000) NC
      DO 144 IC=1,NC
c     ----------------------------------------------------------------
c          TITLE IS TITLE FOR EACH CASE  (20A4)
c     ----------------------------------------------------------------
      READ(5,1002) TITLE
      WRITE(6,3002) TITLE
      WRITE(6,3001) IC
c     ----------------------------------------------------------------
c          MODE0 SELECTS OUTPUT (I5)
c           MODE0 = 0  HYDRAULIC PROPERTIES FOR SOIL ARE NOT PRINTED
c           MODE0 = 1  HYDRAULIC PROPERTIES FOR SOIL ARE PRINTED
c
c          MODE1 SELECTS MODEL TO BE FITTED (I5)
c           MODE1 = 0  ALPHA AND N BOTH VARIABLE
c           MODE1 = 1  N-DRYING = N-WETTING
c
c          NOB IS NUMBER OBSERVATIONS (I5) , NOB MUST BE LESS OR
c           EQUAL 40
c
c          NDATA IS DATA INPUT CODE (I5)
c           NDATA = 0  NEW DATA ARE READ IN
c           NDATA = 1  DATA FROM PREVIOUS CASE ARE USED
c
c          WCS IS SATURATED WATER CONTENT (F10.0), OR SAT WATER
c              CONTENT ON DRYING CURVE IF LOOP NOT CLOSED
c
c          SATK IS SATURATED CONDUCTIVITY (F10.0), USED ONLY WHEN
c           MODE0 = 1 . SATK IS SET TO 1.0 WHEN FIELD IS LEFT BLANK
c
c         WCSW= VALUE OF WCS FOR WETTING CURVE (OPTIONAL)
c     ----------------------------------------------------------------
      READ(5,1000) MODE0,MODE1,NOB,NDATA,WCS,SATK,WCSW
      satk=1.0
cc    IF(SATK.EQ.0.0) SATK=1.0
cc    IF(SATK.le.0.0) SATK=1.0
cc    IF(WCSW.EQ.0.0)WRITE(6,1005) NOB,WCS,SATK
```

```
cc      IF(WCSW.le.0.0)WRITE(6,1005) MODE0, MODE1,NOB,NDATA,WCS,SATK
cc      IF(WCSW.NE.0.0)WRITE(6,2005) NOB,WCS,WCSW,SATK
cc      IF(WCSW.gt.0.0)WRITE(6,2005) NOB,WCS,WCSW,SATK
        IF(WCSW.le.0.0)WRITE(6,1005) MODE0, MODE1,NOB,NDATA,WCS
        IF(WCSW.gt.0.0)WRITE(6,2005) NOB,WCS,WCSW
c       ------------------------------------------------------------------
c            BI IS ARRAY CONTAINING NAMES FOR EACH PARAMETER (4(A6,4X))
c       ------------------------------------------------------------------
c       READ(5,1007) (BI(I),I=1,5)  | YSW
c       ------------------------------------------------------------------
c            B IS ARRAY CONTAINING INITIAL VALUES FOR PARAMETERS (4F10.0)
c             N.B. ! PARAMETERS MUST BE ENTERED IN THE FOLLOWING ORDER:
c                    A-DRYING, A-WETTING, N-DRYING, N-WETTING, WCR
c
c            INDEX IS FLAG FOR EACH PARAMETER (5I10)
c             INDEX(I) = 0  THE I-TH PARAMETER IS KEPT CONSTANT
c             INDEX(I) = 1  THE I-TH PARAMETER IS FITTED TO DATA
c       ------------------------------------------------------------------
        READ(5,1006) (B(I),I=1,5)
        WRITE(6,1009)(B(I),I=1,5)
        READ(5,2000) (INDEX(I),I=1,5)
 2000   FORMAT(5I10)
c
c       ----- READ AND WRITE EXPERIMENTAL DATA -----
        WRITE(6,1008)
        IF(NDATA.GT.0) GO TO 16
c       ------------------------------------------------------------------
c            X IS ARRAY OF OBSERVED PRESSURE HEADS (F10.0)
c             N.B. ! PRESSURE HEADS ARE ASSUMED TO BE POSITIVE !
c
c            Y IS ARRAY OF OBSERVED WATER CONTENTS (F10.0)
c
c            WT IS ARRAY OF WEIGHTING FACTORS (F10.0)
c             IF WT(I) = 0.0 (OR LEFT BLANK), A WEIGHT OF 1.0 IS
c             GIVEN TO THE I-TH OBSERVATION.
c
c            MODE2 INDICATES WETHER DATAPOINT CORRESPONDS TO DRYING
c            (MODE2=0) OR TO WETTING (MODE2=1)
c
c           !! DATA POINTS ON DRYING CURVE MUST BE ENTERED FIRST !!
c
c       ------------------------------------------------------------------
        NOBD=0
        NOBW=0
        DO 8 I=1,NOB
          READ(5,1010,end=9,err=9) X(I),Y(I),WT(I),MODE2
          IF(MODE2.EQ.0) NOBD=NOBD+1
          IF(MODE2.EQ.1) NOBW=NOBW+1
c         IF(WT(I).EQ.0.) WT(I)=1.0
          IF(WT(I).le.0.) WT(I)=1.0
          WRITE(6,1011) I,X(I),Y(I),WT(I),MODE2
      8 continue
        go to 10
      9 stop 'ERROR IN INPUT DATA'
     10 if(nobd.eq.0.or.nobw.eq.0)  then
          mode1=1
          nobd=max(nobd,nobw)
          nobw=0
          write(6,1080)
        endif
c
c       ---- assign parameter names ----
     16 if(mode1.eq.0) then
          if(nobw.ne.0.and.nobd.ne.0) then
            BI(1)='A-DRY'
            BI(2)='A-WET'
            BI(3)='B-DRY'
            BI(4)='B-WET'
            BI(5)='WCR'
          else
            bi(1)='ALPHA'
            bi(2)='ALPHA'
            bi(3)='BETA'
            bi(4)='BETA'
            bi(5)='WCR'
            if(index(1).eq.0.and.index(2).ne.0) then
              b(1)=b(2)
              index(1)=1
            else
              b(2)=b(1)
```

```
          endif
          if(index(3).eq.0.and.index(4).ne.0) then
            b(3)=b(4)
            index(3)=1
          else
            b(4)=b(3)
          endif
          index(2)=0
          index(4)=0
        endif
      endif
      if(model.eq.1) then
        if(index(3).eq.0.and.index(4).ne.0) then
          b(3)=b(4)
          index(3)=1
        endif
        b(4)=b(3)
        index(4)=0
        if(nobw.ne.0.and.nobd.ne.0) then
          bi(1)='A-DRY'
          bi(2)='A-WET'
          bi(3)='BETA'
          bi(4)='BETA'
          bi(5)='WCR'
        else
          bi(1)='ALPHA'
          bi(2)='ALPHA'
          bi(3)='BETA'
          bi(4)='BETA'
          bi(5)='WCR'
          if(index(1).eq.0.and.index(2).ne.0) then
            b(1)=b(2)
            index(1)=1
            index(2)=0
          else
            b(2)=b(1)
            index(2)=0
          endif
        endif
      endif
c
c     ---------- REARRANGE  PARAMETER ARRAY  ------
      NU1=6
      NU2=10
      NP=0
      DO 2 I=NU1,NU2
      I1=I-5
      TB(I)=B(I1)
      IF(INDEX(I1).EQ.0) GO TO 2
      NP=NP+1
      BI(NP)=BI(I1)
      TB(NP)=B(I1)
      TH(NP)=B(I1)
    2 TH(I)=B(I1)
c
c     -----
      GA=0.02
      CALL MODEL(TH,F,NOBD,NOBW,X,WCS,NP,INDEX,MODE1)
      SSQ=0.
      DO 32 I=1,NOB
      R(I)=WT(I)*(Y(I)-F(I))
   32 SSQ=SSQ+R(I)*R(I)
      NIT=0
      IF(NP.NE.0)WRITE(6,1030)(BI(I),I=1,NP)
      IF(NP.EQ.0)WRITE(6,1030)
      IF(NP.NE.0)WRITE(6,1026)NIT,SSQ,(TH(I),I=1,NP)
      IF(NP.EQ.0)WRITE(6,1026)NIT,SSQ
      IF(NP.EQ.0) GO TO 110
c
c     ----- BEGIN OF ITERATION -----
   34 NIT=NIT+1
      NTRIAL=0
      GA=0.1*GA
      DO 38 J=1,NP
      if(th(j).lt.1.e-20) th(j)=1.0e-20
      TEMP=TH(J)
      TH(J)=1.01*TH(J)
      Q(J)=0.
      CALL MODEL(TH,DELZ(1,J),NOBD,NOBW,X,WCS,NP,INDEX,MODE1)
      DO 36 I=1,NOB
```

```
      DELZ(I,J)=WT(I)*(DELZ(I,J)-F(I))
   36 Q(J)=Q(J)+DELZ(I,J)*R(I)
      Q(J)=100.*Q(J)/TH(J)
C
C     ----- STEEPEST DESCENT -----
   38 TH(J)=TEMP
      DO 44 I=1,NP
      DO 42 J=1,I
      SUM=0
      DO 40 K=1,NOB
   40 SUM=SUM+DELZ(K,I)*DELZ(K,J)
      D(I,J)=10000.*SUM/(TH(I)*TH(J))
   42 D(J,I)=D(I,J)
C
C     ----- D = MOMENT MATRIX -----
      E(I)=SQRT(D(I,I))
c  44 IF(E(I).EQ.0.) E(I)=1.E-30
   44 IF(E(I).lt.1.e-20) E(I)=1.E-20
   50 DO 52 I=1,NP
      DO 52 J=1,NP
   52 A(I,J)=D(I,J)/(E(I)*E(J))
C
C     ----- A IS THE SCALED MOMENT MATRIX -----
      DO 54 I=1,NP
      P(I)=Q(I)/E(I)
      PHI(I)=P(I)
   54 A(I,I)=A(I,I)+GA
      CALL MATINV(A,NP,P)
C
C     ----- P/E IS THE CORRECTION VECTOR -----
      STEP=1.0
   56 DO 58 I=1,NP
      TB(I)=P(I)*STEP/E(I)+TH(I)
   58 CONTINUE
      DO 62 I=1,NP
      IF(TH(I)*TB(I))66,66,62
   62 CONTINUE
      SUMB=0.0
      CALL MODEL(TB,F,NOBD,NOBW,X,WCS,NP,INDEX,MODE1)
      DO 64 I=1,NOB
      R(I)=WT(I)*(Y(I)-F(I))
   64 SUMB=SUMB+R(I)*R(I)
   66 SUM1=0.0
      SUM2=0.0
      SUM3=0.0
      DO 68 I=1,NP
      SUM1=SUM1+P(I)*PHI(I)
      SUM2=SUM2+P(I)*P(I)
   68 SUM3=SUM3+PHI(I)*PHI(I)
      xyzau=SUM1/SQRT(SUM2*SUM3)
      ANGLE=57.29578*ACOS(xyzau)
C
C     ----------
      DO 72 I=1,NP
      IF(TH(I)*TB(I))74,74,72
   72 CONTINUE
      NTRIAL=NTRIAL+1
      IF(NTRIAL.GT.MAXTRY) GO TO 96
      IF(SUMB/SSQ-1.0)80,80,74
   74 IF(ANGLE-30.0)76,76,78
   76 STEP=STEP/2.0
      GO TO 56
   78 GA=10.*GA
      GO TO 50
C
C     ----- PRINT COEFFICIENTS AFTER EACH ITERATION -----
   80 CONTINUE
      DO 82 I=1,NP
   82 TH(I)=TB(I)
      WRITE(6,1026) NIT,SUMB,(TB(I),I=1,NP)
      DO 92 I=1,NP
      IF(ABS(P(I)*STEP/E(I))/(1.0E-20+ABS(TH(I)))-STOPCR) 92,92,94
   92 CONTINUE
      GO TO 96
   94 SSQ=SUMB
      IF(NIT.LE.MIT) GO TO 34
C
C     ----- END OF ITERATION LOOP -----
   96 CONTINUE
      CALL MATINV(D,NP,P)
```

```
C
C     ----- WRITE CORRELATION MATRIX -----
      DO 98 I=1,NP
   98 E(I)=SQRT(D(I,I))
      WRITE(6,1044) (I,I=1,NP)
      DO 102 I=1,NP
      DO 100 J=1,I
  100 A(J,I)=D(J,I)/(E(I)*E(J))
  102 WRITE(6,1048) I,(A(J,I),J=1,I)
C
C     ----- CALCULATE 95% CONFIDENCE INTERVAL -----
      Z=1./FLOAT(NOB-NP)
      SDEV=SQRT(Z*SUMB)
      WRITE(6,1052)
      TVAR=1.96+Z*(2.3779+Z*(2.7135+Z*(3.187936+2.466666*Z**2)))
      DO 108 I=1,NP
      SECOEF= E(I)*SDEV
      TVALUE= TH(I)/SECOEF
      TSEC=TVAR*SECOEF
      TMCOE=TH(I)-TSEC
      TPCOE=TH(I)+TSEC
  108 WRITE(6,1058) BI(I),TH(I),SECOEF,TVALUE,TMCOE,TPCOE
c
c     ----- Brooks-Corey n parameter ----
      bcn=3.+2./(tb(8)-1.)
      write(6,1074) bcn
C
C     ----- PREPARE FINAL OUTPUT -----
  110 WRITE(6,1066)
      DO 118 I=1,NOB
  118 WRITE(6,1068) I,X(I),Y(I),F(I),R(I)
      IF(MODE0.EQ.0) GO TO 144
C
C     ----- WRITE SOIL HYDRAULIC PROPERTIES -----
      WRITE(6,1069)
      PRESS=1.18850
      RN1=0.0
      RKLN=1.0
cjbk  WRITE(6,1072) RN1,WCS,RKLN,SATK
      WRITE(6,1072) RN1,WCS,RKLN
      WCR=TB(10)
      ALPHA=TB(6)
      RN=TB(8)
      RM=1.-1./RN
      DO 140 I=1,75
      IF(RKLN.LT.(-16.)) GO TO 142
      PRESS=1.18850*PRESS
      RN1=RM*RN
      RWC=1./(1.+(ALPHA*PRESS)**RN)**RM
      WC=WCR+(WCS-WCR)*RWC
      TERM=1.-RWC*(ALPHA*PRESS)**RN1
      IF((TERM.LT.5.E-05).OR.(RWC.LT.0.06)) TERM = RM*RWC**(1./RM)
      RK=SQRT(RWC)*TERM*TERM
      AK=SATK*RK
      TERM=ALPHA*RN1*(WCS-WCR)*RWC*RWC**(1./RM)*(ALPHA*PRESS)**(RN-1.)
      DIFFUS=AK/TERM
      GO TO 138
  138 PRLN=dlog10(PRESS)
      AKLN=dlog10(AK)
      RKLN=dlog10(RK)
      DIFLN=dlog10(DIFFUS)
C  140 WRITE(6,1070) PRESS,PRLN,WC,RK,RKLN,AK,AKLN,DIFFUS,DIFLN
cjbk  140 WRITE(6,1070) PRESS,PRLN,WC,RK,RKLN,AK,AKLN
  140 WRITE(6,1070) PRESS,PRLN,WC,RK,RKLN
  142 CONTINUE
  144 CONTINUE
C
C     ----- END OF PROBLEM -----
 1000 FORMAT(4I5,5F10.0)
 1002 FORMAT(A)
 2002 format(///10X,'DATA FILE NAME: ',A)
 3002 FORMAT(///10x,'CASE TITLE: ', A/)
 1004 FORMAT(///10X,52(1H*)/10X,1H*,50X,1H*
     + /10X,1H*, 9X,'          CAPFIT                  ',8X,1H*/10X,
     +  1H*, 9X,'                                      ',8X,1H*/10X,
     +  1H*, 9X,'CAPILLARY PRESSURE CURVE FITTING ',8X,1H*/10X,
     +  1H*, 9X,'                                      ',8X,1H*/10X,
     +  1H*,6X,'USING NON-LINEAR LEAST SQUARES ANALYSIS',5X,1H*/10X,
     +1H*,50X,1H*/10X,52(1H*)/)
C      IF(WCSW.le.0.0)WRITE(6,1005) MODE0, MODE2,NOB,NDATA,WCS,SATK
```

