Unsaturated Fractured Rock Characterization Methods and Data Sets at the Apache Leap Tuff Site

NUREG/CR--5596

TI90 016722

Manuscript Completed: June 1990
Date Published: August 1990

Prepared by
T. C. Rasmussen, D. D. Evans, P. J. Sheets, J. H. Blanford

Department of Hydrology and Water Resources
College of Engineering and Mines
University of Arizona
Tucson, AZ 85721

Prepared for
Division of Engineering
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC FIN D1662

MASTER

OTHER REPORTS IN THIS SERIES

- Evans, D.D., 1983, Unsaturated Flow and Transport Through Fractured Rock - Related to High-Level Waste Repositories, NUREG/CR-3206, 231 pp.
- Schrauf, T.W. and D.D. Evans, 1984, Relationship Between the Gas Conductivity and Geometry of a Natural Fracture, NUREG/CR-3680, 131 pp.
- Huang, C. and D.D. Evans, 1985, A 3-Dimensional Computer Model to Simulate Fluid Flow and Contaminant Transport Through a Rock Fracture System, NUREG/CR-4042, 109 pp.
- Green, R.T. and D.D. Evans, 1987, Radionuclide Transport as Vapor Through Unsaturated Fractured Rock, NUREG-CR-4654, 163 pp.
- Rasmussen, T.C. and D.D. Evans, 1987, Unsaturated Flow and Transport Through Fractured Rock - Related to High-Level Waste Repositories, NUREG/CR-4655, 474 pp.
- Yeh, T.C.J., T.C. Rasmussen and D.D. Evans, 1988, Simulation of Liquid and Vapor Movement in Unsaturated Fractured Rock at the Apache Leap Tuff Site: Models and Strategies, NUREG/CR-5097, 73 pp.
- Weber, D.S. and D.D. Evans, 1988, Stable Isotopes of Authigenic Minerals in Variably-Saturated Fractured Tuff, NUREG/CR-5255, 70 pp.
- Rasmussen, T.C. and D.D. Evans, 1989, Fluid Flow and Solute Transport Modeling Through Three-Dimensional Networks of Variably Saturated Discrete Fractures, NUREG/CR-5239, 193 pp.
- Chuang, Y., W.R. Haldeman, T.C. Rasmussen, and D.D. Evans, 1990, Laboratory Analysis of Fluid Flow and Solute Transport Through a Variably Saturated Fracture Embedded in Porous Tuff, NUREG/CR-5482, 328 pp.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

Performance assessment of high-level nuclear waste containment feasibility requires representative values of parameters as input, including parameter moments, distributional characteristics, and covariance structures between parameters. To meet this need, characterization methods and data sets for interstitial, hydraulic, pneumatic and thermal parameters for a slightly welded fractured tuff at the Apache Leap Tuff Site situated in central Arizona are reported in this document. The data sets include the influence of matric suction on measured parameters. Spatial variability is investigated by sampling along nine boreholes at regular distances. Laboratory parameter estimates for 105 core segments are provided, as well as field estimates centered on the intervals where the core segments were collected. Measurement uncertainty is estimated by repetitively testing control samples.

TABLE OF CONTENTS

	<u>Page</u>
0. Executive Summary	xiii
1. Introduction	1
1.1 Objective	1
1.2 Field Site Description	2
2. Interstitial Characterization Parameters	9
2.1 Matrix Interstitial Properties	9
2.1.1 Bulk Density	9
2.1.2 Effective Porosity	10
2.1.3 Skeletal Density	12
2.1.4 Pore Surface Area	13
2.1.5 Pore Size Distribution	14
2.2 Fracture Interstitial Properties	16
2.2.1 Location	16
2.2.2 Density and Spacing	16
2.2.3 Orientation	17
3. Hydraulic Characterization Parameters	19
3.1 Matrix Hydraulic Properties	19
3.1.1 Saturated Hydraulic Conductivity.	19
3.1.2 Moisture Characteristic Curve	20
3.1.3 Unsaturated Hydraulic Conductivity	24
3.2 Field Hydraulic Properties	26
3.2.1 Field Hydraulic Conductivity	26
3.2.2 Field Water Content	27
4. Pneumatic Characterization Parameters	33
4.1 Matrix Pneumatic Permeability	33
4.2 Field Pneumatic Properties	35
5. Thermal Characterization Parameters	38
5.1 Matrix Thermal Properties	38
5.2 Field Thermal Properties	41
6. Quantification of Parameter Uncertainties	42
7. Summary	47
8. References	48
A. Appendix	50

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1 Site location map for the Apache Leap Tuff Site in central Arizona.	3
2 Aerial view of ALTS and surrounding terrain showing extensive fracture network.	4
3 Borehole configuration showing inclined boreholes and 30 m by 50 m plastic cover.	6
4 Core sample locations with associated two letter identification label.	7
5 Diagram of three borehole core segments and uses.	8
6 Permeameter used to obtain saturated hydraulic conductivity for large core segments.	21
7 Laboratory apparatus for obtaining unsaturated hydraulic conductivity using the outflow method.	25
8 Location of neutron water content calibration boreholes.	29
9 Diagram of field single hole air injection experiment.	37
10 Apparatus used to estimate water content dependent thermal properties.	39

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1 Summary of bulk density values obtained from core segments at the Apache Leap Tuff Site.	10
2 Summary of effective porosity values obtained from core segments at the Apache Leap Tuff Site.	11
3 Summary of skeletal density values obtained from core segments at the Apache Leap Tuff Site.	12
4 Summary of pore area values obtained from medium core segments at the Apache Leap Tuff Site.	14
5 Summary of cumulative intrusion volume as a function of equivalent pore diameter obtained from medium core segments at the Apache Leap Tuff Site.	15
6 Summary of fracture density and orientation obtained from borehole cores at the Apache Leap Tuff Site.	17
7 Summary of saturated hydraulic conductivity values obtained from large core segments at the Apache Leap Tuff Site.	20
8 Summary of laboratory moisture characteristic curve values obtained from pressure extraction vessel and Tempe Pressure Cells using large core segments and from thermocouple psychrometer data using small core segments at the Apache Leap Tuff Site. Mean wetting curves for 10 large core segments are also presented. Also shown are summary statistics for Van Genuchten moisture characteristic curve function.	23
9 Summary of unsaturated hydraulic conductivity values obtained from large core segments at the Apache Leap Tuff Site.	24
10 Summary of field determined outflow rates and saturated hydraulic conductivity values at the Apache Leap Tuff Site.	27
11 Observed neutron counts with depth at two calibration bore holes, Apache Leap Tuff Site.	30
12 Results for neutron calibration borehole tests, Apache Leap Tuff Site.	30
13 Field water contents for various dates at the Apache Leap Tuff Site.	32

LIST OF TABLES (Continued)

<u>Table</u>	<u>Page</u>
14 Summary of laboratory air permeabilities.	34
15 Summary of laboratory determined Klinkenberg slip flow coefficient.	35
16 Summary of field determined air permeability.	36
17 Summary of laboratory thermal conductivity.	40
18 Oven dry air permeability for parameter variation estimation.	43
19 Saturated hydraulic permeability for parameter variation estimation.	44
20 Moisture characteristic curves for parameter variation estimation.	45
21 Unsaturated hydraulic conductivity values for parameter variation estimation.	46
A1 Local coordinates in meters of borehole casing lip, ground surface and borehole bottom at the Apache Leap Tuff Site.	50
A2 Local coordinates in meters of borehole sample locations at the Apache Leap Tuff Site.	51
A3 Bulk and skeletal densities for three core segment sizes.	52
A4 Effective porosity for three core segment sizes and pore area values for small core segment sizes at 105 locations at the Apache Leap Tuff Site.	55
A5a Equivalent pore diameters (in micrometers) for mercury intrusion injection pressures.	58
A5b Cumulative volumetric porosity determined from mercury intrusion volumes for 105 medium core segments.	69
A6 Fracture geometric information obtained from oriented drill core.	80

LIST OF TABLES (Continued)

<u>Table</u>	<u>Page</u>
A7 Fracture density values obtained from borehole cores at the Apache Leap Tuff Site.	84
A8 Saturated hydraulic conductivity (Ksat) obtained from 105 large core segments at the Apache Leap Tuff Site.	85
A9a Laboratory moisture characteristic curves for 105 large core segments as a function of matric suction using pressure extractor.	86
A9b Laboratory moisture characteristic curves for 105 small segments using themocouple psychrometer device.	89
A9c Laboratory moisture characteristic curves for 105 large core segments as a function of matric suction using Tempe Pressure cells.	95
A9d Laboratory moisture characteristic curves for 10 large core segments as a function of matric suction for wetting phase.	98
A9e Van Genuchten moisture characteristic curve function parameters. Least squares estimate using relative saturation objective function and a constant n-value for all samples. Optimal parameter estimates obtained when residual saturation is zero and when the n-parameter is equal to 1.26.	99
A10 Laboratory determined unsaturated hydraulic conductivity values for large core segments obtained using outflow method.	100
A11 Field determined saturated hydraulic conductivity values at the Apache Leap Tuff Site using three methods: (1) Philip, (2) Glover, and (3) Dachler.	103
A12 Outflow rates during borehole flooding experiments.	106
A13 Field volumetric water content in percent determined from neutron count data.	110
A14 Laboratory unsaturated air permeability.	113
A15 Klinkenberg coefficients obtained from laboratory air/water permeability ratios for 105 large core segments.	116

LIST OF TABLES (Continued)

<u>Table</u>		<u>Page</u>
A16	Field observed flow rates and interpreted air permeability.	117
A17	Laboratory-estimated thermal conductivity and dry rock specific heat for saturated, variably saturated and oven-dried large core segments.	122
A18	Field observed temperatures in Borehole Y3.	125

ACKNOWLEDGEMENTS

Professor Daniel D. Evans was responsible for project management and supervision. Dr. Todd C. Rasmussen assisted in project management and was responsible for the preparation of this manuscript. Priscilla Sheets performed much of the laboratory analysis, with contributions by Gerald Vogt for the mercury intrusion analysis and Guo Zede for the design of the thermal properties procedure. Jim Blanford was responsible for much of the field testing program, with contributions by Vince Tidwell. This research was funded by the US Nuclear Regulatory Commission (USNRC) under contract number NRC-04-86-114. The USNRC project monitor was Thomas J. Nicholson. Additional funding was provided by the Center for Nuclear Waste Regulatory Analysis (CNWRA) under subcontract number 65626. The CNWRA project monitor was Dr. John Russell.

EXECUTIVE SUMMARY

The feasibility of long-term containment of radioactive and toxic wastes in geologic media is the concern of regulatory agencies empowered with the responsibility of assuring the continued health and safety of the public. In particular, the U.S. Nuclear Regulatory Commission (USNRC) has promulgated regulations which require that high-level nuclear wastes (HLW), consisting chiefly of spent fuel from nuclear reactors, be stored in a safe manner. The feasibility of HLW storage in unsaturated fractured rock remains uncertain, and data bases which can be used to determine the feasibility of long-term containment are lacking.

In 1986, USNRC funded a field and laboratory program (Contract NRC-04-86-114, FIN D1662) whose purpose was to provide data sets related to the interstitial, hydraulic, pneumatic and thermal properties of unsaturated fractured rock. The purpose of these data sets was to provide USNRC with estimates of parameter uncertainties related to measurement errors and geologic variability. Task 1 of the program was to determine the important contributors to measurement errors and uncertainties associated with hydrologic instrumentation and measurement in the unsaturated zone. An additional purpose of the data sets will be the application to the INTRAVAL program to evaluate numerical models of flow and transport in unsaturated fractured rock systems.

To meet the needs specified by USNRC, a field site in unsaturated fractured tuff near the town of Superior in central Arizona, termed the Apache Leap Tuff Site (ALTS), was selected for acquiring characterization data sets. Boreholes were drilled at ALTS to a maximum depth of 30 m and at a vertical angle of 45° for the purpose of intersecting vertical fractures at the site. Over 270 m of oriented core were collected from the nine boreholes. Characterization parameters for core segments of three sizes collected at approximately three meter intervals have been estimated for 105 samples. The three core segments sizes are:

- 1 cm long by 1 cm in diameter;
- 2.5 cm long by 2.5 cm in diameter; and
- 5 cm long by 6 cm in diameter.

Field parameters are obtained at the same three meter interval centered on the position where the core segments were collected. Data obtained from field and laboratory tests are of the following types:

- Rock matrix interstitial properties, consisting of bulk and skeletal densities, effective porosity, pore surface area, and pore size distributions collected from the core segments;
- Rock fracture interstitial properties, consisting of fracture location, density, and orientation, collected from oriented cores;
- Rock matrix hydraulic properties, consisting of the laboratory saturated hydraulic conductivity, moisture characteristic curves, and unsaturated

hydraulic conductivity curves collected from core segments, as well as field saturated hydraulic conductivity determined from borehole interval testing.

- Time series of field borehole water contents derived from neutron count measurements;
- Water content dependent pneumatic permeability of unfractured rock cores for a range of water contents, as well as the air permeability of fractured rock at ambient water contents at the ALTS; and
- Water content dependent thermal conductivity and specific heat of unfractured rock core segments.

Summary statistical data are presented for the parameters, including the mean, coefficient of variation, minimum, median and maximum values. The data were collected either from 105 core segments located at approximately three meter intervals, or from borehole test intervals which test three meter intervals coincident with the core segment locations.

For the 105 samples tested, bulk densities of the largest segments lie between 1.86 and 2.20 Mg/m³, with an arithmetic average of 2.10 Mg/m³ and a coefficient of variation of 3%. The effective porosity of the largest segments ranges between 14.30 and 27.51 percent volumetric, with a mean of 17.54 percent and a variation of 13%. Mean skeletal density is 2.55 Mg/m³ with a variation of 2%. Mean pore area of the medium sized segments is 3.466 m²/gm with a variation of 65%. For the 105 borehole intervals examined, the fracture density ranged from 0 to 4.33 fractures per meter, with a mean of 0.77 and a coefficient of variation of 108%.

The relative saturation of rock core segments decreases from a mean of 95.5 percent at 10 kPa, to 70.2 percent at 100 kPa, to 47.5 percent at 1000 kPa, to 22.2 percent at 10,000 kPa, to 12.8 % at 100,000 kPa. Results of hydraulic testing of core segments indicate a mean saturated hydraulic conductivity of 21.31×10^{-9} m/s with a coefficient of variation of 301% and a range of approximately three orders of magnitude. The unsaturated hydraulic conductivity means at 10, 25, 50 and 100 kPa are 3.346, 1.475, 0.908, and 0.364×10^{-9} m/s. Field estimates of saturated hydraulic conductivity range from a mean of 29.19 to 59.42×10^{-9} m/s depending upon the method used to interpret the field tests. The variation of the field estimate is approximately 700% and ranges over five orders of magnitude. Field water contents are estimated using neutron count data calibrated in the field at two locations with different water contents. Field volumetric water contents range from a low of 9.53 percent to a high of 18.75 percent on different dates.

Data sets for core segments yield an oven-dried air permeability of 57.12×10^{-16} m², decreasing to half that value at approximately 100 kPa. The laboratory air permeability also displays great variability, ranging over three orders of magnitude with a coefficient of variation of 272%. A difference between air and water permeability is explained by the Klinkenberg effect. Measured field air permeabilities are generally less than oven-dried core segments.

A mean saturated thermal conductivity of $1.821 \text{ J/ms}^\circ\text{C}$ is observed for large core segments, with a coefficient of variation of 10.7%. The mean thermal conductivity for oven-dried samples is $1.266 \text{ J/ms}^\circ\text{C}$, with a coefficient of variation of 11.5%. For the thermal conductivity parameter, the influence of relative saturation is substantially less than for the hydraulic conductivity. A thermal conductivity of $1.95 \text{ J/ms}^\circ\text{C}$ and a heat capacity of $2.4 \times 10^6 \text{ J/m}^3^\circ\text{C}$ provide a good fit to field observations of thermal responses to an annual thermal cycle.

Characterization parameters demonstrate substantial spatial variability, with some parameters evidencing variations over many orders of magnitude. In particular, the saturated and unsaturated hydraulic conductivities and the air permeability parameters range over at least three orders of magnitude. Other parameters have less significant variation, such as the bulk density and thermal conductivity which range over just ten percent of the mean.

1. Introduction

A program to characterize fluid flow and solute transport in unsaturated fractured rock related to high-level waste repositories is being conducted by the University of Arizona, Department of Hydrology and Water Resources under the sponsorship of the U.S. Nuclear Regulatory Commission (USNRC). The activities are conducted in support of USNRC's licensing actions with respect to the site characterization program conducted by the U.S. Department of Energy at the candidate high level repository site at Yucca Mountain, Nevada. Characterization is being performed with respect to the fluid, heat, and solute transport properties of fractured tuffaceous rock.

An earlier document (Yeh et al., 1988) described proposed simulation models and modeling strategies to be used for investigating liquid and vapor movement in unsaturated fractured rock. Other documents (Evans, 1983; Rasmussen and Evans, 1987) which focused on characterization methods for unsaturated fractured rock contain additional details regarding characterization strategies. This document focuses on other aspects of the characterization process for use in parameterizing, calibrating and validating models of fluid, heat and solute transport;

- Procedures necessary for obtaining characterization data sets;
- Representative data sets for the Apache Leap site; and
- Limited interpretations based on gathered data sets.

Characterization methods for interstitial, hydraulic, pneumatic, and thermal properties under conditions of variable saturation in both the rock matrix and embedded fractures are presented using laboratory and field techniques. This report summarizes the properties for a regular sampling grid of 105 points, both in the laboratory for core segments, and in the field for corresponding intervals. A description of the field test site where the samples were collected and the intervals were tested is presented in this chapter. The second chapter describes the interstitial properties of the matrix and fractures. Chapter three presents the hydraulic properties, while chapters four and five present the pneumatic and thermal properties, respectively. Chapter six presents data summarizing the precision of the laboratory testing techniques employed.

1.1 Objective

One objective of the characterization process is to understand the mechanisms which govern solute and contaminant transport through unsaturated fractured rock. The objective of this document is to provide data sets suitable for the characterization of the interstitial, hydraulic, pneumatic and thermal properties of unsaturated fractured rock at a field site located in tuff. By quantifying these properties, analytic and numeric models can be employed to forecast solute transport behavior.

1.2 Field Site Description

To meet the objectives of the research program, a field site has been selected in unsaturated fractured tuff. The field site, named the Apache Leap Tuff Site (ALTS) is located near Superior, Arizona, approximately 160 km north of Tucson, Arizona, (Figure 1). ALTS lies in the uppermost part of an approximately 20 m.y. old tuff formation which varies from a slightly welded unit on top (where the Apache Leap site is situated) through a moderately welded unit below, to a densely welded unit near the base of the formation. The base of the unit is composed of a non-welded unit underlying a vitrophyre. The entire formation was originally 600 m thick on average, but has weathered to an average thickness of approximately 150 m (Peterson, 1961, 1968).

An aerial view of the Apache Leap site is shown in Figure 2. The exposed rock at the site is the uppermost unit of a sequence of ash-flow tuff sheets. At the site, the tuff is over 300 m thick and grades from densely welded near the bottom to slightly welded at the top with the different units dipping to the east. In addition to the volcanic groundmass, the tuff contains various mixtures of phenocrysts, pumice fragments, and entrained foreign rocks. Peterson (1968) gives a detailed description of the origin and spatial characteristics of the tuff, which covers an area of 1000 km² and has a maximum depth of 600 m. About one kilometer to the west of the Apache Leap site is a 600-m escarpment and immediately to the north there is a 200-m drop-off. The rest of the surface is dissected by ephemeral streams. The topography of the experimental area is nearly level compared to the surroundings.

Linear fracture traces are evident in Figure 2 with some extending through the study site. A slight depression with a thin layer of unconsolidated material and sparse vegetation normally occurs along surface fracture traces. These conditions provide an important water reservoir for water intake by the fractures (Yeh et al., 1988). The annual average precipitation at the 1200-m elevation site is approximately 640 mm. The precipitation occurs in two seasons, from mid-July to late-September (characterized by high-intensity, short-duration thunderstorms during periods of high temperature and evapotranspiration demand), and from mid-November to late-March (characterized by longer duration and lower intensity storms during cooler periods with much lower evapotranspiration demands) (Yeh et al., 1988). The regional ground-water level has been lowered by mine dewatering operations to a depth of over 1500 m below surface.

To obtain parameters for the rock matrix and the fractures at the site, three sets (named X-, Y-, and Z-series) of three boreholes (named 1, 2, and 3) each were installed with each borehole at a 45° angle from the horizontal. A diamond bit drill was used for installing the boreholes. The drill was also used to cut a 6.35-cm diameter core. A specially designed scribing technique provided an orientation mark every 1.52 or 3.05 m along the borehole. Nearly 100 percent core orientation for all boreholes was obtained by using the scribe marks. Approximately 270 m of oriented core were obtained.

Figure 1: Site location map for the Apache Leap Tuff Site in central Arizona.

Figure 2: Aerial view of ALTS and surrounding terrain showing extensive fracture network.

The 10-cm diameter boreholes of each set are in a vertical plane and offset by 10 m as shown in Figure 3. The sets are parallel and offset by 5 m. Sets X and Y dip to the west while set Z dips to the east. The variable lengths, approximately 15, 30 and 45 m, provide fracture-borehole intersections for individual fractures at different depths below the surface. The double letter designations in Figure 4 indicate common core sampling and field measurement locations.

Characterization data sets for the tuff matrix were obtained from the oriented cores using sections cut from the core at approximately three meter increments. Three segments are removed from each section, as indicated in Figure 5. The segments are labeled 'large' (5 cm long by 6 cm diameter), 'medium' (2.5 cm long by 2.5 cm diameter) and 'small' (1 cm long by 1 cm diameter) to differentiate between the three segments. Table A1 in the appendix presents geometric relationships between the boreholes and a local coordinate system, while Table A2 presents the estimated (x,y,z) coordinates for each of the samples. All coordinates are local to the site, with the base elevation arbitrarily set to the elevation of the lip of the casing of Borehole X1.

The nine boreholes provide ready access for various in situ measurements while the cores provide information on fracture spacing and orientation as well as samples for measuring matrix properties in the laboratory. To control water inputs (e.g., precipitation) and outputs (e.g., evaporation) at the test area, the area was covered with plastic to a distance of 10 m in all directions beyond the boreholes for a total area of 1500 m². Surface water is directed away from the site to prevent wetting of the region around the boreholes.

PLAN VIEW

PROFILE VIEW

Figure 3: Borehole configuration showing inclined boreholes and 30 m x 50 m plastic cover.

*APACHE LEAP TUFF SITE
CORE SAMPLE LOCATIONS*

Figure 4: Core sample locations with associated two letter identification label.

Figure 5: Diagram of three borehole core segments and uses.

2. Interstitial Characterization Parameters

Characterization of the rock interstitial properties is performed using oriented cores obtained during borehole drilling. The cores were extracted during the drilling of the 10 cm diameter boreholes, and measure 6.34 cm in diameter for the X-boreholes, and 6.08 cm in diameter for the Y- and Z-boreholes. Approximately 270 m of core were obtained from the nine boreholes. Properties of the rock matrix were obtained using a regular sampling system, while fracture parameters were obtained by performing an inventory of all apparent fissures observed in the cores. A description of the matrix and fracture parameters follows, along with data sets and the procedures employed to collect the data.

2.1 Matrix Interstitial Properties

Interstitial properties of the rock matrix are obtained at 105 sample locations using rock core samples of the three segment sizes described above. The measured interstitial properties of the core segments include the bulk density, skeletal density, effective porosity, and pore area. The pore area is available only for the medium segment, while the other properties are reported for the three segment sizes.

2.1.1 Bulk Density

The bulk density is the dry rock mass per unit volume, determined by oven drying the rock sample at 105°C until a constant mass is obtained, weighing the rock segment to determine its mass, and then measuring the dimensions of the segment for computing its volume if it is a regular solid:

$$(1) \quad \rho_b = M_d / V$$

where

ρ_b segment bulk density, Mg/m³;
 M_d segment dry mass, Mg; and
 V segment volume, m³.

For segments that are not regular, the volume is determined using Archimedes' principle:

$$(2) \quad V = M_t / \rho_w$$

where

M_t tare mass of sample suspended under water with respect to initial mass of water, kg; and
 ρ_w density of water, Mg/m³.

The tare mass of the suspended segment is determined by first saturating the segment by placing the segment in a vacuum chamber for a day and then introducing a sterile, 0.001 M CaSO₄ solution of previously deionized water into the chamber (which is still under a vacuum) and allowing the segment

to remain immersed for another day. Biological activity is prevented by adding thymol to the water. The segment is then removed from the chamber, blotted so that no free water coats the surface of the sample, suspended by a fine wire and immersed in a beaker of water which has been previously tared to zero. If significant, the mass of the fine wire can be subtracted from the tare mass by noting the depth of immersion of the fine wire and measuring the tare mass of the wire without the segment.

Equations (1) and (2) are used to determine the bulk density of the large and small segments. The bulk density of the medium segment was determined using the mercury intrusion method, which takes advantage of the nonwetting property of mercury. A rock segment with a known dry mass is placed inside a chamber of known volume and the mass of mercury needed to fill the chamber is measured. The volume of the rock segment is calculated by subtracting the volume of intruded mercury (equal to the mass of the mercury intruded divided by the density of mercury) from the volume of the chamber. Equation (1) is used to find bulk density.

Table 1 summarizes bulk density data for all 105 samples and for all three segments. Table A3 presents bulk density data at each location within each borehole. Only moderate dispersion about the mean is evident, equal to approximately three percent of the mean value of 2.10 Mg/m³ for the large segment. The range of values shown in Table 1 varies with the segment size, and is between 1.75 and 2.25 Mg/m³. A substantial skew in the data is not evident, as noted by the similarity between the mean and median values in Table 1. The bulk density data for the small segment is generally less than for the other segments.

Table 1: Summary of bulk density values obtained from core segments at the Apache Leap Tuff Site.

	BULK DENSITY (Mg/m ³)		
	small	medium	large
Mean	1.99	2.13	2.10
Coef. Var.	4 %	3 %	3 %
Minimum	1.75	1.94	1.86
Median	2.00	2.14	2.12
Maximum	2.17	2.25	2.20

2.1.2 Effective Porosity

The effective porosity of the rock matrix is the volume of interconnected voids per unit volume of rock, exclusive of any isolated pores or large openings, such as fractures and sizable solution openings. The effective

porosity is measured for the small and large segments by determining the difference in mass between a saturated segment and an oven-dried segment. The difference in mass is divided by the density of water and the volume of the segment, or:

$$(3) \quad n_e = (M_s - M_d) / \rho_w V$$

where

n_e effective porosity, m^3/m^3 ; and
 M_s mass of saturated rock segment, kg.

For the medium segments, mercury is forced under pressure into the segment. The effective porosity is calculated by measuring the volume of mercury intruded into the sample and dividing by the volume of the sample and the density of mercury. The mercury intrusion method will underestimate the effective porosity because the volume of mercury intruded at the maximum pressure is less than the volume of water intruded due to the nonwetting property of mercury. Using capillary theory, rock pores and crevices with curvatures corresponding to a diameter of less than approximately 6 nm will not be intruded with mercury for the experimental equipment we used.

Table 2 presents a summary of effective porosity data for all three segments at all 105 sample locations, while Table A4 presents effective porosity data for each segment. The mean effective porosity varies from 14.62 to 17.50 percent, depending upon the method of analysis, with the mercury intrusion method consistently underestimating the porosity due to the non-wetting property of mercury. The variability using both methods is greater than the estimated bulk density, with the coefficient of variation ranging from 13 to 26 percent of the mean value. The range is also large, 11 to 25 percent for the small, 9 to 48 percent for the medium segment, and 14 to 28 percent for the large segment.

Table 2: Summary of effective porosity values obtained from core segments at the Apache Leap Tuff Site. Medium segment obtained using mercury intrusion method which underestimates effective porosity.

	EFFECTIVE POROSITY (%)		
	small	medium	large
Mean	17.15	14.62	17.54
Coef. Var.	16 %	26 %	13 %
Minimum	11.02	9.18	14.30
Median	16.52	14.31	17.21
Maximum	24.73	47.58	27.51

2.1.3 Skeletal Density

Skeletal density, ρ_s , is a measure of the density of the rock matrix, expressed in units of Mg/m^3 . The skeletal density is determined from the bulk density in conjunction with the effective porosity, according to the expression:

$$(4) \quad \rho_s = \rho_b / (1 - n_e)$$

The estimated skeletal density will underestimate the true density due to the inclusion of isolated pores within the matrix. If the total porosity of the sample were available, then a more accurate estimate of the skeletal density would be possible. In spite of this bias, skeletal densities have been computed using data in Tables A3 and A4 for the three segments at all 105 core locations, and are reported in Tables 3 and A3, for summaries and individual measurements, respectively.

The mean skeletal density reported by Peterson (1961) is 2.53 Mg/m^3 for the Apache Leap tuff samples he examined which compares favorably to the observed mean values of 2.50 to 2.55 Mg/m^3 obtained using the medium and large segments, but compares poorly to the mean value of 2.40 Mg/m^3 obtained using the small segments. The low value obtained from the small segment could possibly be attributed to the presence of unconnected microfractures induced during drilling. The variation in the skeletal density is low, from two to seven percent depending on the method used, with a range from 2.21 to 2.68 Mg/m^3 excluding one anomaly.

Table 3: Summary of skeletal density values obtained from core segments at the Apache Leap Tuff Site.

	SKELETAL DENSITY (Mg/m^3)		
	small	medium	large
Mean	2.40	2.51	2.55
Coef. Var.	3 %	7 %	2 %
Minimum	2.23	2.21	2.34
Median	2.41	2.51	2.55
Maximum	2.53	4.11	2.68

2.1.4 Pore Surface Area

The pore surface area is the interfacial area between the wetting fluid and the rock matrix, obtained using the mercury intrusion method. The medium sized segment is placed inside a penetrometer, which is then evacuated and filled with mercury. The volume of mercury added is measured gravimetrically and the volume of the sample is determined by subtracting the volume of mercury from the volume of the penetrometer. Mercury is then intruded under pressures up to 175 MPa in predetermined increments. The volume of intruded mercury at each pressure increment is determined by measuring the change in electrical capacitance of mercury in a fill tube. The applied pressure is used to determine a pore diameter using capillary theory (Micromeritics, 1986):

$$(5) \quad d = 4 \tau \cos(\alpha) / P$$

where

- d equivalent pore diameter, m;
- τ surface tension of mercury, approximately 0.485 Pa m;
- α contact angle of mercury, assumed equal to 130°; and
- P applied pressure, Pa.

The surface area for each increment of intruded volume is calculated by noting that the total work expended per unit area of surface covered during a pressure step is equal to (Micromeritics, 1986):

$$(6) \quad dW/dA = \tau \cos(\alpha)$$

where W is work, J, and A is area, m². The amount of work expended to cover pore surfaces is calculated using:

$$(7) \quad dW = W_f - W_i = P_f(V_f - V_o) - P_i(V_i - V_o) = P_f(V_f - V_i) = P_f dV$$

where

- W_i, W_f initial and final work, J;
- P_i, P_f initial and final pressure, Pa; and
- V_o, V_i, V_f reference, initial and final volume of intruded mercury, m³.

