OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
ANALYSIS/MODEL COVER SHEET
*Complete Only Applicable Items*

1. QA: QA



2. ☒ Analysis — Check all that apply

Type of Analysis:
- ☐ Engineering
- ☐ Performance Assessment
- ☒ Scientific

Intended Use of Analysis:
- ☐ Input to Calculation
- ☒ Input to another Analysis or Model
- ☐ 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.

3. ☐ Model — Check all that apply

Type of Model:
- ☐ Conceptual Model
- ☐ Abstraction Model
- ☐ Mathematical Model
- ☐ System Model
- ☐ Process Model

Intended Use of Model:
- ☐ Input to Calculation
- ☐ Input to another Model or Analysis
- ☐ Input to Technical Document

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:

4

7. Attachment Numbers - No. of Pages in Each:

I-36, II-8, III-4, IV-~~9~~ 100 ar 6/19/00

| | Printed Name | Signature | Date |
|---|---|---|---|
| 8. Originator | H.H. Liu | [signature] | 3/12/00 |
| | C.F. Ahlers | Mark A. Cushey for C.F. Ahlers | 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 IV do not affect technical content JEH 4/28/00

**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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## TABLES

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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 $\alpha$ and $m$ parameters, aperture, porosity, and interface area) for each UZ Model layer
- Matrix properties (porosity, permeability, and van Genuchten $\alpha$ 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 $\alpha$ and $m$, matrix permeability, and van Genuchten matrix $\alpha$ 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<br>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 $\alpha$ 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<br>GS951108312232.008<br>GS960308312232.001<br>GS960808312232.004<br>GS970108312232.002<br>GS970808312232.005<br>GS971108312232.007<br>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<br>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<br>LB980120123142.004<br>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<br>GS990408314224.002<br>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<br>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 BT1*a* (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 $\alpha$ 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 $\alpha$ 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.

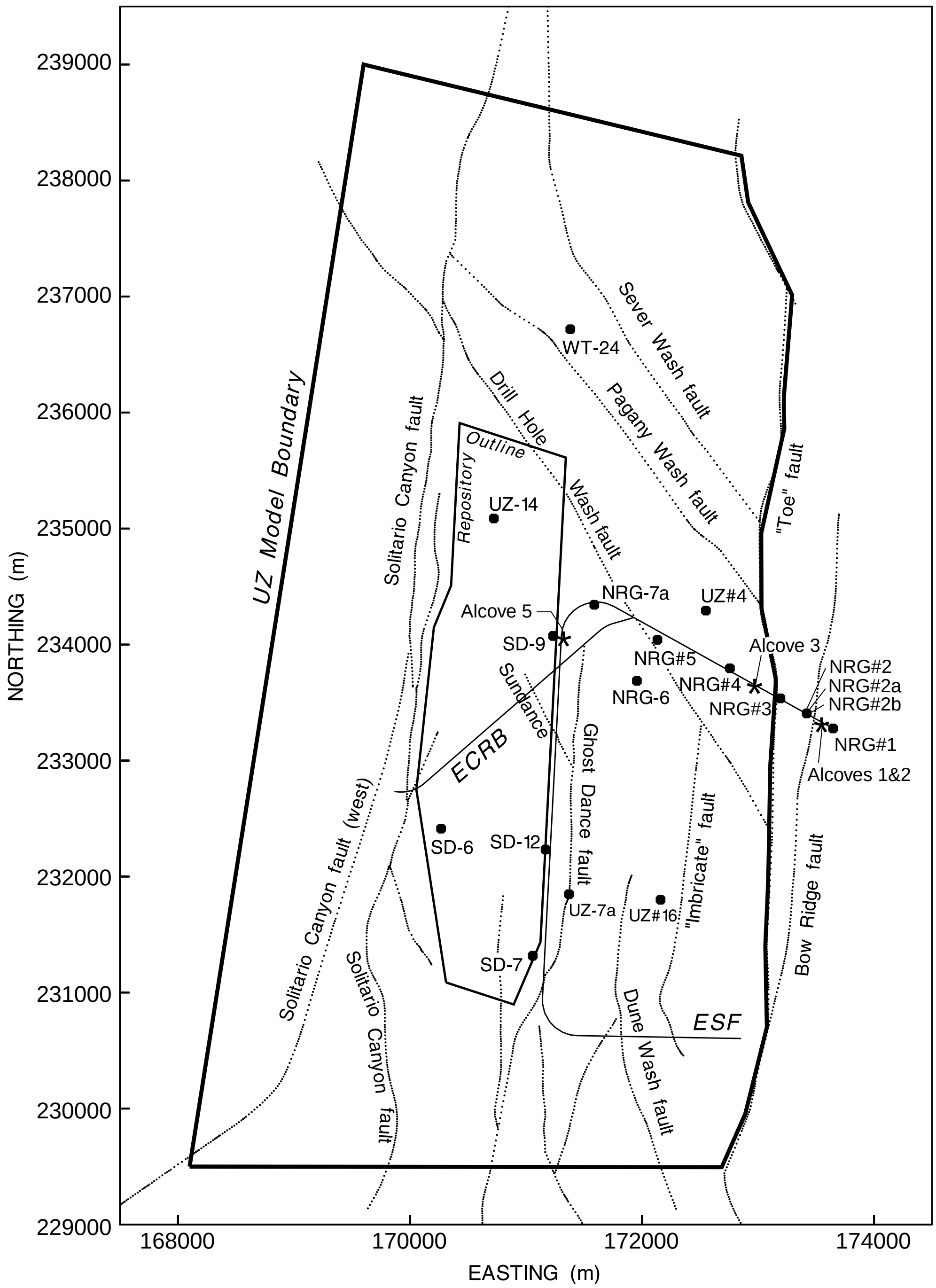



Figure 1. Schematic showing locations of selected boreholes and alcoves.

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<br>UPCA<br>NRG-6<br>NRG-7a<br>SD-12<br>UZ#16 | 5.3E-12 | -11.279 | 0.778 | 80 |
| tcw13 | UPCA<br>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<br>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<br>TSW | 6.4E-13 | -12.195 | - | - |
| tsw32 | NRG-6<br>NRG-7a<br>SD-12<br>UZ#16 | 7.1E-13 | -12.146 | 0.658 | 31 |
| tsw33 | NRG-6<br>NRG-7a<br>SD-12<br>UZ#16 | 7.7E-13 | -12.112 | 0.612 | 27 |
| tsw34 | SHT<br>DST<br>NRG-6<br>NRG-7a<br>SD-12<br>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<br>DST<br>NRG-6<br>NRG-7a<br>SD-12<br>UZ#16 | 1.6E-13 | -12.805 | - | 180 |
| tsw35 | NRG-7a<br>UZ#16 | 9.0E-13 | -12.044 | 0.544 | 31 |
| tsw3[67] | SD-12<br>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