```
 3001 FORMAT(//
     +10X,'CASE NUMBER ..............................(IC) =',I3/)
 1005 FORMAT(//10x,'INPUT PARAMETERS'/10x,16(1H=),                //
     +10X,'PARAMETER TABLE OUTPUT OPTION (0=NO, 1=YES)',          /
     +10X,'.....................................(MODE0) =',I3/
     +10X,'PARAMETER FITTING OPTION',                              /
     +10X,'(=0, BOTH ALPHA & BETA ARE VARYING)',                   /
     +10X,'(=1, BETA(DRYING)=BETA(WETTING)          (MODE1) =',I3/
     +10X,'NUMBER OF OBSERVATIONS....................(NOB) =',I3/
     +10X,'NEW DATA READ INDEX(0=NO, 1=YES).........(NDATA) =',I3/
     +10X,'SATURATED FUID CONTENT ...................(WCS) =',F7.4)
ccc  +10X,'SATURATED HYDRAULIC CONDUCTIVITY.........(SATK) =',F10.4)
 2005 FORMAT(//10x,'INPUT PARAMETERS'/10x,16(1H=)//
     +10X,'NUMBER OF OBSERVATIONS...........................',I3/
     +10X,'SATURATED FLUID CONTENT.(DRYING) .............',F7.4/
     +10X,'SATURATED FLUID CONTENT.(WETTING) ............',F7.4)
cjbk +10X,'SATURATED HYDRAULIC CONDUCTIVITY..............',F10.4)
 1006 FORMAT(5F10.0)
C1007 FORMAT(5(A6,4X))
 1008 FORMAT(//3x,'OBSERVED DATA',/3x,13(1H=)//3x,'OBS. NO.',4X,
     1'PRESSURE HEAD',2X,' FLUID  CONTENT ',6X,'WEIGHT',6X,'TYPE')
 1009 FORMAT(//10x,'INITIAL PARAMETER VALUES'/10x,24(1H=)//
     +10X,'ALPHA DRYING.....................................',F10.4/
     +10X,'ALPHA WETTING....................................',F10.4/
     +10X,'BETA DRYING......................................',F10.4/
     +10X,'BETA WETTING.....................................',F10.4/
     +10X,'RESIDUAL FLUID CONTENT...........................',F10.4/)
cels2/4/97 1010 FORMAT(3F10.0,I5)
 1010 FORMAT(E10.4,2F10.4,I5)
c---
cels2/4/97 1011 FORMAT(3X,I5,5X,F12.2,4X,F12.4,10X,F6.2,8X,I2)
 1011 FORMAT(3X,I5,5X,F12.2,4X,F12.4,10X,F6.2,8X,I2)
c---
cels 1026 FORMAT(8X,I2,4X,F12.7,5X,5(F8.4,2X))
 1026 FORMAT(8X,I2,4X,F12.7,5X,e12.4,2x,4(f8.4,2X))
 1030 FORMAT(//3X,'ITERATION NO',5X,'SSQ',6X,5(4X,A))
 1044 FORMAT(//3x,'CORRELATION MATRIX'/3x,18(1H=)/7X,10(4X,I2,5X))
 1049 FORMAT(3X,I3,10(2X,F7.4,2X))
 1052 FORMAT(//3x,'NON-LINEAR LEAST-SQUARES ANALYSIS: FINAL RESULTS'/
     +3X,48(1H=)/52X,'95% CONFIDENCE LIMITS'/3x,'VARIABLE',7X,'VALUE',
     +6X,'S.E.COEFF.',2X,'T-VALUE',5X,'LOWER',9X,'UPPER')
cels 1058 FORMAT(4X,A6,4X,F10.5,4X,F9.4,4X,F6.2,3X,F9.4,4X,F9.4)
 1058 FORMAT(4X,A6,2X,e12.4,2X,e12.4,2X,F6.2,2X,e12.4,2X,e12.4)
 1066 FORMAT(//3x,8(1H-),'ORDERED BY COMPUTER INPUT',8(1H-)/
     19X,'PRESSURE',2X,'  FLUID CONTENT ',3X,'RESI-'
     1/3x,'NO',3X,'  HEAD  ',5X,'OBS'
     2,4X,'FITTED',4X,'DUAL')
cels2/4/97 1068 FORMAT(3X,I2,F10.2,1X,3F9.4,8X,I2,F10.2,1X,3F9.4)
 1068 FORMAT(3X,I2,F10.2,1X,F10.4,2F9.4,8X,I2,F10.2,1X,3F9.4)
c
cjbk 1069 FORMAT(//6X,'PRESS-HEAD (P)',3X,'LOG P',6X,'WC',7X,'  Kr ',
cjbk     1 5X,'LOG Kr',6X,'ABS Ka',4X,'LOG Ka')
 1069 FORMAT(//3X,'PRESS-HEAD (h)',2X,'LOG h',5X,'THETA',5X,'  Kr ',
     1 5X,'LOG Kr')
C     1',6X,'ABS K',4X,'LOG KA',5X,'DIFFUS',5X,'LOG D')
 1070 FORMAT(3X,E10.3,3x,F8.3,1x,F10.4,3(E13.3,F8.3))
 1072 FORMAT(3X,E10.3,12x,f10.4,E13.3)
 1074 FORMAT(//3x,'BROOKS-COREY n PARAMETER = ',f10.4)
 1080 format(//3x,'WARNING: CANNOT FIT SEPARATE WETTING AND DRYING',
     & ' PARAMETERS,'/12x,'REDUCED MODEL IS USED !'/)
      STOP
      END
c
c
      subroutine get_files(infil,outfil)
c
c     purpose: to get or set the input and output file names
c
      implicit real (a-h,o-z)
      character*30 infil,outfil
      character*1 period,space
      integer*4 ios
      logical isfil
      data period, space /'.',' '/
c
c
      isfil=.false.
C
C     -------- DISPLAY OPENING SCREEN -------
      WRITE(*,*) ' '
```

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      WRITE(*,*) ' '
      WRITE(*,*) ' ÚÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄ¿'
      WRITE(*,*) ' ³                                                      ³'
      WRITE(*,*) ' ³     ÚßßßÄ   ßßßÚ   ßßßßÚ  ßßßßÄ  ßßÚ  ßßßßßßßÄ    ³'
      WRITE(*,*) ' ³     Ú      ßßßßßß  ßßßßß  ßßß     Ú      Ú       ³'
      WRITE(*,*) ' ³     ßßßßß  Ú    Ú  Ú      Ú      ßßß     Ú       ³'
      WRITE(*,*) ' ³                                                      ³'
      WRITE(*,*) ' ³                                                      ³'
      WRITE(*,*) ' ³        CAPpillary pressure curve FITting             ³'
      WRITE(*,*) ' ³      for two-phase drainage and imbibition           ³'
      WRITE(*,*) ' ³                    data                              ³'
      WRITE(*,*) ' ³                                                      ³'
      WRITE(*,*) ' ³                  Version 1.0                         ³'
      WRITE(*,*) ' ³                                                      ³'
      WRITE(*,*) ' ³                  Developed by                        ³'
      WRITE(*,*) ' ³               HydroGeoLogic, Inc                     ³'
      WRITE(*,*) ' ³                     for                              ³'
      WRITE(*,*) ' ³          WESTINGHOUSE HANFORD COMPANY                ³'
      WRITE(*,*) ' ³                                                      ³'
      WRITE(*,*) ' ÀÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÙ'
      WRITE(*,*) ' '
      WRITE(*,*) ' '
c     ------
 2    write(*,10)
      read(*,'(a)') infil
      inquire(file=infil,exist=isfil,iostat=ios)     ! check if file exists
      if(.not.isfil.or.ios.ne.0) then                ! invalid name
        write(*,30)
        go to 2
      endif
      iposi=index(infil,period)
      if(iposi.eq.0) then
        iposi=index(infil,space)
      endif
      iposi=iposi-1
c     ----
 4    write(*,20)
      read(*,'(a)') outfil
      if(outfil.eq.' ') then
        outfil=infil(1:iposi)//'.out'
      else
        open(2,file=outfil,form='formatted',err=6)            ! check name
        goto 8
 6      close(2)
        write(*,40)
        go to 4
      endif
 8    continue
      close(2)
c
      return
c     ------
10    format(' Enter CAPFIT INPUT Filename: ',$)
20    format(' Enter CAPFIT OUTPUT Filename: ',$)
30    format(/' Invalid name or file not found, try again .. '/)
40    format(/' Invalid file name, try again .. '/)
      end
C
C
      SUBROUTINE MODEL(B,FY,NOBD,NOBW,X,WCS,NP,INDEX,MODE1)

      implicit reaL*8 (A-H,O-Z)
      parameter (mxobs=100)
      DIMENSION B(10),FY(mxobs),X(mxobs),INDEX(10)
      COMMON/SPR/ WCSW
C     ----------
C
C     UPDATE PARAMETER ARRAY
      K=0
      NU1=6
      NU2=10
      DO 2 I=NU1,NU2
      IF(INDEX(I-5).EQ.0) GO TO 2
      K=K+1
      B(I)=B(K)
    2 CONTINUE
      AD=B(6)
      AW=B(7)
      DN=B(8)
      WN=B(9)
```

```
      IF(MODE1.EQ.1) WN=DN
      WCR=B(10)
      SWC=WCS
      NOB=NOBD+NOBW
      AX=AD
      XN=DN
c  10 CONTINUE
      DO 12 J=1,NOB
      IF(J.GT.NOBD) THEN
        AX=AW
        XN=WN
c       IF(WCSW.NE.0.0) SWC=WCSW
        IF(WCSW.gt.0.0) SWC=WCSW
      ENDIF
      FY(J)=WCR+(SWC-WCR)/(1.+(AX*X(J))**XN)**(1.-1./XN)
   12 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE MATINV(A,NP,B)
      implicit reaL*8 (A-H,O-Z)
      DIMENSION A(5,5),B(5),INDEX(5,2)
      DO 2 J=1,NP
    2 INDEX(J,1)=0
      I=0
    4 AMAX=-1.0
      DO 1001 J=1,NP
      IF(INDEX(J,1).ne.0)goto1001
      DO 10 K=1,NP
      IF(INDEX(K,1).ne.0)goto1000
      P=ABS(A(J,K))
      IF(P.LE.AMAX) GO TO 10
      IR=J
      IC=K
      AMAX=P
1000  continue
   10 CONTINUE
1001  continue
      IF(AMAX) 30,30,14
   14 INDEX(IC,1)=IR
      IF(IR.EQ.IC) GO TO 18
      DO 16 L=1,NP
      P=A(IR,L)
      A(IR,L)=A(IC,L)
   16 A(IC,L)=P
      P=B(IR)
      B(IR)=B(IC)
      B(IC)=P
      I=I+1
      INDEX(I,2)=IC
   18 P=1./A(IC,IC)
      A(IC,IC)=1.0
      DO 20 L=1,NP
   20 A(IC,L)=A(IC,L)*P
      B(IC)=B(IC)*P
      DO 24 K=1,NP
      IF(K.EQ.IC) GO TO 24
      P=A(K,IC)
      A(K,IC)=0.0
      DO 22 L=1,NP
   22 A(K,L)=A(K,L)-A(IC,L)*P
      B(K)=B(K)-B(IC)*P
   24 CONTINUE
      GO TO 4
   26 IC=INDEX(I,2)
      IR=INDEX(IC,1)
      DO 28 K=1,NP
      P=A(K,IR)
      A(K,IR)=A(K,IC)
   28 A(K,IC)=P
      I=I-1
   30 IF(I) 26,32,26
   32 RETURN
      END
```

frac_calc V1.1
Routine/Macro Documentation Form*

Note: All relevant scientific notebook (SN) pages are included in this records package. In some instances, the included SN pages cross-reference other pages that are not included here because these were not essential to the documentation of this routine.

1. Name of routine/macro with version/OS/hardware environment:
   frac_calc / Version 1.1 / DOS (or Windows with DOS) / PC

2. Name of commercial software with version/OS/hardware used to develop routine/macro:
   FORTRAN 77 / FORTRAN Powerstation 4.0 (see SN YMP-LBNL-GSB-MC-1.1, p. 105)

3. Description and Test Plan.

   - Explain whether this is a routine or macro and describe what it does: (frac_calc is a routine)

The software routine frac_calc is a FORTRAN code which performs simple calculations using Detailed Line Survey (DLS) data including fracture location, strike, dip, and trace lengths above and below the traceline to compute fracture hydrologic properties. The user can select a minimum and maximum fracture length to include in the calculations. Version 1.1 is a minor revision of Version 1.0 and calculates additional fracture properties from the same data. The fracture properties calculated include fracture frequency, aperture and other properties. These properties are listed and the computation methods are described on pages 60-65 in YMP-LBNL-GSB-MC-1, pp. 102-104 in YMP-LBNL-GSB-MC-1.1, and p. 14 in YMP-LBNL-GSB-MC-1.2. To install the software, copy frac_calc11.f and datablk11.f from a disk onto the hard drive of a PC. Then, compile frac_calc using a FORTRAN 77 compiler and run executable.

Changes between Version 1.1 and 1.0 are discussed on p. 14 in YMP-LBNL-GSB-MC-1.2 for the source code (filename: frac_calc11.f) and on pp. 12-13 in YMP-LBNL-GSB-MC-1.2 for the parameter dimensions file (filename: datablk11.f).

This software routine is documented in the following scientific notebook pages (the order below provides a chronology of the documentation from Version 1.1 back to Version 1.0):

YMP-LBNL-GSB-MC-1.2	pp. 14-16, 12-13
Reference Binder YMP-LBNL-GSB-MC-1.2A	pp. 67-87, 63-66
YMP-LBNL-GSB-MC-1.1	pp. 114-115, 105-109, 101-104
YMP-LBNL-GSB-MC-1	pp. 60-65

Inputs:

The code is designed to use an ASCII input file. The first row is a header and is not read. Each row represents a single fracture. It must have five columns of data for each fracture – location (in meters), strike (in degrees), dip (in degrees), length above (in meters), and length below (in meters) – in that order. The fractures must be in increasing order of location (distance along the ESF, an alcove, or the ECRB). All values must be numbers (no text, except the first row). All values must be positive. The limit on size of the input values is that the strike must be less than 360 degrees and the dip must be less than 90 degrees. For other values, there are no limits except those for double precision parameters and computations.

- Source code: (including equations or algorithms from software setup (LabView, Excel, etc.):
  pp. 72-87, in Reference Binder YMP-LBNL-GSB-MC-1.2A for frac_calc.f, the source code.
  pp. 63-66, in Reference Binder YMP-LBNL-GSB-MC-1.2A for datablk11.f, the include file that sets parameter dimensions and values.

- Description of test(s) to be performed (be specific):
  A sample case using site data will be used to test the routine. The test case for Version 1.0 is rerun for Version 1.1 to test the new features as well as confirm that the previous computations

are still performed correctly. The Version 1.0 test case included selecting a minimum fracture length of 1 meter to confirm that fractures smaller than 1 meter in the sample case will be excluded from the computations (the Version 1.0 test case is on pp. 105 – 108 in YMP-LBNL-GSB-MC-1.1). All new output from the output files all1.par and all2.par will be compared with computations performed using a calculator (previous output will be compared to Version 1.0). The acceptance criterion is that the values computed by hand and from the routine are the same within the round-off difference between the code and the calculator.

- Specify the range of input values to be used and why the range is valid:
  The input values are a direct sample from the TDMS (see p. 105 in YMP-LBNL-GSB-MC-1) after pre-processing using the routine Read_TDB. The sample input includes small and large fracture lengths and a range of strikes and dips that are representative of the fracture parameters found at Yucca Mtn.

4. Test Results.

- Output from test :
  Test results are shown on p. 15 in YMP-LBNL-GSB-MC-1.2 and in Reference Binder YMP-LBNL-GSB-MC-1.2A, pp. 67-71.

- Description of how the testing shows that the results are correct for the specified input:
  Values from Version 1.1 matched exactly with those from Version 1.0 (regression testing), see p. 15 in YMP-LBNL-MC-1.2. Calculated values for new fracture calculations (gmlen and intarea) matched with rounding to 3 decimal places (the output format of frac_calc).

- List limitations or assumptions to this test case and code in general:
  As noted above the fractures must be listed in order of their locations with increasing distances along a survey line.

- Electronic files identified by name and location (include disc if necessary):
  See pp. 15-16 in YMP-LBNL-GSB-MC-1.2. No electronic files submitted.

5. Supporting Information. Include background information, such as revision to a previous routine or macro, or explanation of the steps performed to run the software. Include listings of all electronic files and codes used. Attach Scientific Notebook pages with appropriate information annotated:

   See attached pages for technical review forms, referenced scientific notebook pages and other supporting documentation. Pages from YMP-LBNL-GSB-MC-1.1 and YMP-LBN-GSB-MC-1 are for Version 1.0 and provide the necessary background information for Version 1.1. The original qualification and references for Version 1.0 are provided on pp. 114-115 of YMP-LBNL-GSB-MC-1.1.

MAINTAIN PAGES IN THIS ORDER:

This 2 page "Routine Documentation" summarization form	
YMP-LBNL-GSB-MC-1.2	pp. 14-16, 12-13
Reference Binder YMP-LBNL-GSB-MC-1.2A	pp. 67-87, 63-66
YMP-LBNL-GSB-MC-1.1	pp. 114-115, 105-109, 101-104
YMP-LBNL-GSB-MC-1	pp. 60-65

*Note that this supplement includes:
-Addition of this 2-page "Routine Documentation" summarization form
-Addition of pp. 63-66, Reference Binder YMP-LBNL-GSB-MC-1.2A
-Addition of pp. 12-13, S/N YMP-LBNL-GSB-MC-1.2

3/1/2000

Computing Fracture Frequencies - Preliminary 7/21/99

The multi-user macro frac_calc Version 1.0 ~~was~~ MC 7/21/99 (YMP-LBNL-GSB-MC-1.1 p.114) was updated to reflect the new layering for the UZ model for FY99. Essentially GSB MC 7/21/99

FY98	FY99
ptn 24	ptn 24
ptn 25	
ptn 26 →	ptn 25
ptn 27 →	ptn 26

The model layers for FY97, FY98 & FY99 are summarized in Reference Binder YMP-LBNL-~~MC~~GSB-MC-1.2A on pp. 52-54. MC 7/21/99

The assignment of ESF stations to model layers was also re-evaluated. An error was found in the assignment of layers for the South Ramp. The contacts given for the South Ramp are "exit" points whereas these for the North Ramp & Main Drift are "entrance" points. The South Ramp assignments were therefore shifted. In particular tsw35 was misassigned:

previous 57+29.2 – 63+08
correct 57+29.2 – 58+78.3

The original assignments are in YMP-LBNL-GSB-MC-1.1 pp. 36-39.

The new assignments are in Reference Binder YMP-LBNL-GSB-MC-1.2A pp. 55-58
These were reviewed by Jennifer Hinds on 3/24/99

Intervals that were less than 5 meters were considered too small & these data were excluded.

Reference Binder YMP-LBNL-GSB-MC-1.2A p.59 gives a summary of these assignments.

PROJECT NAME MC-1.2 NOTEBOOK NO.

Fracture permeabilities in frac_calc were revised to reflect the new layer MC 7/21/99

	log k (k in m^2)
ptn 24	-11.53
ptn 25	-12.78
ptn 26	-12.66

old old

previous values assigned to ptn 24 were for ptn 25 & considered analogous ∴ only old ptn 25 used for new ptn 24

The original fracture permeabilities are given in YMP-LBNL-GSB-MC-1.1 p. 61.

Page 65 in YMP-LBNL-GSB-MC-1.1 provides a summary of ~~where~~ the files and data used to determine fracture permeabilities MC 7/21/99

Pages 53 - 54 in Reference Binder YMP-LBNL-GSB-1.2A show how the model layers have changed from FY98 to FY99.

2A

The file 'datablk.f' (see pp. 62-63 in YMP-LBNL-GSB-MC-1.1) which is part of 'frac_calc' was updated to reflect these changes and a new file was created 'datablk11.f' which is for Version 1.1 of frac_calc. ~~This file is included in Reference Binder YMP-LBNL-GSB-MC-1.2A pp.~~ MC 7/21/99

The assignment of ECRB stations to model layers was completed using the locations of lithostratigraphic contacts from MOL. 19981229.0038. This is in Reference Binder YMP-LBNL-GSB-MC-1.2A pp. 60-62. The corresponding model layers are recorded on that page also. These were also put in 'datablk11.f' with a header of "9" (see p. 10)

The file "datablk11.f" is given in YMP-LBNL-GSB-MC-1.2A pp. 63-66. & stored on "nwd-cushey" in d:\code\~~frac_calc~~\frac_calc11 calc_frac MC 7/21/99