Equation (7) assumes that the initial work is taken as the reference (i.e., $V_i = V_o$). Equations (6) and (7) can be combined and, by assuming constant contact angle and surface tension, used to obtain the change in area as a function of the final pressure and the volume increment:

$$(8) \quad dA = P_f dV / \tau \cos(\alpha)$$

The total area is obtained by accumulating the calculated pore area at every pressure increment. Table 4 presents summary pore surface area statistics, while Table A4 presents the results for all samples. The data indicate that the mean pore area is 3,466 m²/kg with a coefficient of variation of 65 percent, which is large relative to other matrix interstitial parameters, and ranges from 1960 to 16,510 m²/kg.

Table 4: Summary of pore area values obtained from medium core segments at the Apache Leap Tuff Site.

PORE AREA (m ² /kg)	
Mean	3,466.
Coef. Var.	65 %
Minimum	1,960.
Median	3,009.
Maximum	16,510.

2.1.5 Pore Size Distribution

The distribution of pore sizes can be estimated using the mercury intrusion technique described in the previous section. If a uniform contact angle and surface tension is assumed between the mercury and the rock surface, then an equivalent pore diameter can be estimated using capillary theory, i.e., Equation (5). As part of the mercury intrusion procedure, the cumulative intrusion volume is measured for each pressure increment, which can then be used to construct a distribution of intrusion volume as a function of equivalent pore diameter. Table 5 summarizes cumulative intrusion volumes. Tables A5a and A5b present laboratory data for all samples for the associated effective pore diameter, and incremental intrusion volumes, respectively.

Table 5: Summary of cumulative intrusion volume as a function of equivalent pore diameter.

CUMULATIVE INTRUSION VOLUME (m^3/m^3)								
- - - - Equivalent Mean Pore Diameter (μm) - - - - -								
	13.8	9.19	7.64	6.30	5.08	4.06	3.27	2.61
Mean	0.0003	0.0005	0.0011	0.0024	0.0060	0.0125	0.0213	0.0308
Coef. Var.	869 %	601 %	317 %	173 %	108 %	79 %	58 %	44 %
Minimum	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Median	0.0000	0.0002	0.0004	0.0009	0.0032	0.0106	0.0205	0.0310
Maximum	0.0295	0.0310	0.0318	0.0329	0.0346	0.0447	0.0580	0.0684
- - - - Equivalent Mean Pore Diameter (μm) - - - - -								
	2.07	1.65	1.30	1.03	0.802	0.627	0.494	0.385
Mean	0.0410	0.0487	0.0544	0.0590	0.0631	0.0666	0.0696	0.0726
Coef. Var.	36 %	36 %	35 %	35 %	34 %	33 %	32 %	32 %
Minimum	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0019	0.0029
Median	0.0426	0.0494	0.0560	0.0608	0.0643	0.0672	0.0714	0.0747
Maximum	0.0762	0.0907	0.1067	0.1154	0.1221	0.1273	0.1319	0.1356
- - - - Equivalent Mean Pore Diameter (μm) - - - - -								
	0.302	0.237	0.187	0.146	0.115	0.0896	0.0700	0.0548
Mean	0.0756	0.0787	0.0819	0.0859	0.0907	0.0969	0.1042	0.1116
Coef. Var.	31 %	30 %	29 %	26 %	24 %	22 %	21 %	20 %
Minimum	0.0043	0.0058	0.0076	0.0107	0.0149	0.0196	0.0239	0.0287
Median	0.0774	0.0807	0.0829	0.0861	0.0901	0.0975	0.1042	0.1110
Maximum	0.1387	0.1421	0.1456	0.1489	0.1527	0.1568	0.1614	0.1662
- - - - Equivalent Mean Pore Diameter (μm) - - - - -								
	0.0429	0.0336	0.0262	0.0205	0.0160	0.0125	0.0098	0.0077
Mean	0.1182	0.1237	0.1284	0.1327	0.1369	0.1397	0.1417	0.1428
Coef. Var.	19 %	19 %	17 %	16 %	15 %	15 %	14 %	14 %
Minimum	0.0345	0.0398	0.0535	0.0759	0.0871	0.0888	0.0901	0.0911
Median	0.1189	0.1250	0.1294	0.1330	0.1358	0.1389	0.1410	0.1423
Maximum	0.1710	0.1749	0.1776	0.1795	0.2023	0.2064	0.2092	0.2113

2.2 Fracture Interstitial Properties

Interstitial properties of fractures are obtained primarily from oriented cores extracted at the time of borehole construction. To orient the core, the end of the each core was scribed using a tool weighted on one side and affixed with a sharp point on the end which, when dropped down the borehole, left a mark on the stub of the core. Also, each core was noted with the depth and borehole identification.

2.2.1 Location

Fracture locations are identified by position with respect to an arbitrary coordinate system which is oriented to be coincident with the borehole orientations. The zero azimuth of the arbitrary borehole coordinate system is 8° west of north. The vertical elevation is also arbitrarily selected. Table A6 presents location data along with other interstitial properties of the fracture. It should be noted that the locations are not oriented with respect to true north. To convert from the local coordinate system described previously to a global coordinate system oriented on true north, the following transformation is applied:

$$(9) \quad \begin{vmatrix} x_g \\ y_g \end{vmatrix} = \begin{bmatrix} x & y \end{bmatrix} \begin{vmatrix} 0.990 & 0.139 \\ -0.139 & 0.990 \end{vmatrix}$$

where

x, y local cartesian coordinate system, m; and
 x_g, y_g global cartesian coordinate system, m.

Table A6 presents fracture location and orientation data (described below) for mapped fractures. It is apparent from the table that fractures are located throughout the boreholes, with some intervals having more fractures.

2.2.2 Density and Spacing

Fracture density can be described in terms of either one, two, and three dimensional measures. The one-dimensional measure consists of determining the number of fractures which intersect a line, such as a borehole, per unit length. A second measure consists of determining the number of fractures which intersect a plane, such as a mine shaft, quarry wall or ground surface, per unit area of the surface. A third measure consists of the number of fractures within a volume of extracted rock.

At the Apache Leap site, only the one dimensional measure is available from the borehole core logs. The observed density data are presented as Tables 6 and A7. From the Apache Leap site data it can be observed that fracture density variation is high, ranging from a density of no fractures per three meter interval to a maximum of 4.3 fractures per meter, which is noted at two locations. The distribution has the appearance of an exponential distribution, which is consistent with a Poisson process for fracture locations. Mean fracture spacing is the reciprocal of fracture density.

Table 6: Summary of fracture density and orientation obtained from borehole cores at the Apache Leap Tuff Site.

	FRACTURE DENSITY (1/m)	FRACTURE ORIENTATION	
		Strike (°)	Dip (°)
Mean	0.77	214.4	64.5
Coef. Var.	108 %	56 %	37 %
Minimum	0.00	3.	1.
Median	0.67	109.	55.
Maximum	4.33	359.	89.

2.2.3 Orientation

A downhole scribing tool was used to provide an orientation mark by etching the end of each core length prior to drilling. The X-series boreholes were scribed on the top of the core while the Y- and Z-series were scribed on the bottom. Mathematical, graphical and mechanical methods were used for correcting the apparent dips of fractures in the oriented drill cores taken from inclined boreholes (Weber, 1986). A graphical technique using a stereonet was used to verify the results. The procedure consists of assuming that the borehole lies in a vertical position when the observed angles are measured for a fracture plane intersecting the core. The borehole is then tilted into its inclined position and the resulting true dip and strike are calculated. The absolute orientation of fracture traces in the drill core are determined by measurement of two angles:

- The angle between the fracture plane and the core axis; and
- The angle between the major axis of the elliptical trace of the fracture plane and a line scribed on the drill core, measured on the circumference of the core.

The apparent angles of the fracture plane were measured in the laboratory using a goniometer, constructed after Goodman (1976). Zimmer (1963) provides a solution for converting the apparent angles to their true orientation, of the form:

$$(10) \quad S = \text{atan}((\cos \alpha \sin \beta + \tan \Gamma \cos \beta) / \sin \Gamma)$$

$$(11) \quad D = \text{acot}(\tan \beta / \sin(\text{atan}(\cos \alpha \tan \beta + \tan \Gamma / \sin \alpha \tan \beta))) \\ + \text{acot}(\tan \Gamma / \sin(\text{atan}(\cos \alpha \tan \Gamma + \tan \beta / \sin \alpha \tan \Gamma)))$$

where

- β inclination of the borehole from the horizontal;
- α azimuthal angle between the lower axis of the fracture plane ellipse and the scribe line;
- Γ vertical angle between the major axis of the fracture plane ellipse and the normal to the fracture plane;
- S strike of fracture plane with respect to the borehole axis; and,
- D dip of fracture plane with respect to the horizontal plane;

Fracture orientation data are presented as Table A6 for all nine boreholes. The data indicate the presence of many north-south trending fractures which dip steeply to the west as well as a few randomly oriented fractures. This is not entirely consistent with surface fracture traces, which also indicate steeply dipping, east-west trending fractures. This additional fracture set is not manifested in the borehole cores either due to the positioning of the boreholes parallel to the fracture set, or due to the lack of such fractures in the immediate vicinity of the boreholes.

3. Hydraulic Characterization Parameters

Hydraulic properties as reported here are divided into three elements; matrix, fracture and combined fracture-matrix properties. Matrix properties are obtained from core segments, as described above, while combined fracture-matrix properties are derived from field testing procedures. The fracture properties are obtained by removing the effects of matrix properties from field data, and also by using laboratory tests to specifically evaluate fracture hydraulic characteristics.

The measured hydraulic properties of the rock matrix include the saturated hydraulic conductivity, moisture characteristic curve, and the unsaturated hydraulic conductivity curve. Field water content data are used to estimate field matrix potentials using laboratory moisture characteristic curves. In addition to the rock matrix characteristics, field and laboratory data are used to characterize fracture hydraulic properties, as well as coupled fracture-matrix properties when they can not be differentiated.

3.1 Matrix Hydraulic Properties

Laboratory analysis of oriented borehole core segments are used to determine the hydraulic properties of the rock matrix. Because the rock segments were selected specifically excluding fractured intervals, the analyses are only appropriate for characterizing the rock matrix. Addressed in this section are the saturated flow properties, as well as the effect of variable saturation on the hydraulic properties.

3.1.1 Saturated Hydraulic Conductivity

The saturated hydraulic conductivity is a coefficient which relates the hydraulic head gradient to fluid flux according to Darcy's law:

$$(12) \quad K_s = -q / i$$

where

K_s hydraulic conductivity, m/s;
 q fluid flux, m/s; and
 i hydraulic gradient, m/m.

The fluid flux is determined by dividing the volumetric flow rate, Q (m^3/s) as measured by a flow meter, by the cross sectional area, A (m^2):

$$(13) \quad q = Q / A$$

For one-dimensional steady flow, the hydraulic gradient is determined by dividing the total head drop, ΔH (m), across the sample by the length of the sample, L (m). The total head drop is calculated by noting that the total head is the sum of the pressure and elevation heads, or:

$$(14) \quad i = \Delta H / L = [(p_o + z_o) - (p_i + z_i)] / L$$

where

p_i, p_o inflow and outflow pressure heads, respectively, m; and
 z_i, z_o inflow and outflow elevation heads, respectively, m.

The procedure employed to measure the saturated hydraulic conductivity from rock core segments uses the large segments in conjunction with a permeameter (Figure 6). The permeameter consists of an inflatable packer which is used to seal the annulus between the rock segment and an outer brass collar. Covers are placed over each end of the permeameter and water is introduced under pressure at the upper surface of the rock segment. Outflow from the lower surface is collected and measured using a flow meter. Prior to performing the measurement, the rock core is saturated using sterile, 0.001 M CaSO_4 solution as presented in Section 2.1.

Tables 7 and A8 present summaries and individual measurements of saturated hydraulic conductivity for each segment at all sample locations. The hydraulic conductivity values vary substantially, over three orders of magnitude, from 0.4 to over 400×10^{-9} m/s, with a mean value of approximately 20×10^{-9} m/s. The distribution of the values appears lognormal, with an extended tail toward higher values.

Table 7: Summary of saturated hydraulic conductivity values obtained from large core segments at the Apache Leap Tuff Site.

LABORATORY SATURATED HYDRAULIC CONDUCTIVITY
(E-9 m/s)

Mean	21.31
Coef. Var.	301 %
Minimum	0.69
Median	4.24
Maximum	438.28

3.1.2 Moisture Characteristic Curve

The moisture characteristic curve relates the water content or relative saturation of a rock sample to the matric suction of the water in the sample. The drainage portion of the moisture characteristic curve is obtained for the wet region (i.e., matric suctions less than 500 kPa) using the large segments in conjunction with a pressure extraction vessel, while the data for the dry region (i.e., matric suctions greater than 500 kPa) are obtained using the small segments in conjunction with a thermocouple psychrometer and a sample changer.

Figure 6: Permeameter used to obtain saturated hydraulic conductivity for large core segments.

For matrix suctions less than or equal to 500 kPa, a pressure plate extractor is used to control the matric suction within a core segment. The procedure consists of saturating a large rock segment, placing the segment on a pressure plate (using a silica paste to establish a good hydraulic connection between the plate and the segment), sealing the pressure plate within the pressure vessel, and applying a desired matric suction using nitrogen gas to pressurize the vessel. Once the sample has reached equilibrium, the pressure is released, the vessel is opened, the sample is removed and the moisture content of the sample is determined gravimetrically. The sample is then returned to the pressure plate and a greater pressure is applied. Pressures of 10, 25, 50, 100, 300 and 500 kPa were applied to the cores and corresponding sample water contents were determined.

For matrix suctions greater than 500 kPa, a thermocouple psychrometer is used in conjunction with a sample changer chamber. The procedure consists of saturating a small rock segment, placing the segment on a precision balance and drying until the desired relative saturation is achieved, transferring the segment to a chamber in the sample changer, and allowing the matric suction within the segment to equilibrate. Once the suction has stabilized within the chamber, the wet bulb depression of the atmosphere surrounding the rock segment is determined, along with the ambient temperature. From these two measurements the fluid potential within the chamber is determined. The sample is then dried to the next desired relative saturation. Relative saturations from 70 to 10 percent in 10 percent increments are used.

Tables 8 and A9 present summaries and complete data listings for pressure extractor, Tempe cell, and thermocouple psychrometer results in tabular form. The data presented here indicate that the saturation of the matrix at a specified matric suction is highly variable, with increasing variation as the suction increases.

The characteristic curve data can be used to estimate the parameters of the Van Genuchten equation (Van Genuchten, 1978, 1980) of the form:

$$(15) \quad S = (1 + (\alpha\psi)^n)^{-m}$$

where

- S relative saturation, dimensionless;
- α scaling parameter, kPa^{-1} ;
- ψ matric suction, kPa;
- n fitting parameter, dimensionless; and
- m fitting parameter, dimensionless, equal to $1-1/n$.

Data from Tables A9a and A9b were used to provide the least squared error estimate of relative saturation assuming a constant value of n and m for all samples, and no residual saturation. The procedure provided a minimum error for n equal to 1.26 (m equal to 0.793). Table 8 presents the summary statistics for the estimated value of α , while Table A9e provides the individual estimates of alpha.

Table 8: Summary of laboratory moisture characteristic curve values obtained from pressure extraction vessel and Tempe Pressure Cells using large core segments and from thermocouple psychrometer data using small core segments at the Apache Leap Tuff Site. Mean wetting curves for 10 large core segments are also presented. Also shown are summary statistics for Van Genuchten moisture characteristic curve function.

RELATIVE SATURATION (%)						
Suction (kPa)						
	10	25	50	100	300	500
Pressure Extractor						
- Drying Curve						
Mean	95.54	90.54	83.91	70.20	55.90	48.91
Coef. Var.	4.7%	7.6%	11.3%	12.1%	12.9%	14.4%
Minimum	76.03	70.10	59.05	48.82	38.23	32.71
Median	96.87	92.76	84.93	70.08	56.86	49.18
Maximum	101.21	99.10	97.57	89.07	75.06	69.71
- Wetting Curve						
Mean	72.79	68.48	60.23	51.47	42.66	41.08
Tempe Pressure Cell						
- Drying Curve						
Mean	96.71	92.69	85.43	66.33	-	-
Coef. Var.	3.7%	7.6%	11.2%	10.5%	-	-
Minimum	83.56	65.55	57.36	42.50	-	-
Median	98.17	95.18	86.57	66.78	-	-
Maximum	99.92	99.46	97.97	83.37	-	-
Suction (kPa)						
	1,000	5,000	10,000	50,000	100,000	
Psychrometer						
- Drying Curve						
Mean	47.5	40.0	22.2	20.8	12.8	
Coef. Var.	19.4%	21.3%	15.6%	26.3%	20.3%	
Minimum	30.	20.	18.	9.	9.	
Median	48.	40.	21.	20.	13.	
Maximum	68.	60.	31.	34.	16.	

Van Genuchten Moisture Characteristic Function ($n = 1.26$, $\theta_r = 0.$)

	α -value
Mean	0.0224 kPa ⁻¹
Coef. Var.	37.7%
Minimum	0.0102
Median	0.0203
Maximum	0.0643

3.1.3 Unsaturated Hydraulic Conductivity

The hydraulic conductivity of a rock or soil sample is normally lower at higher matric suctions, or, equivalently at lower water contents. The outflow technique is used to determine the unsaturated hydraulic conductivity (Klute, 1964) of the 105 large core segments. The segments are saturated under a vacuum and then placed inside a Tempe pressure cell (Figure 7). A pressure increment is applied and the rate of outflow from the pressure cell is monitored using a small capacity pipette in conjunction with an air bubble which is injected through a septum at the upstream end of the pipette. A recirculation pump is occasionally used to remove accumulated air from the bottom of the porous plate. A burette is used to collect and measure the cumulative outflow from the plate. Klute (1964) presents an analytic solution for the outflow method when the hydraulic diffusivity is a constant over each pressure increment. For the samples and pressure increments employed in this analysis, however, the hydraulic diffusivity can not be assumed constant. Instead, an exponentially decreasing hydraulic conductivity is assumed over each pressure step:

$$(16) \quad K(p_f) = K(p_i) \exp[a(p_f - p_i)]$$

where

- K hydraulic conductivity at pressure p, m/s;
- p_f, p_i final and initial pressures, Pa, respectively; and
- a regression coefficient, 1/Pa.

Using the saturated hydraulic conductivity at zero pressure to begin the procedure, Equation (16) provides stepwise estimates of the unsaturated hydraulic conductivity. Lacking an analytic solution for the outflow method using this technique, a nonlinear least squares finite element program provided by Kool and Parker (1987) is modified to estimate the unsaturated hydraulic conductivity at each pressure step. Table 9 provides summaries for the unsaturated hydraulic conductivity data presented as Table A10.

Table 9: Summary of hydraulic conductivity values obtained from 105 large core segments at the Apache Leap Tuff Site.

	HYDRAULIC CONDUCTIVITY (E-9 m/s)				
	Suction (kPa)				
	0	10	25	50	100
Mean	21.31	3.346	1.475	0.908	0.364
Coef. Var.	301 %	105 %	156 %	115 %	112 %
Minimum	0.69	0.126	0.110	0.002	0.005
Median	4.24	2.610	0.556	0.498	0.235
Maximum	438.28	25.750	14.588	5.041	2.541

OUTFLOW METHOD EXPERIMENTAL SETUP

Figure 7: Laboratory apparatus for obtaining unsaturated hydraulic conductivity using the outflow method.

3.2 Field Hydraulic Properties

Field tests of hydraulic conductivity and water content are important for comparison with laboratory data as well as for providing information about the ambient moisture regime at the site of interest. While field hydraulic tests cannot provide data about unsaturated hydraulic properties, they can be used to determine fracture hydraulic properties which are unavailable from core segments. Also, estimates of field water contents can be used to infer the ambient matric suction, and other unsaturated matrix properties.

3.2.1 Field Hydraulic Conductivity

Hydraulic tests in fractured rock with substantial matrix hydraulic conductivity are difficult to interpret due to the possibility for flow to occur in both the fractures and the matrix. The methodology described here assumes that an effective hydraulic conductivity exists which accounts for saturated liquid flow through both pathways. The equivalent saturated hydraulic conductivities of the fractures intersecting each three-meter borehole interval were determined using a modified falling-head borehole permeability test as described by Tidwell (1988) and Tidwell et al. (1988). The test yields the equivalent conductivity for both the matrix and the fractures.

The method for obtaining the equivalent conductivity involves maintaining a constant water level near the top of a borehole until a constant injection rate is established. A short packer with a tube through it and extending to the surface is lowered to a selected depth in the borehole. The tube extending to the surface is connected to one of three falling-head flow meters calibrated for different flow ranges. When the packer is inflated and the head above and below the packer are maintained equal, the meter measures the injection rate for the length of borehole below the packer. The packer is then lowered 3 m and a similar measurement is made. The difference in measured flow rates is the injection rate for the 3-m borehole segment.

The injection rate is converted to equivalent hydraulic conductivity using three alternate mathematical solution. The first solution is a modification by Tidwell (1988) of the equation presented by Glover (1953) to incorporate inclined boreholes:

$$(17) \quad K = [Q \operatorname{asinh}(L/r) - L/h] / [2\pi (2hL - 2Lz - L^2) \sin \beta]$$

where

- K effective hydraulic conductivity, m/s;
- Q interval outflow rate, m³/s;
- L length of injection interval, m;
- r borehole radius, m;
- h total borehole length, m;
- z distance from bottom of borehole to lower edge of tested interval, m.
- β angle of borehole inclination.

The second solution is a modification by Tidwell (1988) of the equation presented by Philip (1985) to again account for the sloping borehole and the packer contained flow:

$$(18) \quad K = [h^2 Q C_o] / [(3/2)^{2/3} r^2 \pi \sin \beta (z'^2 - z^2)]$$

where

- C_o geometric factor related to the eccentricity of the assumed prolate spheroid shape of the borehole (Philip, 1985); and
- z' distance from bottom of borehole to upper edge of tested interval, m.

The third solution is a method presented by Dachler (1936):

$$(19) \quad K = Q \ln(L/r) / 2\pi L h_w$$

where h_w is the mean pressure head in the injection interval. The calculated hydraulic conductivities of the boreholes using the three methods are presented in Tables 11 and A12 as a summary and complete data sets, respectively. Like the matrix hydraulic conductivity data, the field data demonstrate a high variability, ranging over five orders of magnitude. The data indicate a high degree of skewness toward the higher values, with two intervals in particular accounting for extreme rates of flow.

Table 10: Summary of field determined outflow rates and saturated hydraulic conductivity values at the Apache Leap Tuff Site.

	OUTFLOW (E-6 m ³ /s)	HYDRAULIC CONDUCTIVITY (E-9 m/s)		
		Philip	Glover	Dachler
Mean	26.349	59.42	29.10	30.20
Coef. Var.	612 %	729 %	729 %	662 %
Minimum	0.016	0.48	0.27	0.41
Median	0.633	11.63	5.64	10.33
Maximum	1232.	39224.	19126.	17900.

3.2.2 Field Water Content

Matric suction is difficult to assess in a consolidated rock because the suction is disturbed by the process of measurement. At present, the matric suction is inferred from the field measured water content and the laboratory derived characteristic curves. The inferred value indicates the

general water status but may not be sufficient to reliably estimate hydraulic head gradients.

The determination of field water content is possible using a neutron source and detector (Blanford and Rasmussen, 1988). The measurement of thermalized neutron flux makes possible the long term monitoring of water content changes within the rock at the ALTS. Prior to estimating the water content, however, a calibration curve must be developed to relate observed neutron counts with field water contents. The following sections describe calibration activities, along with observed water content changes using the developed calibration equation.

Changes in rock water content using neutron logging have been measured within the nine inclined boreholes at the ALTS. In addition, investigations of heat flow in welded tuff by Davies (1987) using heaters placed in 5.1 cm diameter boreholes have shown long term changes in rock water content. In order to quantify these changes a theoretical calibration curve has been developed by Elder (thesis in preparation). While the calibration curve has been validated for soils, negative water contents occasionally result when using the calibration for welded tuff near the Apache Leap Test Site. Because negative water contents are impossible and also because accurate estimates of rock water contents are important, a calibration curve derived from field data was deemed necessary. The observed calibration curve is also necessary to adjust the theoretical calibration curve for differences in geometric factors, such as borehole diameter, and for differences in rock bulk densities.

Calibration of rock water content with neutron counts is difficult due to the difficulties associated with extracting rock samples. Existing augering and drilling methods are inappropriate for correlating field estimates of thermalization properties to water content due to the large thermal and hydraulic disturbances induced using these methods. Alternately, rock chips can be placed in large drums and the thermalization properties determined for various water contents. Substantial differences in bulk density will occur, however, due to the difficulty in repacking the rock chips to the original bulk density.

To obtain a relationship between neutron counts and water content at the ALTS, two neutron calibration holes were excavated to a depth of 1.8 m using a pneumatic hammer. The calibration holes have a diameter of 5.1 cm and were located so that one hole was more likely to have a higher water content than the other. The wetter hole was located in the middle of an ephemeral stream channel, while the drier hole was located away from water sources other than precipitation. The locations of the neutron calibration boreholes are indicated in Figure 8. Each hole was capped with a stopper to prevent evaporation or saturation due to unexpected precipitation or surface flows. Both holes were then allowed to equilibrate for 21 and 32 days, respectively, to allow any effects of excavation to dissipate. Neutron counts at various depths in the calibration holes after equilibration are presented in Table 11.

Figure 8: Location of neutron water content calibration boreholes.

Table 11: Observed neutron counts with depth at two calibration boreholes, Apache Leap Tuff Site. Counts in the dry and wet boreholes were obtained on 10/24 and 11/4/87, respectively.

Depth (m)	Dry Borehole - - - (Counts/120 s) - - -	Wet Borehole - - - (Counts/120 s) - - -
0.30	63,984	81,667
0.40	64,252	83,370
0.50	64,437	82,722
0.60	64,417	80,722
0.85	65,360	84,276
1.10	65,263	83,639
1.35	65,902	79,590
1.60	69,567	81,417

After the equilibration period, a pneumatic hammer was used to remove rock samples from the surface down to a depth of 0.42 m in the dry hole and 0.50 m in the wet hole. Upon excavation, the rock samples were immediately placed inside a collection can and weighed. Approximately twenty rock samples were removed from around each calibration hole. Each sample weighed approximately 0.150 kg. The samples were taken to the laboratory where they were oven-dried and reweighed to determine the field water content. To determine the relative saturation, porosity, and volumetric water content the samples were saturated under a vacuum and reweighed while suspended under water. Table 12 presents the results of the analyses for rock samples extracted from the two neutron calibration boreholes.

Table 12: Results for neutron calibration borehole tests, Apache Leap Tuff Site. Neutron measurements were obtained at a depth of 0.40 m.

	'Dry' Borehole	'Wet' Borehole
Neutron Counts per 120 s	64,239 $\pm$ 80	82,547 $\pm$ 64
Bulk Density (Mg/m ³)	2.13	2.09
Water Content		
Observed	10.2 %	14.2 %
Predicted	5.8 %	10.3 %

The predicted water content in Table 12 was obtained using a nonlinear theoretical model developed by Elder (1988). A linearized approximation to the weakly nonlinear model is:

$$(20) \quad \theta = 4.938\text{E-}6 C - 0.1008$$

where θ is the water content, dimensionless, and C is the number of neutron counts per minute for a 5-cm diameter borehole. A linear relationship between water content and neutron counts based upon the calibrated data is:

$$(21) \quad \theta = 4.380\text{E-}6 C - 0.0387$$

It can be observed from the two equations that the slopes of the linear relationships are reasonably similar (within 12 percent of each other) which is because the number of neutron counts is directly related to the change in the amount of water present, and is not expected to vary significantly between theory and field data. The intercepts, however, are substantially different (varying by 260 percent) due to the failure of model parameters to predict the effect of the rock mass on the thermalization of neutrons. The diffusion of neutrons through a rock mass of high density is probably not described by a theory which was developed for applications involving neutron diffusion through the lower bulk density of unconsolidated soil particles.

Additional calibration of neutron counts at various water contents within 5 and 10 cm diameter boreholes will be performed to further validate the calibration curve. A third hole in a dryer location will be drilled, monitored and excavated to validate the present empirical calibration curve and to verify the linearity of the curve over the full range of water contents expected at the ALTS.

The X-series of boreholes were the first to be drilled, in September of 1985. The Y- and Z-series were drilled in November of 1986. Seven sheets of 30 mil high density polyethylene were emplaced in January 1987 and welded together in April of that year to form a 30 x 50 m barrier to infiltration into the rock surrounding the boreholes. A concrete berm was placed along the margin of the plastic to prevent water from seeping in along the sides. Neutron logging of the boreholes at approximately 3- m intervals was begun on February 10, 1987 and continues at roughly 50 day intervals. The initial water contents may have been affected by drilling of the boreholes, which was performed using liquid recirculation.

Hydraulic testing of the boreholes occurred intermittently between March and July of 1987. The testing was conducted on all nine boreholes and consisted of flooding each borehole individually. In August and September Boreholes X1, Y1, X2 and Y2 were filled immediately with water and maintained at nearly constant water levels throughout the experiment. In Boreholes X2 and Y2, a head of 0.5 meters above the upper end of the casings was maintained by using a siphon, while boreholes X1 and Y1 were allowed to fluctuate between 1 and 4 m below the top of the casing from time = 0 to 415 hours. The mean head during this period was approximately

2 m below the casing. After 415 hours, a constant head of 0.5 m above the casing was applied to the two boreholes. When the head was maintained constant at 0.5 m of head, the outflow was measured while maintaining a nearly constant head.

Until 415 hours, the water levels in boreholes X1 and Y1 were allowed to drop and the elapsed time and volume of water required to refill the holes was used to calculate outflow. At times, small bubbles accumulated in the siphons causing a slight head drop and lessening of flow rate. At various times the siphons were re-established, as indicated by the data. At the end of the test interval, the boreholes were drained. The volume of water required to fill and drain the boreholes was not recorded, but the water removed at the end of the test is estimated to be approximately equal to the borehole volumes for X1 and Y1, and equal to about 1.5 times the borehole volumes for X2 and Y2. Reported outflow data are precise to two significant digits.

Boreholes X1, X2, and Y1 were flooded for twenty days while Borehole Y2 was flooded for an additional three days. Table A12 presents the observed outflow rates for the four boreholes. Tables 13 and A13 present summary and individual water content data, respectively, for the nine boreholes for dates ranging from February 10, 1987 (Julian day 41 from 1/1/87) through May 19, 1988 (Julian day 505 from 1/1/87). Continuous flooding of Boreholes X1, Y1, X2 and Y2 occurred between days 236 and 255.

Table 13: Field water contents for various dates at the Apache Leap Tuff Site.

	BOREHOLE WATER CONTENTS (m^3/m^3)							
	- - - - - Julian Date From 1/1/87 - - - - -							
	41	236	255	279	372	406	448	505
Mean	13.75	14.12	14.59	14.50	14.36	14.32	14.32	14.26
Coef. Var.	11 %	11 %	12 %	12 %	12 %	12 %	12 %	12 %
Minimum	10.19	10.85	10.89	10.77	9.99	9.53	9.85	10.14
Median	13.71	14.04	14.46	14.48	14.33	14.35	14.18	14.23
Maximum	17.63	17.29	18.75	18.42	17.74	17.77	17.57	17.51

4. Pneumatic Characterization Parameters

Air flow through the unsaturated zone can result from pressure and density gradients induced by atmospheric driving forces or subsurface heat generation. The induced air flow can affect subsurface moisture contents and, hence liquid redistribution, by transporting water vapor through air filled porosity. Also, equilibrium of matric potentials between isolated liquid phases can be attained as a result of water transport as vapor. To evaluate rates and pathways for air flow in the unsaturated zone, methods for estimating the moisture dependent pneumatic permeability of the rock matrix and fracture system are addressed in this section.