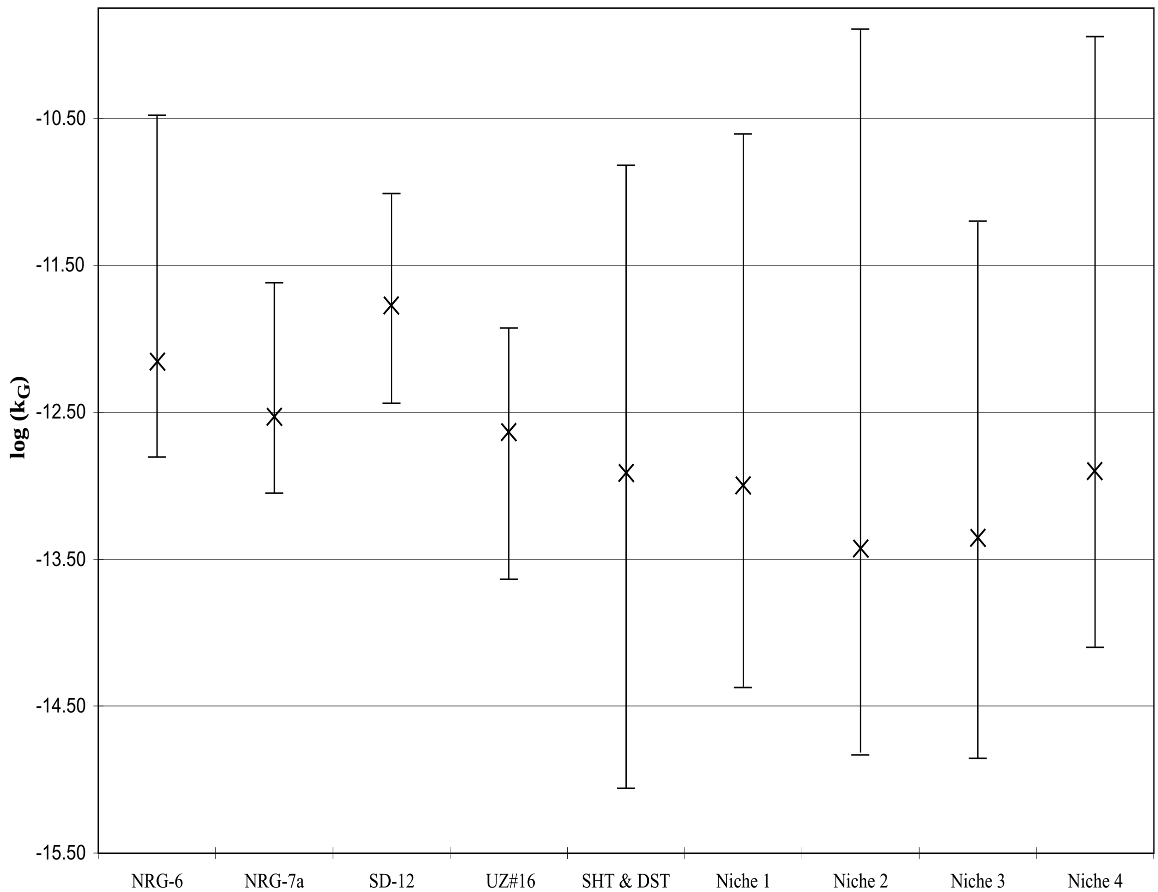
[d]Number of sampled intervals

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:

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

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 $\bar{f}$ 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):

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

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

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

where $\tau$ is the surface tension of pure water at 20 ºC (0.072 N/m) and $\theta$ is the contact angle. Essentially, Equation 9 assumes that van Genuchten $\alpha$ 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 $\theta$ 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 ($\alpha_f$) 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 ($\alpha_f$) 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 x $10^{-3}$ 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.

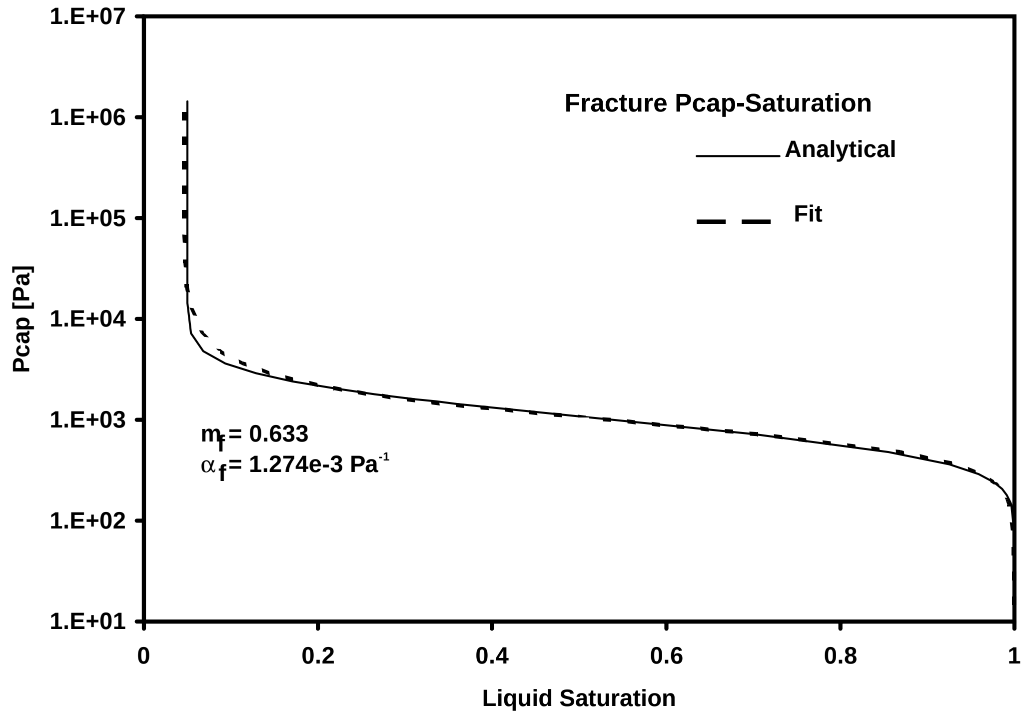



Figure 3. Analytical and Fitted Curves for Fracture Capillary Pressure (Pcap) and Liquid Saturation

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[b] | $\sigma_f$ | N | | | | $\alpha$ ($Pa^{-1}$) | $\log(\alpha_f)$ | $m_f$ (-) | | |
| 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] | $\sigma_f$ | N | | | | $\alpha$ ($Pa^{-1}$) | $\log(\alpha_f)$ | $m_f$ (-) | | |
| 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:

$$\phi_{2-D} = bI \tag{Eq.10}$$

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:

$$\phi_{1-D} = b\overline{f} \tag{Eq.11}$$

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 $\phi_{\text{tsw34}}$ is 0.01 and $\phi_{\text{2-D}}$ and $\phi_{\text{1-D}}$ 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 ($m^2$) | | | | | Porosity (-) | | | van Genuchten Parameters | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | k | log(k) | $\sigma_{log(k)}$ | N | N non-detect | $\phi$ | $\sigma_\phi$ | N | $\alpha$ ($Pa^{-1}$) | log($\alpha$) | m (-) | $SE_m$ | $S_r$ (-) | $S_s$ |
| CUC | tcw11 | 4.7E-15 | -14.326 | 0.471 | 3 | 0 | 0.253 | 0.060 | 101 | 3.77E-5 | -4.424 | 0.485 | 0.068 | 0.07 | 1.0 |
| CUL | - | 1.3E-15 | -14.894 | - | 1 | 0 | 0.164 | 0.062 | 98 | 3.76E-5 | -4.425 | 0.649 | 0.116 | 0.23 | 1.0 |
| CW | tcw12 | 2.6E-19 | -18.579 | 1.459 | 39 | 25 | 0.082 | 0.030 | 599 | 8.80E-6 | -5.056 | 0.253 | 0.028 | 0.19 | 1.0 |
| CMW | tcw13 | 1.8E-16 | -15.737 | 2.380 | 6 | 1 | 0.203 | 0.055 | 90 | 3.72E-6 | -5.430 | 0.418 | 0.094 | 0.31 | 1.0 |
| CNW | ptn21 | 4.0E-14 | -13.397 | 2.047 | 10 | 0 | 0.387 | 0.070 | 101 | 1.91E-4 | -3.720 | 0.202 | 0.043 | 0.23 | 1.0 |
| BT4 | ptn22 | 1.9E-12 | -11.728 | 2.379 | 4 | 0 | 0.439 | 0.125 | 33 | 2.52E-5 | -4.599 | 0.299 | 0.041 | 0.16 | 1.0 |
| TPY | ptn23 | 1.5E-13 | -12.833 | 1.582 | 3 | 0 | 0.254 | 0.083 | 43 | 5.46E-6 | -5.263 | 0.405 | 0.076 | 0.08 | 1.0 |
| BT3 | ptn24 | 1.1E-13 | -12.950 | 1.041 | 18 | 1 | 0.411 | 0.080 | 85 | 8.72E-5 | -4.059 | 0.197 | 0.029 | 0.14 | 1.0 |
| TPP | ptn25 | 1.1E-13 | -12.964 | 0.389 | 11 | 0 | 0.499 | 0.041 | 164 | 3.93E-5 | -4.406 | 0.293 | 0.085 | 0.06 | 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 | 0.053 | 0.036 | 71 | 2.41E-5 | -4.618 | 0.278 | 0.036 | 0.22 | 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 |
| TUL | tsw33 | 2.3E-17 | -16.637 | 1.511 | 51 | 14 | 0.154 | 0.031 | 455 | 1.81E-5 | -4.743 | 0.280 | 0.022 | 0.12 | 1.0 |
| TMN | tsw34 | 7.5E-19 | -18.124 | 1.965 | 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 | 1.573 | 65 | 21 | 0.131 | 0.030 | 451 | 6.41E-6 | -5.193 | 0.242 | 0.034 | 0.12 | 1.0 |
| TM2 | tsw36 | 3.9E-19 | -18.406 | 3.564 | 48 | 32 | 0.112 | 0.031 | 225 | 2.23E-6 | -5.652 | 0.416 | 0.027 | 0.18 | 1.0 |
| TM1 | tsw37 | 2.8E-19 | -18.558 | 1.285 | 23 | 13 | 0.094 | 0.019 | 102 | 1.01E-6 | -5.995 | 0.460 | 0.052 | 0.25 | 1.0 |
| PV3 | tsw38 | 3.8E-18 | -17.419 | 1.707 | 16 | 2 | 0.037 | 0.039 | 88 | 4.90E-7 | -6.310 | 0.319 | 0.045 | 0.44 | 1.0 |
| PV2 | tsw39 | 4.4E-17 | -16.355 | 1.499 | 9 | 0 | 0.173 | 0.107 | 39 | 1.60E-5 | -4.797 | 0.360 | 0.106 | 0.29 | 1.0 |
| BT1a | ch1Ze | 1.7E-19 | -18.778 | 0.841 | 8 | 1 | 0.288 | 0.073 | 36 | 4.06E-7 | -6.391 | 0.339 | 0.071 | 0.33 | 1.0 |
| BT1 | ch1VI | 2.6E-14 | -13.584 | 1.076 | 16 | 0 | 0.273 | 0.068 | 43 | 2.91E-5 | -4.535 | 0.337 | 0.035 | 0.03 | 1.0 |
| CHV | ch[2345]VI | 8.9E-14 | -13.050 | 1.639 | 24 | 0 | 0.345 | 0.035 | 69 | 7.20E-5 | -4.143 | 0.220 | 0.057 | 0.07 | 1.0 |
| CHZ | ch[2345]Ze | 5.4E-18 | -17.269 | 0.890 | 125 | 17 | 0.331 | 0.039 | 293 | 8.12E-6 | -5.090 | 0.248 | 0.026 | 0.28 | 1.0 |
| BT | ch6 | 1.0E-18 | -17.995 | 1.608 | 14 | 8 | 0.266 | 0.041 | 69 | 3.36E-7 | -6.473 | 0.505 | 0.036 | 0.37 | 1.0 |
| PP4 | pp4 | 4.4E-17 | -16.356 | 2.275 | 10 | 2 | 0.325 | 0.045 | 47 | 1.80E-7 | -6.744 | 0.684 | 0.042 | 0.28 | 1.0 |
| PP3 | pp3 | 6.6E-15 | -14.179 | 0.940 | 55 | 0 | 0.303 | 0.044 | 166 | 7.89E-5 | -4.103 | 0.337 | 0.038 | 0.10 | 1.0 |
| PP2 | pp2 | 5.2E-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 | -16.376 | 1.454 | 40 | 4 | 0.280 | 0.053 | 245 | 3.22E-6 | -5.493 | 0.401 | 0.059 | 0.30 | 1.0 |
| BF3 | bf3 | 3.9E-15 | -14.414 | 1.815 | 5 | 1 | 0.115 | 0.041 | 86 | 1.69E-6 | -5.771 | 0.416 | 0.082 | 0.11 | 1.0 |
| BF2 | bf2 | 3.9E-17 | -16.410 | 2.669 | 5 | 3 | 0.259 | 0.085 | 65 | 2.49E-7 | -6.603 | 0.585 | 0.040 | 0.18 | 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 $\mu_w$ is the viscosity of water (0.001 N s/$m^2$), *g* is the acceleration of gravity (9.81 m/$s^2$), and $\rho_w$ 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), $\alpha$, 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, $\alpha$ 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 $\alpha$ 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 $\alpha$ and $m$ fitting parameters for each layer. The best-fit parameters are obtained by minimizing the sum of the squared saturation residuals,

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

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, $\Psi_i$.

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

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

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

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

Because the data used to estimate $\alpha$ and *m* are from laboratory desaturation experiments, the estimate of $\alpha$ 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 $\alpha$ is re-estimated based solely on the field condition data. For the layers with no field condition data, an analogously modified parameter, $\alpha'$, is calculated by

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

where $\alpha_d'$ is the estimate of $\alpha$ for that layer from desaturation data and *c* is a modification factor given by

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

where *n* is either the number of welded or non-welded units with field condition data, $\alpha_{I,i}$ is the estimate of $\alpha$ from field condition data for unit *i*, and , $\alpha_{d,i}$ is the estimate of $\alpha$ 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 |
| ch1VI | 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 |

Submitted with this AMR under DTN: LB99109123129.006

## 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 $\alpha$ 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 $\alpha$ is used to calculate the equivalent $\alpha$ for the faults.

Table 9. Calculated Fault Matrix Properties

| Model Layer | Permeability ($m^2$) | Porosity (-) | van Genuchten $\alpha$ ($Pa^{-1}$) | 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 |

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### 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 $\alpha$, 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 $\alpha$ ($\alpha_f$) 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 ($m^{-1}$) | $\alpha_f$ ($Pa^{-1}$) | $m_f$ (-) | 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 |

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### 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):

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

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 $\alpha$ 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 $\alpha$ ($\alpha_f$) 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 $\alpha$ 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, $\Psi$ (m), that is exponential in nature.

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

where $K_0$ (m/s) is the hydraulic conductivity at a referential water potential $\Psi_0$ (m), and $\alpha'$ (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

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

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), $\vartheta_{max}$ 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 ($\alpha_f$) 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 $\alpha_f$ (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 $\theta_r$ is the residual water content, and $\theta_{av}$ 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 $\theta_r = 0$, $\theta_{av}$ can be estimated for each seepage test. The estimated ($\theta_{av} - \theta_r$) 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 $\alpha$ 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 $\alpha$ 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 $\alpha$. 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 $\alpha$ Estimated from the ESF Seepage Tests (Niche 3650)

| **Borehole (Depth(m))**[a] | **Log($\alpha_f$)**[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($\alpha_f$)**[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($\alpha_f$) 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($\alpha_f$) value is –3.16, which is very close to the log($\alpha_f$) 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.

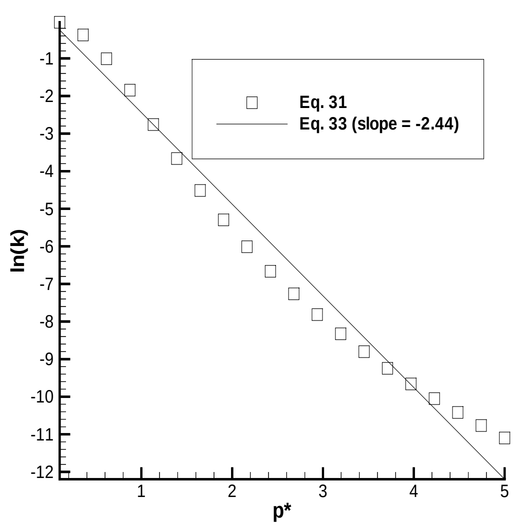


Figure 4. Graph of fitting of Equation 33 to Equation 31 using a number of data points for $p^* < 5$