SIGNATURE [signature] DATE 7/21 19 99
READ AND UNDERSTOOD DATE 19

Mc-1.2A

File 'datablk11.f'
File with data blocks for
frac_calc Version 1.1

Referenced on p. 13

```
c-----------------------------------------------------------------------
c     Includes data statements for assigning model layers for use in
c     the program frac_calc.f
c     Created by Mark Cushey

c     Made into a separate file 6/98
c     Original data statements created by MAC 4/98 - 5/98

c     Data statements added to identify subunits and later combine
c     subunits for each model layer.
c
c     MAC 6/16/98
c     The following assignment of stations for PTN (new UZ model layers)
c     is based my analysis of data in Table 2, CRWSM M&O, 1998.
c     See Scientific Notebook YMP-LBNL-GSB-MC-1.1 pages 8-9

c     MAC 6/25/98
c     Stations reassigned for TCw and TSw (new UZ model layers)
c     based on my analysis of data in Table 2, CRWSM M&O, 1998.
c     Also reassigned alcoves.
c     See Scientific Notebook YMP-LBNL-GSB-MC-1.1 pages 38-39, 47

c     MAC 7/98
c     Most recent fracture permeabilities are in d:\permeability\
c     properties\airk.xls which is linked to other data spreadsheets
c     See Scientific Notebook YMP-LBNL-GSB-MC-1.1 pages 34, 61

c     MAC V 1.1
c     Version 1.1 - reevaluated station assignments, assigned values
c     to 1999 Model layers, and added ECRB

c     Alcove stations are entered with Alcove # in the
c     ten thousandth location.  ECRB has a '9' in the ten
c     thousandth location.

c     First, set up arrays
c         ntotal is the total number of UZ model layers and
c         nlayers is the total number of segments along the ESF
c         for the data statements

      integer nlayers,ntotal
      parameter(nlayers=57,ntotal=16)
      integer modlayer(ntotal)
      double precision logairk(nlayers),unitsta(nlayers),
     +        unitend(nlayers)
      character*5 unitname(nlayers)

      data unitname /'tcw11'
     +    ,'tcw12','tcw12','tcw12','tcw12','tcw12'
     +    ,'tcw12'                                    !Alcove 3
     +    ,'tcw13','tcw13','tcw13','tcw13'
     +    ,'ptn21','ptn21','ptn21'
     +    ,'ptn22'                    ! no fracture data
     +    ,'ptn23'                    ! no fracture data
     +    ,'ptn24','ptn24','ptn24'
     +    ,'ptn25','ptn25'
     +    ,'ptn26','ptn26','ptn26','ptn26'
```

```
     +    ,'ptn26','ptn26'                          ! Alcove 4
     +    ,'tsw31','tsw31','tsw31','tsw31'
     +    ,'tsw32','tsw32','tsw32','tsw32','tsw32'
     +    ,'tsw33','tsw33','tsw33','tsw33','tsw33','tsw33'
     +    ,'tsw33'                                  !ECRB
     +    ,'tsw34','tsw34','tsw34','tsw34'
     +    ,'tsw34','tsw34','tsw34','tsw34','tsw34'    !Alcove 5 & 6
     +    ,'tsw34'                                  !ECRB
     +    ,'tsw35'
     +    ,'tsw35'                                  !ECRB
     +    ,'tsw36'                                  !ECRB
     +    ,'tsw37'                                  !ECRB
c    +    ,'burst'
     +    /
      data modlayer / 1,2,8
     +                ,12,15,16,17,20,22
     +                ,28,32,37,44,54,56,57
c     +   ,58
     +    /
c     station for start and end of unit in meters & log airk (m2)
      data unitsta /348.8                          !tcw11
     +    ,61.7,441.9,6725.5,6769.4,7514.2                !tcw12
     +    ,30003.00                                       !tcw12 alcove 3
     +    ,776.5,6718.5,6761.4,7507.8                     !tcw13
     +    ,793.6,6697.5,7495.4                            !ptn21
     +    ,0.0                          !ptn22
     +    ,0.0                                            !ptn23 - no data
     +    ,875.8,6680.7,7481.3                                    !ptn24
     +    ,894.6,7476.3                                   !ptn25
     +    ,1021.0,6637.5,6996.5,7451.9                !ptn26
     +    ,40000.0,40029.55                               !ptn26 alcove 4
     +    ,1075.7,6632.8,6990.3,7440.0                    !tsw31
     +    ,1191.0,6507.7,6527.4,6885.0,7341.5                 !tsw32
     +    ,1716.0,6308.0,6327.5,6791.8,7167.5,7290.0      !tsw33
     +    ,90000.0                                !tsw33 ECRB
     +    ,2720.0,5878.3,7057.4,7143.0                    !tsw34
     +    ,50000.0,51000.0,52000.0,60000.0,61000.0        !tsw34 alc 5 & 6
     +    ,91015.0                                        !tsw34 ECRB
     +    ,5729.2                                         !tsw35
     +    ,91444.0                                  !tsw35 ECRB
     +    ,92326.0                                  !tsw36/37 ECRB
     +    ,92326.0                                  !tsw36/37 ECRB
c     +   ,4000.0
     +    /
      data unitend /435.2                          !tcw11
     +    ,198.6,776.5,6761.4,6787.5,7875.0               !tcw12
     +    ,30035.0                                        !tcw12 alcove 3
     +    ,793.6, 6725.5,6769.4,7514.2                        !tcw13
     +    ,869.3,6718.5,7507.8                            !ptn21
     +    ,0.0                                            !ptn22
     +    ,0.0                                            !ptn23 - no data
     +    ,894.6,6694.0,7494.0                                    !ptn24
     +    ,1021.0,7481.3                                  !ptn25
     +    ,1075.7,6680.7,7057.4,7476.3                !ptn26
     +    ,40022.2,40051.0                                !ptn26 alcove 4
     +    ,1191.0,6637.5,6996.5,7451.9                !tsw31
     +    ,1716.0,6525.2,6632.8,6990.3,7440.0             !tsw32
```

```
     +    ,2720.0,6324.2,6507.7,6885.0,7255.0,7341.5  !tsw33
     +    ,91015.0                                    !tsw33 ECRB
     +    ,5729.2,6308.0,7100.0,7167.5                !tsw34
     +    ,50012.0,51015.0,52140.0,60024.0,61175.0    !tsw34 alc 5 & 6
     +    ,91444.0                                    !tsw34 ECRB
     +    ,5878.3                                     !tsw35
     +    ,92326.0                                    !tsw35 ECRB
     +    ,92583.0                                    !tsw36 ECRB
     +    ,92583.0                                    !tsw37 ECRB
c    +    ,5200.0
     +    /
      data logairk /-10.52                            !tcw11
     +    ,-11.28,-11.28,-11.28,-11.28,-11.28         !tcw12
     +    ,-11.28                                     !tcw12 alcove 3
     +    ,-11.34,-11.34,-11.34,-11.34                !tcw13
     +    ,-11.49,-11.49,-11.49                       !ptn21
     +    ,-12.52                                     !ptn22
     +    ,-12.52                                     !ptn23
     +    ,-11.53,-11.53,-11.53                       !ptn24
     +    ,-12.78,-12.78                              !ptn25
     +    ,-12.66,-12.66,-12.66,-12.66                !ptn26
     +    ,-12.66,-12.66                              !ptn26 alcove 4
     +    ,-12.20,-12.20,-12.20,-12.20                !tsw31
     +    ,-12.15,-12.15,-12.15,-12.15,-12.15         !tsw32
     +    ,-12.11,-12.11,-12.11,-12.11,-12.11,-12.11  !tsw33
     +    ,-12.11                                     !tsw33 ECRB
     +    ,-12.80,-12.80,-12.80,-12.80                !tsw34
     +    ,-12.80,-12.80,-12.80,-12.80,-12.80         !tsw34 alc 5 & 6
     +    ,-12.80                                     !tsw34 ECRB
     +    ,-12.04                                     !tsw35
     +    ,-12.04                                     !tsw35 ECRB
     +    ,-11.87                                     !tsw36 ECRB
     +    ,-11.87                                     !tsw37 ECRB
c    +    ,-12.80
     +    /
```

Version 1.1 of frac-calc 7/21/99

The following changes were made to Version 1.0
(see p. 114 in YMP-LBNL-GSB-MC-1.1
pp. 88-97 in YMP-LBNL-GSB-MC-1.1A)

- kf = kfrc(n) * freq
  was replaced with
  kf = kfrc(n) * aper
  see discussion on p. 103 in YMP-LBNL-GSB-MC-1.1 a1

- The parameters intarea & gmlen were added.

  gmlen - geo metric mean of the fracture length

  mc 7/21/99 ~~While fracture lengths are being~~
  mc 7/21/99 ~~summed added~~
  mc 7/21/99 ~~gmlen = gmlen + log (trace length)~~ a11

$$\log[gmlen] = \frac{\sum_{i=1}^{n} \log(t_i)}{n}$$

  t_i = trace length for fracture i
  n = number of fractures

  intarea - fracture interface area

$$intarea = \frac{\sum_{i=1}^{n} \pi r_i^2}{(\text{block length})(gmlen)^2}$$

  mc 7/21/99 along wall

  essentially the fracture area divided by the block volume
  Gmlen is used vertical length & depth into wall since these are unknown.
  r_i = radius of fracture i

- The output file "calibrate.par" was revised to include "gmlen" & "intarea" and was reformatted

* - All of these changes are marked with MAC V1.1 in the comments.

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Rerun ~~V~~ MC 7/21/99 test case used for Version 1.0
(pages 101-108 YMP-LBNL-GSB-MC-1.1)
[using setting that limits calculations to 1m or larger]

		Version 1.1	Version 1.0
all1.par	min-m	0.43	0.43
	Min Use	1.00	1.00
	Max-m	8.00	8.00
	# Frac	5	5
	Spac-m	3.61	3.61
	SD Spac	2.78	2.78
	Fq-1/m	0.28	0.28
	SD Freq	0.21	0.21
	Leng-m	3.68	3.68
	SD Leng	2.91	2.91
	Intens	0.16	0.16
all2.par	Apr-um	504.	504.0
	Por-3D	5.93×10^{-5}	5.93×10^{-5}
	Por-2D	8.21×10^{-5}	8.21×10^{-5}
	Por-1D	1.40×10^{-4}	1.40×10^{-4}
	alpha	3.50×10^{-3}	3.50×10^{-3}
	kzz/kxx	1.69	1.69
	kyy/kxx	1.81	1.81
	kzz/kyy	0.93	0.93

~~MC 7/21/99 m alpha~~
~~MC 7/21/99 s alpha~~

				Version 1.0 headers
Fr-porosity	8.21×10^{-5}		8.21×10^{-5}	Por-3D
Aperture	5.04×10^{-4} m	checks	504.0 μm	Apr-um
Frequency	0.28		0.28	Fq-1/m
Intr-Area	0.547		NA	
Gm-length	2.784		NA	
Fr-Alpha	3.50×10^{-3}		3.50×10^{-3}	alpha
SD-Alpha	2.41×10^{-4}		2.41×10^{-4}	sdalpha
Log Alpha	-2.54		MC 7/21/99 ~~-2.46~~ -2.54	loga
SD-Log Alpha	0.34		MC 7/21/99 ~~-3.62~~ 0.344	logsda

The output files & input files for this test case are in Refrence Binder YMP-LBNL-GSB-MC-1.2A pp. 67-71. These are in d:/dlls/code/calc.frac/frac-calc11/TestCase MC 7/21/99

The above indicates that the calculations for Version 1.1

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check for those included in Version 1.0.
The two new computations are checked below.

(formulas on p 14)

fractures less than 2 m excluded

$$\log[\text{gmlen}] = [\log(8) + \log(5.17) + \log(1.11) + \cancel{\log(0.45)} + \log(1.3) + \log(2.8)] / 6$$

MC 7/21/99

$$\text{gmlen} = 2.7836 \text{ m}$$

$$\text{intarea} = \pi\left[(4)^2 + (2.585)^2 + (0.555)^2 + \cancel{(0.215)^2} + (0.65)^2 + (1.4)^2\right] / (18.8)(2.7836)^2$$

$$= 0.5472 \text{ m}^2/\text{m}^3$$

frac_calc Version 1.1 gives

gmlen = 2.784 m

intarea = 0.547 m^2/m^3

frac_calc Version 1.1 checks

MC 7/21

The code frac_calc Version 1.1 is included in Reference Binder YMP-LBNL-GSB-MC-1.2A pp. 72-87

The file is on "nwd-cushey" in d:\code\~~frac-calc~~ calc_frac MC 7/21/99
frac_calc 11

The filenames are frac_calc11.f & frac_calc11.exe

MC
9/23/99

SIGNATURE [signature] DATE 7/21 19 99
READ AND UNDERSTOOD DATE 19

filenames are
frac_calc11.f and
frac_calc11.ex
MC
9/23/99

Input and Output files for test case for frac_calc Version 1.1

Input: test.dat

Output: all1.par, all2.par, & calibrate.par

(S/N YMP LBNL GSB-
MC-1.2A)

LOCATION	STRIKE	DIP	LENGTH A	LENGTH B
879.700	20.000	8.000	2.000	6.000
882.370	184.000	78.000	3.500	1.670
887.300	299.000	78.000	.000	1.110
893.860	20.000	49.000	.100	.330
893.920	22.000	80.000	.680	.620
894.130	20.000	67.000	1.200	1.600

For test case run, program excludes this because minimum fracture length cutoff is set to 1 m (see next page)

selected cutoff length

Unit	<---Station--->		Min-m	MinUse	Max-m	#Frac	Spac-m	SDSpac	Fq-1/m	SDFreq	Leng-m	SDLeng	Intens
ptn24	875.80	894.60	.43	1.00	8.00	5	3.61	2.78	.28	.21	3.68	2.91	.16
	879.70	894.13		(m)				(m)		(1/m)		(m)	

all1.pdr

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Unit	MinUse	#Frac	Fq-1/m	Apr-um	Por-3D	Por-2D	Por-1D	alpha	kzz/kxx	kyy/kxx	kzz/kyy
ptn24	1.00	5	.28	504.	5.93E-05	8.21E-05	1.40E-04	3.50E-03	1.69	1.81	.93

all 2.par

70 77
MC 7/24/

Unit	Min-Fr-Length	Fr-Porosity	Aperture	Frequency	Inter-Area	Gm-length	Fr-Alpha	SD-Alpha	LogAlpha	SD-LogAlpha
tcw11										
tcw12										
tcw13										
ptn21										
ptn22										
ptn23										
ptn24	1.00	8.21E-05	5.04E-04	.28	.547	2.784	3.50E-03	2.41E-04	-2.54	.34
ptn25										
ptn26										
tsw31										
tsw32										
tsw33										
tsw34										
tsw35										
tsw36										
tsw37										