4.1 Matrix Pneumatic Permeability

The pneumatic permeability for both oven-dried and partially saturated large rock core segments is obtained by employing the permeameter previously described in Section 3.1.1 and illustrated in Figure 6. A core segment is brought to a desired potential by either drying the segment in a drying oven or by allowing the sample to equilibrate within a pressure extraction vessel, as described in Section 3.1.2. Once a prescribed suction is achieved, the core sample is placed inside the permeameter with the packer inflated to prevent bypassing of air around the outside of the core. A known pressure gradient is applied longitudinally across the core segment and the air flow volume is measured using a calibrated flow meter. The pneumatic permeability at each suction is determined using the measured air flow rate, cross sectional area and core segment length. Because air is compressible, the ideal gas law is employed with the assumption of isothermal flow:

$$(22) \quad k_a = 2 Q L H_o \mu / \gamma A (H^2 - H_o^2)$$

where

- k_a pneumatic permeability, m^2 ;
- Q measured flow rate, m^3/s ;
- L core length, m ;
- H_o outflow pressure head, m ;
- μ viscosity of air, $Pa \cdot s$;
- A core cross sectional area, m^2 ;
- γ specific weight of water, Pa/m ; and
- H inflow pressure head, m .

Table 14 summarizes the test results and demonstrate the large variability between samples, while Table A14 presents the test results for individual segments. The variability is highly skewed, as evidenced by the discrepancy between the mean and median values for all applied suctions. The measured air permeability of an oven-dried sample is usually similar to the measured water permeability. However, for the tuff cores, the estimates may not be similar due to slip flow along the walls of pores (Klinkenberg, 1941). The importance of the Klinkenberg phenomenon, as

Table 14: Summary of laboratory air permeabilities (m² E-16).

	Suction (kPa)						Oven Dried
	10	25	50	100	300	500	
Mean	1.54	11.20	16.88	26.67	35.11	38.23	57.12
Coef. Var.	434%	436%	344%	326%	309%	295%	272 %
Minimum	<0.01	<0.01	0.02	0.25	1.29	1.91	3.81
Median	0.05	0.10	0.39	2.10	5.09	6.04	12.08
Maximum	41.90	333.10	389.80	678.70	780.50	780.50	1012.60

it is commonly called, can be evaluated by comparing the computed air permeability for oven-dried cores with the computed water permeability for completely saturated cores. The two values should be a function of the ambient air pressure used to conduct the air permeability test, as well as the mean free path of the gas molecules and the pore diameter (Klinkenberg, 1941):

$$(23) \quad k_a = k_w (1 + b/p') = k_w (1 + 8C\lambda/d)$$

where

- b Klinkenberg slip-flow coefficient, Pa;
- p' mean air pressure on the sample, Pa;
- C proportionality factor, approximately equal to one;
- λ mean free path at pressure p', m; and
- d pore diameter, m.

The Klinkenberg slip-flow coefficient is important because the Knudsen diffusion coefficient, D_k (m²), can be derived from it using $D_k = k_w b / \mu$ (Thorstenson and Pollock, 1989), where μ is the gas viscosity (Pa s).

Data in Tables A8 (laboratory saturated hydraulic conductivity) and A14 (laboratory oven-dried pneumatic permeability) are used to calculate the Klinkenberg coefficient and equivalent pore sizes of oven-dried cores for nitrogen gas at mean air pressures of 108 kPa and an assumed mean free path of 9×10^{-8} m. Table 15 presents summaries of the observed values, while Table A15 presents the data for all samples.

Table 15: Summary of laboratory determined Klinkenberg slip flow coefficient.

KLINKENBERG COEFFICIENT (kPa)	
Mean	322.1
Coef. Var.	82 %
Minimum	35.
Median	217.
Maximum	1277.

4.2 Field Pneumatic Properties

Field estimates of pneumatic permeabilities are obtained using single hole air injection tests over three meter intervals corresponding to sample locations coincident with laboratory core segment tests and field hydraulic tests. The field test procedure consists of locating two inflatable packers at either end of a test interval, inflating the packers to isolate the test interval, injecting a controlled mass flow rate of air into the interval, and measuring the absolute pressure in the injection interval. The air permeability is calculated using an equation developed by Dachler (1936) and subsequently adapted for compressible air flow (Figure 9). The analytic equation is of the form:

$$(24) \quad k_a = Q \mu P_o \ln(L/r_w) / \gamma L (P_2^2 - P_1^2)$$

where

- k_a pneumatic permeability, m^2 ;
- Q volumetric flow rate at standard temperature and pressure, m^3/s ;
- μ dynamic viscosity of air, $Pa \cdot s$;
- P_o standard pressure, Pa ;
- L borehole interval length, m ;
- r_w borehole radius, m ;
- P_2 pressure in injection interval, Pa ; and
- P_1 atmospheric pressure, 86.0 kPa .

The analytic solution assumes that the test medium is homogeneous in the vicinity of the test interval, and that no leakage around the packers occurs. Also, the assumption is made that no air leakage through the rock into the borehole above or below the packers is occurring. Flow rate is in standard cubic meters per second, which has been adjusted from a mass flow rate using standard temperature and pressure. Table 16 summarizes results

of the single hole tests, and Table A16 present data for all tested intervals.

Of interest is the greater air permeability in the laboratory when compared to the water permeability. As described in the previous section this difference can be attributed to the Klinkenberg effect. Of more serious concern, however, is the observation that the field estimated air permeability is lower than the field estimated water permeability. This difference can most likely be attributed to the presence of water in the rock, which is not the case for an oven-dried sample.

Table 16: Summary of field determined air permeability. One interval exceeded capacity of measurement device, while a second interval was less than the measurement threshold.

FIELD AIR PERMEABILITY
(m²E-16)

Mean	178.1
Coef. Var.	667 %
Minimum	< 0.420
Median	4.02
Maximum	> 13,366.

Figure 9: Diagram of field single hole air injection experiment.

5. Thermal Characterization Parameters

Thermal gradients can substantially affect the movement of water as liquid and vapor in the subsurface (Tsang and Pruess, 1987). Characterization of thermal sources and sinks, as well as the moisture dependent thermal properties of the rock matrix and fractures, is important for modeling thermal effects on fluid and solute transport. This section presents laboratory and field data sets for thermal parameters corresponding to sample locations consistent with other data sets presented in this report.

5.1 Matrix Thermal Properties

Thermal properties of the rock matrix are estimated by drilling two holes in the large core segments (Figure 10). The holes are 0.36 cm in diameter, one hole lying along the radial axis of the core segment extending into the rock 4.5 cm. The second hole lies approximately 0.7 cm from the central hole and extends 2.5 cm into the core. At desired water contents, liquid mercury at room temperature is added to each hole until the level of mercury is slightly below the core surface. A heating unit composed of precision resistance wire wrapped around a copper wire core is placed in the central hole. A thermistor probe is placed near the bottom of the outer hole. The rock is then placed within an insulating plexiglas chamber which fits snugly around the core. The entire apparatus is then placed within a constant temperature chamber. A known electric current is used to heat the unit in the central hole for approximately 150 seconds. A response to the heating event is observed in the outer hole, the magnitude of which is used to evaluate the thermal conductivity of the sample for each water content.

The thermal conductivity is found by using a radial flow equation:

$$(25) \quad \Delta T = Q/4 K_t W(u)$$

where

ΔT temperature change from initial conditions, °C;

Q heat flux per unit thickness, W/m;

K_t thermal conductivity, J/ms°C; and

$W(u)$ exponential integral, defined here as:

$$(26) \quad W(u) = \int_u^{\infty} [e^{-x} / x] dx$$

and

$$(27) \quad u = r^2 C / 4 K_t t$$

where

r distance between the center and observation hole, m;

C heat capacity, J/m³°C; and

t time, s.

Figure 10: Apparatus used to estimate water content dependent thermal properties.

Inversion of Equations (26) and (27) to obtain estimates of K_t and C is obtained using an iterative procedure suggested by Grimestad (1981):

$$(28) \quad (C/K_t)_{n+1} = (C/K_t)_n (1 + \ln(T_1 W_2 / T_2 W_1) / (\exp[-u_2]/W_2 - \exp[-u_1]/W_1))$$

where

- n iteration number;
- T_1, T_2 observed temperatures at successive times, °C;
- u_1, u_2 values of u at successive times; and
- W_1, W_2 values of $W(u)$ at successive times.

Once the value of C/K_t has stabilized, the value of C and K_t can be determined using:

$$(29) \quad K_t = q W_1 / 4 T_1 = q W_2 / 4 T_2$$

and

$$(30) \quad C = K_t (C/K_t)_{n+1}$$

A check of C can be made by noting that:

$$(31) \quad C = C_w \theta \rho_w + C_s (1-n) \rho_s = C_w \theta \rho_w + C_s \rho_b$$

where

- C_w specific heat of water, approximately 4184 J/kg°C;
- C_s specific heat of dry rock, approximately 800 J/kg°C;
- θ volumetric water content, m³/m³;
- n volumetric porosity, m³/m³;
- ρ_w density of water, kg/m³;
- ρ_s grain density of rock, kg/m³; and
- ρ_b bulk density of rock, kg/m³.

Table 17 summarizes laboratory thermal properties, and Table A17 present data sets for individual laboratory segments.

Table 17: Summary of laboratory thermal conductivity (J/ms°C).

	-	-	-	-	-	-	-	-	Oven
	Suction (kPa)								
	0	10	25	50	100	300	500	Dried	
Mean	1.821	1.800	1.820	1.775	1.817	1.729	1.727	1.266	
Coef. Var.	10.7%	9.2%	10.6%	11.8%	11.8%	11.4%	10.7%	11.5%	
Minimum	1.291	1.381	1.464	1.356	1.382	1.445	1.095	0.829	
Median	1.839	1.792	1.801	1.758	1.779	1.696	1.717	1.281	
Maximum	2.491	2.484	2.580	3.568	2.785	2.575	2.138	1.966	

5.2 Field Thermal Properties

Potential sources of thermal effects in the unsaturated zone near a HLW repository include surface heating, the geothermal gradient from below; repository waste decay, and latent heating due to phase changes. Surface heating effects result from annual and daily solar cycles, while the geothermal gradient results from heat flux from depth. Temperature profiles are tabulated in Table A18. For the Apache Leap Tuff Site data set, the effects of daily solar cycles and latent heating are not easily detected and waste decay is not relevant. Only the effects of an annual solar cycle and the geothermal gradient are readily apparent. The geothermal gradient, in turn, appears to be constant, approximating 0.03 °C/m. Without a measure of the heat flux, however, no estimate of thermal properties can be determined.

The effects of an annual solar cycle can be used to estimate thermal diffusivity at ambient conditions. Carslaw and Jaeger (1959, Eq 2.6.8) present an analytic solution for the temperature distribution in a semi-infinite solid in response to a steady harmonic heating source:

$$(32) \quad T = A \cos(\lambda t - \omega_0)$$

where

- T depth and time dependent temperature, °C;
- A amplitude of the annual solar cycle, °C;
- λ frequency of the annual cycle, 1/s;
- t time, s; and
- ω_0 phase shift between solar maximum and calendar year.

At any point in the subsurface, the analytic solution takes the form:

$$(33) \quad T = A \exp(-\nu z) \cos(\lambda t - \nu z - \omega_0)$$

where z is depth, m, and:

$$(34) \quad \nu = (\lambda/2D_t)^{1/2}$$

and D_t is the thermal diffusivity, m²/s. For the ALTS, one estimate of D_t can be obtained using the phase shift with depth. By assuming a solar maximum near July 10, and by noting the depth at which the temperature is a maximum for a given date, effective thermal diffusivities of 0.81, 0.23, 0.57, and 0.35 E-6 m²/s are estimated using data for 4/22/87, 12/18/87, 3/23/88 and 12/10/88. These value can be compared with data from Table 17 for laboratory cores. Assuming a thermal conductivity of 1.95 J/ms°C and a saturated heat capacity of 2.4 E6 J/m³°C, a thermal diffusivity of 0.81 m²/s is estimated. The mathematical model will not exactly replicate the physical system, however. In particular, the driving force is not an exact harmonic and the date of the assumed maximum may or may not be accurate. Also, the thermal diffusivity is most likely not a constant, but varies both spatially and temporally due to changes in material properties and moisture content.

6. Quantification of Parameter Uncertainties

The quality assurance goal is to assure the reproducibility of research results and to minimize parameter uncertainties. Uncertainties are introduced by natural variations in parameters due to geologic processes, as well as inaccurate and imprecise measurements and methods. The methods and techniques used to collect, reduce, and interpret research data are designed to be precise, accurate, traceable, and articulated in such a manner that the work can be reproduced and independently evaluated. Written procedures must be used for the test design, equipment calibrations, control of procedures, and reports. Various accuracy improvement methods are employed to assure a high degree of precision and accuracy. Methods to minimize and quantify parameter uncertainties include test replication, duplication, and redundancy.

Replication involves repeated sampling using a single instrument which is used to collect information about parameters of interest. Testing is performed multiple times on selected samples if the analysis does not involve destructive testing. If the testing is destructive, testing is performed in conjunction with samples obtained at locations close to each other. The purpose of the replicated sampling is to provide an estimate of the precision of the measurement technique, as well as to provide estimates of spatial variability.

Duplication is the use of a number of identical instruments to measure a specific parameter. Variability induced by inaccurate instruments can be determined using this technique. Wherever possible, multiple instruments of identical manufacture are used to determine the variability induced by each, and to estimate the magnitude of bias generated by using an inaccurate measurement device.

Redundancy is the use of a number of different instruments or techniques to determine system parameters. By estimating parameters using independent techniques, an additional estimate of bias can be obtained. In addition, systematic errors induced by ignoring controlling variables can be examined. This is possible because each technique may not respond in the same way to a controlling variable. Further discussion of the use of multiple analyses and techniques for model specification can be found in Rasmussen (1986).

To demonstrate representative parameter uncertainty analyses, four parameters were evaluated using repetition and duplication procedures. Tables 18 through 21 present data for air permeability, saturated water permeability, relative saturation as a function of matric suction, and unsaturated hydraulic conductivity for selected samples.

Dry air permeability was estimated for three control samples in two different permeameters on various dates. Samples GA, JA, and MA were repeated in different permeameters, with the coefficient of variation for Permeameters 1 and 2 being computed for Sample GA. The air permeability values measured at two separate times are compared for Sample EH. The results of these experiments are presented as Table 18.

Table 18: Oven dry air permeability for parameter variation estimation.

Sample	Permeameter	Date	Air Permeability	Mean	Coef. Var.
GA	1	11/3/87	7.40 x 10 ⁻¹⁶ m ²		
	1	11/5/87	6.89		
	1	11/5/87	6.82	7.04	4.50 %
	2	11/4/87	5.48		
	2	11/5/87	5.23		
	2	11/6/87	5.09	5.27	3.75
			For all permeameters:	6.15	16.22
JA	1	11/5/87	6.28		
	2	11/5/87	5.36		
	3	11/5/87	5.66		
	3	11/5/87	5.69		
	1	11/6/87	6.44		
			For all permeameters:	5.89	7.72
MA	1	11/3/87	7.55		
	2	11/3/87	6.86		
	2	11/3/87	6.79		
	3	11/5/87	6.83		
	1	11/6/87	7.77		
			For all permeameters:	7.16	6.48
EH	3	1/31/88	9.49		
	2	1/31/88	9.53		
	2	4/25/88	9.37		
			For all permeameters:	9.46	0.88

Saturated hydraulic conductivity tests on Samples AC and AE were repeated in different permeameters. Sample EA has an additional determination 5 months later. Results for the saturated hydraulic conductivity tests are presented as Table 19.

Table 19: Saturated hydraulic permeability for parameter variation estimation.

Sample	Permeameter	Date	Hydraulic Permeability	Mean	Coef.Var.
AC	1	11/16/87	2.10 x 10 ⁻⁶ m ²		
	2	11/16/87	2.05		
	3	11/16/87	1.91		
	3	11/19/87	2.09		
	For all permeameters:			2.04	4.30%
AE	2	11/16/87	0.88		
	3	11/17/87	0.84		
	1	11/18/87	1.02		
	1	11/18/87	0.93		
	3	11/19/87	1.02		
	For all permeameters:			0.94	8.67
EA	3	11/16/87	6.62		
	1	11/18/87	6.57		
	2	11/19/87	6.57		
	2	11/19/87	5.92		
	3	4/28/88	5.36		
	For all permeameters:			6.04	10.59

Table 20 presents relative saturation data for two samples. From the table, the coefficient of variation is shown to be approximately three to four percent. The reported coefficient of variation in porosity reported for all samples was approximately thirteen percent. If the assumption can be made that the measurement error is independent of geologic variations, then the total variance is the sum of the geologic variation plus the measurement variance. Using the independence assumption, it can be concluded that the geologic coefficient of variation is about four times the measurement error.

Table 20: Moisture characteristic curves for parameter variation estimation.

Sample	Effective Porosity	RELATIVE SATURATION (%)					
		Suction (kPa)					
		10	25	50	100	300	500
SA	0.150	99.37	98.51	95.17	68.94	60.77	53.63
	0.165	99.55	98.49	96.28	70.44	51.61*	43.73*
	0.157	99.87	99.78	95.95	68.02	49.72*	43.75*
Mean	0.158	99.60	98.63	95.80	69.13	54.04	47.04
Coef. Var.	3.9 %	0.2%	0.6%	0.5%	1.4%	8.9%	9.9%

Sample	Effective Porosity	RELATIVE SATURATION (%)					
		Suction (kPa)					
		10	25	50	100	300	500
UA	0.160	99.74	97.78	96.25	78.43	73.53	67.14
	0.172	99.60	98.97	97.47	78.10	57.75*	47.27*
	0.164	100.00	98.85	97.25	77.62	54.83*	48.38*
Mean	0.165	99.87	98.85	96.99	78.05	62.03	54.26
Coef. Var.	3.2 %	0.3%	0.8%	0.6%	0.4%	13.2%	16.8%

* Different pressure plate used.

Unsaturated hydraulic conductivity tests for one of two samples, GC or UC, were run once every tenth sample. Sample GC was tested in the same permeameter while sample UC was tested repeatedly in a different permeameter. Table 21 presents the test results. As can be observed in the table, the coefficient of variation increased for the sample tested in different permeameters over the coefficient of variation for the sample tested in the same permeameter.

Table 21: Unsaturated hydraulic conductivity values for parameter variation estimation.

Sample	UNSATURATED HYDRAULIC CONDUCTIVITY (m/s E-6)			
	- - - - Suction (kPa) - - - -			
	10	25	50	100
GC	1.127	0.759	1.106	0.569
	2.407	1.711	0.974	0.886
	2.745	2.744	1.928	0.813
	1.658	1.596	0.731	0.424
Mean	1.984	1.703	1.185	0.673
Coef. Var.	37 %	48 %	44 %	32 %

Sample	UNSATURATED HYDRAULIC CONDUCTIVITY (m/s E-6)			
	- - - - Suction (kPa) - - - -			
	10	25	50	100
UC	2.623	3.040	2.507	1.014
	6.214	4.649	2.616	0.883
	9.523	5.972	2.070	0.978
	1.512	15.700	1.705	1.105
Mean	4.968	7.340	2.225	0.995
Coef. Var.	73 %	78 %	19 %	9 %

7. Summary

Data sets for the interstitial, hydraulic, pneumatic and thermal properties of unsaturated fractured tuff at the Apache Leap Tuff Site (ALTS) in central Arizona are presented for both the rock matrix and embedded fractures. The properties are reported for core segments collected at 105 locations in nine boreholes, as well as for field tests over three meter intervals. Estimates from the core segments are compared to field tests whenever possible. Summary statistics for core and field data are also presented.

The reported interstitial properties include the bulk and grain densities, effective porosity and pore area for the rock matrix, along with fracture location, density, orientation, interconnectivity and porosity. Rock bulk densities are near 2.1 Mg/m^3 , grain densities are approximately 2.55 Mg/m^3 , effective porosities are near 17.5 percent and pore areas are approximately $3500 \text{ m}^2/\text{kg}$. Logging of fractures from core data yield fracture densities of 0.77 per meter and predominately vertical orientations, striking N20W.

Saturated hydraulic conductivities estimated in the laboratory for unfractured core segments yield a mean value of $20 \times 10^{-9} \text{ m/s}$, with individual segments varying over three orders of magnitude. Field estimates are larger, ranging from 29 to $59 \times 10^{-9} \text{ m/s}$ depending upon the method used to calculate the conductivity estimate. The range of field values is also larger, covering five orders of magnitude, due to the presence of fracture flow during field tests. Calibration of a neutron probe provided the ability to monitor field water contents, observed to be approximately 75 percent of saturation.

Pneumatic properties include laboratory and field estimates. Laboratory estimates of oven-dry pneumatic permeability are larger than hydraulic permeabilities of saturated samples, explained by the presence of slip flow. The ratio of the permeabilities provides an estimate of the Klinkenberg coefficient, approximately 322 kPa.

Thermal properties of the rock include the thermal conductivity, diffusivity, and heat capacity. The effect of relative saturation on thermal conductivity is negligible except for very dry rock. Saturated heat conductivities of $1.8 \text{ J/ms}^\circ\text{C}$ are found in the laboratory. Laboratory estimates of thermal diffusivity compare favorable with field estimates based on the observed lag between annual surface heating and temperature peaks in the subsurface.

All data sets demonstrate variation as a function of location as well as between estimation techniques. For some parameters (e.g., matrix grain and bulk densities) the variance is small among samples and estimation techniques. Other parameters (e.g., effective matrix porosity) demonstrates substantial spatial variability as well as only a fair agreement between estimation techniques.

8. References

- Anderson, Ingrid, 1987, Measurement of Unsaturated Rock-Water Potential In Situ, M.S. Thesis, University of Arizona.
- Barackman, M.L., 1986, Diverging Flow Tracer Tests in Fractured Granite: Equipment Design and Data Collection, M.S. Thesis, University of Arizona, 72 pp.
- Carslaw, H.S. and J.C. Jaeger, 1959, Conduction of Heat in Solids, Clarendon Press, 510 pp.
- Dachler, 1936, cited from Hvorslev, M.J., 1951, Time Lag and Soil Permeability in Groundwater Observations, Bulletin 36, US Army Eng. Waterways Exp. Sta., Vicksburg, Miss.
- Davies, Bill, 1987, Measurement of Thermal Conductivity and Diffusivity in an Unsaturated, Welded Tuff, M.S. Thesis, University of Arizona.
- Elder, Alexander N., 1988, Theoretical Calibration of Neutron Gauges, M.S. Thesis, University of Arizona.
- Evans, D.D., 1983, Unsaturated Flow and Transport Through Fractured Rock - Related to High-Level Waste Repositories, NUREG/CR-3206, 231 pp.
- Gelhar, L.W., 1982, Analysis of Two-Well Tracer Tests with a Pulse Input, RHO-BW-CR-131 P.
- Glover, R.E., 1953, Flow From a Test-Hole Above Groundwater Level, in Theory and Problems of Water Percolation, U.S. Bureau of Reclamation Engineering Monograph No. 8, p. 66-71.
- Goodman, R.E., 1976, Methods of Geological Engineering in Discontinuous Rocks, West Publishing, 472 pp.
- Grimestad, G., 1981, Inverse Solutions of the Theis Equation Determined with Programmable Calculators, Ground Water, 19(4):387-391.
- Klinkenberg, L.J., 1941, The Permeability of Porous Media to Liquids and Gases, Am. Pet. Inst., Drilling and Production Practice.
- Klute, A., 1964, Water Diffusivity, in Methods of Soil Analysis, Part 1, Am. Soc. Agron., Soil Sci. Soc. Am., 262:272.
- Kool, J.B. and J.C. Parker, 1987, SFIT: Estimating Soil Hydraulic Properties from Transient Flow Experiments, User's Guide, v. 1.0, Soil and Environmental Sciences, Agron. Dept., Virginia Tech, Blacksburg, VA.
- Micromeritics, 1986, Instruction Manual for Poresizer 9310.
- Peterson, D.W., 1961, Dacitic Ash-Flow Sheet Near Superior and Globe, Arizona, Ph.D. Dissertation, Stanford University.
- Peterson, D.W., 1968, Zoned Ash-Flow Sheet in the Region Around Superior, Arizona, in Titley, S.R. (ed.), Southern Arizona Guidebook III, Geol. Soc. Am., p. 215-222.
- Philip, J.R., 1985, Approximate Analysis of the Borehole Permeameter in Unsaturated Soil, Water Resour. Res., 21(7):1025-1033.
- Rasmussen, T.C., 1986, Improved Site Characterization Using Multiple Approaches, in Groundwater Flow and Transport Modeling for Performance Assessment of Deep Geologic Disposal of Radioactive Waste, NUREG/CP-0079, pp. 101-113.
- Rasmussen, T.C. and D.D. Evans, 1987, Unsaturated Flow and Transport Through Fractured Rock - Related To High-Level Waste Repositories, Phase II, NUREG/CR-4655, 475 pp.

- Thorstenson, D.C. and D.W. Pollock, 1989, Gas Transport in Unsaturated Porous Media: The Adequacy of Fick's Law, Review of Geophysics, 27(1):-61-78.
- Tidwell, V.C., 1988, Determination of the Equivalent Saturated Hydraulic Conductivity of Fractured Rock Located in the Vadose Zone, M.S. Thesis, University of Arizona, 135 pp.
- Tidwell, V.C., T.C. Rasmussen, and D.D. Evans, 1988, Saturated Hydraulic Conductivity Estimates for Fractured Rock in the Unsaturated Zone, Proc. of International Conference and Workshop on the Validation of Flow and Transport Models for the Unsaturated Zone, Ruidoso, N.M., May 25-28.
- Tsang, Y.W. and K. Pruess, 1987, A Study of Thermally Induced Convection Near a High-Level Nuclear Waste Repository in Partially Saturated Fractured Tuff, Water Resour. Res., 23(3):467-480.
- Van Genuchten, R., 1978, Calculating the Unsaturated Hydraulic Conductivity with a New Closed-Form Analytical Model, Research Report 78-WR-08, Princeton University, N.J., 50 pp.
- Van Genuchten, R., 1980, "A Closed-Form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils", Soil Sci. Am. J., (44):892-898.
- Vogt, G.T., 1988, Porosity, Pore-Size Distribution and Pore Surface Area of the Apache Leap Tuff Near Superior, Arizona Using Mercury Intrusion, 130 pp.
- Weber, D., 1986, Mineralogic, Isotopic and Spatial Properties of Fractures in an Unsaturated Partially-Welded Tuff near Superior, Arizona, M.S. Thesis, University of Arizona, Tucson, 128 pp.
- Yeh, T.-C.J., T.C. Rasmussen and D.D. Evans, 1988, Simulation of Liquid and Vapor Movement in Unsaturated Fractured Rock at the Apache Leap Tuff Site: Models and Strategies, NUREG/CR-5097, 73 pp.
- Zimmer, P.W., 1963, Orientation of Small Diameter Drill Core, Econ. Geol., 58:1313-1325.

Table A1: Local coordinates in meters of borehole casing lip, ground surface and borehole bottom at the Apache Leap Tuff Site. (x,y) plane is perpendicular to local gravity vector, z, directed upward.

	Casing Lip (m)			Ground Surface (m)			Borehole Bottom (m)		
	(x)	(y)	(z)	(x)	(y)	(z)	(x)	(y)	(z)
X1	0.00	0.00	0.00	0.00	0.00	-0.95	-13.68	0.00	-13.68
X2	10.12	0.01	-0.05	9.14	0.01	-0.38	-13.16	0.01	-23.33
X3	20.15	0.00	0.00	19.02	0.08	-0.33	-12.52	0.00	-32.68
Y1	-0.12	-4.94	-0.04	-1.15	-4.81	-0.33	-12.29	-4.94	-12.21
Y2	9.75	-4.85	-0.34	8.65	-4.74	-0.59	-12.26	-4.85	-22.35
Y3	19.78	-4.68	-0.32	19.04	-4.61	-0.61	-12.04	-4.68	-32.14
Z1	9.25	-10.04	-0.36	10.17	-9.96	-0.56	21.32	-10.04	-12.43
Z2	-0.58	-9.99	-0.21	1.05	-9.95	-0.54	21.66	-9.99	-22.59
Z3	-10.31	-10.04	-0.02	-9.32	-9.96	-0.23	21.64	-10.04	-31.67

Table A2: Location of borehole samples at the Apache Leap Tuff Site.
Depth is inclined distance along borehole.

ID	Depth (m)	ID	Depth (m)	ID	Depth (m)
X1:		Y1:		Z1:	
AA	2.1	GB	1.8	PB	1.8
AB	3.0	GC	3.3	PC	3.0
AC	3.8	GD	4.1	PD	4.0
AD	6.9	GA	6.6	PE	5.9
AE	10.0	GF	9.9	PF	9.2
AF	12.7	GG	12.2	PG	12.4
AG	15.8	GH	15.7	PH	15.3
X2:		Y2:		Z2:	
CA	1.8	JB	1.8	SB	2.0
CB	2.8	JC	3.3	SC	3.0
CC	3.5	JD	4.1	SD	4.0
CD	6.6	JE	6.2	SE	6.5
CE	10.0	JF	9.3	SF	9.3
CF	12.7	JG	12.3	SG	12.4
CG	16.1	JH	15.3	SH	15.3
CH	18.5	JJ	18.5	SJ	18.7
CJ	21.6	JK	21.3	SK	21.3
CK	24.7	JM	24.5	SM	24.5
CM	27.9	JN	27.3	SN	27.4
CN	30.8	JP	30.3	SP	30.5
X3:		Y3:		Z3:	
EA	1.8	MB	2.0	UW	2.0
EB	2.7	MC	3.1	UC	3.0
EC	3.8	MD	4.1	UD	3.8
ED	6.8	ME	6.2	UE	6.6
EE	9.9	MF	9.3	UF	9.8
EF	12.9	MG	12.4	UG	12.7
EG	15.8	MH	16.0	UH	15.8
EH	18.8	MJ	18.2	UJ	18.8
EJ	21.6	MK	21.4	UK	21.6
EK	24.7	MM	24.2	UM	24.7
EM	27.7	MN	27.4	UN	27.7
EN	31.0	MP	30.3	UP	30.7
EP	33.7	MR	33.2	UR	33.7
ER	36.9	MS	36.5	US	36.8
ES	39.9	MT	39.3	UT	39.7
ET	42.9	MU	42.1	UU	42.9

Table A3: Bulk and skeletal densities, in Mg/m³ for three core segment sizes at 105 locations at the Apache Leap Tuff Site.