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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# 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 |
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| Input Document | | | 4. Input Status | 5. Section Used in | 6. Input Description | 7. TBV/TBD Priority | 8. TBV Due To | | |
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| 2. Technical Product Input Source Title and Identifier(s) with Version | | 3. Section | | | | | Unqual. | From Uncontrolled Source | Un-confirmed |
| 2a | | | | | | | | | |
| 1. | DTN: GS00039991221.004. 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 | 4. Input Status | 5. Section Used in | 6. Input Description | 7. TBV/TBD Priority | 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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| 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 |

| OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT<br>DOCUMENT INPUT REFERENCE SHEET | | | | | | | | | |
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| 1. Document Identifier No./Rev.:<br>ANL-NBS-HS-000002/Rev.00 | | | Change: | Title:<br>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 |
| 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 Permeabilit y 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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| 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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| 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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| 1. Document Identifier No./Rev.: ANL-NBS-HS-000002/Rev.00 | | | Change: | Title: Analysis of Hydrologic Properties Data | | | | | |
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| 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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| 1. Document Identifier No./Rev.: ANL-NBS-HS-000002/Rev.00 | | | Change: | Title: Analysis of Hydrologic Properties Data | | | | | |
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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 |
| 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<br>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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| 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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| 1. Document Identifier No./Rev.: ANL-NBS-HS-000002/Rev.00 | | | Change: | Title: Analysis of Hydrologic Properties Data | | | | | |
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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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| 1. Document Identifier No./Rev.: ANL-NBS-HS-000002/Rev.00 | | | Change: | Title: Analysis of Hydrologic Properties Data | | | | | |
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| 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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| 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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| 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 |
| 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: LB9605008342444.001. 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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| 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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| 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<br>34-35<br>Fig. 5<br>Att. II | TBV | 6.1.2.1<br>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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|---|---|---|---|---|---|---|---|---|---|
| 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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| 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 |
| 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<br>p. 21 | N/A - Reference only | 6.1.1<br>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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| 2. Technical Product Input Source Title and Identifier(s) with Version | | 3. Section | | | | | Unqual. | From Uncontrolled Source | Un-confirmed |
| 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 $\alpha$ | 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**

| Borehole | Unit | k ($m^2$) |
|---|---|---|
| uz-16 | Tac | 2.48E-14 |
| nrg-7a | Tpcpv1 | 1.20E-13 |
| nrg-7a | Tpcpv1 | 2.87E-13 |
| nrg-7a | Tpy | 2.12E-13 |
| nrg-7a | Tpy | 2.40E-13 |
| nrg-7a | Tpy | 2.65E-13 |
| nrg-7a | Tpy | 5.92E-13 |
| nrg-7a | Tpbt3 | 2.97E-12 |
| nrg-7a | Tpp | 1.24E-13 |
| nrg-7a | Tpp | 1.37E-13 |
| nrg-7a | Tpp | 1.40E-13 |
| nrg-7a | Tpp | 1.50E-13 |
| nrg-7a | Tpp | 2.01E-13 |
| nrg-7a | Tpp | 2.10E-13 |
| nrg-7a | Tpp | 2.19E-13 |
| nrg-7a | Tpp-Tpbt2-Tptrv3 | 2.18E-13 |
| nrg-6 | Tpcplnc | 2.78E-13 |
| nrg-6 | Tpcplnc | 2.29E-12 |
| nrg-6 | Tpcpll | 1.40E-11 |
| nrg-6 | Tpcpll-Tpcplnh | 2.82E-11 |
| nrg-7a | Tpcplnc | 1.09E-11 |
| nrg-7a | Tpcplnc | 4.06E-11 |
| nrg-7a | Tpcplnh-Tpcplnc | 5.39E-11 |
| sd-12 | Tpcplnc | 7.71E-13 |
| sd-12 | Tpcpll-Tpcplnh | 9.16E-13 |
| sd-12 | Tpcpll | 9.23E-13 |
| sd-12 | Tpcplnh | 1.66E-12 |
| sd-12 | Tpcplnc | 2.10E-12 |
| sd-12 | Tpcplnc-Tpcpv2 | 3.16E-12 |
| sd-12 | Tpcplnc | 5.86E-12 |
| sd-12 | Tpcplnh-Tpcplnc | 5.97E-12 |
| sd-12 | Tpcplnc-Tpcpv2 | 6.77E-12 |
| sd-12 | Tpcplnh-Tpcplnc | 1.10E-11 |
| sd-12 | Tpcpll | 3.83E-11 |
| uz-16 | Tpcpll/Tpcplnh | 1.50E-12 |
| uz-16 | Tpcpll | 5.48E-12 |
| uz-16 | Tpcplnc | 1.50E-11 |
| uz-16 | Tpcplnh/Tpcplnc | 2.74E-11 |
| nrg-7a | Tpcplnc-Tpcpv2 | 2.42E-13 |
| nrg-6 | Tptrn | 8.15E-14 |
| nrg-6 | Tptrn | 1.30E-13 |
| nrg-6 | Tptrn | 1.68E-13 |
| nrg-6 | Tptrn | 1.87E-13 |

**UPCA**
**Upper PTn Contact Alcove (Alcove 3)**
**LeCain, 1998**
**DTN: GS970183122410.001**

| Borehole | Unit | k ($m^2$) |
|---|---|---|
| RBT #1 | Tpcplnc | 1.6E-12 |
| RBT #1 | Tpcplnc | 2E-13 |
| RBT #4 | Tpcplnc | 2E-12 |
| RBT #4 | Tpcplnc | 2E-14 |
| RBT #4 | Tpcplnc | 6E-14 |
| RBT #4 | Tpcplnc | 4E-13 |
| RBT #4 | Tpcplnh | 4E-13 |
| RBT #4 | Tpcplnh | 4.7E-12 |
| RBT #4 | Tpcplnh | 1.7E-12 |
| RBT #4 | Tpcplnh | 1E-13 |
| RBT #4 | Tpcplnh | 6.2E-12 |
| RBT #4 | Tpcplnh | 3.1E-12 |
| RBT #4 | Tpcplnh | 1.2E-11 |
| RBT #4 | Tpcplnh | 6.2E-12 |
| RBT #4 | Tpcplnh | 1E-12 |
| RBT #4 | Tpcplnh | 2.3E-12 |
| RBT #4 | Tpcplnh | 2.9E-12 |
| RBT #1 | Tpcpv2 | 9.3E-12 |
| RBT #1 | Tpcpv2 | 4.11E-11 |
| RBT #1 | Tpcpv1 | 5.7E-11 |
| RBT #1 | Tpcpv1 | 3.39E-11 |
| RBT #1 | Tpcpv1 | 1.5E-11 |
| RBT #1 | Tpcpv1 | 4E-13 |
| RBT #1 | Tpcpv1 | 1.3E-11 |
| RBT #1 | Tpcpv1 | 1.1E-12 |
| RBT #1 | Tpcpv1 | 7.7E-12 |
| RBT #1 | Tpcpv1 | 9E-13 |
| RBT #1 | Tpcpv1 | 1.9E-12 |
| RBT #1 | Tpcpv1 | 1.7E-11 |

**UTCA**
**Upper Tiva Canyon Alcove (Alcove 1)**
**LeCain, 1998**
**DTN: GS970183122410.001**

| Borehole | Unit | k ($m^2$) |
|---|---|---|
| RBT #1 | Tpcpul | 5.5E-12 |
| RBT #1 | Tpcpul | 1.13E-11 |
| RBT #1 | Tpcpul | 3.4E-12 |
| RBT #1 | Tpcpul | 2.3E-12 |
| RBT #1 | Tpcpul | 2.4E-11 |
| RBT #1 | Tpcpul | 2.7E-11 |
| RBT #1 | Tpcpul | 3.2E-12 |
| RBT #2 | Tpcpul | 4.7E-11 |