calibrate.par

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9/21/94

Code for
Frac_calc
Version 1.1

```
      program Frac_Calc

c     Version 1.1
c     All changes for Version 1.1 are indicated by MAC V1.1
c     See Scientific Notebook YMP-LBNL-GSB-MC-1.2 pages 14-16

c     Discussion for Version 1.0
c
c     The purpose of this program is to calculate means and variances
c     for fracture properties for UZ model layers based on detailed
c     line survey (DLS) data for the Exploratory Studies Facility (ESF)
c     that has been downloaded from the Technical Database (TDB).

c     This program was originally written by Eric Sonnenthal with
c     revisions and additions by Mark Cushey (4/98 to 7/98) which are
c     labeled MAC and dated.  Major additions include using data
c     statements and coding to combine subunits for model layers
c     internally in the program; calculating additional parameters;
c     program recalculates all numbers for each model layer each time
c     it is executed; calculate apertures; calculate alpha & log alpha
c     and its statistics; calculates spacing, frequencies and intensity
c     for selected interval lengths; new input format for direct reading
c     of data from TDB after processing through read_tdb.f; and new
c     output formats.

c       MAC V1.1 - updated pages below for references for Version 1.0
c     See Scientific Notebook YMP-LBNL-GSB-MC-1 pages 60-69, 124-125, 137
c     See Scientific Notebook YMP-LBNL-GSB-MC-1.1 pages 98, 101-108, 114-115
c     See Reference Binder YMP-LBNL-GSB-MC-1.1A pages 88-97, 98-106

c    - Mark Cushey 7/98
c-----------------------------------------------------------------------
c     Below comments by E.Sonnenthal
c...  Program to read USGS ESF data and calculate fracture geometries
c...  and densities for plotting (11/4/96: E. Sonnenthal)
c...  Components of hydraulic conductivity tensor (de Marsily, 1986)
c...  11/11/96 E. Sonnenthal
c...  revised 2/6/97 for a fracture size range
c     nf     = Number of fractures
c     blksiz = Block size (m)
c     kfrc   = Hydraulic conductivity of each fracture (m/s)
c     aper   = Aperture of each fracture (m)
c     strike = Strike of each fracture (azimuth in radians)
c     dip    = Dip of each fracture (dip in radians)
c     ktens  = Conductivity tensor (9 component)
c      k(9) = (kxx,kxy,kxz,kyx,kyy,kyz,kzx,kzy,kzz)
c          | kxx  kxy  kxz |
c          | kyx  kyy  kyz |
c          | kzx  kzy  kzz |
c-----------------------------------------------------------------------

c Commented out variables no longer used MAC 7/98
c     integer ni1,ni2
      integer i,k,ni,n,nn,nm1,nfr,nf,ns1,ns2
      parameter (nf = 50000)
      parameter (pi=3.1415926536d0)
      parameter (ni = 199)
```

```
c Added MAC 4/13/98
      character*32 fname

c Commented out variables no longer used MAC 7/98
c      character*8 outfile, header2, fstat
c      character*200 header
c      integer dist1
c      double precision height(nf),dist2

      integer nfrint(ni),ns
      double precision blksiz,kf,sdsq,stkrad,diprad,proptf
      double precision fmin,fmax
      double precision kfrc(nf),aper(nf)
      double precision ktens(9)
      double precision kxx,kxy,kxz,kyx,kyy,kyz,kzx,kzy,kzz
      double precision endp1,endp2,totaltr,totalht,adip,bdip
      double precision dist(nf),nfrc(nf)
      double precision strike(nf),dip(nf),alen(nf),blen(nf)
      double precision atrace(nf),btrace(nf),trace(nf)
      double precision trlen,fmasf,frint,fgrp1,fgrp2,fsiz
      double precision trcmax,dipmin,dipmax,aperture
      double precision avgsp,frcint,varsp,sdspac
      double precision freq,sdfreq,frcvol,frcrad,frcpor,blkht,blkdp
      double precision sdlen,varlen,avglen,frarea,frcp2d
      character*1 ans1,ans2

c     MAC V1.1
      double precision intarea, gmlen

c
c-----------------------------------------------------------------------
c     Below added by MAC 4/98 - 5/98
c     Data statements added to identify subunits and later combine
c     subunits for each model layer.
c     Moved to include MAC 6/98 so that various combinations could be
c     used by simply using a different file for include
c     Note that alcove stations are entered with Alcove # in the
c     ten thousandth location.
c     Assignment for model layers based on CRWSM M&O, 1998.
c     For most recent assignment see
c     Scientific Notebook YMP-LBNL-GSB-MC-1.1 pages 36-39.
c
c     Include file 'datablk.f' includes data statements for
c     unitname, modlayer, unitsta, unitend, and logairk

c     MAC V1.1
      include 'datablk11.f'
c
c     For testing, instead of 'datablk.f', include file 'uzmodel97.f'
c     for comparison with calculations performed for the July 97
c     milestone (Chapter 7, Sonnethal et. al, 1997) or include
c    'sweetkind.f' for comparison with calculations in
c     Sweetkind et. al (1997). Use the data files ericdls.dat and
c     sweetdls.dat, respectively.
c     include 'uzmodel97.f'
c     include 'sweetkind.f'
```

```
c     MAC 7/98 For the more detailed PTn model layers use
c     include 'ptnblk.f'

c-----------------------------------------------------------------------
c Below added MAC 4/98 - 6/98
c     ntotal is the total number of UZ model layers
c     nlayers is the total number of segments along the ESF
c     Both are used for the data statements and are defined in the
c         file 'datablk.f'
c     npar is the number of parameters saved for calculating properties
c     for entire model layer
c     variables with 'int' are for calculating fracture properties for
c         intervals
c     variables for data statements [integer modlayer(ntotal);
c         double precision logairk(nlayers),unitsta(nlayers),
c         unitend(nlayers)] are in file 'datablk.f'

      integer layer,first,last,npar
c     MAC V1.1 changed npar from 16 to 18
      parameter(npar=18)
      double precision spac,frcpld,trcmin, combine,kzzkxx,kyykxx,kzzkyy,
     +    alpha,loga,logf,sdalpha
      dimension combine(nlayers,npar)
      character*5 outfile

      integer intn,intmax,intnfr,intlayer
      parameter(intmax=10000)
      double precision intfreq,intspace, intlength, inttrace
      dimension intfreq(intmax),intspace(intmax),intnfr(intmax),
     +    inttrace(intmax)

c...Input file name
2     print *, 'Enter fracture data filename: '
      read (*,*) fname
      open(unit=12,file=fname,status='old',err=5)
      go to 7
5     write(*,*)'File not found'
      go to 2
7     continue

c Removed call to station file -- all in one file MAC 4/13/98

c revised MAC 4/13/98 - starting and end points for model layers
c         now determined internally

c revised MAC 4/17/98 - changed input process
      dipmin = 0.d0
      dipmax = 90.d0
      ans1 = 'n'
      ans2 = 'y'
      write(*,*)'Enter minimum and maximum fracture length to use'
      read(*,*)fmin,fmax

c Added MAC 7/8/98 - query user for interval length
      write(*,*)'Enter interval length (in meters)'
      read(*,*)intlength
```

```
c--------------------
c... Read station file - Removed MAC 4/13/98

c     MAC 4/98 open output files
      open(13,file='all1.par',status='unknown')
      open(14,file='all2.par',status='unknown')
      write(13,441)
      write(14,442)
      open(18,file='interval.par',status='unknown')
      write(18,1999)
      open(20,file='tmp.par')

c
c... Read fracture data file
c Rev MAC 4/13/98
      read (12,*)
      i = 0
10    i = i + 1
c     rev MAC 6/29/98 - Don't read in height
c     read(12,*,end=99)dist(i),strike(i),dip(i),atrace(i),
c    &    btrace(i),height(i)
      read(12,*,end=99)dist(i),strike(i),dip(i),atrace(i),
     &    btrace(i)
      go to 10
99    ns = i - 1
      dist(ns+1)=99999.9
      close(12)
c
c Added MAC 6/25/98
c     initialize combine
      do j=1,npar
          do i=1,nlayers
              combine(i,j) = 0d0
          end do
      end do

c----------------
c Added MAC 4/17/98
c     Loop through model layers, assiging station ranges
c     Define endp1, endp2, ns1, ns2
c
      DO layer = 1,nlayers
          endp1 = unitsta(layer)
          endp2 = unitend(layer)
          write(*,*)unitname(layer),endp1,endp2
          ns1 = 0
          ns2 = 0
          do i = 1,ns+1
              if (((dist(i).ge.endp1).and.(dist(i-1).lt.endp1))
     &        .or.((dist(i).ge.endp1).and.(i.eq.1)))
     &            ns1 = i
              if ((dist(i).gt.endp2).and.(dist(i-1).le.endp2))
     &            ns2 = i - 1
          end do
c         MAC V1.1 - changed 0.0 to 0
          if ((ns2-ns1).le.0) go to 999
          write(*,*)'     ',dist(ns1),dist(ns2)
```

```
c         outfile = unitname(layer)
          outfile = 'dummy'
c         if ((layer.eq.48).or.(layer.eq.27)) then
c             outfile = unitname(layer)
c             write(*,*)'Tecplot file for',unitname(layer),
c    +            unitsta(layer),unitend(layer)
c         end if
c... Find size distribution for all fractures
      if(ans2.eq.'y')then
          fmesf = 0.3d0
          frint = 0.2d0
      do i = ns1,ns2
          trlen = atrace(i) + btrace(i)
        do k = 1, ni
          fgrp1 = fmesf + dble(k-1)*frint
          fgrp2 = fmesf + dble(k)*frint
          if(trlen.ge.fgrp1.and.trlen.lt.fgrp2)
     &        nfrint(k)=nfrint(k)+1
        enddo
      enddo
      endif
c

c Added MAC 4/98 find minimum trace length before excluding
      trcmin = fmax
      do i = ns1,ns2
        trcmin = min((atrace(i)+btrace(i)),trcmin)
      enddo

c... Find fractures that are within range if given
      n = 0
      nfr = 0
      do i = ns1,ns2
        if(dip(i).ge.dipmin.and.dip(i).le.dipmax.and.atrace(i)+
     +    btrace(i).ge.fmin.and.atrace(i)+btrace(i).le.fmax)
     +    then
            n = n + 1
            nfrc(n) = i
            nfr = n
        endif
      enddo
      if (nfr.le.1) go to 999

c
c... Calculate proportion of total fractures
      proptf = dble(nfr)/(dble(ns2-ns1+1))

c
c... Find total trace length
        do n = 1, nfr
          nn = nfrc(n)
          trace(n) = atrace(nn) + btrace(nn)
        enddo
c
c... Find maximum trace length
      trcmax = -1.d5
```

```
      do n = 1, nfr
        trcmax = max(trace(n),trcmax)
      enddo

c
c... Length of fracture segment for plotting is 0.15 inch/meter
      do n = 1, nfr
        nn = nfrc(n)
        alen(n) = atrace(nn)*0.15d0
        blen(n) = btrace(nn)*0.15d0
      enddo
c
c... Calculate blocksize (interval length)
      blksiz = endp2 - endp1
      blkht = 6.d0
      blkdp = 6.d0
c
c Rev MAC 4/17/98 - moved perm, frac volume, porisity to after
c parameters

c Rev MAC 4/98 - zero sum parameters
      totalht = 0d0
      totaltr = 0d0
      ssqht = 0d0
      ssqtr = 0d0
      sspac = 0d0
      ssqsp = 0d0
      ssqlsp =0d0
      slgsp = 0d0
c     MAC V1.1
      gmlen = 0d0
      intarea = 0d0

c Added MAC 5/98
      do n = 1, intmax
          intspace(n) = 0d0
          intfreq(n) = 0d0
          intnfr(n) = 0
          inttrace(n) = 0d0
      end do
      intn = 0
      intlayar = 0
c
c... Calculate fracture parameters - loop through fractures
        do n = 1, nfr
          nn = nfrc(n)
          totaltr = trace(n) + totaltr
          ssqtr = trace(n)**2 + ssqtr

c         MAC V1.1
          gmlen = gmlen + dlog10(trace(n))

          if(n.gt.1)then
            nm1 = nfrc(n-1)
c rev MAC 4/13/98 - put in if
            spac = dabs(dist(nn)-dist(nm1))
            if (spac.eq.0.0) then
```

```
            write(*,*)'station overlap',dist(nn),nn,nm1
          end if
2099  format(1x,a5,3(1x,f9.2))


          sspac = spac + sspac
c correction MAC 4/13/98
c           put in '+ slgsp' in place of '+ sspac'
c           put in dlog10 and if-then
          if (spac.ne.0.0) then
             slgsp = dlog10(spac) + slgsp
c correction MAC 4/98
c           put in '+ ssqlsp' in place of '+ ssqsp'
c           put in dlog10
             ssqlsp = (dlog10(spac))**2 + ssqlsp
          else
c rev MAC 4/98 for zero spacing use 0.005 m which is 1/2
c           of the measurement precision
             slgsp = dlog10(5d-3) + slgsp
             ssqlsp = (dlog10(5d-3))**2 + ssqlsp
          end if

          ssqsp = spac**2 + ssqsp


c added MAC 5/98 - for determining frequency and intensity over interval
c           added MAC 7/98 - if-then statment to prevent from
c           overextending interval boundary
            intn = INT((dist(nn)-endp1)/intlength)+1
            if ( (endp1+(intn*intlength)).le.endp2 ) then
                if (intn.gt.intmax) then
                    write(*,*)'Max number of intervals exceeded -',
     +                      ' program stopped'
                    write(*,*)'Resize intmax - intmax,intn',intmax,intn
                    stop
                end if
                intspace(intn) = intspace(intn) + spac
                intnfr(intn) = intnfr(intn) + 1
                inttrace(intn) = inttrace(intn) + trace(n)
                intlayer = intn
            end if
        endif
300     continue
      enddo

        avgsp = sspac/dble(nfr-1)
        freq = 1.d0/avgsp

c added MAC 5/98 - for determining frequency and intensity over interval
        do intn = 1,intlayer
            if (intnfr(intn).gt.1) then
                intspace(intn) = intspace(intn)/dble(intnfr(intn)-1)
                intfreq(intn) = 1d0/intspace(intn)
            else
                intfreq(intn) = 1d0/intlength
            end if
            inttrace(intn) = inttrace(intn)/intlength/blkht
```

```
          end do

c         MAC 5/98 added if-then for small # of fractures
          if (nfr.gt.2) then
c             nfr-1 is the number of pairs used to calculate spacing
              varsp = (ssqsp - ((sspac**2)/dble(nfr-1)))/(dble(nfr-2))
              if (varsp.gt.0.0) then
                  sdspac = sqrt(varsp)
c added comment and put in varsp rather than sdspac**2 by MAC 5/98
c V[f]= V[s]*(-E[s]**-2)**2
                  sdfreq = sqrt((((-avgsp)**(-2))**2)*varsp)
              else
                  sdspac = 0d0
                  sdfreq = 0d0
              end if
          else
              varsp = 0d0
              sdspac = 0d0
              sdfreq = 0d0
          end if

          frcint = totaltr/blksiz/blkht
          avglen = totaltr/dble(nfr)
          varlen = (ssqtr - ((totaltr**2)/dble(nfr)))/dble(nfr-1)
          if (varlen.gt.0.0) then
              sdlen = sqrt(varlen)
          else
              sdlen = 0d0
          end if

c Rev MAC 4/17/98 - calculate b (in um) from airk
          aperture = 1d6*(12d0*(10**logairk(layer))/freq)**(1.0/3.0)

c... Calculate permeability of each fracture and pass to ktensor
      do n = 1, nfr
        aper(n) = aperture*1.d-6
        kfrc(n) = (aper(n)**3)/12.d0
      enddo

c Rev MAC 4/98 - zero sum parameters
      frcvol = 0d0
      frarea = 0d0
      do i = 1,9
          ktens(i) = 0d0
      end do

c... Calculate fracture volume based on penny-shaped fractures
      do n = 1, nfr
        frcrad = trace(n)*0.5d0
        frcvol = pi*aper(n)*frcrad**2 + frcvol
        frarea = aper(n)*frcrad*2.d0 + frarea
c         MAC V1.1 - will divide by block volume after combining
        intarea = pi*frcrad**2 + intarea

      enddo
c... Calculate fracture porosity
      frcpor = frcvol/(blksiz*blkht*blkdp)
```

```
      frcp2d = frarea/(blksiz*blkht)

c Added MAC 4/22/98 - include 1-D porosity
      frcp1d = freq*aperture*1d-6
c
c... Calculate components associated with each fracture, then sum
        radian = pi/180.d0
      do n = 1, nfr
        nn = nfrc(n)
        if(strike(nn).le.90.d0)then
          stkrad = strike(nn)*radian
          diprad = dip(nn)*radian
        elseif(strike(nn).gt.90.d0.and.strike(nn).le.180.d0)then
          stkrad = strike(nn)*radian
          diprad = (180.d0-dip(nn))*radian
        elseif(strike(nn).gt.180.d0.and.strike(nn).le.270.d0)then
          stkrad = strike(nn)*radian
          diprad = (180.d0-dip(nn))*radian
        else
          stkrad = strike(nn)*radian
          diprad = dip(nn)*radian
        endif
        sdsq = (dsin(diprad))**2
        kxx = 1.d0 - ((dcos(stkrad))**2)*sdsq
        kxy = 0.5d0*dsin(2.d0*stkrad)*sdsq
        kxz = -0.5d0*dsin(2.d0*diprad)*dcos(stkrad)
        kyx = kxy
        kyy = 1.d0 - ((dsin(stkrad))**2)*sdsq
        kyz = 0.5d0*dsin(2.d0*diprad)*dsin(stkrad)
        kzx = kxz
        kzy = kyz
        kzz = sdsq
        kf = kfrc(n)*freq
        ktens(1) = kxx*kf + ktens(1)
        ktens(2) = kxy*kf + ktens(2)
        ktens(3) = kxz*kf + ktens(3)
        ktens(4) = kyx*kf + ktens(4)
        ktens(5) = kyy*kf + ktens(5)
        ktens(6) = kyz*kf + ktens(6)
        ktens(7) = kzx*kf + ktens(7)
        ktens(8) = kzy*kf + ktens(8)
        ktens(9) = kzz*kf + ktens(9)
      enddo

c Added MAC 4/21/98
      kzzkxx = ktens(9)/ktens(1)
      kyykxx = ktens(5)/ktens(1)
      kzzkyy = ktens(9)/ktens(5)

c Added MAC 4/21/98
c     Calculate alpha (see equation 7)
      alpha = aperture*1d-6/2d0/72d-3
c
c Commented out MAC 7/98
c... Open and write permeability components of fracture networks
c      open(11,file=outfile//'.prm',status='unknown')
c        write(11,*)'Permeability Tensor for: ',outfile
```

```
c         write(11,450)'kxx','kxy','kxz','kyx','kyy','kyz','kzx',
c      +   'kzy','kzz'
c         write(11,460)ktens(1),ktens(2),ktens(3),ktens(4),
c      +    ktens(5),ktens(6),ktens(7),ktens(8),ktens(9)
c         write(11,*)'kzz/kxx= ',ktens(9)/ktens(1)
c         write(11,*)'kyy/kxx= ',ktens(5)/ktens(1)
c       close(11)

c... Calculate orientations and open and write GMT plot file
          open(11,file=outfile//'.plt',status='unknown')
      do n = 1, nfr
          nn = nfrc(n)
          if(strike(nn).le.90.d0)then
            adip = dip(nn)
            bdip = dip(nn) + 180.d0
          elseif(strike(nn).gt.90.d0.and.strike(nn).le.270.d0)then
            adip = 180.d0 - dip(nn)
            bdip = 360.d0 - dip(nn)
          else
            adip = dip(nn)
            bdip = dip(nn) + 180.d0
          endif
          write(11,404)dist(nn),adip,alen(n),unitname(layer)
          write(11,404)dist(nn),bdip,blen(n),unitname(layer)
        enddo
      close(11)
c-----------------------------------------------------------------
c     Below by MAC 4/98
c     Completely changed output file formatting
c     now 'all1.par' and 'all2.par' which list data for each subunit
c     Deleted E.S. output file writing

      if (endp2.lt.9999.0) then
          write(13,443)unitname(layer),endp1,endp2,trcmin,fmin,
     +    trcmax,nfr,avgsp,sdspac,freq,sdfreq,avglen,sdlen,frcint
          write(14,444)unitname(layer),fmin,nfr,freq,
     +    aperture,frcpor,frcp2d,frcp1d,alpha,kzzkxx,kyykxx,kzzkyy
          write(13,443)'      ',dist(ns1),dist(ns2)
      else
c         alcove data & ECRB data
c         ECRB is read in as if it is alcove 9 MAC 3-23-99
          if (endp1.lt.90000.0) then
           write(13,2443)unitname(layer),INT(endp1/10000.0),trcmin,fmin,
     +     trcmax,nfr,avgsp,sdspac,freq,sdfreq,avglen,sdlen,frcint
          else
           write(13,2445)unitname(layer),trcmin,fmin,
     +     trcmax,nfr,avgsp,sdspac,freq,sdfreq,avglen,sdlen,frcint
          end if
          write(14,444)unitname(layer),fmin,nfr,freq,
     +    aperture,frcpor,frcp2d,frcp1d,alpha,kzzkxx,kyykxx,kzzkyy
          write(13,2444)(dist(ns2)-dist(ns1))

      end if
441   format(1x,' Unit',1x,'<---Station--->',1x,
     +    ' Min-m',1x,'MinUse',1x,' Max-m',1x,' #Frac',1x,
     +    'Spac-m',1x,'SDSpac',1x,'Fq-1/m',
     +    1x,'SDFreq',1x,'Leng-m',1x,'SDLeng',1x,'Intens')
```

```
442   format(1x,' Unit',1x,
     +    'MinUse',1x,' #Frac',1x,'Fq-1/m'
     +    ,1x,'Apr-um',1x,'   Por-3D',1x,'   Por-2D',1x,'   Por-1D'
     +    ,1x,'    alpha',1x,'kzz/kxx',1x,'kyy/kxx',1x,'kzz/kyy')
443   format(1x,a5,2(1x,f7.2),3(1x,f6.2),1x,i6,7(1x,f6.2))
444   format(1x,a5,1x,f6.2,1x,i6,1x,f6.2,1x,f6.0,4(1x,es9.2),
     +        3(1x,f7.2))
2443  format(1x,a5,4x,'Alcove',i2,4x,3(1x,f6.2),1x,i6,7(1x,f6.2))
2444  format(7x,f7.2,1x,'meters')
2445  format(1x,a5,4x,'ECRB  ',2x,4x,3(1x,f6.2),1x,i6,7(1x,f6.2))

c     Save results for combined output
c     added MAC 4/98
      combine(layer,1)=endp1
      combine(layer,2)=endp2
      combine(layer,3)=trcmin
      combine(layer,4)=trcmax
      combine(layer,5)=dble(nfr)
      combine(layer,6)=avgsp*dble(nfr-1)
      combine(layer,7)=ssqsp
      combine(layer,8)=avglen*dble(nfr)
      combine(layer,9)=ssqtr
      combine(layer,10)=frcpor*blksiz/(aperture*1d-6)
      combine(layer,11)=frcp2d*blksiz/(aperture*1d-6)
      combine(layer,12)=ktens(1)/freq
      combine(layer,13)=ktens(5)/freq
      combine(layer,14)=ktens(9)/freq
      combine(layer,15)=slgsp
      combine(layer,16)=ssqlsp
c     MAC V1.1
      combine(layer,17)=intarea
      combine(layer,18)=gmlen

c Added MAC 5/98 - Output interval results to 'interval.par'
      do intn=1,intlayer
              write(18,2000)unitname(layer),
     +        (endp1+(intn-1)*intlength),
     +        (endp1+(intn)*intlength),
     +        intnfr(intn),intspace(intn),intfreq(intn),
     +        (dble(intnfr(intn))/intlength),inttrace(intn)
      end do
1999  format(1x,' Unit',2(1x,'  Station'),1x,'   #Frac',4x,
     +    'Spacing',2x,'Frequency',3x,'#/Length',2x,'Intensity')
2000  format(1x,a5,2(1x,f9.1),1x,i8,4(1x,f10.2))
c-----------------------------------------------------------------------

c... Write fracture size distributions
      if(ans2.eq.'y')then
      open(12,file=outfile//'.szd',status='unknown')
      do k = 1, ni
          fgrp1 = fmesf + dble(k-1)*frint
          fsiz = fgrp1 + frint*0.5d0
c rev MAC 5/12/97  write(12,470)fsiz,dble(nfrint(k))/dble(ns)
        write(12,475)fsiz,nfrint(k)
      enddo
      close(12)
        fsum = 0.d0
```

```
c          write cumulative size distributions
      open(12,file=outfile//'.csd',status='unknown')
        ftot = 1.d0
        write(12,470)fmesf,ftot
      do k = 1, ni
        fgrpl = fmesf + dble(k)*frint
        fsum = dble(nfrint(k))/dble(ns) + fsum
        write(12,470)fgrpl,1.d0 - fsum
      enddo
      close(12)
      endif
c

c Added MAC 4/17/98
999   continue
      END DO
      close(13)
      close(14)

c-----------------------------------------------------------------------------------------
---
c     Below is all new code added by MAC 4/98

c     Combine results for single values for each model layer
c
c     Output to files 'comb1.par' & 'comb2.par' - combined results of
c     all1.par & all2.par
c     Output to file 'calibrate.par' - data to be used for inversion
c
      open(13,file='comb1.par',status='unknown')
      open(14,file='comb2.par',status='unknown')
      open(15,file='calibrate.par',status='unknown')
      write(13,1441)
      write(14,442)
      write(15,2501)
      DO i = 1,ntotal
          trcmin = 1d6
          trcmax = 0d0
          nfr = 0
          avgsp = 0d0
          sspac = 0d0
          sdspace = 0d0
          ssqsp = 0d0
          avglen = 0d0
          sdlen = 0d0
          ssqtr = 0d0
          frcpor = 0d0
          frcp2d = 0d0
          blksiz = 0d0
          kxx = 0d0
          kyy = 0d0
          kzz = 0d0
          slgsp = 0d0
          sslgsp = 0d0
c         MAC V1.1
          intarea = 0d0
          gmlen = 0d0
```

```
            first = modlayer(i)
            if (i.ne.ntotal) then
                last = modlayer(i+1) - 1
            else
                last = nlayers
            end if
            n = last - first + 1
        DO layer = first,last
            trcmin = min(trcmin,combine(layer,3))
            trcmax = max(trcmax,combine(layer,4))
            nfr = nfr + NINT(combine(layer,5))
            sspac = sspac + combine(layer,6)
            ssqsp = ssqsp + combine(layer,7)
            avglen = avglen + combine(layer,8)
            ssqtr = ssqtr + combine(layer,9)
            frcpor = frcpor + combine(layer,10)
            frcp2d = frcp2d + combine(layer,11)
            blksiz = blksiz + combine(layer,2) - combine(layer,1)
            kxx = kxx + combine(layer,12)
            kyy = kyy + combine(layer,13)
            kzz = kzz + combine(layer,14)
c
            slgsp = slgsp + combine(layer,15)
            ssqlsp = ssqlsp + combine(layer,16)

c           MAC V1.1
            intarea = intarea + combine(layer,17)
            gmlen = gmlen + combine(layer,18)

            if ((layer.eq.last).and.(nfr.gt.(n+1))) then
                avgsp = sspac/dble(nfr-n)
                freq = 1.d0/avgsp
c               nfr-n is the number of pairs used to calculate spacing
                varsp = (ssqsp - ((sspac**2)/dble(nfr-n)))/(dble(nfr-n-1))
                if (varsp.gt.0.0) then
                    sdspac = dsqrt(varsp)
                else
                    sdspac = 0d0
                end if
                varlen = (ssqtr - ((avglen**2)/dble(nfr-n))) /
     >                    (dble(nfr-n-1))
                avglen = avglen/dble(nfr)
                if (varlen.gt.0.0) then
                    sdlen = dsqrt(varlen)
                else
                    sdlen = 0d0
                end if
                if (sdspac .gt. 0.0) then
                    sdfreq = dsqrt(varsp/(avgsp**4))
                else
                    sdfreq = 0d0
                end if
                aperture = 1d6*(12d0*(10**logairk(layer))/freq)
     &                    **(1.0/3.0)
                alpha = aperture*1d-6/2d0/72d-3
                frcpor = frcpor*(aperture*1d-6)/blksiz
```

```
                frcp2d = frcp2d*(aperture*1d-6)/blksiz
                frcp1d = freq*aperture*1d-6
c               calculate k ratios (note freq cancels)
                kzzkxx = kzz/kxx
                kyykxx = kyy/kxx
                kzzkyy = kzz/kyy
c               calulate fracture intensity
                frcint = avglen*dble(nfr)/blksiz/6e0
c               MAC V1.1
                gmlen = 10**(gmlen/dble(nfr))
                intarea = intarea/blksiz/(gmlen**2)

                write(13,1443)unitname(layer),trcmin,fmin,
     +           trcmax,nfr,avgsp,sdspac,freq,sdfreq,avglen,sdlen,frcint
                write(14,444)unitname(layer),fmin,nfr,freq,
     +          aperture,frcpor,frcp2d,frcp1d,alpha,kzzkxx,kyykxx,kzzkyy

c
                ssqlsp = (ssqlsp - slgsp**2/dble(nfr-n) )/ dble(nfr-n-1)
                slgsp = slgsp / dble(nfr-n)
                logf = - slgsp
                loga = (1d0/3d0)*(dlog10(12d0)+logairk(layer)-logf)
     >                - dlog10(2d0*72d-3)
                sdalpha = sdfreq*dsqrt(1d0/72d-3) *
     >          ( (10**logairk(layer)) /18d0/(freq**4) )**(1.0/3.0)
                if (ssqlsp.le.0.0) then
                    write(*,2500)unitname(layer),slgsp,ssqlsp
                    ssqlsp = 0.0
                end if

c           MAC V1.1 add new parameters gmlen (gemetric mean length) and
c           intarea (fracture area/block volume where block volume is
c           block length * gmlen^2).  Also changed output for calibrate.par
        write(15,2500)unitname(layer),fmin,frcp2d,(aperture*1d-6),freq,
     +      intarea,gmlen,alpha,sdalpha,loga,dsqrt(ssqlsp/9d0)
2500    format(1x,a5,5x,f9.2,2(3x,es9.2),3x,f9.2,2(3x,f9.3),
     +      2(3x,es9.2),2(3x,f9.2))
2501    format(1x,' Unit',1x,'Min-Fr-Length',1x,'Fr-Porosity',4x,
     +      'Aperture',3x,'Frequency',2x,'Inter-Area',3x,'Gm-length',
     +      4x,'Fr-Alpha',4x,'SD-Alpha',4x,'LogAlpha',1x,'SD-LogAlpha')
c2500 format(1x,a5,2(1x,f7.2),2(1x,es9.2),3(1x,f7.2),1x,f7.3,1x,f7.2,
c    +      1x,i5,2(1x,f7.2))
c2501 format(1x,' Unit',4x,'Freq',2x,'SDFreq',5x,'alpha',3x,'sdalpha',
c    +      4x,'loga',2x,'logsda',2x,'<loga>',
c    +      1x,'s<loga>',2x,'gmFreq',1x,'#Frac',3x,'Block',3x,'#Freq')

c       added else statement - MAC 6/25/98
            else
                if (layer.eq.last) then
                    write(13,2500)unitname(layer)
                    write(14,2500)unitname(layer)
                    write(15,2500)unitname(layer)
                end if

            end if
        END DO
        END DO
```

```
1441  format(1x,' Unit',1x,
     +     ' Min-m',1x,'MinUse',1x,' Max-m',1x,' #Frac',1x,
     +     'Spac-m',1x,'SDSpac',1x,'Fq-1/m',
     +    1x,'SDFreq',1x,'Leng-m',1x,'SDLeng',1x,'Intense')
1443  format(1x,a5,3(1x,f6.2),1x,i6,7(1x,f6.2))
      close(13)
      close(14)


      stop


  400 format(a200)
  404 format(f13.2,1x,f8.4,1x,f9.5,1x,a5)
  408 format(a10)
  410 format(i2,1x,f5.2)
  415 format(a21,2(1x,f7.2))
  420 format(a48,2(1x,f7.3),1x,i5,1x,f5.3)
  425 format(a78)
  430 format(f8.4,5(2x,f8.4),2(2x,e10.4))
  440 format(a40)
  450 format(9(4x,a4,3x))
  460 format(9(1x,e10.3))
  470 format(f10.3,1x,f8.4)
  475 format(f10.3,1x,i8)
c
      stop
      end
```