Sample ID	Bulk Density (Mg/m ³)			Skeletal Density (Mg/m ³)		
	small	medium	large	small	medium	large
X1 AA	1.99	2.11	2.11	2.43	2.37	2.56
AB	2.02	2.13	2.13	2.34	2.42	2.55
AC	1.99	2.15	2.13	2.33	2.48	2.59
AD	2.05	2.18	2.12	2.46	2.46	2.54
AE	1.94	2.18	1.99	2.32	2.50	2.34
AF	1.88	2.16	2.18	2.28	2.54	2.60
AG	1.88	2.16	2.18	2.24	2.52	2.60
X2 CA	1.94	2.08	1.97	2.46	2.43	2.50
CB	1.90	2.04	2.06	2.35	2.26	2.54
CC	1.98	2.03	2.04	2.36	2.27	2.51
CD	2.04	2.14	2.12	2.40	2.47	2.48
CE	2.07	2.11	2.13	2.46	2.51	2.57
CF	1.90	2.13	2.00	2.29	2.51	2.44
CG	2.09	2.00	2.06	2.47	2.44	2.52
CH	2.09	2.18	2.07	2.44	2.56	2.57
CJ	1.85	2.17	2.15	2.35	2.53	2.59
CK	1.88	2.15	2.06	2.30	2.56	2.56
CM	2.00	2.10	2.09	2.43	2.51	2.58
CN	1.98	2.15	2.09	2.33	2.55	2.59
X3 EA	1.85	1.94	2.04	2.45	2.21	2.58
EB	2.05	2.01	1.97	2.47	2.34	2.47
EC	1.93	2.07	2.00	2.41	2.45	2.47
ED	2.01	2.13	2.10	2.40	2.44	2.51
EE	2.06	2.15	2.16	2.42	2.47	2.55
EF	2.07	2.18	2.15	2.41	2.51	2.52
EG	1.90	2.23	2.14	2.27	2.57	2.54
EH	2.10	2.16	2.19	2.43	2.53	2.56
EJ	2.12	2.20	2.16	2.38	2.51	2.56
EK	2.02	2.19	2.17	2.35	2.55	2.58
EM	2.00	2.25	2.16	2.40	2.56	2.58
EN	2.05	2.11	2.07	2.40	2.52	2.50
EP	1.97	2.10	2.12	2.44	2.54	2.56
ER	1.98	2.19	2.12	2.41	2.59	2.56
ES	2.03	2.15	2.11	2.42	2.53	2.58
ET	2.03	2.11	2.12	2.41	2.50	2.57

Table A3 (Continued)

Sample ID	Bulk Density (Mg/m ³)			Skeletal Density (Mg/m ³)		
	small	medium	large	small	medium	large
Y1 GB	2.04	2.12	2.17	2.40	2.46	2.60
GC	2.01	2.15	2.14	2.34	2.44	2.56
GD	2.00	2.14	2.13	2.34	2.47	2.56
GA	2.00	2.10	2.13	2.34	2.43	2.55
GF	1.85	2.11	2.09	2.26	2.53	2.57
GG	1.97	2.13	2.13	2.35	2.54	2.53
GH	2.11	2.18	2.17	2.48	2.54	2.57
Y2 JB	1.77	2.02	2.01	2.26	2.43	2.63
JC	1.91	2.25	2.04	2.41	2.56	2.52
JD	1.75	2.21	2.08	2.23	2.55	2.55
JE	2.03	2.12	2.08	2.37	2.62	2.51
JF	1.89	2.10	2.13	2.30	2.41	2.58
JG	2.01	2.13	2.04	2.39	2.50	2.58
JH	1.86	2.11	2.11	2.43	2.51	2.57
JJ	1.97	2.17	2.00	2.48	2.52	2.53
JK	1.76	2.14	2.11	2.33	2.54	2.54
JM	1.83	2.07	2.08	2.28	2.50	2.53
JN	2.03	2.15	2.08	2.40	2.57	2.53
JP	1.96	2.19	2.12	2.35	2.50	2.61
Y3 MB	1.92	1.99	2.02	2.45	2.32	2.54
MC	1.98	1.94	2.03	2.45	2.28	2.61
MD	1.93	2.14	2.05	2.41	2.72	2.64
ME	1.97	2.15	2.01	2.39	2.52	2.48
MF	2.06	2.15	2.17	2.44	2.57	2.53
MG	1.81	2.02	1.90	2.39	2.44	2.62
MH	1.91	2.11	2.10	2.47	2.47	2.55
MJ	2.14	2.23	2.18	2.47	2.55	2.55
MK	2.11	2.24	2.20	2.48	2.55	2.57
MM	2.07	2.23	2.15	2.44	2.59	2.52
MN	2.02	2.20	2.15	2.38	2.58	2.56
MP	2.08	2.16	2.14	2.48	2.56	2.60
MR	2.00	2.19	2.17	2.44	2.59	2.62
MS	2.05	2.10	2.12	2.48	2.54	2.59
MT	2.00	2.09	2.13	2.49	2.55	2.57
MU	2.17	2.15	2.15	2.45	2.55	2.59

Table A3 (Continued)

Sample ID	Bulk Density (Mg/m ³)			Skeletal Density (Mg/m ³)		
	small	medium	large	small	medium	large
Z1 PB	1.92	2.15	1.94	2.40	2.47	2.37
PC	1.92	2.07	2.03	2.40	2.39	2.47
PD	1.96	2.05	2.07	2.40	2.44	2.68
PE	1.99	2.10	2.11	2.40	2.37	2.50
PF	2.00	2.19	2.16	2.37	2.48	2.55
PG	1.99	2.13	2.09	2.37	2.41	2.52
PH	1.99	2.12	2.12	2.47	2.49	2.51
Z2 SB	2.01	2.18	2.14	2.43	2.53	2.60
SC	2.06	2.20	2.18	2.44	2.51	2.61
SD	2.00	2.08	2.11	2.44	2.38	2.54
SE	2.04	2.13	2.11	2.44	2.50	2.54
SF	2.01	2.06	2.03	2.43	2.47	2.56
SG	2.05	1.94	1.86	2.40	2.22	2.51
SH	2.03	2.03	2.08	2.40	2.36	2.51
SJ	2.07	2.10	2.13	2.45	2.44	2.54
SK	1.94	2.10	2.17	2.34	2.41	2.54
SM	2.05	2.17	2.17	2.40	2.50	2.54
SN	1.98	2.15	2.15	2.45	4.11	2.53
SP	1.99	2.08	2.06	2.42	2.55	2.50
Z3 UW	2.05	2.23	2.17	2.38	2.55	2.58
UC	2.04	2.16	2.12	2.38	2.51	2.55
UD	2.06	2.14	2.05	2.39	2.52	2.53
UE	2.06	2.10	2.10	2.47	2.31	2.54
UF	2.04	2.08	2.10	2.45	2.44	2.52
UG	1.99	2.17	2.06	2.42	2.56	2.56
UH	2.03	2.06	2.00	2.45	2.33	2.48
UJ	1.92	2.19	2.16	2.40	2.52	2.54
UK	2.00	2.25	2.18	2.40	2.56	2.57
UM	2.04	2.18	2.16	2.41	2.56	2.57
UN	2.05	2.23	2.19	2.43	2.63	2.59
UP	2.17	2.22	2.18	2.53	2.50	2.56
UR	2.04	2.19	2.14	2.47	2.59	2.59
US	1.88	2.13	2.09	2.48	2.56	2.50
UT	2.07	2.14	2.11	2.46	2.58	2.54
UU	2.03	2.19	2.12	2.43	2.56	2.54

Table A4: Effective porosity for three core segment sizes and pore area values for small core segment sizes at 105 locations at the Apache Leap Tuff Site.

Sample ID	Effective Porosity (%)			Pore Area (m ² /kg)
	small	medium	large	
X1 AA	17.84	10.91	17.61	3008.
AB	13.97	11.84	16.34	3092.
AC	14.68	13.50	17.45	3163.
AD	16.60	12.40	16.63	3623.
AE	16.02	12.80	15.16	3000.
AF	17.51	15.10	16.23	3172.
AG	16.20	14.10	16.20	3241.
X2 CA	21.05	14.20	21.10	4939.
CB	19.10	9.80	18.79	2666.
CC	16.28	10.50	18.80	3128.
CD	15.04	13.50	14.56	2961.
CE	15.67	15.85	17.39	3208.
CF	17.07	15.31	17.87	3072.
CG	15.56	17.94	18.38	3362.
CH	14.57	14.88	19.56	3158.
CJ	20.99	14.19	16.92	2938.
CK	18.45	16.13	20.52	3435.
CM	17.63	16.33	19.07	3594.
CN	15.23	15.91	19.53	3081.
X3 EA	24.73	12.20	20.71	3202.
EB	16.94	14.36	20.15	4145.
EC	19.80	15.40	18.82	3232.
ED	16.47	12.80	16.41	2812.
EE	14.92	13.20	14.96	2934.
EF	14.04	13.09	14.80	2825.
EG	16.54	13.23	15.68	2963.
EH	13.70	14.31	14.30	2843.
EJ	11.02	12.55	15.37	2207.
EK	14.32	14.02	15.96	2813.
EM	16.57	12.27	16.22	2852.
EN	16.52	16.34	17.26	3492.
EP	19.19	17.47	17.35	2925.
ER	17.91	15.38	17.49	2877.
ES	16.16	14.91	18.31	3408.
ET	15.79	15.39	17.42	3319.

Table A4 (Continued)

Sample ID	Effective Porosity (%)			Pore Area (m ² /kg)
	small	medium	large	
Y1 GB	14.99	13.70	16.71	3258.
GC	14.35	11.90	16.62	3315.
GD	14.41	13.33	16.69	3673.
GA	14.78	13.93	16.37	3312.
GF	18.35	16.61	18.82	2776.
GG	16.19	15.99	15.96	2524.
GH	15.25	11.22	15.65	2667.
Y2 JB	21.61	16.65	23.40	4051.
JC	20.56	12.20	19.16	3429.
JD	21.73	13.30	18.61	5364.
JE	14.34	19.00	16.87	16160.
JF	17.86	12.83	17.21	2291.
JG	15.89	14.95	20.64	3286.
JH	23.55	15.94	18.18	3077.
JJ	20.55	13.76	20.82	2916.
JK	24.30	16.03	16.90	2819.
JM	19.75	17.37	17.59	3570.
JN	15.49	16.60	17.63	3222.
JP	16.64	12.38	18.67	2500.
Y3 MB	21.67	14.40	20.48	10069.
MC	19.15	14.90	21.97	16513.
MD	19.83	21.20	22.43	13743.
ME	19.44	14.64	18.86	2812.
MF	15.58	16.42	14.33	3302.
MG	24.51	17.37	27.51	3559.
MH	22.83	14.64	17.79	3282.
MJ	13.64	12.63	14.55	2402.
MK	14.89	11.96	14.49	2055.
MM	15.10	13.68	14.70	2728.
MN	15.04	14.85	16.15	2620.
MP	16.35	15.50	17.61	2890.
MR	18.00	15.70	16.43	2871.
MS	17.21	17.21	18.17	2851.
MT	19.58	18.10	17.16	2626.
MU	11.48	15.61	16.94	3209.

Table A4 (Continued)

Sample ID	Effective Porosity (%)			Pore Area (m ² /kg)
	small	medium	large	
Z1 PB	19.84	12.80	18.31	3691.
PC	20.27	13.30	17.94	3765.
PD	18.55	15.70	22.56	4015.
PE	17.40	11.61	15.49	2599.
PF	15.64	11.50	15.29	2586.
PG	16.06	11.68	17.23	2491.
PH	19.56	14.75	15.74	2592.
Z2 SB	17.14	13.80	17.57	3603.
SC	15.67	12.50	16.58	3010.
SD	18.03	12.70	16.87	2832.
SE	16.25	14.51	16.93	3572.
SF	17.30	16.92	20.84	3147.
SG	14.88	12.27	25.77	3697.
SH	15.39	14.12	17.44	3241.
SJ	15.57	13.95	16.11	2603.
SK	17.10	12.81	14.55	2430.
SM	14.71	13.24	14.77	2606.
SN	19.30	47.58	14.98	2627.
SP	17.84	18.47	17.54	2148.
Z3 UW	13.73	12.50	16.12	3293.
UC	14.48	14.08	16.80	3207.
UD	13.70	15.07	18.82	2916.
UE	16.37	9.18	17.41	2407.
UF	16.71	14.53	16.53	3133.
UG	17.72	15.18	19.40	2858.
UH	17.14	11.77	19.41	3009.
UJ	19.83	13.12	14.98	2938.
UK	16.52	12.13	14.94	2389.
UM	15.38	14.83	15.71	2181.
UN	15.97	15.19	15.31	2483.
UP	14.29	11.16	14.82	1960.
UR	17.66	15.50	17.45	2679.
US	24.27	16.65	16.47	2686.
UT	15.81	16.99	16.90	2924.
UU	16.14	14.32	16.53	3181.

Table A5a: Equivalent pore diameters (in micrometers) for mercury intrusion injection pressures assuming a surface tension of 0.485 Pa m, and a wetting angle of 130°. Table is for use in evaluating Table A5b.

ID		Pore Diameter (micrometers) for Data in Table A5b							
X1	AA	14.0	9.19	7.64	6.31	4.94	4.05	3.26	2.61
		2.05	1.66	1.27	1.02	0.80	0.619	0.497	0.384
		0.306	0.236	0.186	0.146	0.115	0.0896	0.0699	0.0548
		0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
	AB	14.0	9.19	7.64	6.10	5.09	4.07	3.21	2.61
		2.08	1.64	1.30	1.01	0.808	0.633	0.493	0.389
		0.303	0.238	0.187	0.147	0.115	0.0896	0.0701	0.0550
		0.0430	0.0337	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
	AC	14.0	9.30	7.41	6.37	5.13	4.01	3.29	2.63
		2.08	1.65	1.30	1.03	0.809	0.627	0.491	0.384
		0.303	0.238	0.186	0.147	0.115	0.0896	0.0701	0.0550
		0.0430	0.0337	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
	AD	13.8	9.30	7.71	6.36	4.96	4.07	3.26	2.61
		2.00	1.66	1.29	1.02	0.80	0.626	0.498	0.389
		0.306	0.238	0.187	0.147	0.115	0.0899	0.0701	0.0548
		0.0429	0.0336	0.0262	0.0262	0.0161	0.0125	0.0098	0.0077
AE	13.8	9.30	7.72	6.37	5.12	4.09	3.29	2.59	
	2.06	1.59	1.28	1.03	0.802	0.629	0.499	0.385	
	0.305	0.238	0.188	0.147	0.115	0.0899	0.0703	0.0550	
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077	
AF	13.8	9.30	7.40	6.36	5.11	4.09	3.29	2.62	
	2.08	1.66	1.30	1.03	0.802	0.623	0.494	0.386	
	0.306	0.240	0.187	0.147	0.115	0.0899	0.0703	0.0550	
	0.0430	0.0337	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077	
AG	14.0	9.30	7.71	6.36	5.11	4.08	3.22	2.62	
	2.08	1.65	1.30	1.03	0.795	0.629	0.495	0.387	
	0.306	0.238	0.187	0.147	0.115	0.0896	0.0704	0.0550	
	0.0430	0.0337	0.0262	0.0205	0.0160	0.0125	0.0098	0.0077	
X2	CA	14.0	8.85	7.46	6.41	5.15	4.11	3.24	2.63
		2.06	1.66	1.29	1.03	0.805	0.631	0.497	0.389
		0.303	0.239	0.187	0.146	0.115	0.0896	0.0701	0.0544
		0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
	CB	14.2	9.30	7.40	6.36	5.11	4.00	3.22	2.62
		2.08	1.66	1.29	1.02	0.797	0.628	0.499	0.383
		0.295	0.237	0.188	0.146	0.115	0.0899	0.0701	0.0548
		0.0430	0.0336	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077

Table A5a (Continued)

ID	Pore Diameter (micrometers) for Data in Table A5b							
CC	14.1	9.30	7.71	6.36	4.97	4.08	3.27	2.58
	2.05	1.64	1.25	1.02	0.808	0.595	0.494	0.387
	0.300	0.238	0.186	0.146	0.115	0.0896	0.0701	0.0550
	0.0429	0.0336	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
CD	13.7	9.30	7.72	6.37	5.12	4.10	3.23	2.59
	2.08	1.65	1.30	1.02	0.791	0.633	0.487	0.384
	0.302	0.239	0.188	0.144	0.114	0.0899	0.0701	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
CE	13.9	9.30	7.72	6.37	5.13	4.11	3.30	2.64
	2.09	1.67	1.30	1.03	0.786	0.634	0.498	0.387
	0.306	0.24	0.187	0.147	0.115	0.09	0.0701	0.0550
	0.0430	0.0336	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
CF	13.7	9.30	7.71	6.36	5.12	4.10	3.29	2.63
	2.09	1.67	1.31	1.02	0.799	0.621	0.498	0.383
	0.305	0.238	0.187	0.145	0.115	0.0896	0.0703	0.0550
	0.0430	0.0336	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
CG	13.8	9.30	7.72	6.38	5.15	4.12	3.25	2.60
	2.10	1.64	1.31	1.03	0.804	0.633	0.499	0.388
	0.302	0.238	0.187	0.146	0.115	0.09	0.0704	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0099	0.0077
CH	13.7	8.85	7.72	6.38	5.14	4.02	3.24	2.63
	2.09	1.67	1.31	1.03	0.8110	0.6260	0.498	0.386
	0.299	0.238	0.186	0.147	0.115	0.0896	0.0701	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
CJ	13.6	9.30	7.71	6.36	5.10	3.99	3.27	2.62
	2.08	1.66	1.29	1.03	0.809	0.633	0.495	0.39
	0.302	0.239	0.188	0.147	0.115	0.0899	0.0703	0.0550
	0.0430	0.0336	0.0262	0.0205	0.0160	0.0125	0.0098	0.0077
CK	13.8	9.30	7.71	6.36	5.11	3.99	3.29	2.59
	2.09	1.67	1.30	1.03	0.811	0.635	0.492	0.384
	0.303	0.239	0.188	0.147	0.115	0.09	0.0701	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
CM	13.8	9.30	7.71	5.94	5.11	4.09	3.23	2.59
	2.09	1.67	1.31	1.03	0.806	0.625	0.49	0.385
	0.304	0.237	0.188	0.147	0.115	0.0899	0.0703	0.0550
	0.0430	0.0336	0.0263	0.0206	0.0161	0.0125	0.0098	0.0077
CN	13.9	9.30	7.71	6.36	4.96	4.07	3.26	2.61
	2.09	1.65	1.31	1.03	0.807	0.632	0.50	0.382
	0.306	0.237	0.188	0.146	0.114	0.09	0.0704	0.0550
	0.0430	0.0336	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077

Table A5a (Continued)

ID	Pore Diameter (micrometers) for Data in Table A5b							
X3 EA	14.1	9.30	7.40	6.37	5.11	4.08	3.27	2.62
	2.08	1.66	1.29	1.03	0.808	0.626	0.499	0.386
	0.30	0.239	0.188	0.147	0.115	0.0896	0.0703	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
EB	13.7	8.84	7.71	6.36	4.97	4.07	3.27	2.61
	2.07	1.66	1.28	1.03	0.804	0.633	0.496	0.385
	0.306	0.238	0.188	0.147	0.115	0.0896	0.0703	0.0548
	0.0430	0.0337	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
EC	13.9	9.30	7.72	6.38	5.13	4.01	3.30	2.59
	2.09	1.65	1.31	1.03	0.81	0.634	0.497	0.386
	0.303	0.238	0.187	0.146	0.115	0.09	0.0704	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0160	0.0125	0.0098	
ED	13.7	9.30	7.71	6.37	5.12	4.09	3.28	2.58
	2.08	1.66	1.27	1.03	0.801	0.631	0.497	0.382
	0.302	0.239	0.187	0.146	0.115	0.0899	0.0703	0.0550
	0.0430	0.0337	0.0263	0.0206	0.0161	0.0125	0.0098	0.0077
EE	14.0	9.30	7.72	5.94	5.13	4.10	3.29	2.63
	2.06	1.67	1.31	1.02	0.809	0.625	0.491	0.388
	0.306	0.239	0.187	0.147	0.115	0.0899	0.0704	0.0550
	0.0430	0.0337	0.0263	0.0206	0.0161	0.0125	0.0098	0.0077
EF	13.8	9.30	7.72	6.37	5.13	4.10	3.23	2.62
	2.08	1.66	1.28	1.03	0.801	0.633	0.499	0.385
	0.302	0.238	0.187	0.147	0.115	0.0899	0.0703	0.0550
	0.0430	0.0337	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
EG	14.0	9.30	7.71	6.14	5.10	4.08	3.28	2.62
	2.08	1.66	1.29	1.03	0.805	0.629	0.476	0.388
	0.302	0.236	0.186	0.147	0.114	0.0899	0.0703	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0124	0.0098	0.0077
EH	13.8	8.85	7.71	6.36	5.11	4.08	3.28	2.63
	2.09	1.65	1.31	1.03	0.809	0.625	0.494	0.389
	0.3	0.237	0.186	0.146	0.114	0.0899	0.0701	0.0550
	0.0430	0.0337	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
EJ	13.9	9.30	7.40	6.36	5.11	4.08	3.28	2.62
	2.09	1.67	1.31	1.03	0.806	0.632	0.491	0.389
	0.304	0.24	0.187	0.147	0.115	0.0899	0.0701	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
EK	13.7	9.30	7.71	6.14	4.96	4.08	3.21	2.62
	2.08	1.66	1.30	1.03	0.809	0.634	0.494	0.389
	0.305	0.238	0.187	0.147	0.115	0.0896	0.0701	0.0548
	0.0430	0.0336	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077

- - - - -
Table A5a (Continued)
- - - - -

ID	Pore Diameter (micrometers) for Data in Table A5b							
EM	13.9	9.30	7.71	6.36	5.11	4.08	3.28	2.58
	2.08	1.66	1.31	1.02	0.799	0.632	0.498	0.386
	0.306	0.239	0.187	0.146	0.115	0.0899	0.0701	0.0550
	0.0429	0.0337	0.0263	0.0206	0.0161	0.0125	0.0098	0.0077
EN	13.8	9.30	7.71	6.36	5.11	4.08	3.28	2.62
	2.06	1.67	1.31	1.03	0.81	0.634	0.486	0.386
	0.303	0.239	0.187	0.147	0.115	0.0899	0.0701	0.0550
	0.0430	0.0336	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
EP	13.9	9.30	7.71	6.36	5.11	4.07	3.27	2.62
	2.09	1.67	1.31	1.03	0.803	0.634	0.498	0.388
	0.306	0.238	0.187	0.146	0.115	0.0899	0.0701	0.0550
	0.0430	0.0337	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
ER	13.8	9.30	7.40	6.36	5.10	3.99	3.27	2.62
	2.08	1.66	1.30	1.03	0.806	0.632	0.499	0.387
	0.304	0.238	0.187	0.147	0.115	0.0899	0.0701	0.0550
	0.0430	0.0337	0.0262	0.0205	0.0161	0.0125	0.0098	
ES	13.8	9.30	7.40	6.36	4.96	4.07	3.27	2.61
	2.08	1.65	1.30	1.02	0.802	0.633	0.498	0.384
	0.302	0.239	0.185	0.147	0.115	0.0896	0.0703	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
ET	13.7	8.84	7.40	6.14	5.10	4.08	3.27	2.58
	2.08	1.66	1.30	1.03	0.809	0.625	0.492	0.385
	0.303	0.237	0.186	0.146	0.115	0.0899	0.0703	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
Y1 GB	14.2	9.30	7.71	6.36	5.11	4.09	3.29	2.63
	2.06	1.66	1.30	1.03	0.792	0.634	0.498	0.383
	0.302	0.237	0.187	0.146	0.115	0.0896	0.0704	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
GC	13.9	9.30	7.71	6.14	4.97	4.08	3.28	2.62
	2.08	1.66	1.30	1.03	0.805	0.633	0.493	0.385
	0.301	0.239	0.186	0.147	0.115	0.0899	0.0701	0.0547
	0.0430	0.0336	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
GD	-	9.30	7.71	6.36	5.11	4.08	3.27	2.62
	2.08	1.66	1.27	1.03	0.808	0.631	0.491	0.389
	0.306	0.234	0.187	0.147	0.115	0.0896	0.0703	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
GA	13.6	9.30	7.72	6.37	5.13	4.10	3.29	2.62
	2.08	1.66	1.30	1.03	0.801	0.629	0.499	0.386
	0.301	0.239	0.187	0.146	0.115	0.0896	0.0701	0.0550
	0.0430	0.0336	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077

Table A5a (Continued)

ID	Pore Diameter (micrometers) for Data in Table A5b							
GF	13.9	9.30	7.71	6.38	5.15	4.12	3.31	2.64
	2.07	1.65	1.31	1.03	0.796	0.617	0.495	0.383
	0.30	0.236	0.188	0.146	0.115	0.0899	0.0701	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
GG	13.8	9.30	7.40	6.36	5.12	4.10	3.29	2.59
	2.06	1.67	1.31	1.03	0.807	0.634	0.498	0.386
	0.297	0.237	0.186	0.146	0.113	0.0899	0.0704	0.0547
	0.0430	0.0336	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
GH	13.8	9.30	7.71	6.14	4.97	4.09	3.29	2.62
	2.08	1.66	1.30	1.03	0.807	0.623	0.50	0.39
	0.306	0.238	0.187	0.146	0.115	0.0896	0.0701	0.0547
	0.0430	0.0337	0.0262	0.0206	0.0161	0.0125	0.0098	0.0077
Y2 JB	13.7	8.85	7.40	6.15	5.13	4.10	3.28	2.59
	2.06	1.66	1.30	1.03	0.791	0.61	0.488	0.384
	0.304	0.239	0.188	0.147	0.114	0.0896	0.0704	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
JC	13.8	9.30	7.40	6.36	5.10	4.07	3.21	2.43
	2.07	1.65	1.30	1.03	0.807	0.632	0.487	0.386
	0.3050	0.2380	0.1870	0.1470	0.1150	0.0892	0.0701	0.0550
	0.0429	0.0336	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
JD	13.9	9.30	7.71	6.36	5.10	4.07	3.21	2.61
	2.07	1.66	1.29	1.03	0.796	0.632	0.489	0.387
	0.306	0.239	0.187	0.147	0.115	0.0896	0.0703	0.0548
	0.0430	0.0336	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
JE	-	9.30	7.71	6.36	5.10	4.07	3.20	2.60
	2.07	1.64	1.30	1.03	0.782	0.617	0.498	0.386
	0.302	0.238	0.188	0.147	0.115	0.0895	0.0703	0.0548
	0.0430	0.0336	0.0263	0.0206	0.0161	0.0125	0.0098	0.0077
JF	13.8	9.30	7.74	6.40	5.16	4.03	3.30	2.64
	2.07	1.67	1.31	1.03	0.796	0.634	0.498	0.388
	0.306	0.238	0.187	0.147	0.115	0.0896	0.0704	0.0548
	0.0430	0.0336	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
JG	13.7	9.30	7.71	6.37	5.12	4.10	3.28	2.62
	2.08	1.66	1.29	1.02	0.805	0.618	0.492	0.386
	0.301	0.237	0.186	0.146	0.114	0.0899	0.0703	0.0550
	0.0430	0.0336	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
JH	13.8	9.30	7.71	6.36	5.12	4.10	3.29	2.63
	2.09	1.65	1.31	1.03	0.799	0.617	0.490	0.383
	0.303	0.237	0.187	0.146	0.115	0.0896	0.0704	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077

Table A5a (Continued)

ID	Pore Diameter (micrometers) for Data in Table A5b							
JJ	13.8	9.30	7.40	6.37	5.12	4.09	3.23	2.63
	2.08	1.65	1.30	1.03	0.809	0.633	0.488	0.389
	0.302	0.235	0.185	0.146	0.114	0.0896	0.0701	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
JK	13.8	9.30	7.40	6.37	5.12	4.10	3.29	2.59
	2.09	1.67	1.30	1.03	0.810	0.619	0.490	0.382
	0.303	0.238	0.185	0.147	0.115	0.0899	0.0704	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
JM	13.7	9.30	7.71	6.15	4.98	4.09	3.29	2.63
	2.09	1.67	1.31	1.03	0.810	0.617	0.497	0.381
	0.301	0.237	0.186	0.146	0.115	0.0899	0.0704	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
JN	13.7	8.84	7.71	6.14	5.10	4.07	3.28	2.62
	2.09	1.67	1.31	1.03	0.810	0.634	0.499	0.388
	0.304	0.239	0.187	0.146	0.115	0.0899	0.0701	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
JP	13.7	9.30	7.72	6.37	4.97	3.99	3.28	2.62
	2.08	1.66	1.30	1.03	0.808	0.633	0.499	0.386
	0.298	0.237	0.186	0.146	0.115	0.0896	0.0703	0.0550
	0.0429	0.0337	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
Y3 MB	-	9.30	7.71	6.36	5.10	4.07	3.15	2.60
	2.07	1.65	1.30	1.03	0.803	0.630	0.492	0.384
	0.304	0.236	0.188	0.145	0.115	0.0892	0.0703	0.0549
	0.0429	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
MC	14.0	8.84	7.71	6.36	5.10	4.07	3.26	2.60
	2.04	1.64	1.30	1.03	0.806	0.623	0.495	0.381
	0.3	0.238	0.186	0.147	0.115	0.0899	0.0703	0.0549
	0.0430	0.0336	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
MD	14.0	8.84	7.71	6.36	5.10	4.07	3.26	2.57
	2.07	1.65	1.30	1.03	0.792	0.630	0.498	0.389
	0.304	0.239	0.188	0.147	0.115	0.0896	0.0703	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
ME	13.9	9.30	7.71	6.36	5.12	4.10	3.23	2.62
	2.06	1.65	1.30	1.03	0.809	0.629	0.499	0.382
	0.305	0.238	0.188	0.147	0.115	0.0896	0.0704	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
MF	13.7	8.85	7.72	6.14	5.11	4.08	3.27	2.62
	2.08	1.66	1.30	1.03	0.810	0.632	0.499	0.386
	0.305	0.238	0.187	0.146	0.115	0.0896	0.0704	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077

Table A5a (Continued)

ID	Pore Diameter (micrometers) for Data in Table A5b							
MG	13.7	9.30	7.71	6.36	5.12	3.99	3.22	2.62
	2.05	1.64	1.30	1.03	0.790	0.630	0.497	0.384
	0.304	0.236	0.188	0.146	0.114	0.0899	0.0703	0.0549
	0.0430	0.0336	0.0262	0.0205	0.0160	0.0125	0.0098	0.0077
MH	13.8	9.30	7.71	6.36	4.98	4.09	3.29	2.63
	2.09	1.67	1.30	1.03	0.806	0.625	0.499	0.385
	0.302	0.240	0.187	0.147	0.115	0.0896	0.0704	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
MJ	13.7	9.30	7.71	6.36	5.10	4.07	3.27	2.62
	2.08	1.63	1.30	1.03	0.809	0.627	0.490	0.390
	0.298	0.238	0.188	0.146	0.115	0.0899	0.0701	0.0550
	0.0430	0.0336	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
MK	13.9	9.31	7.72	6.36	5.11	4.07	3.27	2.57
	2.07	1.66	1.30	1.03	0.809	0.633	0.490	0.390
	0.304	0.235	0.186	0.146	0.114	0.0899	0.0701	0.0548
	0.0430	0.0336	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
MM	13.7	8.84	7.71	6.36	5.10	3.98	3.27	2.62
	2.08	1.66	1.30	1.02	0.809	0.627	0.487	0.384
	0.305	0.233	0.188	0.147	0.114	0.0885	0.0701	0.0548
	0.0430	0.0336	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
MN	13.8	9.30	7.71	6.36	5.10	4.07	3.27	2.58
	2.08	1.66	1.30	1.03	0.809	0.614	0.499	0.389
	0.303	0.234	0.187	0.146	0.114	0.0896	0.0703	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
MP	13.6	9.30	7.71	6.36	5.10	4.08	3.28	2.62
	2.08	1.66	1.31	1.03	0.810	0.623	0.494	0.388
	0.304	0.236	0.186	0.146	0.114	0.0892	0.0703	0.0548
	0.0430	0.0337	0.0262	0.0205	0.0160	0.0125	0.0098	0.0077
MR	13.7	9.30	7.40	6.36	4.83	4.07	3.27	2.62
	2.08	1.66	1.31	1.03	0.810	0.625	0.499	0.390
	0.305	0.238	0.187	0.146	0.115	0.0899	0.0704	0.0550
	0.0430	0.0336	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
MS	13.8	8.84	7.40	6.36	5.10	4.07	3.27	2.62
	2.08	1.67	1.31	1.03	0.810	0.632	0.5	0.386
	0.303	0.238	0.184	0.146	0.115	0.0896	0.0704	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
MT	13.7	9.30	7.71	6.36	5.10	4.07	3.26	2.61
	2.08	1.66	1.31	1.03	0.810	0.634	0.5	0.388
	0.303	0.237	0.188	0.147	0.114	0.09	0.0704	0.0550
	0.0430	0.0336	0.0263	0.0206	0.0161	0.0125	0.0098	0.0077