**SHT**
**Observation Drift**
**DTN: LB970600123142.001**

| k ($m^2$) |
|---|
| 4.5E-13 |
| 9E-14 |
| 4.7E-13 |
| 3.4E-13 |
| 4.1E-14 |
| 2E-12 |
| 4.8E-13 |
| 1.4E-13 |
| 4.9E-13 |
| 4.2E-13 |
| 1E-13 |
| 3E-13 |
| 7.8E-14 |
| 2.4E-14 |
| 6.2E-15 |
| 4.4E-13 |
| 3.5E-14 |
| 4.4E-13 |
| 1.2E-13 |
| 1.3E-12 |
| 3.4E-14 |
| 6.1E-14 |
| 9.5E-15 |
| 4.5E-14 |
| 6.8E-15 |
| 1.4E-13 |
| 1.1E-14 |
| 5.8E-14 |
| 4.1E-15 |
| 6.1E-14 |
| 2.4E-14 |
| 8.8E-16 |
| 1E-13 |
| 1.1E-13 |
| 1.9E-15 |
| 2.7E-13 |
| 2.1E-13 |
| 1.9E-14 |
| 6.6E-14 |
| 4.9E-13 |
| 5.5E-14 |

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 ($m^2$)** |
|---|---|---|
| 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 ($m^2$)** |
|---|
| 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 ($m^2$)** |
|---|
| 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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## YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT TECHNICAL DATA INFORMATION FORM

Page 1 of 2

☐ 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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**YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT**
**TECHNICAL DATA INFORMATION**
**CONTINUATION SHEET**

Page 2 of 2

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**

Page 1 of 1

☐ ACQUIRED DATA

☒ DEVELOPED DATA

DTN: LB991091233129.006

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 October 20, 1999
Signature Date

AP-SIII.3Q

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YMP-023-R6
04/99

**YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT**
**TECHNICAL DATA INFORMATION**
**CONTINUATION SHEET**

Page 2 of 2

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 '$\alpha$' 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 $\alpha$ must be appropriate for the hydrogeologic conditions at the site being modeled.**

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

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. version 1.0

mc 3/6/00 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.

Description: mc 3/6/00

capfit fits a curve to water potential and saturation data points to obtain the van Genuchten (1980) fitting parameters α and n. ~~for use~~ LMB 9/30/99 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. LMB 9/30/99 ~~as described~~ in Scientific Notebook YMP-LANL-GSB-1.9 pages 118 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 VanGenuchten fitting parameters are output by the macro.

SIGNATURE LMB DATE 9/30 1999

READ AND UNDERSTOOD ______ DATE ______ 19 ______

saturations and water potentials calculated from vG (1990) equation
$\alpha$ = 10 bars
n = 2.5
m = 0.6

Input range for test case 1

mc 3/6/00

Files located near page 41

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

Case1

| alpha | n | m |
|---|---|---|
| 10 | 2.50 | 0.6 |

| Se | m=.6, alpha=10 |
|---|---|
| 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 |

✓ it

$S_e = 0.1$

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

$\approx 4.6\text{ E-01}$

checks

SIGNATURE MB DATE 9/30 19 99

READ AND UNDERSTOOD DATE 19

41 PROJECT NAME ________ NOTEBOOK NO. ________

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

Input range for test case 2

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

$n = 1.4286$

~~∝~~ RWA 9/30/99

MC 3/6/00

$m = 1 - 1/n$

$= 0.3$

Location of files

Spreadsheet and files found in computer DOE # 6313734

mc 3/6/00

Joewang\ c:\mark \capfitcheck Excel

Excel spreadsheet name: capftchk.xls

capfit.f obtained and compiled on hydra/ tm/bank/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

Case*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 |

SIGNATURE RWA DATE 9/30 1999

READ AND UNDERSTOOD ________ DATE ________ 19 ____

Output file fracture.out

Input DATA FILE NAME: fracture.dat
CASE TITLE: FRACT. PROPERTIES M=.6,a=10
INPUT PARAMETERS run for curve with $\alpha$, m similar to fractures
================
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 – Estimates
=======================

| | |
|---|---|
| ALPHA DRYING........................................ | 8.0000 |
| ALPHA WETTING........................................ | 8.0000 |
| BETA DRYING........................................ | 2.5000 |
| BETA WETTING........................................ | 2.5000 |
| RESIDUAL FLUID CONTENT........................... | 0.0500 |

| 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 | n = 2.5007 | 0.0000 | |

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

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 |
| n ≃ BETA | 0.2501E+01 | 0.1423E-02 | ****** | 0.2498E+01 | 0.2503E+01 |

SIGNATURE ____________ DATE ________ 19 ____
READ AND UNDERSTOOD ____________ DATE ________ 19 ____

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) $\alpha$, m

.....................................(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

output file matrix.out

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 |

| 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 |

CORRELATION MATRIX

=================

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

| | 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

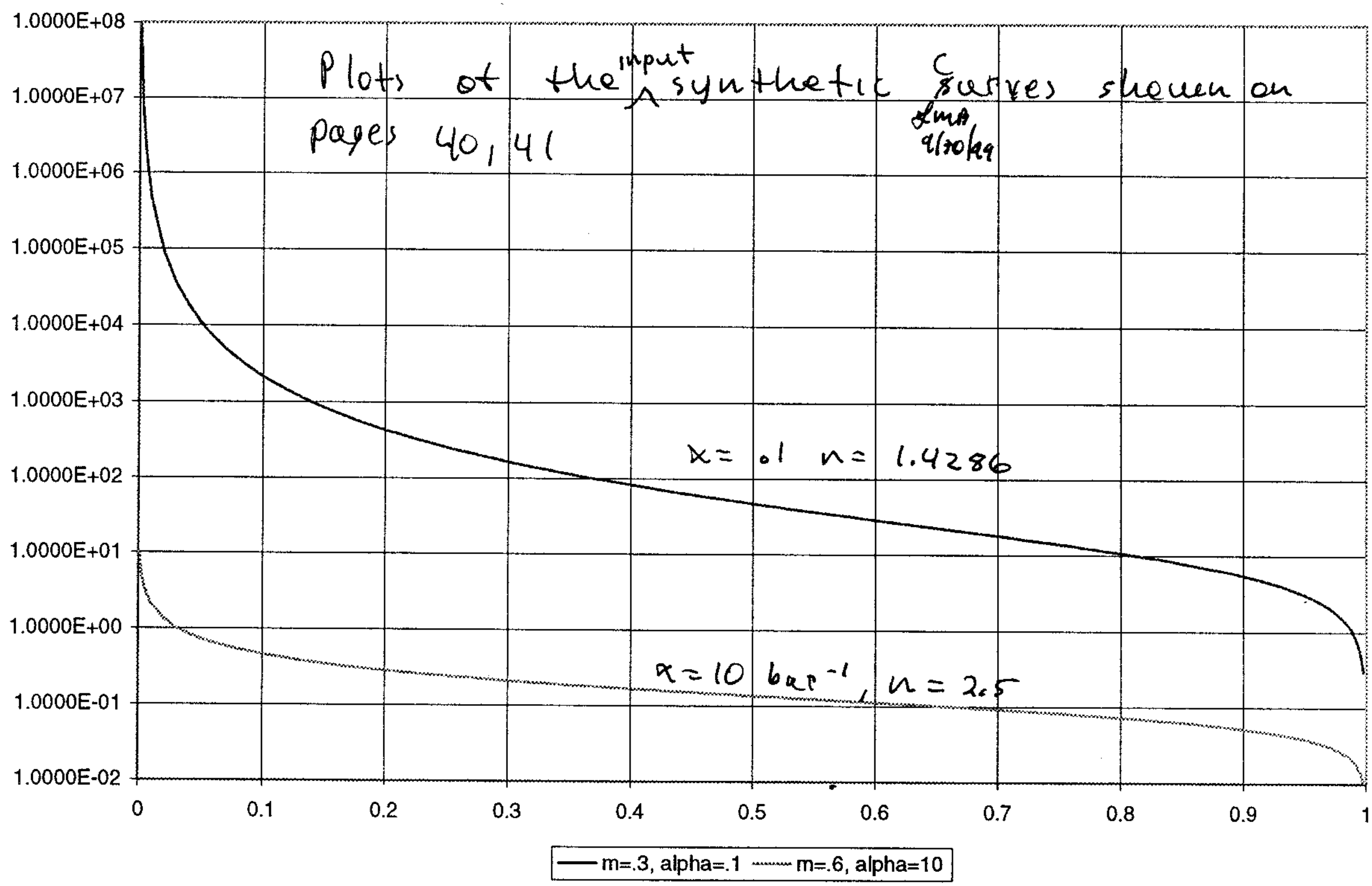
============================================