NB. Mc-1.1

Frac_Calc V.1.0 Qualification 8/27/98

Frac_Calc was reviewed and qualified as a Multiuser Macro. The approval signature form is below and supporting documentation is on file with LBNL ~~ESD Software Qualification~~. Software Manager Don Mangold. MC 8/27

FORM 13
Software Qualification for Multi User Macro

PROCEDURE ID: YMP-LBNL-QP-8.0 | REV. 2, MOD. 1 | EFFECTIVE: 06/30/98

Software name & version: Frac_Calc Version 1.0	SCMS ID: Frac_calc V 1.0
Preparer name: Mark A. Cushey	Date doc. initiated: 8/10/98

If more space is needed, attach separate sheet(s) and address the points on this form.

Objectives—Changes: Calculate fracture properties for UZ model layers based on detailed line survey data from the ESF.

Scientific Notebook Identifier: YMP-LBNL-658-MC-1 YMP-LBNL-658-MC-1.1 YMP-LBNL-658-MC-1.1A (reference binder)

Page numbers where macro or changes were described and tested: mc-1 60-65, 124/125, 157 mc-1.1 98, 101-108 mc-1.1A 88-97 ← code MC 7/21/99

NOTE: If macro is part of a larger code, include results of regression testing of larger code.

Technical Contact Signature: Mark A. Cushey Date: 8/10/98

Technical Review

No mandatory comments, recommend acceptance.

Signature: _____ Date: _____

Mandatory Comments—see attached DRCR form.

Signature: [illegible] Date: 8/25/98

SCM Acceptance

Signature: Donald Mangold Date: 8/26/98

Applicable Manager's signature and date of approval

Name: [illegible] Date: 8/26/98

Attachment 2
Page 1 of 1

YMP-LBNL DOCUMENT REVIEW/COMMENT RESOLUTION FORM (DRCR)
(Form 14)

Document No. and Title: Frac_Calc 1.0 SCMS ID: _____ Page 1 of 1

Date of Document (or revision, if applicable): 8/10/98

Is Scientific Notebooks or other Management documentation included in the scope of this review? ☒ Yes ☐ No (If yes, identify on Attachment 3)

8/27/98

as a
there form is
on file
in software

[redacted]

K V 1.0
8/10/98

c U3 model
ESF

ver)
-0-66,13,4,7,25,1,17
9,10,1-10,8
X 88-97
ns of larger ← code
MC
7/21/99

8/10/98

-0-0-0-0-

Attachment 2
Page 1 of 1

YMP-LBNL DOCUMENT REVIEW/COMMENT RESOLUTION FORM (DRCR)

Document No. and Title: Frac_Calc 1.0 SCMS ID: (Form M) Page 1 of 1

Date of Document (or revision, if applicable): 8/10/98

Are Scientific Notebooks or other background documents/data included in the scope of this review? ☒ Yes ☐ No (If yes, identify on Attachment 3) Identified on Form M

Specific Review Criteria or Governing Procedure:

General Review Criteria: (identify relevant criteria on Attachment 4): Software Review Criteria for Macros

Reviewer Name: Randy Hedegaard

Reviewer Signature: Date: 11 Aug 98 Disposition of Mandatory Comments Completed (initial): RH

REVIEWER'S COMMENTS*			AUTHOR'S RESPONSE*			Reviewer Disposition for Mandatory Comments	
COMMENT NO. MANDATORY (M) NON-MANDATORY (NM)	SECT. AND PAGE NO.	COMMENTS	ACCEPT Initial/Date	REJECT Initial/Date	JUSTIFICATION Justification required for rejected comments only	ACCEPT Initial/Date	REJECT Initial/Date
1-M		List specific software program language used with version number. Also, need to list code compiler and platform software was created on.	MJC 8/25/98		Added ~~[illegible]~~ MJC 8/26 Entered this information into scientific notebook (YMP-LBNL-ESF-MC-1.1 page 109).	RH 8/27/98	

* May be on separate sheets to be attached, in which case the comments shall be numbered and this form will be used to track the comments and their resolution according to such numbers.

Office of Quality Assurance Date

Project Manager Date

YMP-LBNL Management Review (Project Manager Or Designee

8/27/98

Sample Input & Output for ~~Calcs~~ Frac-Calc.f MC 8/10/98 8/10/98

Below are the data for ptn25 in the North Ramp.
✓ → indicates that value checks with hand calculations below.

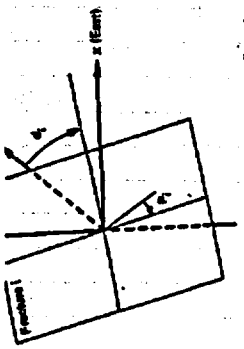


Fig. 4.1. Dip and dip of a fracture in three dimensions.

Sample input data from DLS:

LOCATION	STRIKE	DIP	LENGTH A	LENGTH B
879.700	20.000	8.000	2.000	6.000
882.370	184.000	78.000	3.500	1.670
887.300	299.000	78.000	.000	1.110
893.860	20.000	49.000	.100	.330
893.920	22.000	80.000	.680	.620
894.130	20.000	67.000	1.200	1.600

extracted from 8to10.txt in D:\DLS → DTN: GS97111 08214224.005 using single user macro Read-TDB (see p. 82-87 in YMP-LBNL-658-MC-1 MC 3/31/99

Sample output from frac_calc.f (for fractures ≥ 1 meter in length)

all1.par

Unit	<---Station--->		Min-m	MinDse	Max-m	%Frac	Spac-m	SDSpac	Fq-1/m	SDFreq	Leng-m	SDLeng	Intens
ptn25	875.80	894.60	.43	1.00	8.00	5	3.61	2.78	.28	.21	3.60	2.91	.16

all2.par (see above)

Unit	MinDse	%Frac	Fq-1/m	Apr-um	Por-3D	Por-2D	Por-1D	alpha	kxx/kxx	kyy/kxx	kzz/kyy
ptn25	1.00	5	.28	504.	5.93E-05	8.21E-05	1.40E-04	3.90E-03	1.69	1.01	.93

calibrate.par

Unit	Freq	SDFreq	Alpha	sdalpha	loga	logsda	<logq>	sclogq>	gmFreq	%Frac	Stuck
ptn25	.21	.27	3.85E-03	1.43E-04	-2.41	-3.84	-2.50	.412	.28	5	18.00

MC 8/10/98 MC 8/10/98

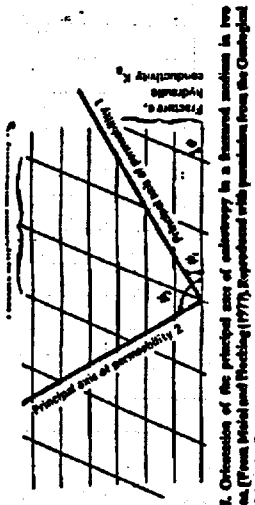


Fig. 4.3. Orientation of the principal axes of anisotropy in a fractured medium in two dimensions. (From Neuzil and Hsieieh (1977). Reproduced with permission from the Geological Society of America.)

Calculations below are by hand (with a calculator)

	length	~~spacing~~ MC 8/10/98
1. 879.7	8	
2. 882.37	5.17	
3. 887.3	1.11	
4. 893.86	0.43	← exclude since ≤ 1
5. 893.92	1.3	
6. 894.13	2.8	

so # Frac = 5, average length = 3.676 m, std. dev. length = 2.912

Spacing:

2-1 2.67 m
3-2 4.93 m
exclude 4 5-3 6.62 m MC 8/10/98
6-5 ~~4-5~~ 0.21 m MC 8/10/98

average = 3.6075 m sd = 2.784 m

Frequency $f = \frac{1}{\bar{x}} = 0.277/m$

$\sigma_f = \frac{2.784\,m}{(3.6075\,m)^2} = 0.214/m$

MC 9/23/99

Hydrology for Engineers, 98

Intensity $I = \frac{\Sigma \text{ trace lengths}}{\text{area}} = \frac{(8+5.17+1.11+1.3+\cancel{0.24})\,m}{(894.6-875.8)\,m\,(6\,m)}$ 2.8 mc 8/10/98

$$I = 0.163\ m/m^2$$

Aperture $b = \left(\frac{12k}{f^3}\right)^{\frac{1}{3}} = \left(\frac{12\ \ 10^{-11.53}\ m^2}{0.277/m}\right)^{1/3} = 5.0377\times10^{-4}\,m$

or 503.8 um

$\log k = -11.53$ from datablk.f
(p. 96-97 in Ref Notebook YMP-LBNL-GSB-MC-1.1A)

Porosity

3D: $\phi_{3D} = \frac{\pi b \left(\Sigma t_i^2\right)/4}{(6m)(6m)(894.6-875.8)m} = 5.933\times10^{-4}$ mc 8/10/98

2D: $\phi_{2D} = bI = (5.0377\times10^{-4}\,m)(0.163\ \frac{m}{m^2}) = 8.212\times10^{-5}$

1D: $\phi_{1D} = bf = (5.0377\times10^{-4}\,m)(0.277/m) = 1.395\times10^{-4}$

Alpha

$$\alpha = \frac{b}{2\tau\cos(0°)} = \frac{5.0377\times10^{-4}\ m}{2\,(.072\ N/m)} = 0.003498\ \frac{1}{Pa}$$

see note on p. 105, calibrate.par expects 2 layers for ptn25 based on datablk.f. Made temporary modification to datablk.f and reran program to get appropriate calibrate.par

calibrate.par see all3.par

Unit	Freq	SUFreq	alpha	sdalpha	loga	logsda	<loga>	s<loga>	gmFreq	gFreq	Block
ptn25	.28	.21	3.50E-03	2.41E-04	-2.46	-3.62	-2.54	.344	.48	5	18.80

see all2.par

assumes 2 degrees of freedom

std dev $\alpha = \frac{\sigma_s}{s^2}\left(\frac{k}{18 f^4}\right)^{1/3}\frac{1}{\tau^{1/2}}$

$$= \frac{2.784\,m}{(3.6075\,m)^2}\left(\frac{10^{-11.53}\ m^2}{18\ (0.277/m)^4}\right)^{1/3}\frac{1}{(.072\ N/m)^{1/2}}$$

$$= 0.00024165\ /Pa$$

(see p. 124-125 in YMP-LBNL-MC-1)

log a =
log σ_s =
log f:
< lo
gmF
< log a >
<
s <
block – 1
k_{zz}/k_{xx}, k
k_{zz}/k_{xx} =

2.8 mc 8/10/98

.17+1.11+1.3+0.24)m

94.6 − 875.8)m (6m)

$\frac{}{}$ m/m²

$\left(\frac{10^{-11.53}\ m^2}{0.277/m}\right)^{1/3} = 5.0371\times10^{-4}\ m$

OR 503.8 um

YMP-LBNL-65B-MC-1.1A)

$= 5.933\times10^{-5}$ ~~X~~ mc 8/10/98

$2.163\ \frac{m}{m^2}) = 8.212\times10^{-5}$

$0.277/m) = 1.395\times10^{-4}$

$\times10^{-4}\ m$ $= 0.003498$ Pa

N/m)

cts 2 layers for ptn25
modification to datablk.f
de calibrate.par

see 112.par

gm>	s<log>	gmFreq	Frac		Block
2.54	.344	.48	5		18.80

assumes 2 degrees of freedom

$\frac{m^2}{(77/m)^4}\Big)^{1/3}\ \frac{1}{(.072\ N/m)^{1/2}}$

24165 /Pa

-MC-1)

$\log\alpha = \log(\alpha) = -2.456$

$\log \sigma_\alpha$ sdg mc 8/10/98 $= \log(\sigma_\alpha) = -3.6168$

$\log f$:

$\langle \log f \rangle = -\langle \log s \rangle$

and

$\langle \log s \rangle = \frac{\log 2.67 + \log 4.93 + \log 6.62 + \log 0.}{4}$

$= 0.3156$ or geometric mean of spacing

$\sigma_{\log s} = 0.6823$

gmFreq = geometric mean f $= 10^{\langle \log f \rangle} = 10^{-\langle \log s \rangle}$

$= 10^{-0.3156} = 0.4835\ /m$

$\langle \log a \rangle$, $s\langle \log a \rangle$ see p124-125 in YMP-LBNL-63B-MC-1

$\langle \log a \rangle = \frac{1}{3}(\log 12 + \log k - \langle \log f \rangle) - \log 2\tau$ ($\langle \log \alpha \rangle =$)

$= \frac{1}{3}(\log 12 - 11.53 + 0.3156) - \log[(2)(0.072\ N/m$

$= -2.537$

$s\langle \log a \rangle = \sigma_{\log \alpha} = \frac{1}{3}\sigma_{\log s} = \frac{1}{3}(0.6823)$

$= 0.2274$ assumes 9 degrees of freedom

block – length of block in ESF – station to station that represents stratigraphic unit

$894.6m - 875.8m = 18.8\ m$

k_{zz}/k_{xx}, k_{yy}/k_{xx}, k_{zz}/k_{yy} (see p. 102-104, this notebook)

~~$\frac{k_{zz}}{k_{xx}} = \sin($~~ mc 8/10/98

go to next page

strike	dip	true dip
20°	8°	8°
194	78	~~X~~ mc 8/10/98 102
299	78	78
22	80	80
20	67	67

in degrees

$\Sigma \sin^2(\text{dip}) = 3.75$

$\Sigma\left(1-\sin^2(\text{strike})\sin^2(\text{dip})\right) = \cancel{X}\ 5\ \text{mc } 8/10/98\ \cancel{-1.92875}\ 0.974 = \cancel{2.07125}\ \text{mc } 8/10/98\ 3.07125\ 4.026\ \text{mc } 8/10/98$

$\Sigma\left(1-\cos^2(\text{strike})\sin^2(\text{dip})\right) = \cancel{X}\ 5\ \text{mc } 8/10/98 - 2.776 = \cancel{1.224}\ \text{mc } 8/10\ \ 2.224$

$$\frac{k_{zz}}{k_{xx}} = \frac{\cancel{3.75}\ \text{mc } 8/10/98}{\cancel{1.224}\ \text{mc } 8/10/98} = \frac{3.75}{2.224} = 1.686$$

$$\frac{k_{yy}}{k_{xx}} = \frac{\cancel{3.07125}\ 4.026\ \text{mc } 8/10/98}{2.224} = \cancel{1.381}\ \text{mc } 8/10/98 = 1.81$$

$$\frac{k_{zz}}{k_{yy}} = \frac{3.75}{4.026} = 0.931$$

All calculations in frac-calc.f check.

Mark A Cichy 8/10/98

Compiler I

The program

Mark C

Compiler Information for Frac_Calc.f 8/25/98

The program Frac_Calc.f was compiled using

Fortran Powerstation 4.0
Microsoft 1994-1995

Product ID: 36785-411-0083773-30563

(part of Microsoft Developer Studio)

74 mc 8/10/98 4.026 mc 8/10/98

75 = ~~2.03125~~ ~~3.03125~~

76 = ~~1.224~~ mc 8/10 2.224

1.686

= 1.81

check.

/98

Mark A. Carly 8/25/98

can be seen at 44+00 and 52+00. after interval Notebook

Also see p.102-103 this notebook MC 8/10/98

Version 1.0 MC 7/21/99

Frac-Calc & ESF Fracture Data

8/10/98

The code frac-calc is listed in Reference Notebook YMP-LBNL-GSB-MC-1.1A pages 88-97. The development of the code was discussed previously on pages 60-69, 124-125, 137 YMP-LBNL-GSB-MC-1. The code was previously listed on p 40-46 in this notebook. Results are used throughout both notebooks. The most recent code addition is discussed on p. 98 of this notebook.

Using dlsalcove.dat (see p. 54-56, this notebook), as input fracture properties were calculated for the model layers (see p. 64, this notebook). More detailed output is given in Reference Notebook YMP-LBNL-GSB-MC-1.1A p. 98-106. This gives

all1.par & all2.par → properties for individual sections of each layer

comb1.par & comp2.par → properties for each model layer (combines above)

calibrate.par → additional properties for each model layer.

see p.114 this notebook for qualification MC 8/12/98

Frac-calc is defined as a "Multi-User" Macro". A Form M was completed and submitted to qualify the code as a "macro".