Table A5a (Continued)

ID	Pore Diameter (micrometers) for Data in Table A5b							
MU	13.7	9.30	7.71	6.36	4.96	4.07	3.26	2.61
	2.05	1.66	1.30	1.02	0.798	0.631	0.492	0.386
	0.303	0.237	0.187	0.147	0.115	0.0899	0.0703	0.0550
	0.0430	0.0336	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
Z1 PB	13.9	9.30	7.71	6.36	5.11	3.99	3.27	2.62
	2.08	1.64	1.27	1.02	0.793	0.617	0.498	0.386
	0.303	0.239	0.187	0.147	0.115	0.0896	0.0699	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
PC	13.9	9.30	7.72	6.36	5.12	4.	3.23	2.62
	2.06	1.65	1.28	1.02	0.805	0.6	0.485	0.386
	0.304	0.238	0.187	0.146	0.114	0.0896	0.0701	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
PD	13.8	9.30	7.71	6.36	5.12	4.08	3.28	2.62
	2.08	1.63	1.30	1.03	0.784	0.629	0.497	0.389
	0.304	0.239	0.187	0.147	0.115	0.0899	0.0703	0.0547
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
PE	13.7	9.30	7.72	6.37	5.12	4.09	3.28	2.62
	2.06	1.66	1.30	1.03	0.801	0.626	0.484	0.384
	0.302	0.240	0.185	0.147	0.115	0.0896	0.0703	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
PF	13.9	8.84	7.71	6.36	5.11	4.08	3.28	2.62
	2.06	1.66	1.30	1.03	0.809	0.633	0.494	0.385
	0.3	0.237	0.187	0.147	0.115	0.0899	0.0704	0.0548
	0.0430	0.0336	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
PG	13.7	9.30	7.72	6.37	5.12	4.09	3.28	2.58
	2.08	1.66	1.28	1.03	0.805	0.633	0.499	0.388
	0.302	0.238	0.187	0.147	0.115	0.0899	0.0703	0.0548
	0.0430	0.0336	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
PH	-	8.85	7.40	6.37	4.99	4.10	3.29	2.63
	2.09	1.65	1.31	1.03	0.810	0.627	0.496	0.388
	0.303	0.238	0.184	0.147	0.115	0.0899	0.0703	0.0550
	0.0430	0.0336	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
Z2 SB	14.2	8.85	7.72	6.36	5.11	4.	3.28	2.59
	2.08	1.63	1.30	1.	0.802	0.625	0.496	0.390
	0.302	0.238	0.187	0.147	0.115	0.0899	0.0701	0.0548
	0.0430	0.0336	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
SC	13.8	8.85	7.72	5.95	5.12	4.09	3.28	2.62
	2.08	1.60	1.29	1.02	0.801	0.627	0.499	0.390
	0.306	0.240	0.188	0.146	0.115	0.0896	0.0704	0.0548
	0.0430	0.0337	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077

Table A5a (Continued)

ID	Pore Diameter (micrometers) for Data in Table A5b							
SD	13.9	9.30	7.74	6.40	5.01	4.11	3.29	2.63
	2.06	1.66	1.30	1.02	0.809	0.633	0.498	0.389
	0.303	0.239	0.187	0.146	0.115	0.0899	0.0701	0.0548
	0.0429	0.0336	0.0262	0.0205	0.0160	0.0125	0.0098	0.0077
SE	13.7	8.85	7.71	6.37	5.12	4.	3.28	2.62
	2.08	1.65	1.30	1.03	0.798	0.633	0.491	0.390
	0.304	0.238	0.187	0.147	0.115	0.0899	0.0703	0.0550
	0.0430	0.0337	0.0263	0.0206	0.0161	0.0125	0.0098	0.0077
SF	13.8	9.30	7.72	6.37	5.12	4.10	3.30	2.63
	2.06	1.65	1.29	1.03	0.806	0.634	0.494	0.391
	0.300	0.238	0.187	0.147	0.115	0.0896	0.0699	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
SG	13.9	9.30	7.71	6.14	5.10	4.07	3.27	2.61
	2.07	1.66	1.30	1.03	0.786	0.632	0.498	0.387
	0.303	0.237	0.188	0.146	0.115	0.0896	0.0703	0.0549
	0.0430	0.0337	0.0263	0.0206	0.0160	0.0125	0.0098	0.0077
SH	13.8	9.30	7.40	6.14	5.11	4.08	3.28	2.62
	2.06	1.66	1.30	1.03	0.805	0.624	0.497	0.389
	0.301	0.238	0.188	0.146	0.115	0.0899	0.0701	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
SJ	13.6	8.85	7.40	6.14	5.11	4.08	3.28	2.62
	2.08	1.66	1.30	1.03	0.799	0.625	0.496	0.390
	0.305	0.238	0.188	0.146	0.115	0.0896	0.0701	0.0546
	0.0430	0.0336	0.0262	0.0205	0.0160	0.0125	0.0098	0.0077
SK	13.7	9.30	7.40	6.36	4.96	4.07	3.28	2.62
	2.08	1.66	1.29	1.03	0.809	0.631	0.492	0.382
	0.304	0.239	0.188	0.147	0.115	0.0896	0.0701	0.0550
	0.0430	0.0337	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
SM	13.8	8.85	7.40	6.14	5.11	3.99	3.28	2.62
	2.06	1.66	1.30	1.03	0.809	0.629	0.499	0.387
	0.302	0.238	0.186	0.146	0.115	0.0892	0.0701	0.0550
	0.0430	0.0336	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
SN	13.8	9.08	7.56	5.67	4.53	3.56	2.80	2.20
	1.72	1.35	1.05	0.819	0.644	0.502	0.386	0.305
	0.239	0.187	0.148	0.115	0.0898	0.0705	0.0550	0.0431
	0.0337	0.0263	0.0206	0.0161	0.0125	0.0098	0.0077	
SP	13.7	9.30	7.71	6.14	5.10	4.07	3.27	2.63
	2.09	1.67	1.31	1.03	0.812	0.635	0.491	0.385
	0.306	0.240	0.186	0.146	0.115	0.09	0.0704	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077

Table A5a (Continued)

ID	Pore Diameter (micrometers) for Data in Table A5b							
Z3 UW	13.8	9.30	7.71	6.15	4.97	4.09	3.28	2.62
	2.08	1.64	1.29	1.03	0.808	0.626	0.499	0.388
	0.303	0.238	0.187	0.147	0.115	0.0899	0.0701	0.0550
	0.0429	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
UC	14.0	8.85	7.73	6.39	5.13	4.02	3.24	2.63
	2.09	1.66	1.31	1.03	0.806	0.623	0.497	0.390
	0.302	0.239	0.188	0.147	0.115	0.0896	0.0704	0.0548
	0.0430	0.0336	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
UD	14.0	9.48	7.84	6.22	5.16	4.11	3.30	2.59
	2.04	1.66	1.30	1.03	0.798	0.634	0.487	0.385
	0.305	0.239	0.186	0.145	0.115	0.0899	0.0703	0.0550
	0.0429	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
UE	13.8	9.30	7.72	6.15	5.12	4.09	3.22	2.62
	2.06	1.62	1.28	1.02	0.794	0.620	0.499	0.383
	0.303	0.238	0.188	0.147	0.115	0.0896	0.0701	0.0550
	0.0430	0.0336	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
UF	13.7	9.30	7.72	6.38	5.13	4.09	3.29	2.62
	2.06	1.65	1.30	1.03	0.795	0.622	0.493	0.383
	0.305	0.239	0.187	0.146	0.115	0.0896	0.0699	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
UG	13.8	9.30	7.40	6.37	5.12	4.10	3.29	2.63
	2.08	1.65	1.31	1.02	0.806	0.632	0.499	0.385
	0.304	0.238	0.187	0.147	0.115	0.0899	0.0701	0.0550
	0.0430	0.0337	0.0262	0.0206	0.0161	0.0125	0.0098	0.0077
UH	13.8	8.85	7.72	6.14	5.11	4.07	3.27	2.62
	2.08	1.66	1.29	1.02	0.805	0.624	0.495	0.381
	0.302	0.239	0.187	0.147	0.114	0.0899	0.0701	0.0547
	0.0430	0.0336	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
UJ	13.8	9.30	7.40	6.36	4.97	4.08	3.28	2.62
	2.08	1.66	1.29	1.03	0.802	0.629	0.499	0.390
	0.297	0.236	0.185	0.147	0.115	0.0899	0.0703	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077
UK	13.6	9.30	7.71	6.36	5.10	4.07	3.21	2.61
	2.08	1.66	1.30	1.03	0.809	0.633	0.499	0.386
	0.303	0.239	0.188	0.147	0.115	0.0899	0.0703	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
UM	13.7	8.84	7.71	6.14	5.10	4.07	3.27	2.62
	2.08	1.66	1.31	1.03	0.810	0.634	0.5	0.382
	0.303	0.238	0.187	0.147	0.115	0.0899	0.0704	0.0548
	0.0430	0.0337	0.0263	0.0205	0.0161	0.0125	0.0098	0.0077

- - - - -
Table A5a (Continued)
- - - - -

ID	Pore Diameter (micrometers) for Data in Table A5b							
UN	13.6	9.30	7.40	6.36	5.10	4.07	3.27	2.62
	2.08	1.66	1.30	1.03	0.810	0.627	0.495	0.390
	0.306	0.239	0.186	0.147	0.115	0.0899	0.0703	0.0550
	0.0430	0.0337	0.0263	0.0205	0.0160	0.0125	0.0098	0.0077
UP	13.7	9.32	7.75	6.18	5.14	4.01	3.28	2.58
	2.08	1.65	1.30	1.03	0.808	0.631	0.489	0.382
	0.304	0.234	0.186	0.145	0.114	0.0899	0.0701	0.0550
	0.0429	0.0337	0.0262	0.0205	0.0161	0.0125	-	-
UR	13.8	8.84	7.40	6.14	4.96	3.98	3.27	2.62
	2.08	1.66	1.30	1.03	0.806	0.621	0.499	0.391
	0.305	0.236	0.186	0.147	0.114	0.0896	0.0704	0.0547
	0.0430	0.0337	0.0262	0.0205	0.0160	0.0125	0.0098	0.0077
US	13.7	8.84	7.71	6.36	5.10	4.07	3.27	2.62
	2.08	1.67	1.31	1.03	0.8	0.623	0.495	0.384
	0.306	0.238	0.187	0.146	0.114	0.0896	0.0704	0.0550
	0.0430	0.0337	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077
UT	13.7	8.84	7.40	6.36	5.10	4.07	3.27	2.62
	2.09	1.67	1.31	1.03	0.811	0.630	0.495	0.386
	0.301	0.238	0.187	0.147	0.115	0.0892	0.0704	0.0548
	0.0430	0.0336	0.0262	0.0205	0.0160	0.0125	0.0098	0.0077
UU	-	9.30	7.71	6.14	4.96	4.07	3.27	2.61
	2.05	1.66	1.30	1.03	0.799	0.634	0.498	0.385
	0.304	0.240	0.187	0.147	0.115	0.0896	0.0701	0.0550
	0.0430	0.0337	0.0262	0.0205	0.0161	0.0125	0.0098	0.0077

Table A5b: Cumulative volumetric porosity, expressed in units of m³ water per m³ rock, determined from mercury intrusion volumes for 105 medium core segments. Table is for equivalent pore diameters reported in Table A5a.

ID	Cumulative Volumetric Porosity (m³/m³) for Data in Table A5a								
X1	AA	0.0000	0.0004	0.0004	0.0006	0.0019	0.0027	0.0076	0.0165
		0.0228	0.0266	0.0293	0.0316	0.0346	0.0373	0.0399	0.0426
		0.0454	0.0483	0.0506	0.0536	0.0578	0.0669	0.0760	0.0827
		0.0884	0.0931	0.0973	0.1009	0.1036	0.1059	0.1076	0.1091
	AB	0.0000	0.0004	0.0011	0.0028	0.0068	0.0121	0.0185	0.0239
		0.0285	0.0324	0.0354	0.0392	0.0422	0.0454	0.0484	0.0511
		0.0539	0.0564	0.0590	0.0620	0.0665	0.0752	0.0843	0.0912
		0.0973	0.1024	0.1067	0.1101	0.1127	0.1150	0.1165	0.1178
	AC	0.0000	0.0004	0.0019	0.0045	0.0110	0.0196	0.0288	0.0370
		0.0419	0.0452	0.0479	0.0507	0.0540	0.0568	0.0598	0.0619
		0.0645	0.0669	0.0697	0.0727	0.0783	0.0886	0.0983	0.1058
		0.1127	0.1185	0.1232	0.1264	0.1294	0.1318	0.1337	0.1350
AD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0007	0.0076	
	0.0148	0.0177	0.0198	0.0222	0.0255	0.0286	0.0320	0.0353	
	0.0353	0.0416	0.0449	0.0484	0.0525	0.0604	0.0739	0.0831	
	0.0905	0.0964	0.1020	0.1057	0.1090	0.1116	0.1134	0.1151	
AE	0.0000	0.0002	0.0004	0.0026	0.0076	0.0150	0.0242	0.0336	
	0.0399	0.0440	0.0464	0.0499	0.0534	0.0567	0.0600	0.0626	
	0.0654	0.0685	0.0711	0.0746	0.0780	0.0833	0.0920	0.1001	
	0.1066	0.1123	0.1166	0.1199	0.1230	0.1247	0.1262	0.1275	
AF	0.0000	0.0000	0.0000	0.0006	0.0037	0.0143	0.0276	0.0367	
	0.0462	0.0516	0.0564	0.0616	0.0659	0.0698	0.0730	0.0765	
	0.0799	0.0832	0.0870	0.0907	0.0948	0.1004	0.1080	0.1190	
	0.1285	0.1356	0.1406	0.1441	0.1467	0.1488	0.1503	0.1514	
AG	0.0000	0.0002	0.0002	0.0004	0.0024	0.0091	0.0208	0.0279	
	0.0329	0.0370	0.0415	0.0461	0.0517	0.0565	0.0610	0.0653	
	0.0694	0.0740	0.0779	0.0820	0.0865	0.0924	0.0997	0.1097	
	0.1177	0.1244	0.1294	0.1330	0.1356	0.1378	0.1391	0.1404	
X2	CA	0.0000	0.0012	0.0112	0.0139	0.0196	0.0266	0.0354	0.0428
		0.0428	0.0428	0.0428	0.0428	0.0428	0.0428	0.0428	0.0449
		0.0474	0.0510	0.0564	0.0657	0.0759	0.0842	0.0913	0.0953
		0.1011	0.1042	0.1073	0.1104	0.1414	0.1417	0.1417	0.1417
	CB	0.0000	0.0002	0.0006	0.0010	0.0031	0.0108	0.0177	0.0233
		0.0275	0.0312	0.0337	0.0353	0.0369	0.0381	0.0394	0.0410
		0.0430	0.0447	0.0473	0.0514	0.0579	0.0651	0.0712	0.0763
		0.0808	0.0847	0.0881	0.0908	0.0934	0.0955	0.0971	0.0983

- - - - -
Table A5b (Continued)
- - - - -

ID	Cumulative Volumetric Porosity (m ³ /m ³) for Data in Table A5a							
CC	0.0000	0.0000	0.0000	0.0006	0.0020	0.0045	0.0112	0.0173
	0.0218	0.0253	0.0279	0.0300	0.0318	0.0335	0.0349	0.0367
	0.0394	0.0422	0.0459	0.0504	0.0579	0.0665	0.0741	0.0800
	0.0853	0.0894	0.0930	0.0963	0.0989	0.1016	0.1030	0.1045
CD	0.0000	0.0002	0.0010	0.0037	0.0116	0.0210	0.0284	0.0361
	0.0412	0.0455	0.0481	0.0514	0.0549	0.0581	0.0616	0.0647
	0.0675	0.0702	0.0728	0.0759	0.0804	0.0887	0.0973	0.1042
	0.1102	0.1147	0.1185	0.1216	0.1236	0.1257	0.1269	0.1283
CE	0.0002	0.0004	0.0004	0.0027	0.0097	0.0268	0.0405	0.0513
	0.0593	0.0641	0.0669	0.0703	0.0732	0.0757	0.0785	0.0814
	0.0842	0.0874	0.0907	0.0945	0.0994	0.1080	0.1205	0.1302
	0.1374	0.1435	0.1479	0.1513	0.1540	0.1559	0.1574	0.1587
CF	0.0000	0.0000	0.0002	0.0013	0.0087	0.0251	0.0390	0.0526
	0.0620	0.0682	0.0726	0.0760	0.0797	0.0826	0.0854	0.0882
	0.0907	0.0937	0.0965	0.0995	0.1022	0.1069	0.1159	0.1250
	0.1321	0.1378	0.1423	0.1457	0.1480	0.1502	0.1517	0.1527
CG	0.0000	0.0000	0.0002	0.0008	0.0072	0.0198	0.0350	0.0476
	0.0592	0.0700	0.0792	0.0850	0.0898	0.0942	0.0978	0.1012
	0.1042	0.1076	0.1106	0.1134	0.1166	0.1214	0.1284	0.1394
	0.1490	0.1572	0.1636	0.1688	0.1722	0.1746	0.1762	0.1778
CH	0.0002	0.0004	0.0020	0.0072	0.0150	0.0266	0.0377	0.0460
	0.0582	0.0676	0.0730	0.0765	0.0804	0.0837	0.0865	0.0896
	0.0922	0.0944	0.0968	0.0996	0.1027	0.1066	0.1131	0.1195
	0.1247	0.1299	0.1347	0.1391	0.1424	0.1452	0.1471	0.1485
CJ	0.0000	0.0002	0.0002	0.0002	0.0011	0.0076	0.0165	0.0258
	0.0369	0.0514	0.0614	0.0668	0.0712	0.0751	0.0792	0.0829
	0.0861	0.0892	0.0929	0.0955	0.0985	0.1020	0.1079	0.1139
	0.1189	0.1259	0.1298	0.1330	0.1358	0.1380	0.1398	0.1410
CK	0.0000	0.0000	0.0000	0.0000	0.0015	0.0095	0.0301	0.0432
	0.0550	0.0645	0.0710	0.0761	0.0802	0.0834	0.0864	0.0892
	0.0916	0.0942	0.0970	0.0998	0.1032	0.1079	0.1172	0.1271
	0.1348	0.1421	0.1488	0.1529	0.1561	0.1580	0.1593	0.1606
CM	0.0000	0.0000	0.0002	0.0015	0.0046	0.0202	0.0328	0.0464
	0.0605	0.0703	0.0756	0.0792	0.0825	0.0859	0.0888	0.0913
	0.0939	0.0964	0.0987	0.1019	0.1050	0.1098	0.1180	0.1283
	0.1363	0.1436	0.1504	0.1548	0.1581	0.1602	0.1617	0.1628
CN	0.0000	0.0002	0.0002	0.0002	0.0002	0.0006	0.0011	0.0108
	0.0413	0.0574	0.0716	0.0744	0.0774	0.0808	0.0838	0.0869
	0.0907	0.0944	0.0972	0.1026	0.1094	0.1125	0.1159	0.1249
	0.1363	0.1443	0.1494	0.1537	0.1555	0.1569	0.1582	0.1589

- - - - -
Table A5b (Continued)
- - - - -

ID	Cumulative Volumetric Porosity (m³/m³) for Data in Table A5a								
X3	EA	0.0000	0.0000	0.0010	0.0023	0.0049	0.0087	0.0130	0.0180
		0.0219	0.0252	0.0287	0.0316	0.0351	0.0390	0.0427	0.0473
		0.0524	0.0576	0.0654	0.0741	0.0821	0.0887	0.0941	0.0993
		0.1036	0.1071	0.1106	0.1131	0.1158	0.1182	0.1199	0.1214
	EB	0.0000	0.0002	0.0004	0.0008	0.0018	0.0038	0.0072	0.0125
		0.0191	0.0241	0.0308	0.0342	0.0370	0.0394	0.0418	0.0446
		0.0478	0.0525	0.0583	0.0687	0.0832	0.0951	0.1047	0.1128
		0.1192	0.1246	0.1290	0.1327	0.1361	0.1389	0.1413	0.1429
	EC	0.0000	0.0000	0.0021	0.0060	0.0116	0.0207	0.0337	0.0414
		0.0474	0.0528	0.0573	0.0609	0.0631	0.0652	0.0669	0.0696
		0.0720	0.0753	0.0795	0.0859	0.0973	0.1091	0.1188	0.1263
		0.1325	0.1377	0.1422	0.1457	0.1493	0.1517	0.1538	0.1538
ED	0.0000	0.0000	0.0004	0.0038	0.0104	0.0168	0.0236	0.0294	
	0.0356	0.0405	0.0452	0.0481	0.0518	0.0556	0.0594	0.0635	
	0.0667	0.0697	0.0728	0.0769	0.0824	0.0903	0.0982	0.1044	
	0.1097	0.1137	0.1176	0.1204	0.1229	0.1248	0.1261	0.1274	
EE	0.0000	0.0000	0.0011	0.0043	0.0099	0.0198	0.0295	0.0370	
	0.0434	0.0486	0.0520	0.0546	0.0578	0.0608	0.0639	0.0664	
	0.0692	0.0718	0.0744	0.0770	0.0806	0.0888	0.0985	0.1064	
	0.1127	0.1178	0.1217	0.1245	0.1273	0.1290	0.1305	0.1316	
EF	0.0000	0.0000	0.0007	0.0053	0.0169	0.0265	0.0348	0.0414	
	0.0477	0.0515	0.0550	0.0578	0.0611	0.0639	0.0668	0.0694	
	0.0716	0.0742	0.0767	0.0795	0.0828	0.0891	0.0977	0.1049	
	0.1108	0.1161	0.1200	0.1233	0.1259	0.1279	0.1292	0.1305	
EG	0.0000	0.0000	0.0000	0.0002	0.0016	0.0085	0.0227	0.0341	
	0.0428	0.0500	0.0546	0.0578	0.0611	0.0642	0.0669	0.0689	
	0.0716	0.0736	0.0756	0.0774	0.0801	0.0870	0.0970	0.1044	
	0.1113	0.1162	0.1209	0.1242	0.1269	0.1291	0.1307	0.1320	
EH	0.0000	0.0002	0.0002	0.0002	0.0022	0.0076	0.0272	0.0445	
	0.0583	0.0678	0.0730	0.0765	0.0797	0.0823	0.0842	0.0864	
	0.0883	0.0903	0.0924	0.0946	0.0974	0.1009	0.1089	0.1169	
	0.1229	0.1277	0.1320	0.1350	0.1374	0.1395	0.1406	0.1421	
EJ	0.0007	0.0007	0.0007	0.0009	0.0013	0.0040	0.0150	0.0293	
	0.0407	0.0477	0.0519	0.0557	0.0585	0.0603	0.0645	0.0682	
	0.0719	0.0748	0.0777	0.0807	0.0838	0.0876	0.0931	0.1014	
	0.1085	0.1142	0.1186	0.1217	0.1236	0.1247	0.1254	0.1256	
EK	0.0000	0.0000	0.0002	0.0002	0.0009	0.0066	0.0142	0.0276	
	0.0425	0.0534	0.0598	0.0644	0.0688	0.0723	0.0753	0.0782	
	0.0810	0.0841	0.0869	0.0900	0.0933	0.0975	0.1029	0.1110	
	0.1191	0.1250	0.1294	0.1327	0.1353	0.1371	0.1384	0.1395	

Table A5b (Continued)

ID	Cumulative Volumetric Porosity (m ³ /m ³) for Data in Table A5a							
EM	0.0000	0.0002	0.0002	0.0007	0.0027	0.0081	0.0160	0.0254
	0.0349	0.0428	0.0504	0.0547	0.0580	0.0610	0.0637	0.0662
	0.0686	0.0711	0.0736	0.0765	0.0792	0.0824	0.0869	0.0934
	0.1006	0.1069	0.1111	0.1143	0.1168	0.1192	0.1208	0.1222
EN	0.0000	0.0000	0.0000	0.0000	0.0017	0.0082	0.0205	0.0344
	0.0538	0.0669	0.0734	0.0787	0.0829	0.0861	0.0890	0.0918
	0.0945	0.0973	0.1002	0.1034	0.1066	0.1108	0.1171	0.1277
	0.1380	0.1464	0.1519	0.1555	0.1583	0.1602	0.1616	0.1629
EP	0.0000	0.0002	0.0002	0.0006	0.0017	0.0050	0.0118	0.0283
	0.0573	0.0775	0.0876	0.0941	0.0991	0.1029	0.1065	0.1100
	0.1132	0.1163	0.1197	0.1231	0.1273	0.1321	0.1388	0.1470
	0.1546	0.1613	0.1655	0.1682	0.1703	0.1720	0.1733	0.1741
ER	0.0000	0.0000	0.0000	0.0000	0.0015	0.0059	0.0153	0.0331
	0.0506	0.0622	0.0683	0.0736	0.0777	0.0815	0.0848	0.0878
	0.0907	0.0937	0.0964	0.0996	0.1029	0.1071	0.1128	0.1204
	0.1294	0.1373	0.1437	0.1472	0.1500	0.1520	0.1537	
ES	0.0000	0.0000	0.0002	0.0004	0.0004	0.0013	0.0045	0.0112
	0.0312	0.0432	0.0503	0.0570	0.0621	0.0667	0.0714	0.0761
	0.0802	0.0828	0.0854	0.0877	0.0920	0.0983	0.1058	0.1137
	0.1234	0.1312	0.1367	0.1406	0.1434	0.1456	0.1469	0.1484
ET	0.0000	0.0000	0.0000	0.0002	0.0011	0.0057	0.0120	0.0217
	0.0428	0.0563	0.0627	0.0679	0.0726	0.0760	0.0779	0.0795
	0.0829	0.0893	0.0924	0.0960	0.0996	0.1015	0.1066	0.1196
	0.1287	0.1369	0.1431	0.1467	0.1490	0.1506	0.1521	0.1530
Y1 GB	0.0000	0.0002	0.0002	0.0006	0.0034	0.0129	0.0257	0.0343
	0.0394	0.0430	0.0460	0.0496	0.0534	0.0562	0.0585	0.0608
	0.0632	0.0659	0.0685	0.0721	0.0772	0.0886	0.0992	0.1079
	0.1149	0.1208	0.1255	0.1293	0.1321	0.1344	0.1361	0.1374
GC	0.0000	0.0002	0.0002	0.0009	0.0024	0.0071	0.0174	0.0258
	0.0306	0.0336	0.0366	0.0394	0.0422	0.0448	0.0469	0.0495
	0.0516	0.0538	0.0564	0.0592	0.0626	0.0708	0.0805	0.0887
	0.0951	0.1016	0.1061	0.1100	0.1134	0.1158	0.1175	0.1188
GD	-	0.0000	0.0000	0.0002	0.0036	0.0086	0.0156	0.0248
	0.0310	0.0353	0.0396	0.0439	0.0484	0.0527	0.0561	0.0589
	0.0612	0.0642	0.0664	0.0693	0.0728	0.0792	0.0916	0.1008
	0.1077	0.1137	0.1190	0.1229	0.1263	0.1286	0.1310	0.1325
GA	0.0000	0.0000	0.0008	0.0050	0.0161	0.0256	0.0337	0.0402
	0.0448	0.0488	0.0528	0.0566	0.0599	0.0633	0.0664	0.0696
	0.0723	0.0750	0.0779	0.0811	0.0847	0.0895	0.0983	0.1081
	0.1157	0.1219	0.1274	0.1310	0.1337	0.1360	0.1375	0.1389

Table A5b (Continued)

ID	Cumulative Volumetric Porosity (m ³ /m ³) for Data in Table A5a							
GF	0.0000	0.0000	0.0013	0.0091	0.0279	0.0447	0.0580	0.0684
	0.0762	0.0814	0.0867	0.0918	0.0960	0.0992	0.1021	0.1047
	0.1074	0.1099	0.1125	0.1154	0.1190	0.1234	0.1312	0.1401
	0.1471	0.1525	0.1568	0.1597	0.1618	0.1637	0.1652	0.1658
GG	0.0000	0.0000	0.0002	0.0017	0.0094	0.0224	0.0343	0.0464
	0.0573	0.0665	0.0739	0.0812	0.0880	0.0937	0.0988	0.1042
	0.1088	0.1127	0.1163	0.1199	0.1233	0.1272	0.1314	0.1370
	0.1423	0.1472	0.1506	0.1532	0.1555	0.1570	0.1583	0.1591
GH	0.0002	0.0002	0.0004	0.0011	0.0046	0.0122	0.0243	0.0315
	0.0393	0.0480	0.0571	0.0644	0.0707	0.0764	0.0801	0.0840
	0.0872	0.0905	0.0935	0.0963	0.0994	0.1035	0.1081	0.1152
	0.1217	0.1278	0.1317	0.1345	0.1369	0.1389	0.1404	0.1410
Y2 JB	0.0000	0.0004	0.0010	0.0040	0.0137	0.0224	0.0307	0.0384
	0.0454	0.0499	0.0533	0.0558	0.0584	0.0612	0.0632	0.0657
	0.0685	0.0723	0.0806	0.0937	0.1060	0.1170	0.1265	0.1349
	0.1418	0.1475	0.1521	0.1559	0.1596	0.1624	0.1642	0.1660
JC	0.0000	0.0002	0.0004	0.0007	0.0014	0.0018	0.0029	0.0049
	0.0094	0.0135	0.0176	0.0223	0.0268	0.0311	0.0342	0.0373
	0.0414	0.0472	0.0571	0.0689	0.0787	0.0869	0.0936	0.0992
	0.1040	0.1082	0.1116	0.1147	0.1179	0.1197	0.1213	0.1222
JD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0038	0.0108	0.0155
	0.0197	0.0221	0.0252	0.0274	0.0303	0.0331	0.0362	0.0389
	0.0415	0.0442	0.0473	0.0517	0.0603	0.0683	0.0754	0.0818
	0.0899	0.0997	0.1039	0.1074	0.1233	0.1268	0.1295	0.1315
JE	-	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006
	0.0047	0.0081	0.0104	0.0125	0.0157	0.0178	0.0199	0.0220
	0.0242	0.0261	0.0280	0.0301	0.0335	0.0394	0.0454	0.0500
	0.0541	0.0581	0.0668	0.0897	0.1187	0.1836	0.1866	0.1887
JF	0.0000	0.0000	0.0044	0.0109	0.0212	0.0309	0.0397	0.0470
	0.0525	0.0569	0.0603	0.0636	0.0670	0.0706	0.0739	0.0773
	0.0808	0.0842	0.0880	0.0916	0.0956	0.1002	0.1042	0.1084
	0.1121	0.1159	0.1193	0.1218	0.1243	0.1260	0.1270	0.1279
JG	0.0000	0.0000	0.0004	0.0040	0.0115	0.0234	0.0354	0.0432
	0.0498	0.0547	0.0599	0.0645	0.0692	0.0731	0.0765	0.0799
	0.0831	0.0861	0.0892	0.0927	0.0969	0.1022	0.1114	0.1199
	0.1269	0.1327	0.1374	0.1410	0.1440	0.1463	0.1480	0.1491
JH	0.0000	0.0000	0.0002	0.0013	0.0089	0.0224	0.0369	0.0462
	0.0561	0.0637	0.0692	0.0745	0.0798	0.0838	0.0871	0.0903
	0.0935	0.0964	0.0992	0.1028	0.1066	0.1133	0.1230	0.1314
	0.1382	0.1441	0.1492	0.1521	0.1547	0.1568	0.1578	0.1589