| 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 |

SIGNATURE ______ DATE ______ 19 ______

READ AND UNDERSTOOD ______ DATE ______ 19 ______

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




SIGNATURE
READ AND UNDERSTOOD
DATE 19
DATE 19

<u>Results</u>

| | matrix.dat | | fracture.dat | |
|---|---|---|---|---|
| | $\alpha$ | m | $\alpha$ | 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

```
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(model.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))
 1048 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(*,*) ' '
```

```
      WRITE(*,*) ' '
      WRITE(*,*) ' ÚÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄ¿'
      WRITE(*,*) ' ³                                                  ³'
      WRITE(*,*) ' ³     Ûßßßß   ÜßßÜ   ÛßßßÛ  Ûßßßß  ßÛß  ßßßÛßßß    ³'
      WRITE(*,*) ' ³     Û      ÛÜÜÜÜÛ  ÛÜÜÜÛ  Ûßß     Û      Û       ³'
      WRITE(*,*) ' ³     ÛÜÜÜÜ  Û    Û  Û      Û      ÜÛÜ     Û       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(*,*) ' ÀÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÙ'
      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

 PROJECT NAME Mc-1.2 NOTEBOOK NO.

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

| FY98 | FY99 |
|---|---|
| ptn 24, ptn 25 | ptn 24 |
| ptn 26 | → ptn 25 |
| ptn 27 | → ptn 26 |

The model layers for FY97, FY98 & FY99 are summarized in Reference Binder YMP-LBNL-~~M~~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 those for the North Ramp & Main Drift are "entrance" points. The South Ramp assignments were therefore shifted. In particular tsw35 was mis assigned:

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 those assignments.

SIGNATURE ______ DATE ______ 19 ___
READ AND UNDERSTOOD ______ DATE ______ 19 ___

mc 7/21/99

Fracture permeabilities in frac_calc were old old revised to reflect the new layer

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

previous values assigned to ptn 24 were for ptn 25 & considered analogous ∴ only old ptn25 used for new ptn24

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.

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 'datablk11f' 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~~ calc_frac MC 7/21/99 \frac_calc11

SIGNATURE [signature] DATE 7/21 1999
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'
```



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```
     +    ,'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
     +    /
```



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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

- 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)~~

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

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

intarea - fracture interface area

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

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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Reran ~~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 | $5.93 \times 10^{-5}$ | $5.93 \times 10^{-5}$ |
| | Por-2D | $8.21 \times 10^{-5}$ | $8.21 \times 10^{-5}$ |
| | Por-1D | $1.40 \times 10^{-4}$ | $1.40 \times 10^{-4}$ |
| | alpha | $3.50 \times 10^{-3}$ | $3.50 \times 10^{-3}$ |
| | kzz / kxx | 1.69 | 1.69 |
| | kyy / kxx | 1.81 | 1.81 |
| | kzz / kyy | 0.93 | 0.93 |

MC 7/21/99 ~~alpha~~
MC 7/21/99 ~~salpha~~

| | Version 1.1 | | Version 1.0 | Version 1.0 headers |
|---|---|---|---|---|
| Fr-porosity | $8.21 \times 10^{-5}$ | | $8.21 \times 10^{-5}$ | Por-~~3~~2D MC 7/21/99 |
| Aperture | $5.04 \times 10^{-4}$ m | checks | 504.0 μm | Apr-um |
| Frequency | 0.28 | | 0.28 | Fq-1/m |
| Inter-Area | 0.547 | | NA | |
| Gm-length | 2.784 | | NA | |
| Fr-Alpha | $3.50 \times 10^{-3}$ | | $3.50 \times 10^{-3}$ | alpha |
| SD-Alpha | $2.41 \times 10^{-4}$ | | $2.41 \times 10^{-4}$ | 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 Reference Binder YMP-LBNL-GSB-MC-1.2A pp. 67-71. These are in d:/~~dls~~/code/calc-frac/frac-calc11/Test Case. 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 1 m excluded MC 7/21/99

$$\log[\text{gmlen}] = [\log(8) + \log(5.17) + \log(1.11) + \cancel{\log(0.43)} + \log(1.3) + \log(2.8)] / \cancel{6}\,5$$

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

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

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

frac_calc Version 1.1 gives

gmlen = 2.784 m

intarea = 0.547 m²/m³

frac_calc Version 1.1 <u>checks</u>

The code frac_calc Version 1.1 is included in Reference Binder YMP-LBNL-GSB-MC-1.24 pp. 72-87. MC 7/21/99

The file is on "nwd-cushey" in d:\code\ ~~frac-calc~~ calc_frac\ frac_calc 11.

The filenames are frac_calc11.f & frac_calc11.exe

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file names are
frac_calc11.f and
frac_calc11.exe
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.par

| 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 |

all2.par

70 7f
MC 7/22/

| 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

71 ~~70~~ mc 7/22/99

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,fmesf,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,frcp1d,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
```

```fortran
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)
```



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```
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
      intlayer = 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
        fgrp1 = fmesf + dble(k)*frint
        fsum = dble(nfrint(k))/dble(ns) + fsum
        write(12,470)fgrp1,1.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
```



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```fortran
            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
```