The code is in d:\code\calc_frac\frac-calc.f and includes datablk.f

8/10/98

Fracture Permeability Components Calculations 8/10/98 from d

from Sonnenthal et.al. (1997) ref. on p.60 in YMP-LBNL-GSR-MC-1.
page 7-21 mc 9/3/99

The large-scale saturated fracture permeability is dependent on the fracture connectivity and the permeability of individual fractures. Although the connectivity of the fractures is difficult to ascertain, over a large scale the ratios of the permeability components can give some indication as to the preferred flow directions. Assuming an array of infinite fractures in three dimensions, the permeability tensor for a fracture network modified from the conductivity tensor in de Marsily (1986) is given by:

$$\overline{k_f} = \begin{vmatrix} k_{xx} & k_{xy} & k_{xz} \\ k_{yx} & k_{yy} & k_{yz} \\ k_{zx} & k_{zy} & k_{zz} \end{vmatrix} = \sum_{i=1}^{N} k_{f,i}\overline{R_i} \quad (16)$$

part 1

The permeability of each fracture is given by the cubic law (Equation (5)), assuming uniform apertures. The tensor $\overline{R_i}$ relates the strike (d_i) and dip (p_i) of each fracture to the components of the permeability tensor, as follows:

$$\overline{R_i} = \begin{bmatrix} 1-\cos^2 d_i \sin^2 p_i & \frac{1}{2}\sin 2d_i \sin^2 p_i & -\frac{1}{2}\sin 2p_i \cos d_i \\ \frac{1}{2}\sin 2d_i \sin^2 p_i & 1-\sin^2 d_i \sin^2 p_i & \frac{1}{2}\sin 2p_i \sin d_i \\ -\frac{1}{2}\sin 2p_i \cos d_i & \frac{1}{2}\sin 2p_i \sin d_i & \sin^2 p_i \end{bmatrix} \quad (17)$$

part 2

The permeabilities in the principal directions would have to be derived from this matrix; however as the UZ model does not at this time incorporate the off-diagonal terms, and because our fracture permeabilities are based on air-injection measurements, this is not necessary at present.

The code ~~calc~~ mc 8/10 frac calc.f includes these calculations. parts 3 & 4
The first portion converts the angle from degrees to radians and gives the dip angle in terms of the "true" dip rather than the "apparent" dip. The second part computes the components of the matrix shown in equation 17 above. The third part then multiplies each component by the fracture permeability (kfrc) and the frequency (f) (see eqn 16 above). The 4th part sums these for all the fractures in the layer. The 5th and last part (added by myself mc 9/21/98) calculates the ratios k_{zz}/k_{xx}, k_{yy}/k_{xx}, & k_{zz}/k_{yy}. Note that the ratios are independent of k and f. part 5

The parts 1-4 were written by Eric Sonnenthal.

The code (excerpt is shown on the next page).

Reference for de Marsily given on p104 (with excerpt)

c... Cal
ra
dc

c Added
k
k
k

lations 8/10/98

(YMP-LBNL-GSB)

on p.60 in SA-MC-1.

MC 9/24/99

connectivity and the perme-
difficult to ascertain, over a
tion as to the preferred flow
permeability tensor for a frac-
iven by:

$$\mu\theta \qquad (16)$$

part 1

assuming uniform apertures.
ments of the permeability ten-

$$\begin{bmatrix} \sin 2p_i \cos d_i \\ \sin 2p_i \sin d_i \\ \sin^2 p_i \end{bmatrix} \qquad (17)$$

part 2

m this matrix; however as the
use our fracture permeabilities

these calculations. parts 3 & 4
n degrees to
s of the "true"
second part
ix shown in
m multiplies
neability (kfrc)
bove). The 4th
s in the layer.
ell/m 9/21/98)
yy/kxx, & kzz/kyy.
ut of k and f
conventional.
t page).
(with except)

from d:\code\calc_frac\frac_calcf

```
c... Calculate components associated with each fracture, then sum
      radian = pi/180.d0
      do n = 1, nfr
        nn = nfrc(n)
        if(strike(nn).le.90.d0)then
          stkrad = strike(nn)*radian
          diprad = dip(nn)*radian
        elseif(strike(nn).gt.90.d0.and.strike(nn).le.180.d0)then
          stkrad = strike(nn)*radian
          diprad = (180.d0-dip(nn))*radian
        elseif(strike(nn).gt.180.d0.and.strike(nn).le.270.d0)then
          stkrad = strike(nn)*radian
          diprad = (180.d0-dip(nn))*radian
        else
          stkrad = strike(nn)*radian
          diprad = dip(nn)*radian
        endif
        sdsq = (dsin(diprad))**2
        kxx = 1.d0 - ((dcos(stkrad))**2)*sdsq
        kxy = 0.5d0*dsin(2.d0*stkrad)*sdsq
        kxz = -0.5d0*dsin(2.d0*diprad)*dcos(stkrad)
        kyx = kxy
        kyy = 1.d0 - ((dsin(stkrad))**2)*sdsq
        kyz = 0.5d0*dsin(2.d0*diprad)*dsin(stkrad)
        kzx = kxz
        kzy = kyz
        kzz = sdsq
        kf = kfrc(n)*tpm
        ktens(1) = kxx*kf + ktens(1)
        ktens(2) = kxy*kf + ktens(2)
        ktens(3) = kxz*kf + ktens(3)
        ktens(4) = kyx*kf + ktens(4)
        ktens(5) = kyy*kf + ktens(5)
        ktens(6) = kyz*kf + ktens(6)
        ktens(7) = kzx*kf + ktens(7)
        ktens(8) = kzy*kf + ktens(8)
        ktens(9) = kzz*kf + ktens(9)
      enddo

c Added KAC 6/21/98
      kzzkxx = ktens(9)/ktens(1)
      kyykxx = ktens(5)/ktens(1)
      kzzkyy = ktens(9)/ktens(5)
```

part 5

aper MC 8/24/98

but does not effect ratios since it cancels out

Mark G. Cauley 8/24/98

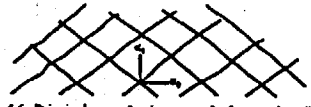


Fig. 4.6. Principal axes of anisotropy of a fractured medium.

For example, in two dimensions, two fracture systems with the same directional conductivity give the principal axes of anisotropy shown in Fig. 4.6. Maini and Hocking (1977) give the following expressions for calculating the directions of anisotropy and the principal hydraulic conductivities of the equivalent medium:

$$\psi_1 = \frac{1}{2}\arctan\left(\frac{\sin 2\theta}{\cos 2\theta\, K_a/K_b}\right)$$

$$K_1 = \frac{K_a K_b \sin^2\theta}{K_a \sin^2\psi_1 + K_b \sin(\theta - \psi_1)}$$

where K_a and K_b are the equivalent directional hydraulic conductivities of the fracture networks a and b, as shown in Fig. 4.7.

In three dimensions, Fouga (1981) gives the following expressions for determining the hydraulic conductivity tensor of a fractured medium with several fracture directions:

$$\mathbf{K} = \frac{1}{l}\sum_{i=1}^{N} e_i k_i \mathbf{R}_i$$

where l is the arbitrary dimension of the side of a square block of the fractured medium, large enough to statistically sample all the families of fractures, N the

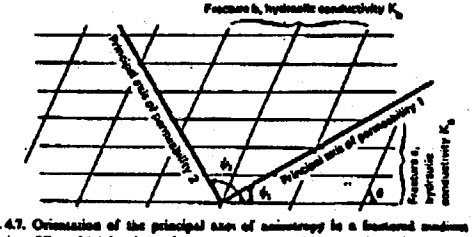


Fig. 4.7. Orientation of the principal axes of anisotropy in a fractured medium in two dimensions. [From Maini and Hocking (1977). Reproduced with permission from the Geological Society of America.]

number of fractures in the block of side l, e_i the aperture of each individual fracture, and k_i the hydraulic conductivity of each individual fracture

$$\mathbf{R}_i = \begin{bmatrix} 1-\cos^2 d_i \sin^2 p_i & \frac{1}{2}\sin 2d_i \sin^2 p_i & -\frac{1}{2}\sin 2p_i \cos d_i \\ \frac{1}{2}\sin 2d_i \sin^2 p_i & 1-\sin^2 d_i \sin^2 p_i & \frac{1}{2}\sin 2p_i \sin d_i \\ -\frac{1}{2}\sin 2p_i \cos d_i & \frac{1}{2}\sin 2p_i \sin d_i & \sin^2 p_i \end{bmatrix}$$

In the matrix $\mathbf{R}_i$, the direction d_i and the dip p_i of each fracture are defined as in Fig. 4.8.

Once the tensor $\mathbf{K}$ has been determined, the principal axes of anisotropy and the diagonal components of $\mathbf{K}$ in these directions can be determined by calculating the eigenvalues and the eigenvectors of the matrix $\mathbf{K}$.

This method of the continuous medium approximation is valid for a certain scale of observation: the flow velocities or the hydraulic heads in each fracture are not described with precision, but a mean value of these magnitudes is taken over all the fractures.

The definition of the hydraulic conductivities of each family of fractures may be approached in two ways: either (1) by measuring (or estimating) the mean geometric properties of the fractures (aperture, distance from each other, roughness, etc.) and using the expressions given above, or (2) through *in situ* tests by injecting water and measuring the hydraulic conductivities K_i of the elementary fractures directly.

The drawback of both methods is that they assume the fractures to be infinite and to have the same properties everywhere. Their results must be taken with caution. The directions of the principal axes of the conductivity tensor are probably more accurate than the value of the conductivities; these

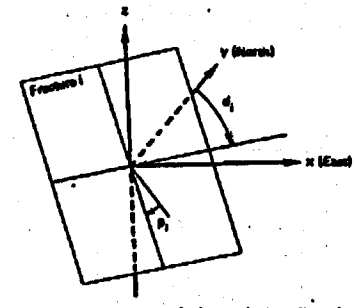


Fig. 4.8. Direction and dip of a fracture in three dimensions.

de Marsily, G. 1986. Quantitative Hydrogeology. Groundwater Hydrology for Engineers, Orlando, Florida: Academic Press. NNA.19910207.0116.

Multiple 8/10/98

Freq vs

Sample.

Below are
V → Index

```
Sample input data:

LOCATION     STRIKE
879.700      20.000
882.370      184.000
887.300      299.000
893.860      20.000
893.920      22.000
894.130      20.000

Sample output from
all1.par

Unit <---Station---> Mi
prazs 875.00 894.00

all2.par  see above

Unit minmax Mrzac Pc-1
prazs 1.00  5  .2

calibrate.par
```

Calculations below

1. 879.7
2. 882.37
3. 887.3
4. 893.86
5. 893.92
6. 894.13

so #1

spacing

exists 1

6

Freq vs

Unit
prazs
.21
.2
3.5

MC 8

this portion assumes that there would be two phases sections one in the North ramp and one in the South ramp. see p 106

TDB- fracture properties 4/17/98

Began analyzing fracture data. The first step was to recreate and verify the calculations in Chapter 7 of the Site-Scale Unsaturated Zone Model of Yucca Mountain.

I started with the code from E. Sonnenthal. It is located on hydra.lbl.gov in the directory
/m/ultra2/u/esonn/ymp/~~6m~~/src
MC 8/25/98

The name of the code is cnvfr2.f
The original data analyzed (which only is up to station 10+00) was in the file

~~These data were only used for testing code results and also not used for YMP Q-work MC 4/28/99~~ ~/ymp/fractures/esf/frcpar.dat
and
~/ymp/fractures/esf/station.dat

All changes to the code are indicated with my initials (MAC) and dated. The new filename for the code is: MC 8/25/98
calc_frac.f
and it is located on NWD-cushey in
d:/code/calc_frac/
MC 8/25/98

This code differs in that it processes all of the DLS data at once. Station numbers are assigned to model layers in data statements.

The following calculations are performed:

$$\text{avg. spacing} = \frac{1}{nf-1}\sum_{i=2}^{nf}(D_i - D_{i-1})$$

where nf - the number of fractures
D_i - is the location of fracture i

$$\text{fracture frequency} = \frac{1}{\text{avg. spacing}} = \frac{1}{\bar{s}}$$

$\bar{s}$ - average spacing

rek MC 8/25/98

Sonnenthal, E.L.; Ahern, C.F.; and Bodvarsson, G.S. 1997. "Fracture and Fault Properties for the UZ Site-Scale Flow Model." Chapter 7 of The Site-scale Unsaturated Zone Model of Yucca Mountain, Nevada, for the Viability Assessment, edited by G.S. Bodvarsson, T.M. Bandurraga, and Y.S. Wu. Yucca Mountain Site Characterization Project Level 4 Milestone SP24UFM4; Report LBNL-40376. Berkeley, California: Lawrence Berkeley National Laboratory. LB970601233129.001 (Q).

$$b = \left(\frac{12\,k}{f}\right)^{\frac{1}{3}}$$

where b - aperture
k - air permeability (frac. perm.)
f - frequency

$$\alpha = \frac{b}{2\tau\cos\theta}$$

where α - van Genuchten α for fractures
b - aperture
τ - surface tension of pure water at 20°C (0.072 N/m)
θ - contact angle (assumed to be 0)

This calculation was not previously in the code

porosities:

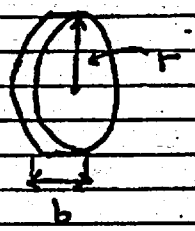
$$\phi_{1D} = f\,b$$

$$\phi_{2D} = \frac{b\sum_{i=1}^{nf} t_i}{\text{area}} = \frac{b\sum_{i=1}^{nf} t_i}{(6\text{m})\ \text{blocklength}}$$

$$\phi_{3D} = \frac{\pi\, b\sum_{i=1}^{nf} r_i^2}{\text{volume}} = \frac{\pi\, b\sum_{i=1}^{nf} r_i^2}{(6\text{m})(6\text{m})\ \text{blocklength}}$$

t_i - trace length of fracture i
block length - length along DLS corresponding to model layer (full length)
r_i - one-half the trace length
$r_i = t_i/2$

For the above calculations, the fractures are assumed to be circular disks.



volume in 3D = $b \pi r^2$

The probability that the tunnel cut intersects these disks offcenter is not accounted for.

The area about the DLS centerline is assumed to include a 3 meter band on each side.

MC 4/17/98

The ϕ_{3D} may underestimate porosity since it assumes fracture traces represent fracture diameters

The ϕ_{∞} may overestimate porosity since it assumes infinitely long fractures.

ratios of permeability components:

ratios k_{zz}/k_{xx}, k_{yy}/k_{xx}, and k_{zz}/k_{yy} were calculated as defined in eqns 16 & 17 in Chapter 7.

For spacing, fractures located at the same station were assumed to be at a separation distance of 0.

The minimum measurement precision was 0.01 m for the DLS (Altman, 1997)

ref Altman, S.J. Determining reasonable ranges for van Genuchten fracture α for use in unsaturated flow modeling Sandia National Laboratory
DTN SNT05091597001.003
TDIF 306502
November 25, 1997.

SIGNATURE [signature] DATE 4/17 19 98
READ AND UNDERSTOOD _____ DATE _____ 19 ____

PROJECT NAME _____ NOTEBOOK NO. _____

TDB- fracture properties - verification of code 4/29/98

To verify the code, the original DLS dataset was used and compared to Chapter 7 results.

Data from /m/ultra1/u/esonn/ymp/fractures/esf

stored on NWD-Cushey as dlsall in di/code/

This data was transformed to a readable (numeric) format (convert station numbers to lengths) and stored in erizdls.dat in di/code/cble_frac.

The code was run and results were compared to those in Chapter 7.

To combine disconnected segments the following formulations were used. This is different from the method used original by E. Sonnenthal as noted in the comparison (typically averages of the segments). The below procedure combines all sublayers into one continuous layer. (the pairing of fractures for spacing are limited to the sublayers). This is similar to the method used by (Altman, 1997)

see nomenclature on p. 60-61

$$\bar{s}_{comb} = \frac{\sum_{j=1}^{ns} \left[\sum_{i=2}^{nf_j} D_{i,j} - D_{i-1,j} \right]}{\sum_{j=1}^{ns} nf_j - j}$$

ns - # of segments
subscript j → segment j
comb - combined

the denominator is the number of pairs of fractures used to calculated the $\bar{s}_{comb}$.

SIGNATURE _____ DATE _____ 19 _____
READ AND UNDERSTOOD _____ DATE _____ 19 _____

$$\bar{f}_{comb} = \frac{1}{\bar{s}_{comb}}$$

$$b_{comb} = \left(\frac{12k}{\bar{f}_{comb}}\right)^{\frac{1}{3}}$$

$$\phi_{3D} = \frac{\pi\, b_{comb} \sum_{j=1}^{ns} \sum_{i=1}^{nf_j} r_{ij}^2}{(6m)(6m) \sum_{j=1}^{ns} \text{blocklength}_j}$$

$$\phi_{2D} = \frac{b_{comb} \sum_{j=1}^{ns} \sum_{i=1}^{nf_j} t_{ij}}{(6m) \sum_{j=1}^{ns} \text{blocklength}_j}$$

$$\phi_{1D} = b_{comb}\, f_{comb}$$

The alternative would be to calculate the each parameter for each sublayer and then ~~[illegible]~~ computed a weighted average based on the segment length

$$X = \frac{\sum_{j=1}^{ns} x_j \text{ blocklength}_j}{\sum_{j=1}^{ns} \text{blocklength}_j}$$

for any parameter X

The first (continuous layer) method was used since the break-up of layers is arbitrary due to the location of the tunneling. On the other hand, the second method might better capture local phenomena which are averaged out by the averaging over longer

lengths. Considering though that these parameters are to represent the entire layer over the site, the first (continuous) method is deemed appropriate at this time.

An additional note is that the spacing calculation is along the DLS centerline and is not the "true" spacing. The calculation of "true" spacing will be considered at a later time. (see Geology of the Exploratory Studies Facility Topopah Spring Loop Attachment I BAB e 01717-0200-00002 REV 1.)

For the following verification - first the individual sublayers and then the overall layers are compared. Only fractures ≥ 1 m are included

YMP-LBNL DOCUMENT REVIEW/COMMENT RESOLUTION (DRCR) FORM

Document No. and Title: Frac_Calc Version 1.1 Page 1 of 1

Date of Document / revision no./ draft revision no. (as applicable): Version 1.1 Author: Mark Cushey

Are Scientific Notebooks or other background documents/data included in the scope of this review? ☒ Yes ☐ No (If yes, identify on Attachment 3)

Specific Review Criteria or Governing Procedure: YMP-LBNL-QIP-6.1 & AP-SI.1Q

General Review Criteria: (identify relevant criteria on Attachment 4): 5-7 to 5-10 in YMP-LBNL-QIP-6.1 & Section 5.1 of AP-SI.1Q

☐ Checker ☒ Technical Reviewer ☐ EA Reviewer ☐ OQA Reviewer

Name: Qinhong Hu Signature: [signature] Date: 9/7/99

REVIEWER'S COMMENTS			AUTHOR'S RESPONSE			Reviewer Disposition for Mandatory Comments	
COMMENT NO. MANDATORY (M) NON-MANDATORY (NM)	SECT. AND PAGE NO.	COMMENTS	ACCEPT Initial/Date	REJECT Initial/Date	Response required for all technical mandatory and non-mandatory comments	ACCEPT Initial/Date	REJECT Initial/Date
1 (NM)	16	the application file is frac_calc11 the Fortran source code file is frac_calc11.f			Added to p.16 and p.67 in reference binder (in YMP-LBNL-MC-1.2) MC 9/23/99		
2 (NM)	68 or other 9/7/99	Check the source code file, there should have more codes to be printed out following p.86			source code continues onto pp. 83-87		
3 (NM)	108	crossed-out = 3.75			Crossed-out 3.75 & initialed/dated		
		comments only: * check the file locations & contents of frac_calc.f, tank, all.par, all.par; no anomaly.		* check the calculation of lower half on p.105 → no mistake, make any			

May be on separate sheets to be attached, in which case the comments shall be numbered and this form will be used to track the comments and their resolution according to such numbers.

Resolution of Disputed Comments

Office of Quality Assurance Date

Project Manager Date

YMP-LBNL Management Approval (Project Manager or Designee)

Mark A Cushey for G.S. Bodvarsson 9/23/99

APPLICABLE REFERENCE INFORMATION

Document No. and Title: Frac_Calc Version 1.1

Date of Document (or revision, draft revision number, as applicable): Version 1.1

Pertinent sections of the scientific notebook(s) or other backup documents/data identified below, support the document which is the subject of this review. These documents/data shall be included in the scope of this review.

Document(s) Title/Data	Relevant Sections/Pages
YMP-LBNL-MC-1.2	14-16
YMP-LBNL-MC-1.2A	67-~~82~~ 87 MC 9/3/99
YMP-LBNL-MC-1.1	114-115, 105-109, 101-104
YMP-LBNL-MC-1	60-65

Read_TDB V1.0
Routine/Macro Documentation Form*

Note: All relevant scientific notebook (SN) pages are included in this records package. In some instances, the included SN pages cross-reference other pages that are not included here because these were not essential to the documentation of this routine.