- - - - -
Table A5b (Continued)
- - - - -

ID	Cumulative Volumetric Porosity (m ³ /m ³) for Data in Table A5a							
JJ	0.0000	0.0000	0.0015	0.0048	0.0115	0.0228	0.0375	0.0488
	0.0575	0.0621	0.0651	0.0681	0.0707	0.0727	0.0749	0.0766
	0.0788	0.0807	0.0829	0.0848	0.0877	0.0920	0.0996	0.1070
	0.1146	0.1213	0.1267	0.1298	0.1326	0.1348	0.1363	0.1371
JK	0.0000	0.0000	0.0015	0.0045	0.0113	0.0268	0.0402	0.0529
	0.0678	0.0790	0.0850	0.0905	0.0950	0.0987	0.1016	0.1044
	0.1072	0.1094	0.1119	0.1143	0.1175	0.1220	0.1282	0.1348
	0.1400	0.1449	0.1496	0.1528	0.1556	0.1575	0.1588	0.1596
JM	0.0000	0.0002	0.0006	0.0021	0.0081	0.0184	0.0346	0.0530
	0.0683	0.0764	0.0811	0.0853	0.0892	0.0923	0.0948	0.0975
	0.1002	0.1029	0.1058	0.1089	0.1130	0.1194	0.1300	0.1397
	0.1493	0.1569	0.1623	0.1660	0.1687	0.1708	0.1722	0.1733
JN	0.0000	0.0000	0.0000	0.0002	0.0006	0.0052	0.0230	0.0424
	0.0591	0.0712	0.0789	0.0847	0.0899	0.0937	0.0970	0.1002
	0.1028	0.1056	0.1081	0.1109	0.1144	0.1189	0.1262	0.1346
	0.1421	0.1492	0.1546	0.1587	0.1610	0.1632	0.1645	0.1658
JP	0.0000	0.0007	0.0018	0.0028	0.0070	0.0120	0.0204	0.0276
	0.0335	0.0383	0.0425	0.0464	0.0510	0.0565	0.0609	0.0655
	0.0692	0.0723	0.0756	0.0791	0.0839	0.0907	0.0970	0.1025
	0.1073	0.1110	0.1141	0.1165	0.1189	0.1204	0.1220	0.1229
Y3 MB	-	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
	0.0012	0.0012	0.0020	0.0036	0.0058	0.0076	0.0096	0.0117
	0.0141	0.0169	0.0205	0.0271	0.0342	0.0410	0.0464	0.0519
	0.0553	0.0585	0.0647	0.0967	0.1351	0.1387	0.1413	0.1427
MC	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0006	0.0019	0.0029
	0.0043	0.0058	0.0076	0.0107	0.0149	0.0196	0.0239	0.0287
	0.0345	0.0398	0.0535	0.0759	0.0890	0.1053	0.1368	0.1492
MD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0004	0.0032	0.0060	0.0090	0.0114	0.0133	0.0163
	0.0196	0.0230	0.0271	0.0338	0.0426	0.0501	0.0563	0.0624
	0.0684	0.0761	0.1060	0.1503	0.2023	0.2064	0.2092	0.2113
ME	0.0000	0.0002	0.0002	0.0013	0.0101	0.0228	0.0327	0.0389
	0.0449	0.0494	0.0540	0.0578	0.0615	0.0656	0.0694	0.0737
	0.0774	0.0815	0.0856	0.0914	0.1006	0.1103	0.1178	0.1243
	0.1294	0.1333	0.1365	0.1393	0.1417	0.1434	0.1449	0.1462
MF	0.0004	0.0004	0.0006	0.0011	0.0032	0.0060	0.0129	0.0254
	0.0426	0.0583	0.0658	0.0720	0.0780	0.0830	0.0873	0.0914
	0.0950	0.0991	0.1026	0.1064	0.1109	0.1159	0.1223	0.1316
	0.1404	0.1481	0.1535	0.1567	0.1593	0.1615	0.1625	0.1638

- - - - -
Table A5b (Continued)
- - - - -

ID	Cumulative Volumetric Porosity (m ³ /m ³) for Data in Table A5a							
MG	0.0000	0.0000	0.0010	0.0050	0.0156	0.0273	0.0378	0.0467
	0.0543	0.0600	0.0659	0.0709	0.0768	0.0816	0.0859	0.0903
	0.0947	0.0998	0.1048	0.1117	0.1194	0.1279	0.1362	0.1442
	0.1507	0.1566	0.1620	0.1656	0.1683	0.1703	0.1719	0.1729
MH	0.0000	0.0002	0.0004	0.0011	0.0072	0.0150	0.0257	0.0373
	0.0475	0.0532	0.0582	0.0627	0.0665	0.0694	0.0720	0.0747
	0.0772	0.0795	0.0821	0.0855	0.0901	0.0987	0.1095	0.1177
	0.1247	0.1304	0.1348	0.1382	0.1409	0.1431	0.1445	0.1458
MJ	0.0000	0.0000	0.0002	0.0002	0.0009	0.0027	0.0111	0.0317
	0.0426	0.0511	0.0584	0.0642	0.0682	0.0718	0.0745	0.0769
	0.0794	0.0818	0.0836	0.0861	0.0888	0.0919	0.0970	0.1032
	0.1084	0.1126	0.1164	0.1193	0.1218	0.1235	0.1249	0.1258
MK	0.0020	0.0020	0.0020	0.0025	0.0032	0.0047	0.0065	0.0106
	0.0184	0.0335	0.0486	0.0549	0.0608	0.0655	0.0693	0.0729
	0.0765	0.0801	0.0828	0.0857	0.0889	0.0922	0.0958	0.1001
	0.1049	0.1087	0.1118	0.1141	0.1161	0.1172	0.1185	0.1192
MM	0.0000	0.0000	0.0000	0.0004	0.0016	0.0038	0.0109	0.0223
	0.0368	0.0475	0.0569	0.0631	0.0682	0.0723	0.0754	0.0785
	0.0812	0.0847	0.0870	0.0903	0.0941	0.0981	0.1035	0.1104
	0.1164	0.1218	0.1260	0.1289	0.1316	0.1333	0.1349	0.1360
MN	0.0002	0.0004	0.0004	0.0004	0.0015	0.0037	0.0114	0.0216
	0.0385	0.0530	0.0631	0.0708	0.0768	0.0823	0.0856	0.0895
	0.0933	0.0968	0.0999	0.1034	0.1069	0.1109	0.1162	0.1232
	0.1300	0.1351	0.1390	0.1421	0.1443	0.1459	0.1472	0.1485
MP	0.0000	0.0000	0.0000	0.0000	0.0013	0.0054	0.0177	0.0313
	0.0462	0.0583	0.0652	0.0713	0.0771	0.0819	0.0855	0.0890
	0.0922	0.0957	0.0987	0.1022	0.1061	0.1108	0.1171	0.1266
	0.1352	0.1410	0.1454	0.1484	0.1508	0.1525	0.1538	0.1549
MR	0.0000	0.0002	0.0002	0.0004	0.0022	0.0048	0.0118	0.0278
	0.0473	0.0593	0.0675	0.0738	0.0797	0.0845	0.0878	0.0915
	0.0950	0.0985	0.1018	0.1053	0.1093	0.1137	0.1194	0.1277
	0.1364	0.1430	0.1474	0.1505	0.1526	0.1546	0.1557	0.1568
MS	0.0000	0.0000	0.0002	0.0004	0.0010	0.0027	0.0107	0.0304
	0.0510	0.0662	0.0746	0.0846	0.0909	0.0962	0.1006	0.1046
	0.1094	0.1132	0.1163	0.1201	0.1237	0.1283	0.1355	0.1449
	0.1535	0.1590	0.1634	0.1659	0.1682	0.1697	0.1709	0.1720
MT	0.0000	0.0002	0.0002	0.0002	0.0006	0.0015	0.0033	0.0107
	0.0376	0.0623	0.0767	0.0897	0.0993	0.1058	0.1101	0.1173
	0.1218	0.1254	0.1283	0.1346	0.1394	0.1440	0.1503	0.1582
	0.1651	0.1699	0.1733	0.1756	0.1777	0.1787	0.1799	0.1812

- - - - -
Table A5b (Continued)
- - - - -

ID	Cumulative Volumetric Porosity (m ³ /m ³) for Data in Table A5a							
MU	0.0000	0.0000	0.0000	0.0000	0.0002	0.0004	0.0032	0.0153
	0.0320	0.0428	0.0522	0.0608	0.0673	0.0727	0.0774	0.0817
	0.0860	0.0903	0.0944	0.0985	0.1032	0.1084	0.1152	0.1243
	0.1337	0.1408	0.1453	0.1486	0.1509	0.1531	0.1544	0.1557
Z1 PB	0.0000	0.0000	0.0000	0.0000	0.0030	0.0086	0.0157	0.0230
	0.0262	0.0292	0.0314	0.0333	0.0350	0.0370	0.0381	0.0398
	0.0421	0.0456	0.0514	0.0617	0.0727	0.0817	0.0899	0.0970
	0.1032	0.1084	0.1131	0.1168	0.1202	0.1232	0.1251	0.1268
PC	0.0000	0.0002	0.0008	0.0019	0.0087	0.0161	0.0236	0.0290
	0.0342	0.0377	0.0404	0.0428	0.0443	0.0464	0.0480	0.0497
	0.0524	0.0559	0.0609	0.0691	0.0795	0.0884	0.0956	0.1027
	0.1087	0.1138	0.1184	0.1223	0.1254	0.1281	0.1300	0.1319
PD	0.0000	0.0002	0.0004	0.0025	0.0072	0.0133	0.0238	0.0310
	0.0371	0.0430	0.0465	0.0498	0.0529	0.0558	0.0584	0.0619
	0.0656	0.0699	0.0761	0.0849	0.0961	0.1064	0.1156	0.1240
	0.1314	0.1373	0.1425	0.1468	0.1503	0.1529	0.1550	0.1562
PE	0.0000	0.0004	0.0008	0.0040	0.0078	0.0197	0.0271	0.0317
	0.0365	0.0399	0.0428	0.0454	0.0477	0.0500	0.0525	0.0550
	0.0580	0.0611	0.0653	0.0699	0.0762	0.0832	0.0895	0.0951
	0.0995	0.1033	0.1065	0.1094	0.1117	0.1134	0.1147	0.1157
PF	0.0000	0.0000	0.0002	0.0009	0.0035	0.0077	0.0162	0.0261
	0.0331	0.0379	0.0416	0.0436	0.0462	0.0495	0.0528	0.0558
	0.0585	0.0611	0.0637	0.0666	0.0712	0.0793	0.0867	0.0929
	0.0975	0.1014	0.1045	0.1073	0.1093	0.1115	0.1128	0.1141
PG	0.0000	0.0002	0.0023	0.0053	0.0115	0.0192	0.0266	0.0339
	0.0394	0.0439	0.0473	0.0501	0.0532	0.0567	0.0594	0.0628
	0.0660	0.0692	0.0724	0.0756	0.0801	0.0852	0.0905	0.0958
	0.0999	0.1037	0.1067	0.1097	0.1118	0.1140	0.1152	0.1165
PH	0.0000	0.0002	0.0006	0.0032	0.0138	0.0273	0.0396	0.0502
	0.0594	0.0664	0.0721	0.0759	0.0799	0.0835	0.0865	0.0899
	0.0924	0.0952	0.0979	0.1005	0.1047	0.1100	0.1183	0.1249
	0.1297	0.1344	0.1378	0.1408	0.1431	0.1448	0.1461	0.1469
Z2 SB	0.0000	0.0002	0.0004	0.0011	0.0050	0.0113	0.0198	0.0279
	0.0331	0.0371	0.0395	0.0432	0.0464	0.0499	0.0530	0.0565
	0.0597	0.0630	0.0667	0.0717	0.0817	0.0931	0.1018	0.1086
	0.1147	0.1195	0.1236	0.1269	0.1302	0.1334	0.1358	0.1376
SC	0.0002	0.0004	0.0009	0.0022	0.0055	0.0108	0.0176	0.0240
	0.0290	0.0326	0.0370	0.0416	0.0464	0.0513	0.0548	0.0581
	0.0612	0.0640	0.0669	0.0706	0.0766	0.0860	0.0933	0.0997
	0.1047	0.1091	0.1126	0.1159	0.1186	0.1210	0.1228	0.1241

Table A5b (Continued)

ID	Cumulative Volumetric Porosity (m ³ /m ³) for Data in Table A5a							
SD	0.0000	0.0002	0.0058	0.0150	0.0250	0.0341	0.0420	0.0470
	0.0516	0.0549	0.0578	0.0605	0.0641	0.0672	0.0699	0.0724
	0.0757	0.0782	0.0807	0.0842	0.0880	0.0934	0.0988	0.1034
	0.1080	0.1117	0.1156	0.1186	0.1213	0.1233	0.1250	0.1263
SE	0.0000	0.0002	0.0002	0.0038	0.0108	0.0193	0.0259	0.0326
	0.0367	0.0405	0.0443	0.0485	0.0528	0.0564	0.0600	0.0630
	0.0664	0.0700	0.0738	0.0787	0.0861	0.0956	0.1054	0.1138
	0.1208	0.1264	0.1310	0.1348	0.1378	0.1401	0.1420	0.1433
SF	0.0000	0.0000	0.0006	0.0033	0.0087	0.0208	0.0356	0.0428
	0.0466	0.0490	0.0556	0.0634	0.0702	0.0766	0.0824	0.0875
	0.0929	0.0976	0.1032	0.1098	0.1197	0.1294	0.1378	0.1452
	0.1508	0.1555	0.1594	0.1621	0.1648	0.1666	0.1679	0.1691
SG	0.0000	0.0002	0.0004	0.0006	0.0012	0.0021	0.0070	0.0156
	0.0220	0.0263	0.0304	0.0345	0.0388	0.0415	0.0443	0.0476
	0.0503	0.0532	0.0565	0.0616	0.0694	0.0778	0.0862	0.0932
	0.0998	0.1053	0.1102	0.1137	0.1168	0.1190	0.1209	0.1221
SH	0.0002	0.0008	0.0008	0.0010	0.0024	0.0130	0.0244	0.0333
	0.0428	0.0469	0.0510	0.0566	0.0615	0.0639	0.0664	0.0692
	0.0735	0.0757	0.0782	0.0820	0.0865	0.0983	0.1068	0.1137
	0.1206	0.1263	0.1305	0.1330	0.1358	0.1382	0.1399	0.1407
SJ	0.0000	0.0002	0.0004	0.0010	0.0034	0.0120	0.0265	0.0391
	0.0512	0.0590	0.0653	0.0706	0.0754	0.0790	0.0817	0.0844
	0.0869	0.0895	0.0918	0.0947	0.0976	0.1023	0.1098	0.1165
	0.1218	0.1262	0.1300	0.1327	0.1352	0.1367	0.1380	0.1392
SK	0.0000	0.0004	0.0004	0.0004	0.0006	0.0019	0.0204	0.0288
	0.0433	0.0519	0.0584	0.0636	0.0668	0.0701	0.0727	0.0756
	0.0787	0.0811	0.0834	0.0861	0.0888	0.0922	0.0970	0.1040
	0.1113	0.1161	0.1197	0.1222	0.1243	0.1262	0.1270	0.1277
SM	0.0000	0.0002	0.0002	0.0002	0.0022	0.0106	0.0219	0.0304
	0.0393	0.0480	0.0562	0.0631	0.0679	0.0723	0.0753	0.0779
	0.0805	0.0831	0.0853	0.0879	0.0909	0.0946	0.0992	0.1061
	0.1126	0.1181	0.1224	0.1254	0.1280	0.1295	0.1311	0.1319
SN	0.0000	0.0000	0.0000	0.0002	0.0011	0.0062	0.0258	0.0471
	0.0617	0.0718	0.0776	0.0828	0.0866	0.0901	0.0933	0.0957
	0.0983	0.1008	0.1032	0.1066	0.1101	0.1146	0.1217	0.1279
	0.1333	0.1374	0.1404	0.1428	0.1443	0.1456	0.1466	-
SP	0.0000	0.0000	0.0002	0.0002	0.0004	0.0004	0.0046	0.0412
	0.0680	0.0907	0.1067	0.1154	0.1221	0.1273	0.1319	0.1356
	0.1387	0.1421	0.1456	0.1489	0.1527	0.1568	0.1614	0.1662
	0.1710	0.1749	0.1776	0.1795	0.1810	0.1822	0.1835	0.1841

Table A5b (Continued)

ID	Cumulative Volumetric Porosity (m ³ /m ³) for Data in Table A5a								
Z3	UW	0.0000	0.0004	0.0004	0.0020	0.0069	0.0140	0.0198	0.0261
		0.0323	0.0363	0.0401	0.0435	0.0470	0.0501	0.0528	0.0557
		0.0582	0.0606	0.0631	0.0660	0.0698	0.0773	0.0867	0.0945
		0.1010	0.1065	0.1110	0.1148	0.1179	0.1201	0.1221	0.1237
	UC	0.0002	0.0006	0.0028	0.0073	0.0114	0.0270	0.0348	0.0397
		0.0443	0.0479	0.0527	0.0574	0.0624	0.0663	0.0698	0.0726
		0.0754	0.0780	0.0808	0.0840	0.0879	0.0935	0.1024	0.1110
		0.1181	0.1242	0.1291	0.1324	0.1352	0.1371	0.1386	0.1402
	UD	0.0295	0.0310	0.0318	0.0329	0.0346	0.0406	0.0492	0.0554
		0.0607	0.0646	0.0688	0.0731	0.0772	0.0812	0.0844	0.0872
		0.0900	0.0928	0.0955	0.0988	0.1017	0.1056	0.1126	0.1227
		0.1300	0.1357	0.1402	0.1434	0.1460	0.1479	0.1492	0.1500
UE	0.0000	0.0004	0.0008	0.0021	0.0099	0.0164	0.0212	0.0250	
	0.0286	0.0311	0.0334	0.0357	0.0380	0.0401	0.0420	0.0437	
	0.0460	0.0481	0.0504	0.0531	0.0559	0.0598	0.0645	0.0695	
	0.0741	0.0783	0.0821	0.0848	0.0871	0.0888	0.0901	0.0911	
UF	0.0000	0.0008	0.0023	0.0081	0.0156	0.0233	0.0352	0.0452	
	0.0535	0.0591	0.0637	0.0677	0.0716	0.0747	0.0777	0.0806	
	0.0837	0.0866	0.0904	0.0943	0.0969	0.1035	0.1110	0.1183	
	0.1243	0.1291	0.1333	0.1368	0.1393	0.1416	0.1432	0.1445	
UG	0.0000	0.0002	0.0008	0.0028	0.0096	0.0230	0.0354	0.0450	
	0.0517	0.0589	0.0652	0.0717	0.0769	0.0815	0.0852	0.0886	
	0.0917	0.0949	0.0980	0.1008	0.1043	0.1095	0.1175	0.1247	
	0.1310	0.1366	0.1412	0.1442	0.1468	0.1488	0.1503	0.1512	
UH	0.0000	0.0002	0.0004	0.0010	0.0021	0.0039	0.0093	0.0093	
	0.0255	0.0306	0.0356	0.0401	0.0442	0.0477	0.0506	0.0535	
	0.0559	0.0586	0.0613	0.0644	0.0691	0.0759	0.0841	0.0913	
	0.0973	0.1026	0.1068	0.1100	0.1125	0.1146	0.1160	0.1170	
UJ	0.0000	0.0000	0.0002	0.0002	0.0017	0.0057	0.0190	0.0315	
	0.0433	0.0505	0.0560	0.0608	0.0643	0.0669	0.0693	0.0713	
	0.0739	0.0759	0.0781	0.0803	0.0833	0.0879	0.0960	0.1034	
	0.1098	0.1150	0.1196	0.1231	0.1257	0.1277	0.1292	0.1305	
UK	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0020	0.0137	
	0.0331	0.0434	0.0506	0.0567	0.0614	0.0652	0.0682	0.0709	
	0.0731	0.0756	0.0781	0.0808	0.0835	0.0868	0.0916	0.0979	
	0.1035	0.1075	0.1116	0.1145	0.1165	0.1186	0.1199	0.1208	
UM	0.0000	0.0000	0.0002	0.0002	0.0002	0.0013	0.0081	0.0242	
	0.0390	0.0603	0.0751	0.0854	0.0932	0.0997	0.1034	0.1073	
	0.1095	0.1121	0.1143	0.1165	0.1187	0.1228	0.1265	0.1306	
	0.1324	0.1361	0.1391	0.1413	0.1435	0.1452	0.1468	0.1476	

- - - - -
Table A5b (Continued)
- - - - -

ID	Cumulative Volumetric Porosity (m ³ /m ³) for Data in Table A5a							
UN	0.0000	0.0002	0.0002	0.0004	0.0013	0.0040	0.0160	0.0294
	0.0477	0.0635	0.0739	0.0804	0.0853	0.0889	0.0918	0.0944
	0.0971	0.0998	0.1025	0.1054	0.1087	0.1132	0.1201	0.1276
	0.1341	0.1390	0.1426	0.1457	0.1479	0.1495	0.1506	0.1515
UP	0.0000	0.0031	0.0084	0.0129	0.0177	0.0233	0.0284	0.0328
	0.0368	0.0413	0.0453	0.0486	0.0515	0.0544	0.0572	0.0595
	0.0621	0.0648	0.0670	0.0699	0.0730	0.0763	0.0819	0.0885
	0.0954	0.1007	0.1047	0.1076	0.1103	0.1116	-	-
UR	0.0000	0.0000	0.0000	0.0002	0.0004	0.0015	0.0059	0.0232
	0.0426	0.0595	0.0710	0.0796	0.0859	0.0905	0.0931	0.0966
	0.0992	0.1023	0.1051	0.1080	0.1115	0.1152	0.1207	0.1279
	0.1353	0.1408	0.1451	0.1480	0.1504	0.1523	0.1537	0.1545
US	0.0000	0.0000	0.0002	0.0002	0.0002	0.0128	0.0175	0.0222
	0.0439	0.0646	0.0774	0.0874	0.0945	0.1000	0.1036	0.1070
	0.1100	0.1130	0.1162	0.1198	0.1237	0.1288	0.1350	0.1422
	0.1486	0.1533	0.1569	0.1599	0.1623	0.1638	0.1653	0.1661
UT	0.0000	0.0000	0.0000	0.0002	0.0006	0.0024	0.0088	0.0276
	0.0558	0.0766	0.0888	0.0952	0.0995	0.1025	0.1046	0.1070
	0.1093	0.1115	0.1136	0.1168	0.1207	0.1265	0.1331	0.1419
	0.1498	0.1556	0.1598	0.1628	0.1652	0.1669	0.1682	0.1690
UU	-	0.0000	0.0000	0.0002	0.0009	0.0022	0.0059	0.0134
	0.0296	0.0462	0.0569	0.0622	0.0672	0.0705	0.0736	0.0764
	0.0788	0.0812	0.0839	0.0867	0.0900	0.0942	0.0996	0.1082
	0.1182	0.1261	0.1314	0.1351	0.1380	0.1401	0.1417	0.1425

Table A6: Fracture geometric information obtained from oriented drill core. Depth of fracture is inclined along borehole.

	ID	Depth (m)	Orientation (°)			ID	Depth (m)	Orientation (°)	
			Strike	Dip				Strike	Dip
X1	AA	1.77	345.	75.	X3	EA	-	-	-
	AB	-	-	-		EB	-	-	-
	AC	-	-	-		EC	4.14	356.	74.
	AD	4.14	352.	85.		ED	4.67	338.	14.
		4.33	215.	12.			7.01	19.	6.
		4.36	346.	73.		EE	8.82	5.	79.
		4.62	329.	76.			9.02	337.	76.
		4.79	336.	84.			10.13	20.	73.
		5.73	326.	82.		EF	12.45	332.	83.
		6.92	359.	75.			13.32	343.	76.
		7.13	358.	69.		EG	15.85	336.	66.
	AE	8.92	31.	48.			18.63	11.	67.
		9.79	35.	64.		EH	18.89	6.	71.
	AF	-	-	-		EJ	21.03	334.	71.
	AG	-	-	-		EK	25.60	10.	67.
							25.72	336.	66.
						EM	28.68	8.	74.
						EN	29.66	329.	72.
X2	CA	1.77	359.	82.			29.81	11.	66.
	CB	2.32	300.	56.			30.55	312.	87.
		2.47	359.	85.			30.60	336.	78.
	CC	-	-	-			31.08	328.	66.
	CD	4.85	191.	17.			31.58	336.	64.
		5.18	354.	84.		EP	32.95	332.	85.
	CE	9.45	347.	78.			33.64	337.	82.
	CF	13.38	331.	75.			34.46	339.	87.
		13.56	342.	59.			34.61	342.	72.
	CG	15.59	20.	17.			35.13	324.	81.
		15.51	20.	17.		ER	35.23	323.	80.
	CH	18.68	32.	47.			35.96	316.	36.
	CJ	19.95	327.	89.		ES	-	-	-
		21.03	334.	67.		ET	42.26	52.	55.
		21.67	16.	30.			42.64	309.	86.
		22.49	347.	79.					
	CK	24.78	339.	76.					
	CM	28.47	303.	60.					
		28.65	44.	63.					
	CN	29.23	318.	78.					
		29.52	3.	72.					

- - - - -
Table A6 (Continued)
- - - - -

	ID	Depth (m)	Orientation (°)			ID	Depth (m)	Orientation (°)	
			Strike	Dip				Strike	Dip
Y1	GB	-	-	-	Y3	MB	-	-	-
	GC	3.27	119.	17.		MC	-	-	-
	GD	3.73	169.	89.		MD	4.48	294.	22.
	GA	5.94	12.	81.		ME	5.09	21.	67.
	GF	10.20	316.	34.			5.25	298.	4.
	GG	10.42	13.	88.			6.51	311.	45.
		11.77	291.	1.		MF	9.57	26.	74.
	GH	12.87	11.	59.		MG	13.73	4.	77.
Y2		14.79	21.	72.		MH	15.92	345.	84.
	JB	2.26	336.	69.		MJ	17.21	160.	89.
	JC	3.96	4.	77.			17.37	348.	88.
	JD	-	-	-			19.43	26.	76.
	JE	5.42	344.	77.			19.77	17.	73.
		5.85	345.	69.		MK	20.21	164.	82.
		7.62	3.	65.			20.31	4.	67.
	JF	8.29	264.	76.		MM	23.33	24.	65.
		9.04	251.	44.			23.76	350.	80.
	JG	-	-	-			23.80	341.	89.
	JH	16.43	15.	6.			24.39	340.	77.
	JJ	19.33	102.	40.			24.40	336.	87.
		19.77	237.	26.			24.49	343.	66.
		19.87	293.	17.		MN	26.32	353.	81.
	JK	22.40	25.	56.		MP	29.98	23.	74.
	JM	-	-	-		MR	-	-	-
	JN	28.62	214.	87.		MS	-	-	-
	JP	-	-	-		MT	-	-	-
						MU	44.60	216.	86.

Table A6 (Continued)

	ID	Depth (m)	Orientation (°)			ID	Depth (m)	Orientation (°)	
			Strike	Dip				Strike	Dip
Z1	PB	-	-	-	Z2	SH	14.38	41.	35.
	PC	-	-	-			14.47	336.	73.
	PD	3.95	10.	18.			14.59	335.	83.
		4.57	303.	47.			14.78	327.	75.
	PE	5.16	143.	79.			14.79	339.	80.
		6.21	248.	84.			14.92	304.	85.
		6.26	220.	89.			15.63	184.	80.
		6.35	312.	78.			15.80	223.	73.
		6.38	188.	77.			15.83	232.	88.
	PF	9.39	210.	57.			16.01	342.	68.
		9.49	190.	81.			16.02	296.	61.
		10.49	280.	25.			16.08	321.	65.
	PG	10.56	337.	63.			16.28	297.	68.
		11.06	164.	85.		SJ	18.53	174.	68.
		11.29	20.	19.			19.12	179.	58.
		11.78	70.	20.			19.37	304.	76.
		12.01	341.	75.			19.99	298.	84.
	PH	12.45	174.	87.		SK	22.49	156.	23.
		12.74	317.	65.			22.73	320.	89.
		13.85	340.	85.			22.98	309.	87.
		14.38	310.	83.			23.01	300.	87.
		14.67	4.	22.			23.04	310.	86.
		15.10	109.	10.		SM	23.55	148.	89.
		16.50	112.	89.			24.41	142.	16.
Z2	SB	-	-	-		SN	26.46	131.	23.
	SC	2.90	339.	87.			27.10	80.	55.
	SD	3.65	42.	8.			27.85	207.	2.
		4.51	275.	42.			27.97	36.	7.
	SE	5.19	259.	32.			28.10	211.	77.
		5.74	73.	30.			28.35	93.	62.
		7.64	181.	24.			28.50	170.	34.
		7.76	222.	32.			28.85	256.	16.
		8.30	181.	85.			28.98	94.	74.
	SF	11.75	140.	87.		SP	29.13	166.	84.
	SG	12.02	204.	77.			29.88	183.	65.
		12.73	127.	36.			30.02	309.	74.
		13.18	227.	73.					
		13.80	140.	18.					
		13.89	112.	14.					

Table A7: Fracture density values obtained from borehole cores at the Apache Leap Tuff Site.