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```
               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
```



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```fortran
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

ATTACHMENT 4
FORM M
Software Qualification for Multi User Macro

PROCEDURE ID: YMP-LBNL-QIP-SI.0 | REV. 3, MOD. 1 | EFFECTIVE: 08/30/98

| | |
|---|---|
| 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-GSB-MC-1
YMP-LBNL-GSB-MC-1.1
YMP-LBNL-GSB-MC-1.1A (reference binder)

Page numbers where macro or changes were described and tested: mc-1 60-65, 124, 125, 137
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

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**Technical Review**

No mandatory comments, recommend acceptance.

Signature: ____________ Date: ________

Mandatory Comments—see attached DRCR form.

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

**SCM Acceptance**

Signature: Donald Mangold Date: 8/26/98

Applicable Manager's signature and date of approval

Name: [signature] Date: 8/28/98

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)

8/27/98

'd as a
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tion. Software

Macro

ECTIVE: 06/30/98

.c_calc V 1.0

ated: 8/10/98

is form.

s for UZ model
the ESF

ce binder)
C-1 60-65, 124/125, 137
C-1.1 98 101-108
C-1.1A 88-97 ← code MC 7/21/99
n testing of larger

Date: 8/10/98

-0-0-0-0-0-0-0-0-

25/98

26/98

/98

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: [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. | MC 8/25/98 | | Added ~~Dates~~ this information to scientific notebook (YMP-LBNL-GSB-MC-1.1 page 109). MC 8/25 | 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

[signature]

8/27/98

Frac-Calc.f

## Sample Input & Output for ~~Calcsl~~ 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.

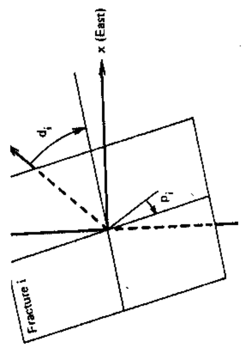



Fig. 4.8. Direction and dip of a fracture in three dimensions.

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: ~~GS9711~~ 08314224.005 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 ✓ | MinUse ✓ | 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 | 3.68 | 2.91 | .16 |

all2.par see above

| Unit | MinUse | #Frac | Fq-1/m | Apr-um ✓ | Por-3D ✓ | Por-2D ✓ | Por-1D ✓ | alpha ✓ | kzz/kxx ✓ | kyy/kxx ✓ | kzz/kyy ✓ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ptn25 | 1.00 | 5 | .28 | 504. | 5.93E-05 | 8.21E-05 | 1.40E-04 | 3.50E-03 | 1.69 | 1.81 | .93 |

calibrate.par MC 8/10/98 MC 8/10/98

| Unit | ~~Freq~~ | ~~SDFreq~~ | ~~alpha~~ | ~~sdalpha~~ | ~~loga~~ | ~~logsda~~ | ~~<loga>~~ | ~~s<loga>~~ | ~~gmFreq~~ | ~~#Frac~~ | ~~Block~~ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ptn25 | ~~.21~~ | ~~.07~~ | ~~3.85E-03~~ | ~~1.23E-04~~ | ~~-2.41~~ | ~~-3.91~~ | ~~-2.50~~ | ~~.412~~ | ~~.38~~ | ~~5~~ | ~~18.80~~ |

this portion assumed that there would be two ptn25 sections one in the north ramp and one in the South Ramp. see p 106

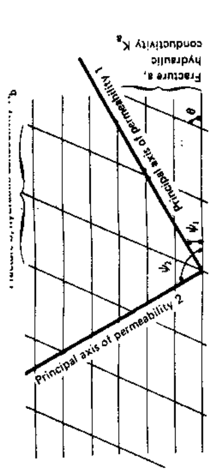



Fig. 4.7. Orientation of the principal axes of anisotropy in a fractured medium in two dimensions. [From Maini and Hocking (1977). Reproduced with permission from the Geological Society of America.]

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-~~4~~-3 MC 8/10/98 6.62 m

6-5-~~4~~ MC 8/10/98 0.21 m

average = 3.6075 m sd = 2.784 m

Frequency $\bar{F} = \frac{1}{\bar{s}} = 0.277$ /m

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

MC 9/23/99



'98

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

$I = 0.163\ m/m^2$

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

or $503.8\ \mu m$

$\log k = -11.53$ from datablk.f

(p. 96-97 in Ref Notebook YMP-LBNL-GSB-MC-1.1A)

Porosity

3D: $\phi_{3D} = \frac{\pi b \ (\sum t_i^2)/4}{(6m)(6m)(894.6-875.8)m} = 5.933 \times 10^{-\cancel{4}\ 5}$ mc 8/10/98

2D: $\phi_{2D} = bI = (5.0377 \times 10^{-4} m)(0.163 \frac{m}{m^2}) = 8.212 \times 10^{-5}$

1D: $\phi_{1D} = bf = (5.0377 \times 10^{-4} m)(0.277/m) = 1.395 \times 10^{-4}$

Alpha

$\alpha = \frac{b}{2\tau \cos(0°)} = \frac{5.0377 \times 10^{-4}\ m}{2\ (.072\ \ N/m)} = 0.003498 \ /Pa$

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 all1.par

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

see all1.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)

loga =

$\log \cancel{\%}$ sda mc =

logf :

<lo

gmF

<loga>,

<

s<

block –

kzz/kxx, k

~~$\frac{k_{zz}}{k_{xx}}$ =~~

2.8 mc 8/10/98

.17+1.11+1.3+~~0.24~~)m

94.6 − 875.8)m (6m)

s m/m²

$\left(\frac{10^{-11.53}\ m^2}{0.277/m}\right)^{1/3} = 5.0377 \times 10^{-4}\ m$

or 503.8 um

YMP-LBNL-GSB-MC-1.1A)

~~= 5.933 x 10^{-X}~~ $^{6}$ mc 8/10/98

2.163 $\frac{m}{m^2}$) = $8.212 \times 10^{-5}$

0.277/m) = $1.395 \times 10^{-4}$

$\frac{\times 10^{-4}\ m}{N/m)}$ = 0.003498 /Pa

cts 2 layers for ptn25

modification to datablk.f

te calibrate.par

see all1.par

| ga> | s<loga> | gmFreq | #Frac | Block |
|---|---|---|---|---|
| -2.54 | .344 | .48 | 5 | 18.80 |

assumes 2 degrees of freedom

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

24165 /Pa

-MC-1)

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

$\log$ ~~X~~ sda mc 8/10/98 $= \log(\sigma_a) = -3.6168$

<u>log f</u>:

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

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

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

<u>$\langle \log a \rangle$, $s\langle \log a \rangle$</u> see p124-125 in YMP-LBNL-GSB-MC-1

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

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

$= -2.537$

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

$= 0.2274$ ← assumes 3 degrees of freedom

<u>block</u> − length of block in ESF − station to station that repres stratigraphic unit

894.6m − 875.8m = 18.8 m

<u>kzz/kxx, kyy/kxx, kzz/kyy</u> (see p. 102-104, this notebook)

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

go to next page

| strike | dip | true dip | in degrees |
|---|---|---|---|
| 20° | 8° | 8° | |
| 184 | 78 | ~~78~~ mc 8/10/98 102 | |
| 299 | 78 | 78 | |
| 22 | 80 | 80 | |
| 20 | 67 | 67 | |

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

$\Sigma\left(1-\sin^2(\text{strike})\sin^2(\text{dip})\right) = \cancel{4}^{5\ mc\ 8/10/98} - \cancel{1.92875}^{0.974} = \cancel{2.07125}^{mc\ 8/10/98\ 4.026} \ \cancel{3.07125}^{mc\ 8/10/98}$

$\Sigma\left(1-\cos^2(\text{strike})\sin^2(\text{dip})\right) = \cancel{4}^{5\ mc\ 8/10/98} - 2.776 = \cancel{1.224}_{mc\ 8/10} \quad 2.224$

$\frac{k_{zz}}{k_{xx}} = \frac{\cancel{3.75}^{mc\ 4/23/99}}{\cancel{1.224}_{mc\ 8/10/98}} = \frac{3.75}{2.224} = 1.686$

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

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

All calculations in frac-calc.f check.

Mark A Cushey 8/10/98

Compiler I

The program

(p

Mark

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

75 = ~~2.07125~~ ~~3.07125~~

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

1.686

= 1.81

check.

/98



Compiler Information for Frac_Calc.f 8/25/98

The program Frac_Calc.f was compiled using

Fortran Powerstation 4.0
Microsoft 1994-1995

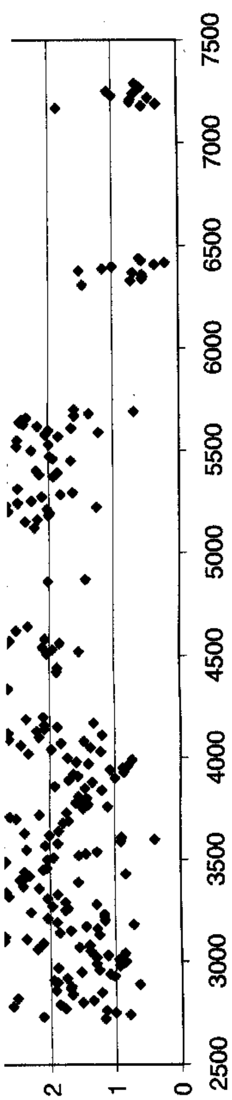
Product ID: 36785-411-0083773-30563

(part of Microsoft Developer Studio)

Mark A Carley 8/25/98

can be seen a
40+00 and 52+00.
other interval
Notebook

e.






Frac-Calc & ESF Fracture Data 8/10/98

Version 1.0
MC 7/21/99

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.

Also see p102-103 this notebook MC 8/10/98

Using dlsalcove.dat as input (see p. 54-56, this notebook), fracture properties were calculated for the model layers (see p. 64, this notebook). ~~X~~ MC 8/10 More detailed output is given in Reference Notebook YMP-LBNL-GSB-MC-1.1A p. 98-106. This gives

all1.par & all2.par → properties ~~by~~ MC 8/10 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 8/27/98

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

<u>Fracture Permeability Components Calculations</u> 8/10/98

(YMP-LBNL-GSB)

from Sonnenthal et.al. (1997) ref. on p.60 in ~~SN~~-MC-1. mc 9/3/99

page 7-21

from d

c... Cal
ra
dc

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:

b mc 8/24/98

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

part 1

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

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

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. 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 m 4/21/98) calculations the ratios $k_{zz}/k_{xx}$, $k_{yy}/k_{xx}$, & $k_{zz}/k_{yy}$. Note that the ratios are independent of k and f.

parts 3 & 4

part 5

e

c Added
k
k
k

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).

mc 8/10

lations 8/10/98

YMP-LBNL-GSB

on p. 60 in ~~SN~~-MC-1. MC 9/3/99

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

,98

(16)

assuming uniform apertures. nents of the permeability ten-

$$\begin{matrix} \text{in}2p_i\cos d_i \\ \text{in}2p_i\sin d_i \\ \sin^2 p_i \end{matrix} \Bigg] \quad (17)$$

m this matrix; however as the use our fracture permeabilities

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

from d:\code\calc_frac\frac_calc.f

part 1

part 2

parts 3 & 4

part 5