1. Name of routine/macro with version/OS/hardware environment:
   Read_TDB / Version 1.0 / DOS (or Windows with DOS) / PC

2. Name of commercial software with version/OS/hardware used to develop routine/macro:
   FORTRAN 77 / FORTRAN Powerstation 4.0 (see SN YMP-LBNL-GSB-MC-1.2, p. 48)

3. Description and Test Plan.

   - Explain whether this is a routine or macro and describe what it does: **(Read_TDB is a routine)**
     The software routine Read_TDB is a FORTRAN code that reads a text file (ASCII format) downloaded from the Technical Data Management System (TDMS), extracts the selected columns and rows of data for use in standard spreadsheet packages, and converts stations into linear meters. It excludes any rows that have incomplete or missing information and notes the rows excluded with a print out to the screen. It is described on pages 52 and 58 in YMP-LBNL-GSB-MC-1. To install the software, copy frac_calc11.f and datablk11.f from a disk onto the hard drive of a PC. Then, compile frac_calc using a FORTRAN 77 compiler and run executable.

     This software routine is documented in the following scientific notebook pages:

YMP-LBNL-GSB-MC-1	**pp. 52, 58, 82-87**
YMP-LBNL-GSB-MC-1.2	**pp. 48-50**
Reference Binder YMP-LBNL-GSB-MC-1.2A	**pp. 120-124**

     Inputs:

     The code is designed to use fracture property data text files as directly downloaded from the TDMS. The test input which is in this very specific TDMS format is provided on pp. 120-124, Reference Binder YMP-LBNL-GSB-MC-1.2A.

   - Source code: (including equations or algorithms from software setup (LabView, Excel, etc.):
     The FORTRAN code is included on pp. 82-87 in YMP-LBNL-GSB-MC-1

   - Description of test(s) to be performed (be specific):
     A test case is to use a downloaded file from the TDMS that has stations to be converted to linear distance and includes some columns with incomplete data (that are to be excluded by the routine). The test case downloaded file is DTN: GS951108314224.005. It was saved as test.dat and is included as pages 121-122 in Reference Binder YMP-LBNL-GSB-MC-1.2A. This routine is primarily used for processing of Detailed Line Survey (DLS) data and the test case uses a DLS file. The acceptance criteria are that it (1) extract the proper columns, (2) print the correct values for the selected columns, (3) exclude rows that have incomplete data, and (4) convert stations into linear distance.

   - Specify the range of input values to be used and why the range is valid:
     The input is a direct sample from the TDMS and includes the columns with incomplete data and station values to be converted to linear distance. It is considered valid because it is the type of the data that the routine was designed to use.

4. Test Results.

   - Output from test (explain difference between input range used and possible input):

Test results are shown on pages 49-50 in YMP-LBNL-GSB-MC-1.2 and in Reference Binder YMP-LBNL-GSB-MC-1.2A, pp. 120-124.

- Description of how the testing shows that the results are correct for the specified input:
  The routine correctly (1) extracted the proper columns (see columns/datatypes selected on p. 50 in YMP-LBNL-GSB-MC-1.2 and output on pp. 123-124 in Reference Binder YMP-LBNL-GSB-MC-1.2A, (2) printed the correct values for the selected columns in output file frac.dat (compare values in output with input pp. 123-124, 121-122 in Reference Binder YMP-LBNL-GSB-MC-1.2A, respectively (3) excluded rows that have incomplete data (see p. 50 in YMP-LBNL-GSB-MC-1.2 and output which excludes these rows on pp. 123-124 in Reference Binder YMP-LBNL-GSB-MC-1.2A, and (4) converted stations into linear distance (compare values under LOCATION in output as a linear distance in meters with input as stations on pp. 123-124, 121-122 in Reference Binder YMP-LBNL-GSB-MC-1.2A, respectively).

- List limitations or assumptions to this test case and code in general:
  The input file must be a downloaded file (ASCII or text) from the TDMS. It also assumes that the TDMS will not change its formatting of having the column heading align directly with the value or text within the column. It also assumes that station measurements correpsond to meters (which has been used for the ESF, ECRB and their alcoves)

- Electronic files identified by name and location (include disc if necessary):
  test.dat and frac.dat (input and output) listed on pp. 120-124 in Reference Binder YMP-LBNL-GSB-MC-1.2A. File sizes and other information given on p. 49 of YMP-LBNL-GSB-MC-1.2.

5. Supporting Information. Include background information, such as revision to a previous routine or macro, or explanation of the steps performed to run the software. Include listings of all electronic files and codes used. Attach Scientific Notebook pages with appropriate information annotated:
   See attached pages for technical review forms, referenced scientific notebook pages and other supporting documentation.

MAINTAIN PAGES IN THIS ORDER:

1) This 2 page "Routine Documentation" summarization form	
2) YMP-LBNL-GSB-MC-1	pp. 52, 58, 82-87
3) YMP-LBNL-GSB-MC-1.2	pp. 48-50
4) Reference Binder YMP-LBNL-GSB-MC-1.2A	pp. 120-124

*Note that this supplement includes:
-Addition of this 2-page "Routine Documentation" summarization form

3/1/2000

TDB - Developed code to read in data from DLS of ESF 4/1/98

This code uses the headings to determine the spacing between parameters. This code extracts:

STATION (only 1ST if range)
STRIKE
DIP
LENGTH ABOVE TRACE
LENGTH BELOW TRACE
HEIGHT
WIDTH

If any of the above are Not Recorded (NR) or NA (Not Available) then the entire line is excluded.
If an * is present indicating a possible range for the value, the value given in the table is used.

All of the above data manipulations are printed to the file index.txt

The code allows the concatenation of data files so that all can be placed together for analysis.

This program was necessary because of the text that is present in the TDB files and allows for direct use of the data as numbers.

The code was tested on 11 DLS files available from the TDB. Spot checks were performed and the program was found to work properly.

The following code and executable is on NWD-Cushey
shared folder DLS\read_dls & DLS\read_dls.f
and
d:\code\read_dls\read_dls.f
d:\code\read_dls\read_dls

Read_DLS is the prototype for Read-TDB which is a single user macro checked on page 87 by R. Ahlers MC 3/31/99

SIGNATURE _____ DATE _____ 19 ____
READ AND UNDERSTOOD _____ DATE _____ 19 ____

PROJECT NAME _____ NOTEBOOK _____

TDB – development of code to read any TDB text file 4/13/98

The previous code read_dls.f (p. 52) was revised extensively to allow the extract of any parameter from any data file.

Again, the header is used as a basis for spacing.

The new code allows the user to select any parameter(s) (assumes all names are unique after 8 letters) and print these separately to a file.

If any of the selected parameters is not recorded (NR) or not available (NA), the entire line of data is excluded (noted in file index.txt)
MC 4/13/98

If a * is present, the number is used by a note is recorded in index.txt.

Any number of files can be concatenated.

This code is called read_tdb.f and resides in both
D:\code\read_tdb
and
share folder dls
on NWD-Cushey

The code was tested on DLS files and spot checked. It appears to work properly.

The code will put in this Scientific Notebook once it is further tested.

SIGNATURE Mike McCurley DATE 4/13 19 98
READ AND UNDERSTOOD _____ DATE _____ 19 _____

Version 1.0 (MC 7/9/99)

This code is a single user macro MC 3/31/99

see p87 reviewed by F. Allars MC 7/1/99

see p.52 and p.58 for initial development & planning of this code MC 6/28/99

```
      program Read_TDB

c     This program reads the data files from the
c     Technical Database.  Output are written
c     unformatted to selected output file.  All messages are
c     recorded to the screen and file 'index.txt'
c     Mark Cushey 4/98

c     Output is limited to 10 numerical datatypes
c     It is assumed that the maximum line length is less than 250

      real anum,bnum,value(10),limvalue(10,2)
      character*4 first
      character*25 filename
      character*250 all
      character*250 datastring
      character*8 astat,bstat,avalue,limtext(10)
      character*1 onestring(250),onedata(8),plus(8),ans
      character*8 dataname(10),limitname(10)
      integer row,iname,istring,idata,icolumn(10),i,loc,rowused,
     +        im,limnum,limtxt,loctype

c     ----------------------------------------

c     open output files
      write(*,*)'Enter name of output file:'
      read(*,1000)filename
      open(unit=20,file=filename)
      open(unit=21,file='index.txt')
      write(*,*)'Details on data retrieval are in index.txt'

c     ----------------------------------------
c     query for different data types to be stored
c
      write(*,*)'List names of data types to be retrieved - up to 10'
      write(*,*)'   Enter only the first 8 letters for each'
      write(*,*)'   Enter the word end for last entry'
      i = 0
40    i = i + 1
      read(*,1010)dataname(i)
      if ((dataname(i).ne.'end').and.
     &       (dataname(i).ne.'END')) go to 40
      iname = i - 1
      write(*,1040)iname
      write(21,1040)iname
      write(20,1041)(dataname(i),i=1,iname)
      write(*,*)'Should header be printed in output file - Y or N'
      read(*,1011)ans
      if ((ans.eq.'Y').or.(ans.eq.'y'))
     &       write(21,1041)(dataname(i),i=1,iname)
1010  format(a8)
1011  format(a1)
1040  format(1x,i7,' datatypes selected')
1041  format(10(2x,a8))
c     ----------------------------------------
```

```
c       query for limits on outputting data
        limnum = iname
        limtxt = iname
        write(*,*)'Are there limits for the output - Y or N ?'
        read(*,1011)ans
        if ((ans.eq.'Y').or.(ans.eq.'y')) then
                i = iname
c               write(*,*)'Enter the parameter names for numerical limits
'
c               write(*,*)'   Enter only the first 8 letters for each'
c               write(*,*)'   Enter the word end for last entry'
c45             i = i + 1
c               read(*,1010)dataname(i)
c               if ((dataname(i).eq.'end').or.
c       &       (dataname(i).eq.'END')) go to 46
c               write(*,*)'Enter upper and lower value for limit'
c               read(*,*)limvalue(i,1),limvalue(i,2)
c               write(*,*)'Enter next limit or end'
c               go to 45
c46             i = i - 1
c               limnum = i
                write(*,*)'Enter the parameter names for text-defined lim
its'
                write(*,*)'   Enter only the first 8 letters for each'
                write(*,*)'   Enter the word end for last entry'
47              i = i + 1
                read(*,1010)dataname(i)
                if ((dataname(i).eq.'end').or.
        &       (dataname(i).eq.'END')) go to 49
                write(*,*)'Enter text to exclude - up to 8 characters'
                read(*,1010)limtext(i)
                write(*,*)'Enter next limit or end'
                go to 47
49              limtxt = i - 1
                do i=(iname+1),limtxt
                        if (i.le.limnum) then
                                write(*,1045)dataname(i),limvalue(i,1),li
mvalue(i,2)
                                write(21,1045)dataname(i),limvalue(i,1),l
imvalue(i,2)
                        else
                                write(*,1046)dataname(i),limtext(i)
                                write(21,1046)dataname(i),limtext(i)
                        end if
                end do
        end if
1045    format(1x,'Limits on',a8,1x,f9.3,1x,f9.3)
1046    format(1x,'Limits on',a8,1x,'exclude',1x,a8)

c       ----------------------------------------
c       query for input filename and open

50      write(*,*)'Enter next data filename (use MS-DOS filename) or quit
'
        read(*,1000)filename
        if ((filename.eq.'quit').or.(filename.eq.'QUIT'))go to 990
```

```
      open(unit=10,file=filename,action='READ',
      &       form='FORMATTED',status='old',err=75)
      write(*,*)filename
      write(21,*)'------------------'
      write(21,*)filename
      write(21,*)'------------------'
1000  format(a25)
      go to 80
75    write(*,*)'File does not exist'
      go to 50

c     ----------------------------------------
c     If one of the parameters is LOCATION, determine type.
c     If LOCATION is station number along DLS, loctype =0
C    If LOCATION is along alcove, loctype = alcove #.
c     If other, then loctype = -1.
80    loctype = -1
      Do i = 1,iname
              if (dataname(i).eq.'LOCATION') then
                      write(*,*)'Is LOCATION a station number along the
',
      +' DLS, alcove, or other - d, a, or o'
                      read(*,*)ans
                      if ((ans.eq.'d').or.(ans.eq.'D')) then
                              loctype = 0
                      else
                              if ((ans.eq.'a').or.(ans.eq.'A')) then
                                      write(*,*)'Which alcove #'
                                      read(*,*)loctype
                              else
                                      loctype = -1
                              end if
                      end if
              end if
      End Do
c     ----------------------------------------

c     find header line (between rows of asteriks)
82    read(10,1001)first
      if (first.ne.'****') go to 82
1001  format(a4)

c     ----------------------------------------

c     find location where different data starts (use header)

      do i=1,limtxt
              icolumn(i)=0
      end do

      read(10,1020)datastring
      read(datastring,1021)(onestring(istring),istring=1,250)
      do i = 1,limtxt
              read(dataname(i),1022)(onedata(idata),idata=1,8)
              do istring = 1,250
               do idata = 1,8
```

```
                    if( (onestring(istring+idata-1).ne.onedata(idata)) )
     &                    go to 98
                   end do
98                 if (idata.eq.9) go to 99
                  end do
99                if (istring.ne.251) then
                          icolumn(i)=istring
                  else
                          write(*,1023)dataname(i)
                          pause
                          stop
                  end if
          end do

          write(*,1003)(icolumn(i),i=1,iname)
          write(21,1003)(icolumn(i),i=1,iname)
1003      format(1x,'Column headers at',10(1x,i5))
1020      format(a250)
1021      format(250(a1))
1022      format(8(a1))
1023      format(1x,a8,' not found in file -- stopped')

c         ---------------------------------------
c         move forward to first data row

105       read(10,1001)first
          if (first.ne.'****') go to 105
c         skip blank line
        read(10,1002)all
1002      format(a72)

c         ----------------------------------------

c         read data lines from file and get values
          rowused = 0
          row = 0
200       read(10,2001,err=900,end=900)datastring
          if (datastring.eq.'End of Report') go to 900
          if (datastring.eq.'                ') go to 200
          row = row + 1
          write(*,*)row

c         first see if data is within text-defined limits
          do ii=(limnum+1),limtxt
                  loc = icolumn(ii)
                  read(datastring,1999)all
                  if (all.eq.limtext(ii)) then
                          write(*,2025)row,dataname(ii),limtext(ii)
                          write(*,2026)datastring
                          write(21,2025)row,dataname(ii),limtext(ii)
                          write(21,2026)datastring
                          go to 200
                  end if
          end do
```

```
        do i=1,iname
                loc = icolumn(i)
                read(datastring,1999)avalue

c               first check to see if any are not recorded (NR) or
c               special (*) -- exclude NR and use *
                read(avalue,2002)(onedata(idata),idata=1,8)
                do idata=1,8
                        if ((onedata(idata)).eq.'N') then
c                       the entire line is excluded
                         write(*,2020)row,onedata(idata),onedata(idata+1)
,
        &                       dataname(i)
                         write(21,2020)row,onedata(idata),onedata(idata+1
),
        &                       dataname(i)
                         go to 200
                        end if
                if (onedata(idata).eq.'*') then
                        write(*,2021)row
                        write(21,2021)row
                        read(avalue,2024)avalue
                end if
                end do

c               check if entry is a station number -- if loctype = 0
c               LOCATION is station number along DLS, if loctype = +#
c               LOCATION is along alcove (number loctype)

                If ((loctype.ge.0).and.(dataname(i).eq.'LOCATION')) then
c                       get station number
                        read(avalue,2005)(plus(ip),ip=1,8)
                        do ip=1,8
                                if (plus(ip).eq.'+') go to 215
                        end do
215                     read(avalue,2010)astat,all,bstat
                        read(astat,*)anum
                        read(bstat,2005)(plus(im),im=1,(8-ip))
                        do im = 1, (8-ip)
                                if (plus(im).eq.'-') go to 216
                        end do
216                     read(bstat,2011)astat
                        read(astat,*)bnum

                        if (loctype.eq.0) then
                                value(i) = anum*100 + bnum
                        else
                                value(i) = real(loctype)*10000 + anum*100
 + bnum
                        end if
                else
                        read(avalue,*)value(i)
                end if

        end do
```

```
2001    format(a250)
c       change a8 to larger value if number is more than 8 digits
1999    format(<loc-1>x,a8)
2002    format(8(a1))
2005    format(8(a1))
2010    format(a<ip-1>,a1,a8)
2011    format(a<im-1>)
2020    format(1x,'Row',i5,' has a ',a1,a1,' for ',a8,
        &                ' - this data row is not used')
2021    format(1x,'Row',i5,' has a * - printed value will be used')
2024    format(a<idata-1>)

2025    format(1x,'Row',i5,' excluded ',a8,' is ',a8)
2026    format(5x,a40)


c       write data to output file and read next line

        write(20,3000)(value(i),i=1,iname)

3000    format(10(f10.3))
        rowused = rowused + 1
        go to 200

900     close(10)
        write(*,*)row,' rows read and',rowused,' used'
        write(21,*)row,' rows read and',rowused,' used'
c       ask for next file
        go to 50

990   close(20)
        close(21)
        pause
        stop
999     write(*,*)'Error in file formatting -- stopped'
        write(*,*)'Error in file formatting -- stopped'
        close(20)
        close(21)
        close(10)
        pause
        stop
        end
```

This code has been reviewed and performs the task intended C Fred Cell 7/1/98

SIGNATURE [signature] DATE 5/7 19 98
READ AND UNDERSTOOD _____ DATE _____ 19 _____

PROJECT NAME QA:L NOTEBOOK NO.

Compiler Information for Read_TDB.f 12/2/99

The routine Read_TDB Version 1.0 was compiled using:

FORTRAN Powerstation 4.0
Microsoft 1994-1995

Product ID: 36785-411-0083773-30563

(part of Microsoft Developer Studio)

SIGNATURE [signature] DATE 12/2 19 99
READ AND UNDERSTOOD DATE 19

PROJECT NAME _____ NOTEBOOK NO. _____

Files used in testing Read_TDB Version 1.0 12/2/99

Read_TDB was previously tested (see YMP-LBNL-GSB-MC-1, p. 58) and reviewed. The test case though was not included in the notebook, though. The files used to test are given below. This case was run on 4/13/98.

```
Volume in drive D is YMP
Volume Serial Number is 0758-0AD0
Directory of D:\code\read_tdb

.            <DIR>          04-13-98 11:11a .
..           <DIR>          04-13-98 11:11a ..
READ_TDB F                8,675 05-21-98  4:31p read_tdb.f
READ_TDB MAK              4,797 04-13-98  2:36p read_tdb.mak
DEBUG        <DIR>               04-13-98 12:16p Debug
TEST     TXT             49,900 04-13-98 12:48p test.txt
FRAC     DAT              7,488 04-13-98  2:56p frac.dat
DIR      TXT                  0 12-02-99  3:22p dir.txt
READ_TDB MDP             33,792 06-11-98  2:41p read_tdb.mdp
DUMMY                    24,800 04-20-98  3:19p dummy
DLS      DAT             16,596 04-29-98  3:19p dls.dat
ALCOVE3  DAT              4,960 05-04-98  3:16p alcove3.dat
         9 file(s)          151,008 bytes
         3 dir(s)     1,693,548,544 bytes free
```

input file → TEST
output file → FRAC

The files Test.dat and Frac.dat are in Reference Binder YMP-LBNL-MC-1.2A pp. 120-124

test.dat is the input - it is a direct example from the TDMS
frac.dat is the output

These can be used to test Read_TDB on other personal computers.

The screen printout that is saved to 'index.txt' is on the next page.