ID	#	Width (m)	Density (1/m)	ID	#	Width (m)	Density (1/m)	ID	#	Width (m)	Density (1/m)			
X1	AA	1	1.	1.00	Y1	GB	0	1.	0.00	Z1	PB	0	1.	0.00
	AB	0	1.	0.00		GC	1	1.	1.00		PC	0	1.	0.00
	AC	0	2.	0.00		GD	1	2.	0.50		PD	2	2.	1.00
	AD	8	3.	2.67		GA	1	3.	0.33		PE	5	3.	1.67
	AE	2	3.	0.67		GF	1	3.	0.33		PF	4	3.	1.33
	AF	0	3.	0.00		GG	2	3.	0.67		PG	7	3.	2.33
	AG	0	3.	0.00		GH	2	3.	0.67		PH	4	3.	1.33
X2	CA	1	1.	1.00	Y2	JB	1	1.	1.00	Z2	SB	0	1.	0.00
	CB	2	1.	2.00		JC	1	1.	1.00		SC	1	1.	0.33
	CC	0	2.	0.00		JD	0	2.	0.00		SD	2	2.	1.00
	CD	2	3.	0.67		JE	3	3.	1.00		SE	4	3.	1.33
	CE	1	3.	0.33		JF	2	3.	0.67		SF	1	3.	0.33
	CF	2	3.	0.67		JG	0	3.	0.00		SG	6	3.	2.00
	CG	2	3.	0.67		JH	1	3.	0.33		SH	13	3.	4.33
	CH	1	3.	0.33		JJ	3	3.	1.00		SJ	4	3.	1.33
	CJ	4	3.	1.33		JK	1	3.	0.33		SK	5	3.	1.67
	CK	1	3.	0.33		JM	0	3.	0.00		SM	2	3.	0.67
	CM	2	3.	0.67		JN	1	3.	0.33		SN	9	3.	3.00
	CN	2	3.	0.67		JP	0	3.	0.00		SP	3	3.	1.00
	X3	EA	0	1.		0.00	Y3	MB	0		1.	0.00	Z3	UW
EB		0	1.	0.00	MC	0		1.	0.00	UC	0	1.		0.00
EC		1	2.	0.50	MD	1		2.	0.50	UD	0	2.		0.00
ED		2	3.	0.67	ME	3		3.	1.00	UE	1	3.		0.33
EE		3	3.	1.00	MF	1		3.	0.33	UF	2	3.		0.67
EF		2	3.	0.67	MG	1		3.	0.33	UG	7	3.		2.33
EG		2	3.	0.67	MH	1		3.	0.33	UH	4	3.		1.33
EH		1	3.	0.33	MJ	4		3.	1.33	UJ	1	3.		0.33
EJ		1	3.	0.33	MK	2		3.	0.67	UK	4	3.		1.33
EK		2	3.	0.67	MM	6		3.	2.00	UM	13	3.		4.33
EM		1	3.	0.33	MN	1		3.	0.33	UN	4	3.		1.33
EN		6	3.	2.00	MP	1		3.	0.33	UP	3	3.		1.00
EP		5	3.	1.67	MR	0		3.	0.00	UR	6	3.		2.00
ER		2	3.	0.67	MS	0		3.	0.00	US	0	3.		0.00
ES		0	3.	0.00	MT	0		3.	0.00	UT	3	3.		1.00
ET		2	3.	0.67	MU	1		3.	0.33	UU	0	3.		0.00

Table A6 (Continued)

	ID	Depth (m)	Orientation (°)			ID	Depth (m)	Orientation (°)	
			Strike	Dip				Strike	Dip
Z3	UW	-	-	-	Z3	UP	29.44	155.	77.
	UC	-	-	-			29.51	137.	85.
	UD	-	-	-			29.87	173.	87.
	UE	8.26	339.	89.		UR	33.02	141.	89.
	UF	9.69	350.	73.			33.45	185.	14.
		11.19	193.	84.			33.60	150.	84.
	UG	11.84	145.	83.			34.83	71.	58.
		11.85	263.	60.			34.89	258.	70.
		12.06	262.	72.			35.20	264.	38.
		13.19	273.	50.		US	-	-	-
		13.31	330.	89.		UT	39.23	212.	81.
		13.63	332.	81.			39.81	80.	56.
		13.72	320.	89.			40.66	104.	58.
	UH	15.30	270.	36.		UU	-	-	-
		15.90	86.	24.					
		17.21	189.	83.					
		17.32	239.	56.					
	UJ	19.62	243.	77.					
	UK	22.16	303.	69.					
		22.17	308.	71.					
		22.32	286.	83.					
		22.94	100.	88.					
	UM	23.49	87.	66.					
		23.57	211.	88.					
		23.63	198.	87.					
		24.32	311.	78.					
		24.89	134.	76.					
		25.57	318.	87.					
		25.75	320.	86.					
		25.81	149.	89.					
		25.88	301.	89.					
		25.94	307.	86.					
		25.98	111.	87.					
		25.98	315.	72.					
		26.26	49.	51.					
	UN	26.45	274.	38.					
		26.70	183.	83.					
		27.80	192.	78.					
		28.41	162.	69.					

Table A8: Saturated hydraulic conductivity (Ksat) obtained from 105 large core segments at the Apache Leap Tuff Site.

ID	Ksat (m/s)	ID	Ksat (m/s)	ID	Ksat (m/s)
X1 AA	14.31 E-9	Y1 GB	1.73 E-9	Z1 PB	5.49 E-9
AB	4.70	GC	4.61	PC	3.49
AC	2.19	GD	3.58	PD	103.57
AD	1.20	GA	1.11	PE	4.50
AE	1.00	GF	1.02	PF	2.39
AF	1.38	GG	1.44	PG	25.75
AG	1.47	GH	2.40	PH	2.61
X2 CA	145.77 E-9	Y2 JB	16.12 E-9	Z2 SB	1.44 E-9
CB	3.36	JC	17.94	SC	2.99
CC	4.47	JD	2.22	SD	16.47
CD	0.69	JE	2.88	SE	4.78
CE	2.46	JF	2.00	SF	54.49
CF	15.72	JG	10.95	SG	376.17
CG	11.13	JH	3.63	SH	9.67
CH	37.59	JJ	82.65	SJ	4.27
CJ	4.84	JK	4.20	SK	3.50
CK	6.61	JM	4.25	SM	2.09
CM	8.14	JN	3.54	SN	4.47
CN	2.73	JP	4.66	SP	8.14
X3 EA	6.89 E-9	Y3 MB	5.76 E-9	Z3 UW	1.34 E-9
EB	4.60	MC	10.54	UC	6.55
EC	3.67	MD	31.25	UD	189.79
ED	2.75	ME	239.74	UE	51.95
EE	2.68	MF	1.40	UF	2.36
EF	3.10	MG	438.28	UG	15.70
EG	4.65	MH	13.34	UH	19.84
EH	5.59	MJ	3.69	UJ	4.07
EJ	2.92	MK	4.24	UK	3.31
EK	3.25	MM	2.63	UM	4.83
EM	2.51	MN	4.22	UN	4.82
EN	2.05	MP	3.64	UP	3.72
EP	5.05	MR	2.06	UR	6.22
ER	3.74	MS	3.94	US	5.69
ES	4.34	MT	4.01	UT	6.14
ET	2.12	MU	1.44	UU	4.31

Table A9a: Laboratory moisture characteristic curves for 105 large core segments as a function of matric suction using pressure extractor. Data is relative saturation in percent.

PRESSURE EXTRACTOR MOISTURE CHARACTERISTIC CURVES						
ID		Suction (kPa)				
		10	25	50	100	300 500
X1	AA	88.42	79.08	67.50	61.90	47.33 41.73
	AB	95.40	82.75	69.72	63.59	50.56 45.57
	AC	95.34	85.29	78.48	66.28	55.16 50.14
	AD	97.07	90.86	82.08	71.85	56.86 49.18
	AE	95.96	93.14	85.87	73.76	57.61 49.54
	AF	94.59	92.28	87.64	74.90	59.46 51.74
	AG	97.27	95.71	90.64	78.94	61.00 51.25
X2	CA	91.11	72.30	67.24	58.34	49.75 46.00
	CB	97.38	87.38	83.80	73.05	59.99 56.35
	CC	91.47	90.10	76.11	61.09	53.58 51.54
	CD	97.22	94.45	89.50	78.31	65.25 48.81
	CE	100.00	96.79	92.27	80.06	60.41 54.54
	CF	99.90	95.32	88.75	74.68	57.95 50.75
	CG	96.23	88.69	84.58	69.50	50.99 45.85
	CH	90.80	87.85	77.34	59.93	42.20 36.29
	CJ	98.14	94.79	82.50	72.81	48.98 40.41
	CK	97.52	96.28	91.62	73.93	49.10 40.10
	CM	96.36	93.39	86.45	68.93	50.74 43.47
	CN	96.47	95.50	88.11	76.54	48.59 39.91
X3	EA	91.99	86.75	77.81	67.95	57.16 51.93
	EB	96.66	91.20	79.36	64.18	57.50 53.55
	EC	91.11	82.19	73.50	61.68	57.57 54.26
	ED	96.53	86.88	78.50	66.58	61.79 58.74
	EE	82.75	79.50	73.40	61.96	61.92 51.71
	EF	101.21	94.59	87.60	78.91	63.52 52.70
	EG	98.79	98.38	93.94	70.49	59.58 53.52
	EH	86.99	85.90	81.63	66.43	58.08 52.28
	EJ	96.72	97.54	93.84	75.38	62.25 54.86
	EK	94.14	97.50	96.75	83.18	70.45 57.72
	EM	97.18	97.18	95.57	78.26	64.17 56.92
	EN	97.84	94.59	92.79	79.09	55.30 48.81
	EP	100.00	97.11	89.88	80.85	50.51 40.03
	ER	97.83	94.95	91.70	77.98	55.60 48.74
	ES	98.98	97.95	96.59	89.07	58.35 48.79
	ET	98.93	95.73	90.04	81.51	58.75 48.08

Table A9a (Continued)

PRESSURE EXTRACTOR MOISTURE CHARACTERISTIC CURVES						
ID		Suction (kPa)				
		10	25	50	100	300 500
Y1	GB	98.75	93.32	80.39	73.30	57.86 48.69
	GC	91.96	84.76	73.75	66.98	49.20 43.69
	GD	93.05	82.00	70.55	62.37	48.88 43.97
	GA	96.66	91.24	89.98	66.22	52.46 44.95
	GF	92.64	86.39	70.58	56.20	40.79 34.90
	GG	92.91	87.91	83.32	69.14	50.79 42.87
	GH	98.70	93.08	90.05	75.77	54.57 45.48
Y2	JB	76.03	70.41	63.89	54.13	47.62 43.47
	JC	96.93	85.74	82.05	70.24	59.45 55.03
	JD	87.57	84.55	68.73	53.28	47.63 45.37
	JE	99.21	89.33	79.84	64.03	56.13 49.01
	JF	98.52	94.61	91.56	81.24	63.11 57.37
	JG	97.33	94.00	80.32	59.97	50.30 46.63
	JH	97.47	92.76	76.47	68.51	46.44 38.47
	JJ	98.70	86.36	76.95	56.49	38.96 33.77
	JK	98.38	93.91	91.88	69.96	47.22 39.91
	JM	98.84	95.36	90.72	74.49	52.45 47.43
	JN	96.18	93.89	90.83	74.79	51.87 45.38
	JP	98.18	94.18	92.36	72.73	50.91 42.91
Y3	MB	90.90	81.16	69.79	59.71	48.99 45.42
	MC	83.14	74.00	65.13	55.99	50.88 42.53
	MD	93.59	81.72	70.81	57.34	50.93 46.44
	ME	96.83	70.10	64.99	56.39	43.72 32.71
	MF	98.35	95.72	88.47	75.44	70.26 66.02
	MG	91.28	79.77	73.43	62.07	53.49 40.76
	MH	97.30	95.76	87.28	68.39	58.75 52.97
	MJ	96.74	96.74	94.88	72.53	57.17 51.12
	MK	99.76	98.02	95.99	83.76	66.29 59.40
	MM	99.55	99.10	93.65	82.79	68.81 61.38
	MN	100.04	98.01	94.63	81.18	64.68 58.42
	MP	98.04	94.50	91.76	78.01	54.85 47.00
	MR	93.50	91.47	84.98	78.08	54.53 47.62
	MS	97.42	93.34	89.70	78.29	53.27 45.92
	MT	98.82	97.63	94.48	81.08	59.01 47.18
	MU	97.17	93.52	87.85	80.97	57.49 47.77

Table A9a (Continued)

		PRESSURE EXTRACTOR MOISTURE CHARACTERISTIC CURVES					
ID		Suction (kPa)					
		10	25	50	100	300	500
Z1	PB	94.28	83.92	75.35	64.63	56.41	52.13
	PC	93.96	87.80	78.75	68.85	58.14	43.34
	PD	93.60	85.28	76.31	63.83	57.11	52.62
	PE	95.54	87.20	81.16	69.81	64.96	60.90
	PF	90.77	87.20	81.80	68.87	62.80	50.67
	PG	90.80	83.49	73.45	63.25	57.31	46.10
	PH	98.09	93.14	84.93	68.11	61.25	55.39
Z2	SB	83.60	78.91	70.71	61.73	53.53	49.24
	SC	96.67	88.75	82.92	67.92	58.75	52.50
	SD	96.87	88.41	82.32	72.48	56.46	55.41
	SE	98.41	90.44	80.88	64.94	56.97	49.80
	SF	96.77	92.89	79.65	62.86	54.13	52.20
	SG	97.62	86.80	71.22	50.37	42.98	40.34
	SH	98.08	95.01	88.11	69.70	57.42	51.29
	SJ	92.82	90.97	85.27	65.34	55.72	40.95
	SK	100.33	97.95	97.57	71.65	64.41	55.90
	SM	99.06	96.26	94.86	81.29	66.32	59.31
	SN	98.80	98.05	96.27	76.10	65.63	50.82
	SP	98.98	98.71	97.08	84.51	64.43	47.95
Z3	UW	97.00	90.16	83.31	70.47	57.64	52.20
	UC	93.17	85.14	71.08	65.06	47.39	40.16
	UD	86.59	71.41	59.05	48.82	38.23	33.64
	UE	82.59	78.14	68.83	56.68	46.56	40.49
	UF	94.05	87.31	82.55	68.68	56.38	49.25
	UG	96.14	91.92	77.53	65.59	43.47	33.99
	UH	96.50	92.30	78.65	60.80	50.65	45.05
	UJ	99.55	98.65	95.52	71.75	59.19	53.81
	UK	96.86	96.41	94.17	75.31	58.71	49.73
	UM	99.57	97.92	94.93	82.96	44.95	58.95
	UN	98.24	97.80	95.59	78.85	60.78	53.28
	UP	100.18	98.99	96.89	81.73	75.06	69.71
	UR	99.23	96.55	94.63	70.08	56.66	50.90
	US	99.96	97.52	96.50	80.16	68.47	65.34
	UT	99.24	98.60	97.16	78.73	67.15	53.04
	UU	92.97	92.72	90.91	75.28	65.85	51.22

Table A9b: Laboratory moisture characteristic curves for 105 small segments. Data is matric suction in MPa and dimensionless relative saturation.

PSYCHROMETRIC MOISTURE CHARACTERISTIC CURVES												
ID	Suction, MPa (above)											
	Relative Saturation, dimensionless (below)											
X1	AA	0.6	0.8	1.8	2.6	4.0	5.6	12.4	17.6	29.3	53.8	60.9
		0.70	0.54	0.47	0.38	0.34	0.30	0.25	0.23	0.20	0.15	0.10
	AB	0.5	0.8	1.2	2.6	3.3	7.4	12.1	25.3	33.7	53.1	5.21
		0.70	0.54	0.48	0.40	0.37	0.29	0.24	0.21	0.20	0.17	0.10
	AC	0.5	0.8	1.1	2.4	2.9	3.7	4.6	7.3	11.5	39.7	61.8
		0.70	0.60	0.56	0.47	0.44	0.40	0.37	0.34	0.30	0.20	0.12
	AD	0.5	0.6	0.7	0.9	1.7	2.6	3.1	4.0	7.6	29.4	68.0
		0.70	0.62	0.60	0.50	0.47	0.44	0.40	0.38	0.30	0.19	0.10
	AE	0.5	0.6	0.7	0.9	1.7	2.9	4.0	5.9	10.2	37.9	62.6
		0.70	0.61	0.56	0.45	0.41	0.36	0.32	0.30	0.25	0.16	0.09
	AF	0.5	0.6	0.6	0.7	0.8	1.1	1.5	3.0	5.8	48.3	
		0.70	0.58	0.53	0.43	0.40	0.34	0.30	0.25	0.20	0.10	
X2	AG	0.6	0.6	0.6	0.8	1.2	2.1	3.2	4.8	7.6	50.2	6.79
		0.70	0.63	0.59	0.46	0.43	0.37	0.33	0.30	0.25	0.13	0.09
	CA	0.4	0.5	0.6	0.6	1.5	1.9	2.1	4.5	7.4	10.1	26.7 42.8
		0.70	0.65	0.58	0.51	0.38	0.36	0.30	0.24	0.20	0.18	0.13 0.09
	CB	0.5	0.5	0.7	1.0	1.9	2.8	3.5	5.0	7.3	11.0	18.4 28.1 33.8
		0.70	0.62	0.57	0.53	0.45	0.40	0.33	0.30	0.25	0.23	0.20 0.17 0.16
		69.3										
		0.10										
	CC	0.6	0.9	1.4	2.2	3.8	4.6	12.5	15.7	16.8	21.2	33.1 65.5 104.
		0.70	0.66	0.60	0.57	0.51	0.45	0.37	0.34	0.34	0.32	0.30 0.20 0.16
	CD	0.5	0.5	0.6	0.6	0.9	1.4	2.0	2.6	3.1	4.0	5.2 7.7 19.5
		0.70	0.67	0.62	0.60	0.54	0.50	0.47	0.43	0.40	0.35	0.32 0.29 0.21
		26.7	36.1	60.0	68.7							
		0.19	0.17	0.14	0.10							
	CE	0.6	0.6	0.6	0.6	0.8	1.3	2.4	3.3	4.6	5.8	10.1 17.8 33.1
		0.70	0.70	0.66	0.62	0.58	0.53	0.47	0.40	0.35	0.30	0.26 0.20 0.17
		48.2	72.1									
		0.15	0.12									
	CF	0.5	0.5	0.5	0.6	0.6	0.9	1.0	1.9	3.3	4.4	6.8 15.7 53.8
		0.70	0.67	0.63	0.59	0.54	0.50	0.45	0.40	0.36	0.30	0.26 0.21 0.11
	CG	0.5	0.5	0.6	0.6	0.6	0.7	1.0	1.7	2.7	3.4	5.0 5.6 9.0
		0.70	0.64	0.60	0.56	0.53	0.50	0.47	0.45	0.40	0.37	0.34 0.31 0.27
		16.4	49.0	67.6								
		0.24	0.15	0.11								
	CH	0.4	0.6	0.5	0.5	0.5	0.6	1.0	1.3	2.5	4.0	5.8 10.3 20.2
		0.68	0.64	0.60	0.55	0.51	0.47	0.45	0.37	0.34	0.30	0.26 0.22 0.18
		51.4										
		0.10										

Table A9b (Continued)

PSYCHROMETRIC MOISTURE CHARACTERISTIC CURVES													
ID	Suction, MPa (above)												
	Relative Saturation, dimensionless (below)												
CJ	0.5	0.5	0.6	0.6	0.5	0.7	0.8	1.0	1.2	2.0	3.7	5.2	7.7
	0.70	0.64	0.60	0.57	0.50	0.45	0.40	0.35	0.30	0.27	0.21	0.19	0.17
	52.3												
CK	0.5	0.5	0.6	0.7	0.9	1.4	2.8	3.6	4.6	6.6	11.3	13.9	51.0
	0.70	0.60	0.54	0.51	0.43	0.37	0.30	0.25	0.22	0.20	0.16	0.15	0.07
	0.06												
CM	0.4	0.4	0.5	0.6	0.8	1.2	1.8	2.8	3.6	4.5	7.9	11.7	16.1
	0.70	0.63	0.58	0.55	0.47	0.42	0.38	0.33	0.30	0.26	0.20	0.18	0.16
	49.1												
CN	0.5	0.5	0.6	0.7	1.4	2.2	3.0	4.3	5.7	12.2	18.2	22.6	21.0
	0.70	0.63	0.57	0.53	0.45	0.40	0.34	0.28	0.24	0.17	0.14	0.14	0.14
	43.9												
X3 EA	0.5	0.5	0.6	0.7	1.4	2.2	3.0	4.3	5.7	12.2	18.2	22.6	21.0
	0.70	0.63	0.57	0.53	0.45	0.40	0.34	0.28	0.24	0.17	0.14	0.14	0.14
	43.9												
EB	0.4	0.6	0.8	0.9	1.3	1.7	2.2	2.6	3.3	4.2	6.5	11.2	34.4
	0.70	0.65	0.61	0.58	0.54	0.50	0.45	0.42	0.40	0.35	0.32	0.27	0.16
	89.2												
EC	0.5	0.5	0.7	1.0	1.5	1.9	3.4	4.2	5.7	8.0	10.7	15.9	34.6
	0.70	0.63	0.56	0.52	0.49	0.45	0.36	0.33	0.31	0.28	0.26	0.24	0.18
	88.5												
ED	0.5	0.6	0.6	0.7	1.1	2.3	3.0	3.8	11.9	16.9	25.1	46.8	80.4
	0.67	0.63	0.59	0.55	0.50	0.42	0.38	0.35	0.25	0.23	0.21	0.16	0.11
	0.09												
EE	0.6	0.8	1.1	3.1	5.1	11.7	47.0						
	0.70	0.57	0.50	0.40	0.29	0.20	0.09						
	0.09												
EF	0.6	1.1	2.1	4.3	3.8	19.0	72.9						
	0.70	0.59	0.50	0.40	0.31	0.22	0.12						
	0.12												
EG	0.5	0.6	0.7	2.3	4.3	10.4	76.2						
	0.72	0.57	0.50	0.40	0.30	0.20	0.09						
	0.09												
EH	0.5	0.6	0.7	2.0	4.6	11.6	46.2						
	0.71	0.60	0.50	0.39	0.30	0.21	0.12						
	0.12												
EJ	0.5	0.7	0.9	2.2	3.3	10.2	44.4						
	0.65	0.58	0.47	0.39	0.29	0.20	0.08						
	0.08												
EK	0.6	0.6	0.8	2.2	4.8	11.3	40.4						
	0.70	0.59	0.50	0.40	0.30	0.21	0.12						
	0.12												
EM	0.6	0.6	0.8	2.5	4.5	10.5	38.0						
	0.70	0.60	0.50	0.40	0.32	0.21	0.11						
	0.11												
EN	0.5	0.6	0.8	2.3	4.1	10.4	40.8						
	0.71	0.60	0.49	0.40	0.32	0.20	0.10						
	0.10												
EP	0.5	0.6	0.7	0.9	1.5	5.7	44.1						
	0.70	0.60	0.50	0.40	0.30	0.20	0.08						
	0.08												
ER	0.5	0.6	0.7	1.7	3.7	9.2	79.2						
	0.70	0.60	0.50	0.40	0.30	0.21	0.09						
	0.09												

Table A9b (Continued)

ID	PSYCHROMETRIC MOISTURE CHARACTERISTIC CURVES							
	Suction, MPa (above)							
	Relative Saturation, dimensionless (below)							
ES	0.5	0.7	1.2	3.1	4.9	14.0	78.9	
	0.70	0.60	0.50	0.40	0.30	0.20	0.10	
ET	0.6	0.7	1.8	3.7	5.8	23.1	82.3	
	0.70	0.60	0.50	0.40	0.30	0.20	0.11	
Y1 GB	0.5	0.9	1.9	3.8	7.5	36.6	126.	
	0.70	0.60	0.50	0.40	0.30	0.20	0.12	
GC	0.6	1.1	2.5	4.5	7.9	34.8	124.	
	0.70	0.60	0.50	0.40	0.31	0.20	0.12	
GD	0.5	0.9	2.5	3.9	6.7	23.4	98.7	
	0.70	0.60	0.50	0.40	0.30	0.20	0.12	
GA	0.6	0.6	1.2	3.0	5.4	15.8	82.9	
	0.70	0.60	0.50	0.40	0.30	0.20	0.10	
GF	0.4	0.5	0.6	0.8	1.3	4.7	55.1	
	0.70	0.60	0.50	0.40	0.30	0.20	0.05	
GG	0.6	0.5	0.6	0.7	1.3	3.5	12.1	27.3
	0.68	0.59	0.50	0.43	0.30	0.19	0.10	0.09
GH	0.5	0.7	0.7	3.0	4.5	9.9	26.2	45.1
	0.69	0.60	0.50	0.36	0.30	0.20	0.11	0.10
Y2 JB	0.5	0.6	1.0	1.5	4.4	11.8	60.0	
	0.70	0.60	0.49	0.44	0.30	0.20	0.12	
JC	0.6	1.3	1.8	2.3	7.3	23.2	67.2	97.6
	0.69	0.58	0.49	0.43	0.31	0.20	0.16	0.14
JD	0.5	0.6	0.5	0.5	1.7	4.5	18.4	42.2
	0.70	0.60	0.50	0.44	0.28	0.19	0.10	0.09
JE	0.6	0.8	1.8	2.5	10.1	26.2	52.4	67.9
	0.69	0.60	0.50	0.45	0.31	0.20	0.15	0.13
JF	0.5	0.5	0.6	0.6	1.6	5.6	24.1	37.0
	0.69	0.60	0.47	0.39	0.26	0.18	0.10	0.10
JG	0.6	0.6	0.9	1.8	4.5	10.5	32.2	35.3
	0.71	0.59	0.48	0.41	0.30	0.21	0.13	0.13
JH	0.5	0.5	0.5	0.8	1.1	3.2	16.2	
	0.70	0.60	0.49	0.40	0.30	0.20	0.09	
JJ	0.5	0.6	0.6	0.6	1.4	2.2	7.3	34.7
	0.70	0.67	0.60	0.50	0.39	0.36	0.20	0.12
JK	0.5	0.5	0.6	0.6	0.7	1.0	3.4	17.3
	0.70	0.66	0.60	0.50	0.38	0.35	0.19	0.10
JM	0.5	0.5	0.4	0.6	0.8	1.2	5.0	25.6
	0.70	0.68	0.60	0.50	0.39	0.37	0.21	0.11
JN	0.5	0.5	0.5	0.8	2.2	3.0	11.4	57.4
	0.70	0.67	0.58	0.49	0.38	0.36	0.20	0.12
JP	0.4	0.6	0.6	0.7	1.5	2.2	7.5	47.5
	0.70	0.67	0.59	0.50	0.40	0.38	0.21	0.11

Table A9b (Continued)

PSYCHROMETRIC MOISTURE CHARACTERISTIC CURVES										
ID	Suction, MPa (above)									
	Relative Saturation, dimensionless (below)									
Y3 MB	0.5	0.5	0.6	0.7	1.4	2.1	7.8	71.0		
	0.71	0.68	0.61	0.49	0.39	0.37	0.21	0.10		
MC	0.5	0.6	0.8	1.5	2.8	3.3	14.6	74.0		
	0.70	0.67	0.60	0.50	0.40	0.38	0.21	0.13		
MD	0.5	0.5	0.6	0.6	0.7	0.9	3.7	25.4		
	0.70	0.67	0.59	0.49	0.38	0.36	0.20	0.10		
ME	0.4	0.6	0.8	2.3	6.9	26.1				
	0.60	0.50	0.38	0.29	0.18	0.11				
MF	0.6	1.8	2.9	9.0	25.7	35.1				
	0.61	0.46	0.40	0.29	0.21	0.15				
MG	0.6	0.5	0.9	1.6	3.1	8.3	49.9			
	0.70	0.61	0.51	0.38	0.28	0.18	0.10			
MH	0.5	0.7	1.8	4.3	12.3	54.2				
	0.63	0.50	0.39	0.30	0.20	0.11				
MJ	0.5	0.8	2.5	5.4	15.2	48.5				
	0.60	0.50	0.39	0.29	0.21	0.12				
MK	0.5	0.6	1.2	4.4	11.5	47.0				
	0.62	0.51	0.39	0.28	0.19	0.11				
MM	0.5	0.4	1.3	3.1	6.4	27.4	31.6	61.6	128.	
	0.69	0.62	0.48	0.39	0.31	0.20	0.18	0.14	0.11	
MN	0.5	0.7	1.6	4.1	10.2	41.5				
	0.64	0.51	0.40	0.27	0.20	0.12				
MP	0.5	0.8	2.4	4.6	11.2	39.3				
	0.61	0.50	0.39	0.30	0.20	0.12				
MR	0.5	0.7	1.3	3.4	7.0	22.4				
	0.62	0.51	0.37	0.30	0.20	0.11				
MS	0.5	0.4	0.9	2.2	4.6	17.7	23.0	43.0	72.9	
	0.68	0.63	0.47	0.40	0.31	0.20	0.17	0.14	0.12	
MT	0.5	0.4	0.7	1.2	2.6	6.3	12.1	53.9	60.1	
	0.69	0.63	0.47	0.40	0.30	0.19	0.15	0.09	0.09	
MU	1.0	1.3	2.4	4.0	7.1	19.4	24.5	57.4	77.3	
	0.68	0.63	0.49	0.40	0.32	0.20	0.18	0.13	0.12	
Z1 PB	0.4	0.4	1.6	2.4	4.6	17.2	23.1	62.8	82.8	
	0.69	0.62	0.48	0.39	0.30	0.19	0.17	0.10	0.10	
PC	0.7	0.5	1.2	1.7	4.6	8.7	39.9			
	0.68	0.60	0.48	0.40	0.29	0.20	0.09			
PD	0.4	0.5	1.9	3.1	5.5	18.6	19.3	44.9	85.7	
	0.69	0.63	0.49	0.39	0.31	0.19	0.18	0.14	0.11	
PE	0.6	0.5	1.3	1.9	6.5	12.8	47.0	70.8		
	0.69	0.59	0.48	0.40	0.28	0.21	0.12	0.10		
PF	0.7	0.5	1.3	2.6	7.4	25.3	44.9	85.4		
	0.66	0.60	0.49	0.39	0.29	0.21	0.13	0.10		
PG	0.6	0.5	0.7	0.8	3.2	6.6	37.2			
	0.68	0.59	0.48	0.41	0.28	0.21	0.10			
PH	0.6	0.5	1.0	1.4	4.1	11.3	39.5	72.3		
	0.70	0.60	0.48	0.40	0.29	0.20	0.11	0.09		

Table A9b (Continued)

		PSYCHROMETRIC MOISTURE CHARACTERISTIC CURVES							
ID		Suction, MPa (above)							
		Relative Saturation, dimensionless (below)							
Z2	SB	0.5	0.5	1.0	1.7	5.0	14.0	36.9	66.5
		0.69	0.70	0.48	0.40	0.29	0.20	0.12	0.10
	SC	0.6	0.6	1.8	2.8	7.6	22.2	36.1	93.9
		0.70	0.60	0.48	0.40	0.30	0.21	0.14	0.09
	SD	0.6	0.7	1.5	2.0	2.8	10.7	39.0	70.2
		0.70	0.60	0.49	0.40	0.29	0.20	0.12	0.10
	SE	0.6	0.7	1.7	2.8	3.9	14.7	41.9	78.9
		0.69	0.60	0.49	0.39	0.30	0.19	0.13	0.10
	SF	0.6	0.6	1.1	2.1	3.2	9.7	43.2	81.7
		0.69	0.59	0.50	0.40	0.30	0.20	0.12	0.09
	SG	0.7	0.5	1.7	2.7	5.1	16.4	45.3	76.6
		0.70	0.60	0.49	0.40	0.30	0.20	0.15	0.12
	SH	0.5	0.5	1.2	2.6	4.8	14.2	44.3	78.8
		0.70	0.59	0.50	0.40	0.30	0.20	0.14	0.11
	SJ	0.5	0.4	0.8	1.2	3.0	8.0	36.2	70.0
		0.70	0.59	0.50	0.40	0.29	0.19	0.11	0.08
	SK	0.4	0.4	0.7	0.9	2.2	6.1	33.4	
		0.69	0.59	0.48	0.40	0.30	0.19	0.10	
	SM	0.4	0.4	0.7	1.2	3.1	7.5	28.8	59.1
		0.70	0.60	0.48	0.40	0.30	0.19	0.11	0.08
	SN	0.6	0.5	0.6	0.7	1.3	4.7	21.0	37.4
		0.71	0.59	0.49	0.39	0.30	0.19	0.10	0.08
	SP	0.6	0.5	0.7	0.7	1.1	3.7	19.6	43.7
		0.71	0.58	0.47	0.40	0.30	0.19	0.09	0.07
Z3	UW	0.4	0.4	1.4	1.9	3.6	10.8	49.5	
		0.67	0.60	0.44	0.40	0.32	0.21	0.10	
	UC	0.4	0.5	0.9	1.2	3.0	9.3	46.0	54.8
		0.70	0.60	0.50	0.41	0.31	0.20	0.08	0.08
	UD	0.5	0.6	1.4	2.3	4.4	12.4	43.9	58.9
		0.72	0.59	0.47	0.40	0.30	0.20	0.12	0.12
	UE	0.4	0.5	0.9	1.6	3.2	7.4	43.2	62.2
		0.70	0.60	0.50	0.40	0.28	0.20	0.11	0.10
	UF	0.4	0.4	0.7	0.7	1.6	6.7	38.1	48.8
		0.70	0.60	0.48	0.40	0.32	0.20	0.10	0.09
	UG	0.4	0.5	0.7	1.1	3.1	7.0	33.7	51.8
		0.71	0.59	0.49	0.39	0.29	0.20	0.09	0.09
	UH	0.4	0.5	0.6	1.3	2.8	9.1	19.9	
		0.69	0.59	0.49	0.37	0.30	0.18	0.10	
	UJ	0.4	0.5	0.6	1.0	2.4	8.0	23.8	
		0.70	0.60	0.49	0.38	0.31	0.18	0.10	
	UK	0.4	0.5	0.5	0.7	1.0	5.7	19.0	
		0.69	0.58	0.49	0.36	0.30	0.16	0.08	
	UM	0.4	0.5	0.5	0.6	1.2	5.0	17.4	
		0.70	0.59	0.48	0.39	0.30	0.20	0.10	
	UN	0.3	0.5	0.5	1.2	1.6	8.2	23.7	
		0.69	0.59	0.50	0.36	0.32	0.20	0.10	

Table A9b (Continued)

ID	PSYCHROMETRIC MOISTURE CHARACTERISTIC CURVES									
	Suction, MPa (above)					Relative Saturation, dimensionless (below)				
UP	0.3	0.4	0.7	1.3	2.4	6.1	22.7			
	0.69	0.59	0.50	0.38	0.32	0.23	0.11			
UR	0.3	0.4	0.7	0.8	1.4	4.5	15.8			
	0.73	0.59	0.50	0.38	0.31	0.21	0.09			
US	0.3	0.4	0.6	0.6	0.8	1.4	3.6	5.7		
	0.70	0.60	0.49	0.38	0.30	0.20	0.09	0.08		
UT	0.4	0.4	0.5	0.8	2.5	5.5	23.0			
	0.71	0.60	0.50	0.43	0.31	0.21	0.11			
UU	0.4	0.4	0.6	0.7	2.1	4.7	22.8			
	0.69	0.60	0.50	0.41	0.40	0.19	0.09			

Table A9c: Laboratory moisture characteristic curves for 105 large core segments as a function of matric suction using Tempe Pressure cells.