```
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)*frac
        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)
```

aper MC 8/24/98

but does not effect ratios since it cancels out

8/24/98

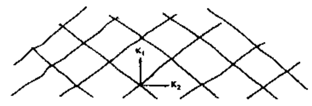



Fig. 4.6. Principal axes of anisotropy of a fractured medium.

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:

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

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

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, Feuga (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

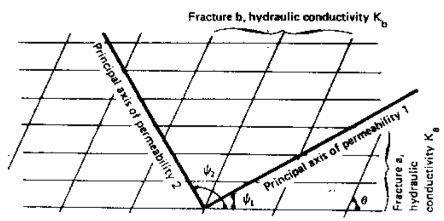



Fig. 4.7. Orientation of the principal axes of anisotropy in a fractured medium in two dimensions. [From Maini and Hocking (1977). Reproduced with permission from the Geological Society of America.]



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 **K** has been determined, the principal axes of anisotropy and the diagonal components of **K** in these directions can be determined by calculating the eigenvalues and the eigenvectors of the matrix **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 $K_f$ 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

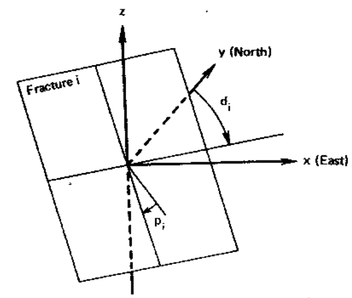



Fig. 4.8. Direction and dip of a fracture in three dimensions.

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

Mark A. Cirby 8/10/98

Sample

Below are

✓ → indica

Sample input data f

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
ptn25 875.80 894.60

all2.par see above

Unit MinUse #Frac Fq-1
ptn25 1.00 5

calibrate.par

MC 8

Unit ~~Freq~~ ~~SDFreq~~
ptn25 .21 .07 3.

Calculations bel

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

this portion assumed that there would be two ptn25 sections one in the north ramp and one in the South Ramp. see p 106

so #1

Spacing

exclude 4

Frequen

PROJECT NAME ______ NOTEBOOK NO. Mc-1

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.

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*, edited by G.S. Bodvarsson, T.M. Bandurraga, and Y.S. Wu. Yucca Mountain Site Characterization Yucca Mountain Project Level 4 Milestone SP24UFM4; Report LBNL-40376. Berkeley, California: Lawrence Berkeley National Laboratory. LB970601233129.001 (Q).

ref MC 7/1/98

I started with the code from E. Sonnenthal. It is located on hydra.lbl.gov in the directory

/m/ultra~~2~~1/u/esonn/ymp/~~bin~~/src MC 8/25/98

The name of the code is cnvfr2.f

The original data analyzed (which only is up to station 40+00) was in the file

~~/ymp/fractures/esf/frcpar.dat

and

~~/ymp/fractures/esf/station.dat

~~these data were~~ only used for testing code results and were not used for YMP Q-work MC 6/28/99

All changes to the code are indicated with my initials (MAC) and ~~x~~ 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/

This code differs in that MC 8/25/98 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

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

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

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

where $\alpha$ - van Genuchten $\alpha$ for fractures
$b$ - aperture
$\tau$ - surface tension of pure water at 20°C (0.072 N/m)
$\theta$ - contact angle (assumed to be 0)

This calculation was not previously in the code

porosities:

$$\phi_{1D} = f\,b$$

$$\phi_{2D} = \frac{b \sum_{i=1}^{nf} t_i}{\text{area}} = \frac{b \sum_{i=1}^{nf} t_i}{(6m)\ \text{blocklength}}$$

$$\phi_{3D} = \frac{\pi b \sum_{i=1}^{nf} r_i^2}{\text{volume}} = \frac{\pi\, b \sum_{i=1}^{nf} r_i^2}{(6m)(6m)\ \text{blocklength}}$$

$t_i$ - 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.

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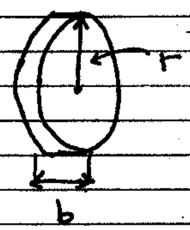


volume in 3D = $b \pi r^2$

The probability that the tunnel cut intersects these disks off center 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 ~~■~~ $\phi_{3D}$ may under estimate porosity since it assumes fracture traces represent fracture diameters

The $\phi_{1D}$ may over estimate 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 $\alpha$ & $\beta$ for use in unsaturated flow modeling Sandia National Laboratory
DTN SNT05091597001.003
TDIF 306502
November 25, 1997.

SIGNATURE [signature] DATE 4/17 1998
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TDB- fracture properties - verification of code 4/24/98

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 d:/code/

This data was transformed to a readable (numeric) format (convert station numbers to lengths) and stored in ericdls.dat in d:/code/calc-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 denominater is the number of pairs of fractures used to calculated the $\bar{s}_{comb}$.

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$$\bar{f}_{comb} = \frac{1}{\bar{s}_{comb}}$$

$$b_{comb} = \left(\frac{12\,k}{\bar{f}_{comb}}\right)^{\frac{1}{3}}$$

$$\phi_{3D} = \frac{\pi\, b_{comb} \sum_{j=1}^{ns} \sum_{i=1}^{nf_j} r_{i,j}^2}{(6m)(6m) \sum_{j=1}^{ns} \text{blocklength}_j}$$

$$\phi_{2D} = \frac{b_{comb} \sum_{j=1}^{ns} \sum_{i=1}^{nf_j} t_{i,j}}{(6m) \sum_{j=1}^{ns} \text{blocklength}_j}$$

$$\phi_{1D} = b_{comb}\, f_{comb}$$

The alternative would be to calculate 2/4/98 each parameter for each sublayer and then ~~[illegible]~~ ML 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 arbritrary 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 0 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<br>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~~ 82 QHu 9/7/99 | check the source code file, there should have more codes to be printed out following p.82 | | | source code continues onto pp. 83-87 | | |
| 3(NM) | 108 | cross-out = 3.75 | | | Crossed-out 3.75 & initialed & dated | | |
| | | comments only: * check the file locations & contents of FRAC_calc11.f, test, all1.par, all2.par; no anomaly. | | spot | * check the calculation of lower half on p.105 do not notice any mistake | | |

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 |
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# 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.

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

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

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PROJECT NAME

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 but 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 [signature] DATE 4/13 1998
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see p87 reviewed by F. Ahlers MC 7/1/98

see p.52 and p.58 for initial development & planning of this code MC 6/28/99

This code is a single user macro MC 3/31/99

```
      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     ----------------------------------------
```

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```
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 [signature] 7/1/98

SIGNATURE [signature] DATE 5/7 1998
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 1999
READ AND UNDERSTOOD DATE 19

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 TXT
output file → FRAC DAT

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 ___

PROJECT NAME ________________ NOTEBOOK NO. ____

```
      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 1999

READ AND UNDERSTOOD ________________ DATE ______ 19 ____

Files used in chocking 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 |

test.dat

TECTONIC CHARACTERISTICS DATA REPORT

View Unit Descriptions

Start of Report...


Reading report specifications and preparing query . . .
Retrieving data . . .

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; IN-Fracture extends under precast invert segments; Air-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 TRACELINE (m) | LENGTH BELOW TRACELINE (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+91.87 | 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 |

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|---|---|---|---|---|---|
| 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 | T | 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+02.58, 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
0.25m 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 10mm (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: C Ahlers 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) Mark Cushey for G.S. 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 |