SIGNATURE _____ DATE _____ 19 ____
READ AND UNDERSTOOD _____ DATE _____ 19 ____

```
      7 datatypes selected
 LOCATION  STRIKE    DIP        LENGTH A  LENGTH B  HEIGHT    WIDTH
------------------
d:\code\read_tdb\test.txt
------------------
Column headers at     28    70    87   104   121   138   155
Row     2 has a NR for LENGTH A - this data row is not used
Row     4 has a * - printed value will be used
Row     5 has a NR for LENGTH B - this data row is not used
Row    18 has a NR for LENGTH B - this data row is not used
Row    19 has a NR for LENGTH B - this data row is not used
Row    20 has a NR for LENGTH B - this data row is not used
Row    24 has a NR for LENGTH B - this data row is not used
Row    26 has a NR for LENGTH B - this data row is not used
Row    29 has a NR for LENGTH B - this data row is not used
Row    30 has a NR for LENGTH B - this data row is not used
Row    31 has a NR for LENGTH B - this data row is not used
Row    34 has a NR for LENGTH A - this data row is not used
Row    63 has a NR for LENGTH A - this data row is not used
Row    70 has a NR for LENGTH B - this data row is not used
Row    72 has a NR for LENGTH B - this data row is not used
Row    81 has a NR for LENGTH B - this data row is not used
Row    82 has a NR for LENGTH B - this data row is not used
Row    84 has a NR for LENGTH B - this data row is not used
Row    86 has a NR for LENGTH B - this data row is not used
Row    87 has a NR for LENGTH B - this data row is not used
Row    95 has a NR for LENGTH B - this data row is not used
         123 rows read and        103 used
```

from file 'index.txt'

SIGNATURE [signature] DATE 12/2 19 99
READ AND UNDERSTOOD _____ DATE _____ 19 _____

Files used in checking Read_TDB Version 1.0
(a software routine)

test.dat – input test file
frac.dat – output test file

These files were created on 4/13/98

LOCATION	STRIKE	DIP	LENGTH A	LENGTH B	HEIGHT	WIDTH
801.360	200.000	86.000	2.450	.700	3.100	.400
802.580	.000	90.000	.700	.200	.900	.100
803.180	325.000	83.000	.850	3.000	3.500	2.600
804.150	220.000	73.000	2.500	.900	3.000	.400
804.640	255.000	85.000	.750	1.300	1.900	.060
804.830	15.000	78.000	.270	.900	1.100	.030
805.600	170.000	50.000	2.500	.500	3.000	.400
806.290	220.000	84.000	1.400	1.100	2.500	.100
806.420	215.000	84.000	4.000	1.000	5.000	.500
806.860	220.000	85.000	1.500	.750	2.250	.080
807.750	210.000	74.000	2.200	2.500	4.500	1.500
808.340	225.000	80.000	4.000	1.300	5.000	.600
808.650	230.000	83.000	6.000	1.000	6.000	3.000
808.900	225.000	83.000	1.800	.900	2.400	.150
809.840	230.000	75.000	.660	.350	1.000	.030
814.960	30.000	84.000	1.200	.700	1.900	.100
815.310	235.000	75.000	4.000	.100	3.500	3.000
816.180	200.000	80.000	5.000	.200	5.000	4.000
817.880	180.000	48.000	1.900	.150	2.000	.100
819.450	230.000	75.000	2.500	1.200	3.500	.800
819.730	170.000	85.000	.950	.500	1.400	.050
824.180	176.000	56.000	.650	.600	1.250	.050
829.830	225.000	77.000	4.000	2.000	5.500	1.500
836.650	195.000	85.000	1.200	.170	1.330	.050
839.950	15.000	78.000	1.790	2.330	3.850	.900
843.310	225.000	77.000	3.000	2.100	4.800	.300
844.580	193.000	80.000	2.150	1.600	3.500	.100
845.000	300.000	84.000	5.400	1.900	7.000	8.000
849.920	197.000	65.000	2.900	1.600	4.400	.200
857.390	.000	40.000	.700	.850	1.500	.050
857.610	230.000	60.000	.550	1.250	1.750	.050
859.370	216.000	55.000	.470	1.500	1.970	.350
859.620	13.000	71.000	1.110	.210	1.300	.100
859.810	20.000	79.000	.730	1.020	1.700	.750
862.840	12.000	82.000	1.020	.220	1.170	.200
863.770	24.000	7.000	.340	2.800	3.000	.250
864.180	212.000	61.000	.570	.800	1.200	.080
864.700	21.000	15.000	.600	.490	1.000	.030
865.370	172.000	68.000	2.750	.490	3.000	.250
865.420	28.000	4.000	.030	.030	.060	.010
865.450	180.000	64.000	.150	.560	.650	.050
865.600	20.000	10.000	3.600	.200	3.400	.030
868.550	5.000	66.000	4.500	2.500	6.500	2.500
868.650	15.000	20.000	5.000	.100	5.000	.300
873.970	176.000	68.000	4.500	1.650	6.000	4.000
874.030	97.000	84.000	.560	.350	.850	.100
874.410	14.000	66.000	.230	.600	.780	.060
874.580	345.000	69.000	.570	.120	.650	.050
875.220	.000	74.000	2.600	.030	2.400	.400
879.700	20.000	8.000	2.000	6.000	8.000	1.500
882.370	184.000	78.000	3.500	1.670	4.000	2.000
893.860	20.000	49.000	.100	.330	.400	.010
893.920	22.000	80.000	.680	.620	1.250	.050
894.130	20.000	67.000	1.200	1.600	2.700	.900
896.190	225.000	50.000	2.660	1.480	3.800	.350

899.090	220.000	61.000	4.500	1.500	5.500	1.000
904.670	220.000	82.000	3.000	2.300	5.000	1.500
911.550	240.000	58.000	15.000	.200	6.000	10.000
916.700	300.000	49.000	5.000	2.500	7.200	9.000
921.670	165.000	76.000	15.000	2.000	8.000	7.000
922.000	205.000	90.000	1.000	1.800	2.500	1.400
923.570	5.000	85.000	1.700	1.800	3.100	1.300
923.950	30.000	80.000	6.000	1.650	7.000	2.700
926.550	15.000	83.000	2.700	1.400	3.500	.800
927.000	15.000	65.000	.400	.200	.500	.200
927.100	175.000	60.000	.500	.600	1.000	.150
929.570	195.000	87.000	13.000	10.000	8.000	8.000
931.760	220.000	90.000	2.700	1.500	3.500	.700
938.700	165.000	73.000	7.500	2.300	7.000	7.000
938.900	190.000	82.000	3.300	.800	3.000	.300
939.900	195.000	60.000	18.000	5.000	12.000	8.000
940.610	210.000	70.000	8.000	3.000	9.000	2.500
942.050	215.000	64.000	.700	.500	1.200	.150
942.430	210.000	65.000	5.000	.800	5.500	1.000
944.780	215.000	64.000	1.800	.900	2.600	.400
955.800	170.000	74.000	1.000	1.100	1.700	.300
956.430	188.000	66.000	18.000	5.000	12.000	8.000
958.020	330.000	82.000	4.000	1.400	5.000	2.200
962.000	200.000	90.000	.600	1.600	2.100	.200
963.230	150.000	84.000	3.500	1.800	5.000	1.000
965.390	160.000	66.000	1.000	1.200	2.000	.300
965.490	180.000	59.000	5.000	1.800	6.500	1.000
969.750	340.000	83.000	7.000	2.000	7.500	3.800
970.030	190.000	75.000	.500	.200	.700	.050
970.070	15.000	85.000	.700	.140	.800	.050
970.210	.000	80.000	4.000	1.900	5.900	1.000
973.600	190.000	70.000	1.200	1.100	2.200	.500
973.740	190.000	75.000	3.300	.220	3.000	.300
974.670	210.000	78.000	2.200	1.800	3.900	.900
983.470	200.000	58.000	5.000	1.900	6.000	1.000
984.760	350.000	88.000	.500	2.000	2.400	1.400
985.140	210.000	75.000	6.000	2.000	7.000	3.800
986.450	340.000	78.000	.700	2.300	2.200	1.900
986.850	210.000	87.000	.050	.900	.900	.300
987.860	190.000	74.000	.400	.600	1.000	.100
991.280	355.000	84.000	1.700	2.450	4.000	2.000
991.610	5.000	85.000	.900	2.400	3.000	2.000
991.870	215.000	88.000	4.000	2.400	6.000	1.500
994.150	340.000	82.000	2.000	2.200	4.000	2.100
995.940	195.000	64.000	.800	2.000	2.500	1.000
996.270	210.000	47.000	2.500	.400	2.700	.300
997.570	.000	82.000	2.400	2.600	4.500	2.200
998.430	340.000	76.000	2.700	3.200	4.500	2.200

View Unit Descriptions

Start of Report...

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Reading report specifications and preparing query . . .
Retrieving data . . .

TECTONIC CHARACTERISTICS DATA REPORT

TABLE DESCRIPTION:
Fracture Type data from North Ramp Tunnel - ESF, and Yucca Mountain Project Detailed Line Survey-Data from Station 8+01.35 to 9+98.43; collected under GP-32, R0, SCP Study Number 8.3.1.4.2.2.4., 06/02/1995 to 06/20/1995.

TDIF: 305055

DTN: GS951108314224.005

FOOTNOTES: Traceline is generally 0.9 meters below right wall springline; BED-Bedding; F-Fracture; FLT-Fault; SH-Shear; RX-Ends blindly in rock mass; ST-End not visible behind ground support; IM-Fracture extends under precast invert segments; AI-Fracture (usually subparallel to tunnel) termination has been excavated; CR-Crown; P-Planar; I-Irregular; U-Undulating; NR-Not recorded; R1-Stepped, Near-normal steps and ridges occur on the fracture surface; R2-Rough, Large, angular asperities can be seen; R3-Moderately rough, asperities are clearly visible and fracture surface feels abrasive; R4-Slightly rough, small asperities on the fracture surface are visible and can be felt; R5-Smooth, no asperities, smooth to the touch; R6- Polished, extremely smooth and shiny; Ja.11-Tightly healed, hard filling; Ja.12-unaltered surface stain only; Ja.13-slightly altered, non softening coating, sandy particles; Ja.14-silty or sandy clay coatings, little clay; Ja.15-softening or clay mineral coatings;

ADDNL FOOTNOTES: Ja.31-zones of disintegrated or crushed rock; Ja.32-zones of silty or sandy clay.

ROW#	Q	FRACTURE TYPE	LOCATION	DATE	STRIKE (^o)	DIP (^o)	LENGTH ABOVE TR ACELINE (m)	LENGTH BELOW TR ACELINE (m)	HEIGHT (m)	WIDTH (m)	FRACTURE ENDS VISIBLE	UPPER TERMINATION
1	Y	F	8+01.36	06/02/95 - 06/20/95	200	86	2.45	0.7	3.1	0.4	2	RK
2	Y	F	8+02.40	06/02/95 - 06/20/95	10	83	NR	1.5	1.3	1	2	RK
3	Y	F	8+02.58	06/02/95 - 06/20/95	0	90	0.7	0.2	0.9	0.1	2	RK
4	Y	F	8+03.18	06/02/95 - 06/20/95	325*	83	0.85	3	3.5	2.6	1	F
5	Y	F	8+03.60	06/02/95 - 06/20/95	210	77	3	NR	3	0.5	2	RK
6	Y	F	8+04.15	06/02/95 - 06/20/95	220	73	2.5	0.9	3	0.4	2	F
7	Y	F	8+04.64	06/02/95 - 06/20/95	255	85	0.75	1.3	1.9	0.06	2	F
8	Y	F	8+04.83	06/02/95 - 06/20/95	15	78	0.27	0.9	1.1	0.03	2	RK
9	Y	F	8+05.60	06/02/95 - 06/20/95	170	50	2.5	0.5	3	0.4	2	F
10	Y	F	8+06.29	06/02/95 - 06/20/95	220	84	1.4	1.1	2.5	0.1	2	F
11	Y	FLT	8+06.42	06/02/95 - 06/20/95	215	84	4	1	5	0.5	2	F
12	Y	FLT	8+06.86	06/02/95 - 06/20/95	220	85	1.5	0.75	2.25	0.08	2	RK
13	Y	F	8+07.75	06/02/95 - 06/20/95	210	74	2.2	2.5	4.5	1.5	1	F
14	Y	F	8+08.34	06/02/95 - 06/20/95	225	80	4	1.3	5	0.6	2	F
15	Y	F	8+08.65	06/02/95 - 06/20/95	230	83	6	1	6	3	2	RK
16	Y	F	8+08.90	06/02/95 - 06/20/95	225	83	1.8	0.9	2.4	0.15	2	F

(Abridged version of file included here.
Full printout can be found on pp. 121-122 of Reference Notebook YMP-LBNL-GSB-MC-1.2A (for Scientific Notebook YMP-LBNL-GSB-MC-1.2) under ACC: MOL.19990903.0031)

107	Y	F	9+73.60	06/02/95 06/20/95	190	70	1.2	1.1	2.2	0.5	2	F
108	Y	F	9+73.74	06/02/95 06/20/95	190	75	3.3	0.22	3	0.3	2	RK
109	Y	F	9+74.67	06/02/95 06/20/95	210	78	2.2	1.8	3.9	0.9	2	F
110	Y	F	9+83.47	06/02/95 - 06/20/95	200	58	5	1.9	6	1	2	RK
111	Y	F	9+84.76	06/02/95 - 06/20/95	350	88	0.5	2	2.4	1.4	2	RK
112	Y	F	9+85.14	06/02/95 - 06/20/95	210	75	6	2	7	3.8	1	RK
113	Y	F	9+86.45	06/02/95 - 06/20/95	340	78	0.7	2.3	2.2	1.9	1	RK
114	Y	F	9+86.85	06/02/95 - 06/20/95	210	87	0.05	0.9	0.9	0.3	2	RK
115	Y	F	9+87.86	06/02/95 - 06/20/95	190	74	0.4	0.6	1	0.1	2	RK
116	Y	F	9+91.28	06/02/95 - 06/20/95	355	84	1.7	2.45	4	2	1	F
117	Y	F	9+91.61	06/02/95 - 06/20/95	5	85	0.9	2.4	3	2	1	F
118	Y	F	9+92.87	06/02/95 - 06/20/95	215	88	4	2.4	6	1.5	0	ST
119	Y	F	9+94.15	06/02/95 - 06/20/95	340	82	2	2.2	4	2.1	1	F
120	Y	F	9+95.94	06/02/95 - 06/20/95	195	64	0.8	2	2.5	1	1	F
121	Y	F	9+96.27	06/02/95 - 06/20/95	210	47	2.5	0.4	2.7	0.3	2	RK
122	Y	F	9+97.57	06/02/95 - 06/20/95	0	82	2.4	2.6	4.5	2.2	1	RK
123	Y	F	9+98.43	06/02/95 - 06/20/95	340	76	2.7	3.2	4.5	2.2	1	RK

End of Report

LOWER TERMINATION	PLANARITY	JOINT ALTERATION NUMBER	FRACTURE ROUGHNESS	MINIMUM APERTURE (mm)	MAXIMUM APERTURE (mm)
RK	P	14	4	0	0
RK	I	14	3	0	0
RK	I	15	3	0	0
IN	P	15	4	0	0
RK	I	15	4	0	0
RK	P	15	5	0	0
F	I	15	4	0	0
F	I	11	3	0	0
F	U	15	6	0	5
RK	P	13	4	0	3
RK	P	15	4	0	3
RK	U	13	4	0	0
IN	U	14	5	0	2
RK	P	15	4	0	10
RK	P	15	4	0	5
RK	P	15	4	0	0
			⋮		
			⋮		
RK	I	11	3	0	0
F	I	11	3	0	0
RK	I	12	3	0	0
RK	I	13	3	0	0
RK	I	13	3	0	0
IN	I	13	3	0	0
IN	I	13	3	0	0
RK	I	13	3	0	0
RK	I	15	3	0	0
IN	I	15	3	0	0
IN	I	15	3	0	0
IN	I	15	3	0	0
IN	P	14	3	0	0
IN	I	14	3	0	0
RK	I	14	3	0	0
IN	U	15	3	0	0
IN	I	15	3	0	0

COMMENTS

upper termination in stratigraphic pumice bed, 1 to 2mm clay coating, mostly in middle of fracture
upper termination at trace line, has small finger fracture coming off which intersects fracture at sta. 8+82.58, finger comes off at 0.15m below trace line, 1 to 2mm clay coating
at 0.65m above trace line fracture has finger that comes off with change in azimuth to 170, dip 90 degrees, this fracture can be traced from 3m to fracture
upper termination in fracture 8+03.60, fracture thinning at bottom, 2 to 3mm clay infilling
2 to 3mm altered clay infilling, zone of alteration on fracture sides, ends in highly altered zone
up to 2mm soft orange colored clay infilling
dip varies + or - 5 degrees along trace
no coatings
amplitude 0.04m, wave length 0.7m, up to 10mm orange clay infilling, fracture surface slicken sided, rake 70 degrees
clean to local patches of up to 1mm thick orange clay infilling
this has movement with 0.1m offset, west side down, up to 1mm clay infilling
0.15m offset, west side down, locally clean, local 1mm clay infilling, unable to determine amplitude and wave length
0 to 10mm orange clay infilling
1mm to 3cm orange clay infilling
0 to 10mm clay (average approx. 4mm) infilling
1 to 3mm orange clay infilling

see next fracture 9+73.74, upper termination has apparent curves into 9+73.74, while the lower termination dies, next fracture is subparallel
see 9+73.60, the lower termination curves near tapeline to intersect 9+73.60
hard to see ends
bottom 1.0m (plus or minus) is in an altered, discolored zone, in local zones, especially at the bottom are up to 15mm mineralized infilling
upper termination is faint, dies out, lower termination is in altered, discolored zone, bottom of fracture anastomoses, has mineralized infilling
local mineralized infilling, especially in bottom altered zone
mineralized infilling, especially in bottom altered zone, up to 30mm (plus or minus)
mineralized infilling, up to 15mm thick, extending about 0.3m above altered zone
mineralized infilling along total height, thickness of mineralized infilling up to 10cm
mineralized infilling 0 to 5cm thick
mineralized infilling 0 to 3.5cm, becomes very faint towards SW invert
mineralized with dark minerals, varies from 0 to 3cm
mineralized with dark minerals, varies from 0 to 4mm
slightly mineralized 0 to 3mm
slightly mineralized 0 to 2mm, fracture is faint and hard to trace in some locations
mineralized 4 to 10mm, fracture terminates at top of hydrothermal alterations
mineralized 3 to 5mm

YMP-LBNL DOCUMENT REVIEW/COMMENT RESOLUTION (DRCR) FORM

Document No. and Title: Software Macro Read_TDB Version 1.0 _____ Page __1__of _1___

Date of Document / revision no./ draft revision no. (as applicable):_____Version 1.0_____ Author:____Mark Cushey_____

Are Scientific Notebooks or other background documents/data included in the scope of this review? ☒ Yes ☐ No (If yes, identify on Attachment 3)

Specific Review Criteria or Governing Procedure: AP-SI.1Q, Rev 1, ICN 0 and YMP-LBNL-QIP-6.1, Rev. 4, Mod. 0 _____

General Review Criteria: (identify relevant criteria on Attachment 4): Section 5.1 of AP-SI.1Q and Software Review Criteria S-7 to S-10 _____

☐ Checker ☒ Technical Reviewer ☐ EA Reviewer ☐ OQA Reviewer

Name:_____C.F. Ahlers_____ Signature: _____ Date: __9/23/99_____

REVIEWER'S COMMENTS			AUTHOR'S RESPONSE			Reviewer Disposition for Mandatory Comments	
COMMENT NO. MANDATORY (M) NON-MANDATORY (NM)	SECT. AND PAGE NO.	COMMENTS	ACCEPT Initial/Date	REJECT Initial/Date	Response required for all technical mandatory and non-mandatory comments	ACCEPT Initial/Date	REJECT Initial/Date
		No comments					

May be on separate sheets to be attached, in which case the comments shall be numbered and this form will be used to track the comments and their resolution according to such numbers.

Resolution of Disputed Comments

Office of Quality Assurance Date

Project Manager Date

YMP-LBNL Management Approval (Project Manager or Designee)

for GS.Bodvarsson 9/23/99

APPLICABLE REFERENCE INFORMATION

Document No. and Title: Software Macro : Read_TDB Version 1.0

Date of Document (or revision, draft revision number, as applicable):
Version 1.0

Pertinent sections of the scientific notebook(s) or other backup documents/data identified below, support the document which is the subject of this review. These documents/data shall be included in the scope of this review.

Document(s) Title/Data	Relevant Sections/Pages
YMP-LBNL-MC-1	pp. 52, 58, 82-87