TEMPE PRESSURE CELL MOISTURE CHARACTERISTIC CURVES					
ID		Suction (kPa)			
		10	25	50	100
X1	AA	95.80	85.85	78.58	63.66
	AB	97.10	88.62	78.53	64.00
	AC	96.43	89.06	76.62	63.42
	AD	96.65	92.35	82.27	66.78
	AE	97.34	94.87	84.61	67.79
	AF	98.70	97.82	93.01	78.60
	AG	99.21	97.60	94.99	74.16
X2	CA	84.53	72.17	64.20	54.66
	CB	93.23	87.20	78.36	64.06
	CC	89.56	81.41	74.33	61.40
	CD	98.04	95.06	87.36	73.34
	CE	98.94	97.10	88.00	69.79
	CF	99.07	93.98	82.31	67.63
	CG	98.77	94.85	85.25	65.00
	CH	98.67	92.52	77.72	56.41
	CJ	99.28	98.74	93.03	67.77
	CK	99.21	98.57	93.15	67.68
	CM	98.99	97.81	86.37	65.71
	CN	99.72	98.00	95.96	71.39
X3	EA	98.43	96.38	82.04	64.71
	EB	91.78	86.71	76.91	64.09
	EC	91.31	85.61	75.49	60.94
	ED	93.69	87.36	78.07	60.22
	EE	97.34	95.03	83.19	65.62
	EF	99.33	98.52	89.69	70.02
	EG	99.02	98.46	91.72	70.00
	EH	99.44	99.16	93.24	66.61
	EJ	95.78	95.18	92.44	68.36
	EK	99.23	98.66	95.99	73.98
	EM	99.55	99.41	97.74	74.76
	EN	98.72	97.91	95.90	75.80
	EP	99.77	99.00	97.12	72.69
	ER	98.18	97.63	95.07	71.32
	ES	99.43	99.07	97.97	83.37
	ET	99.52	97.45	95.95	75.71

Table A9c (Continued)

TEMPE PRESSURE CELL MOISTURE CHARACTERISTIC CURVES					
ID		Suction (kPa)			
		10	25	50	100
Y1	GB	98.50	96.34	89.03	72.68
	GC	94.16	89.14	79.60	66.06
	GD	93.97	89.21	78.86	60.74
	GA	98.37	94.67	84.41	67.60
	GF	98.54	96.01	71.02	58.42
	GG	93.89	89.65	81.65	65.18
	GH	98.22	96.86	93.05	73.76
Y2	JB	89.50	78.99	71.87	61.71
	JC	91.54	84.61	76.34	63.06
	JD	87.51	78.65	70.19	55.58
	JE	97.37	87.23	77.70	60.67
	JF	99.18	98.13	92.11	75.91
	JG	96.52	87.80	75.60	60.96
	JH	99.47	98.44	87.55	65.77
	JJ	98.65	91.33	76.87	53.74
	JK	98.10	97.62	89.98	65.56
	JM	98.05	97.64	92.93	69.18
	JN	98.83	98.50	95.55	70.91
	JP	98.50	98.17	92.52	63.52
Y3	MB	92.68	82.35	68.85	55.53
	MC	83.56	74.06	64.41	53.50
	MD	87.51	76.32	68.75	56.58
	ME	87.97	65.55	57.36	45.65
	MF	97.06	94.79	87.09	68.96
	MG	88.08	75.63	65.52	53.59
	MH	98.08	95.71	85.48	68.57
	MJ	98.17	97.47	95.09	67.89
	MK	99.44	98.71	96.33	72.97
	MM	99.00	98.70	96.91	76.78
	MN	99.14	98.72	96.71	74.76
	MP	98.36	97.52	93.60	75.02
	MR	99.29	98.78	96.52	73.92
	MS	99.42	98.94	96.58	75.78
	MT	98.50	96.90	94.32	73.67
	MU	99.54	99.18	97.68	77.46

Table A9c (Continued)

		TEMPE PRESSURE CELL MOISTURE CHARACTERISTIC CURVES			
ID		Suction (kPa)			
		10	25	50	100
Z1	PB	93.85	85.88	76.83	62.35
	PC	97.07	90.07	79.86	63.55
	PD	89.75	81.79	74.51	58.29
	PE	94.98	88.26	81.77	65.00
	PF	96.87	94.18	86.57	66.41
	PG	97.96	86.93	73.95	57.02
	PH	97.18	94.94	86.44	64.78
Z2	SB	94.32	90.51	81.65	67.31
	SC	94.21	90.19	83.94	68.33
	SD	97.18	88.68	80.19	63.61
	SE	97.88	90.63	81.68	66.98
	SF	94.55	86.19	77.33	62.67
	SG	95.57	80.40	66.02	42.50
	SH	97.26	93.52	84.88	66.04
	SJ	99.11	98.20	91.44	66.45
	SK	99.92	99.46	97.19	66.62
	SM	99.27	98.61	94.65	73.59
	SN	97.11	96.64	93.94	67.39
	SP	99.42	98.94	93.99	67.25
Z3	UW	97.35	95.12	86.68	69.36
	UC	95.98	87.78	76.49	59.72
	UD	89.21	79.90	66.49	52.16
	UE	96.55	86.66	79.48	65.11
	UF	98.96	96.99	86.54	71.73
	UG	99.22	94.71	87.40	61.15
	UH	98.90	88.88	74.99	50.91
	UJ	98.76	98.06	93.50	68.18
	UK	96.76	95.82	93.03	68.40
	UM	98.17	97.24	93.11	71.05
	UN	99.47	99.14	95.98	72.05
	UP	99.51	98.86	96.70	72.53
	UR	99.18	98.70	93.59	64.49
	US	99.56	99.04	96.31	74.07
	UT	99.40	98.90	95.85	71.13
	UU	99.15	98.70	96.09	72.86

Table A9d: Laboratory moisture characteristic curves for 10 large core segments as a function of matric suction for wetting phase.

	RELATIVE SATURATION (%)					
	- - - - Matric Suction (kPa) - - - - -					
	10	25	50	100	300	500
EC	70.14	63.23	56.32	52.60	47.82	46.76
EN	75.90	70.10	60.83	48.67	39.98	38.82
GG	61.40	57.64	49.50	42.61	35.09	32.58
JK	70.41	66.27	56.21	46.15	38.46	36.69
MJ	76.98	75.60	65.98	54.30	42.61	41.24
PF	73.25	69.33	64.09	57.55	50.36	49.05
PG	77.19	70.23	62.10	56.88	49.91	48.17
SA	70.25	68.35	57.60	45.57	37.34	35.44
SD	67.58	62.83	57.50	52.76	46.24	45.64
UA	84.85	81.21	72.12	57.58	38.79	36.36

Table A9e: Van Genuchten moisture characteristic curve function parameters. Least squares estimate using relative saturation objective function and a constant n-value for all samples. Optimal parameter estimates obtained when residual saturation is zero and when the n-parameter is equal to 1.26.

ID	α -value (kPa ⁻¹)	ID	α -value (kPa ⁻¹)	ID	α -value (kPa ⁻¹)
X1 AA	.0289	Y1 GB	.0150	Z1 PB	.0234
AB	.0289	GC	.0194	PC	.0234
AC	.0157	GD	.0234	PD	.0220
AD	.0154	GA	.0200	PE	.0173
AE	.0177	GF	.0430	PF	.0182
AF	.0240	GG	.0323	PG	.0297
AG	.0176	GH	.0201	PH	.0193
X2 CA	.0331	Y2 JB	.0394	Z2 SB	.0257
CB	.0164	JC	.0153	SC	.0177
CC	.0102	JD	.0412	SD	.0179
CD	.0125	JE	.0184	SE	.0192
CE	.0110	JF	.0205	SF	.0216
CF	.0156	JG	.0238	SG	.0311
CG	.0176	JH	.0333	SH	.0182
CH	.0284	JJ	.0329	SJ	.0258
CJ	.0284	JK	.0263	SK	.0198
CK	.0257	JM	.0215	SM	.0171
CM	.0240	JN	.0184	SN	.0200
CN	.0219	JP	.0186	SP	.0200
X3 EA	.0203	Y3 MB	.0256	Z3 UW	.0212
EB	.0139	MC	.0256	UC	.0316
EC	.0176	MD	.0314	UD	.0514
ED	.0161	ME	.0643	UE	.0431
EE	.0217	MF	.0126	UF	.0279
EF	.0124	MG	.0297	UG	.0325
EG	.0167	MH	.0218	UH	.0312
EH	.0208	MJ	.0196	UJ	.0205
EJ	.0172	MK	.0161	UK	.0244
EK	.0127	MM	.0120	UM	.0238
EM	.0136	MN	.0158	UN	.0205
EN	.0168	MP	.0205	UP	.0146
EP	.0221	MR	.0246	UR	.0232
ER	.0183	MS	.0195	US	.0233
ES	.0135	MT	.0195	UT	.0182
ET	.0135	MU	.0130	UU	.0202

Table A10: Laboratory determined unsaturated hydraulic conductivity values in m/s x E-9 for large core segments obtained using outflow method.

ID	UNSATURATED HYDRAULIC CONDUCTIVITY (m/s x E-9)				
	Suction (kPa)				
	0	10	25	50	100
X1 AA	14.31	0.846	0.375	0.160	0.0882
AB	4.70	0.126	0.250	0.136	0.2238
AC	2.19	0.711	0.721	0.558	0.1059
AD	1.20	1.170	0.432	0.409	0.1699
AE	1.00	1.000	0.360	0.571	0.2576
AF	1.38	0.442	0.092	0.028	0.1518
AG	1.47	1.470	1.470	0.959	0.2346
X2 CA	145.77	3.673	1.585	0.185	0.00508
CB	3.36	0.790	0.650	0.378	0.2645
CC	4.47	4.470	1.031	0.243	0.0399
CD	0.69	0.690	0.690	0.420	0.6900
CE	2.46	2.460	0.354	0.166	0.0805
CF	15.72	2.070	1.861	0.752	0.1364
CG	11.13	4.095	10.567	1.021	0.3118
CH	37.59	0.299	8.431	2.330	0.1069
CJ	4.84	4.011	3.122	0.107	0.0485
CK	6.61	6.610	0.315	1.227	0.1596
CM	8.14	8.140	0.375	0.536	0.3795
CN	2.73	1.787	0.460	0.210	0.3041
X3 EA	6.89	2.559	1.070	0.478	0.2063
EB	4.60	4.600	1.955	0.236	0.1989
EC	3.67	1.227	1.163	0.803	0.3736
ED	2.75	2.750	1.867	1.095	0.1587
EE	2.68	2.680	0.455	0.470	0.2723
EF	3.10	3.100	2.080	0.498	0.1488
EG	4.65	4.650	0.556	0.210	0.0691
EH	5.59	5.590	0.405	0.233	0.2109
EJ	2.92	2.920	2.085	0.715	0.4625
EK	3.25	3.250	0.234	0.264	0.1709
EM	2.51	2.510	0.156	0.064	0.3077
EN	2.05	0.449	0.217	0.192	0.3510
EP	5.05	1.023	0.380	0.163	0.5166
ER	3.74	1.434	0.092	3.740	0.2300
ES	4.34	4.340	4.340	1.731	2.5415
ET	2.12	0.278	0.174	0.141	0.3534

Table A10 (Continued)

ID	UNSATURATED HYDRAULIC CONDUCTIVITY (m/s x E-9)				
	Suction (kPa)				
	0	10	25	50	100
Y1 GB	1.73	0.535	0.514	0.168	0.1536
GC	4.61	0.189	0.127	0.184	0.0949
GD	3.58	0.597	0.521	0.177	0.0907
GA	1.11	1.110	0.815	0.760	0.0957
GF	1.02	1.020	0.293	1.020	0.9870
GG	1.44	1.425	0.335	0.183	0.0742
GH	2.40	2.357	1.282	1.048	0.5110
Y2 JB	16.12	1.607	0.550	0.229	0.0564
JC	17.94	7.434	0.540	0.216	0.0257
JD	2.22	1.091	0.339	0.305	0.2114
JE	2.88	2.880	0.409	0.307	0.4648
JF	2.00	2.000	0.119	0.527	0.1249
JG	10.95	10.950	0.699	0.187	0.0227
JH	3.63	2.792	0.811	0.506	0.1993
JJ	82.65	5.234	9.182	2.575	0.5986
JK	4.20	4.098	3.670	1.306	0.0949
JM	4.25	4.250	2.429	1.894	0.3991
JN	3.54	3.540	1.843	3.540	0.1038
JP	4.66	4.660	4.660	4.097	1.0341
Y3 MB	5.76	2.847	5.760	0.528	0.2047
MC	10.54	10.540	1.737	0.242	0.1859
MD	31.25	9.478	0.930	0.352	0.0684
ME	239.74	1.753	0.277	0.00184	0.0074
MF	1.40	1.400	0.648	0.885	0.2650
MG	438.28	7.359	2.286	1.940	0.2981
MH	13.34	3.879	0.374	2.236	0.1097
MJ	3.69	3.690	0.401	0.847	0.5181
MK	4.24	4.240	0.011	2.711	0.5694
MM	2.63	2.630	0.323	1.370	0.6896
MN	4.22	4.220	0.966	1.639	0.3809
MP	3.64	0.170	0.097	1.186	0.6614
MR	2.06	2.060	0.094	1.809	1.4109
MS	3.94	0.812	0.356	0.199	0.1695
MT	4.01	4.010	0.691	0.437	0.2827
MU	1.44	1.440	0.461	0.370	0.1932

Table A10 (Continued)

ID	UNSATURATED HYDRAULIC CONDUCTIVITY (m/s x E-9)				
	Suction (kPa)				
	0	10	25	50	100
Z1 PB	5.49	5.490	1.643	0.528	0.4268
PC	3.49	3.388	2.897	0.469	0.2132
PD	103.57	16.229	1.398	0.236	0.0437
PE	4.50	1.659	1.095	0.891	0.2635
PF	2.39	2.390	0.532	0.734	0.2858
PG	25.75	25.750	6.371	1.414	0.8799
PH	2.61	2.610	0.628	0.268	0.1354
Z2 SB	1.44	1.440	0.359	0.338	0.3361
SC	2.99	0.323	0.294	0.161	0.0791
SD	16.47	3.063	0.621	0.240	0.0358
SE	4.78	0.442	0.383	0.361	0.3255
SF	54.49	1.040	0.834	0.515	0.4933
SG	376.17	10.138	6.816	5.041	0.8742
SH	9.67	6.543	2.007	0.996	0.2339
SJ	4.27	4.270	0.381	0.597	0.2234
SK	3.50	0.166	3.500	3.500	0.3392
SM	2.09	2.090	0.528	0.413	1.0544
SN	4.47	0.626	0.463	4.470	0.4277
SP	8.14	8.140	3.792	3.773	1.6687
Z3 UW	1.34	1.340	0.980	0.481	0.2437
UC	6.55	0.437	0.507	0.418	0.1690
UD	189.79	1.671	0.511	0.00656	0.0174
UE	51.95	1.129	0.144	0.125	0.1230
UF	2.36	0.381	0.160	0.196	0.0622
UG	15.70	0.699	0.880	0.614	0.3616
UH	19.84	0.262	14.588	1.091	0.2377
UJ	4.07	4.070	0.656	2.650	0.1653
UK	3.31	3.310	0.288	0.158	0.2913
UM	4.83	4.830	0.071	2.051	1.2390
UN	4.82	4.820	1.178	0.623	2.0692
UP	3.72	3.720	0.383	0.314	0.7607
UR	6.22	6.220	0.112	0.206	0.3884
US	5.69	5.690	2.512	1.823	0.9150
UT	6.14	6.140	2.174	1.158	0.7153
UU	4.31	4.310	0.280	1.040	0.4590

Table All: Field determined saturated hydraulic conductivity values in m/s x E-9 at the Apache Leap Tuff Site using three methods: (1) Philip, (2) Glover, and (3) Dachler.

Borehole	Sample ID	Outflow (m3/s)	Hydraulic Conductivity (m/s x E-9)		
			- - - Method - - -	(1)	(2)
X1	AA	-	-	-	-
	AB	-	-	-	-
	AC	0.083 E-6	5.50	2.94	5.16
	AD	0.016	0.68	0.36	0.62
	AE	0.183	5.45	2.91	5.17
	AF	0.083	1.94	1.04	1.84
	AG	0.167	1.99	1.14	1.88
X2	CA	-	-	-	-
	CB	-	-	-	-
	CC	1.567	120.31	57.92	100.74
	CD	0.250	11.63	5.62	9.82
	CE	0.267	8.96	4.33	7.58
	CF	2.016	53.04	25.65	44.81
	CG	1.816	39.25	18.98	33.16
	CH	0.967	17.73	8.57	14.99
	CJ	1.616	25.74	12.45	21.75
	CK	0.283	3.98	1.92	3.37
	CM	0.783	9.87	4.77	8.34
	CN	0.216	1.89	0.96	1.53
X3	EA	-	-	-	-
	EB	-	-	-	-
	EC	0.567	45.66	20.23	35.16
	ED	1.117	56.04	24.82	43.14
	EE	0.800	29.14	12.91	22.44
	EF	0.317	9.06	4.01	6.97
	EG	0.067	1.57	0.69	1.21
	EH	0.383	7.66	3.39	5.90
	EJ	0.267	4.64	2.05	3.57
	EK	0.716	11.02	4.88	8.47
	EM	0.183	2.53	1.12	1.94
	EN	0.516	6.45	2.86	4.96
	EP	0.383	4.37	1.94	3.37
	ER	-	-	-	-
	ES	-	-	-	-
	ET	0.200	0.48	0.27	0.41

- - - - -
Table A11 (Continued)
- - - - -

Borehole	Sample ID	Outflow (m3/s)	Hydraulic Conductivity (m/s x E-9)		
			- - - - Method - - - -		
			(1)	(2)	(3)
Y1	GB	-	-	-	-
	GC	-	-	-	-
	GD	0.116	8.02	4.31	7.97
	GA	0.066	2.76	1.48	2.75
	GF	0.083	2.49	1.34	2.49
	GG	0.100	2.33	1.26	2.34
	GH	0.100	1.97	1.06	1.54
Y2	JB	-	-	-	-
	JC	-	-	-	-
	JD	1.216	106.52	51.44	93.75
	JE	0.250	11.68	5.83	10.70
	JF	0.300	10.02	5.00	9.18
	JG	0.967	25.12	12.55	23.03
	JH	3.933	83.63	41.78	76.65
	JJ	1.616	29.08	14.53	26.65
	JK	1.150	17.94	8.96	16.44
	JM	0.516	7.11	3.55	6.51
	JN	0.350	4.31	2.15	3.95
	JP	0.283	4.64	2.15	2.73
Y3	MB	-	-	-	-
	MC	-	-	-	-
	MD	0.816	73.17	34.09	59.32
	ME	0.567	27.32	13.16	23.98
	MF	1.750	60.49	29.15	53.09
	MG	2.350	63.31	30.51	55.58
	MH	2.050	45.25	21.80	39.72
	MJ	0.433	8.10	3.90	7.11
	MK	0.416	6.76	3.26	5.92
	MM	0.700	10.02	4.83	8.80
	MN	0.516	6.62	3.19	5.81
	MP	1.016	11.78	5.68	10.34
	MR	0.367	3.88	1.87	3.41
	MS	0.350	3.41	1.64	3.00
	MT	0.216	1.96	0.94	1.71
	MU	0.167	1.03	0.53	0.78

Table A11 (Continued)

Borehole	Sample ID	Outflow (m3/s)	Hydraulic Conductivity (m/s x E-9)		
			Method		
			(1)	(2)	(3)
Z1	PB	-	-	-	-
	PC	-	-	-	-
	PD	2.216	182.53	95.90	172.17
	PE	1.100	47.37	25.75	47.97
	PF	26.050	797.56	433.59	807.79
	PG	4.716	71.45	41.51	113.46
	PH	1232.0	39224.	19126.	17900.
Z2	SB	-	-	-	-
	SC	-	-	-	-
	SD	0.067	5.74	2.76	5.06
	SE	0.083	4.00	1.96	3.58
	SF	1.600	54.81	26.85	49.21
	SG	7.516	200.09	98.01	179.68
	SH	2.867	62.41	30.57	56.05
	SJ	9.416	173.38	84.93	155.72
	SK	6.583	105.03	51.45	94.33
	SM	2.483	34.95	17.12	31.39
	SN	1.067	13.43	6.58	12.07
	SP	0.633	8.91	4.19	5.91
Z3	UW	-	-	-	-
	UC	-	-	-	-
	UD	0.183	14.11	6.75	12.34
	UE	0.250	11.78	5.64	10.33
	UF	0.650	22.11	10.59	19.39
	UG	0.966	25.73	12.32	22.55
	UH	1.950	42.63	20.42	37.39
	UJ	0.800	14.84	7.11	13.01
	UK	0.416	6.71	3.21	5.88
	UM	2.016	28.69	13.74	25.17
	UN	5.800	73.95	35.42	64.86
	UP	1.583	10.82	5.67	14.45
	UR	-	-	-	-
	US	-	-	-	-
	UT	834.0	6947.9	3435.8	4234.0
	UU	1.383	8.38	4.46	6.87

Table A12: Outflow rates during borehole flooding experiments.

Borehole X1

Elapsed Time (hours)	Outflow (liters/hr)	Comments
0.00	NA	Borehole filled, head between -4 & -1 m.
104.20	1.60	
114.12	0.88	
151.40	1.38	
163.15	1.92	
171.07	1.93	
220.82	1.38	
245.48	1.46	
259.77	1.78	
370.05	1.63	
380.33	1.67	
386.47	2.00	
416.17	3.39	Head at +0.5 m beginning 415 hrs.
453.00	2.98	Borehole drained

Table A12. (Continued)

Borehole X2

Elapsed Time (hours)	Outflow (liters/hr)	Comments
0.00	NA	Borehole filled, head at 0.5 m.
26.25	31.56	
31.00	44.76	Siphon reestablished.
42.75	42.72	
72.75	41.46	
79.00	42.00	
91.25	41.34	
97.50	41.58	
100.25	41.76	
115.25	41.52	
152.67	41.10	
164.25	40.50	
171.83	40.44	
222.00	38.76	
246.00	37.62	
262.50	38.82	Siphon reestablished.
283.33	37.80	
363.25	35.58	
383.17	36.72	Siphon reestablished.
416.83	36.84	
458.83	34.68	Borehole drained.

 Table A12: (Continued)

Borehole Y1

Elapsed Time (hours)	Outflow (liters/hr)	Comments
0.00	NA	Borehole filled, head between -4 & -1 m.
99.32	0.87	
114.00	0.90	
151.08	0.80	
164.90	0.40	
170.30	1.00	
220.43	0.77	
245.08	0.79	
259.60	0.91	
369.30	0.72	
379.77	0.71	
385.92	0.86	
415.83	1.27	Head at +0.5 m beginning 415 hrs.
452.17	1.27	Borehole drained.

- - - - -
Table A12 (Continued)
- - - - -

Borehole Y2

Elapsed Time (hours)	Outflow (liters/hr)	Comments
0.00	NA	Borehole filled, head at 0.5 m.
26.00	35.10	
31.50	39.42	Siphon reestablished.
42.00	37.26	
72.00	33.72	
78.75	33.90	
91.00	33.06	
97.25	32.82	
100.00	33.36	Siphon reestablished.
115.00	32.94	
152.25	32.10	
164.00	31.20	
171.58	31.14	
221.75	29.46	
246.00	28.56	
260.50	28.20	
262.25	28.92	Siphon reestablished.
283.17	27.66	
363.75	21.06	
383.00	27.72	Siphon reestablished.
416.50	26.40	
458.00	26.34	
529.75	25.80	Siphon reestablished, borehole drained.

Table A13: Field volumetric water content in percent determined from neutron count data.

		FIELD VOLUMETRIC WATER CONTENT (%)							
		- - - - - Julian Date from 1/1/87 - - - - -							
ID		41	236	255	279	372	406	448	505
X1	AA	11.89	11.83	12.40	11.88	11.90	12.01	12.09	12.14
	AB	12.22	12.13	12.98	12.41	12.08	12.34	12.24	12.52
	AC	12.04	12.03	13.02	12.40	11.98	12.08	12.16	12.21
	AD	11.11	11.99	13.73	12.95	12.52	12.38	12.31	12.35
	AE	12.12	13.41	15.19	14.59	14.33	14.04	14.01	13.94
	AF	12.21	13.16	14.62	14.13	13.94	13.95	13.91	13.85
	AG	12.62	13.73	14.99	14.70	14.53	14.36	14.40	14.36
X2	CA	14.01	-	15.49	14.67	14.17	14.19	14.16	14.23
	CB	14.00	14.15	15.96	15.04	14.44	14.56	14.55	14.42
	CC	14.42	15.09	18.14	16.64	15.80	15.73	15.48	15.61
	CD	12.32	12.31	13.97	13.71	13.47	13.30	13.24	13.18
	CE	13.08	13.13	15.36	14.97	14.41	14.42	14.35	14.23
	CF	14.04	14.53	16.40	16.16	15.66	15.56	15.23	15.29
	CG	14.99	15.46	17.73	17.22	17.11	16.90	16.62	16.48
	CH	14.52	15.89	18.26	17.94	17.64	17.49	17.31	16.88
	CJ	13.18	15.10	16.42	16.20	16.18	16.05	15.93	14.73
	CK	13.92	15.82	16.88	16.83	16.61	16.74	16.73	15.29
	CM	14.37	16.54	-	17.26	17.11	16.99	17.00	15.53
	CN	14.40	16.20	-	16.59	16.70	16.53	16.60	15.26
X3	EA	16.36	15.13	14.85	14.71	14.33	14.79	14.83	14.80
	EB	14.37	14.31	14.03	13.99	13.48	13.35	13.49	13.43
	EC	13.87	13.89	13.74	13.63	13.18	13.14	13.16	13.12
	ED	12.61	12.71	12.62	12.67	12.60	12.54	12.59	12.35
	EE	12.67	12.73	12.61	12.56	12.47	12.54	12.47	12.40
	EF	13.30	13.32	13.24	13.32	13.27	13.30	13.19	13.22
	EG	14.05	14.49	14.46	14.48	14.42	14.40	14.42	14.46
	EH	14.34	14.54	14.48	14.48	14.63	14.44	14.59	14.57
	EJ	13.45	14.02	13.78	13.76	13.76	13.78	13.95	13.70
	EK	14.47	14.94	15.06	15.18	15.01	14.99	15.03	15.01
	EM	15.37	16.09	16.07	15.94	15.91	15.95	15.92	15.94
	EN	16.35	16.68	16.82	16.80	16.50	16.53	16.40	16.47
	EP	16.71	16.96	16.99	16.88	16.98	16.85	16.95	16.98
	ER	16.75	16.97	16.76	16.89	17.04	16.84	16.82	17.03
	ES	17.08	16.58	16.37	16.42	16.45	16.52	16.59	16.53
	ET	17.22	16.88	16.83	16.89	16.83	16.67	16.84	16.76

Table A13 (Continued)

		FIELD VOLUMETRIC WATER CONTENT (%)							
		Julian Date from 1/1/87							
ID		41	236	255	279	372	406	448	505
Y1	GB	12.25	12.11	12.80	12.45	12.45	12.50	12.60	12.93
	GC	12.23	12.30	13.26	12.90	12.63	12.66	12.72	12.98
	GD	11.70	11.91	13.03	12.37	11.93	12.02	12.10	12.44
	GA	10.45	11.44	13.24	12.55	11.87	11.51	11.62	11.65
	GF	11.55	12.13	14.22	13.54	13.15	12.96	12.79	12.63
	GG	12.01	12.93	14.21	13.70	13.51	13.42	13.37	13.45
	GH	13.01	-	-	-	14.51	14.39	14.42	14.41
Y2	JB	15.46	16.05	16.50	16.40	16.12	16.32	16.13	16.06
	JC	13.84	14.39	16.43	15.76	15.35	15.66	15.63	15.55
	JD	13.71	14.03	15.85	15.38	15.38	15.22	15.47	15.63
	JE	12.55	12.28	13.41	13.28	13.13	13.04	13.02	13.01
	JF	13.04	12.76	15.36	14.98	14.44	14.49	14.18	14.26
	JG	14.44	14.15	17.23	16.71	15.63	15.41	15.22	15.02
	JH	13.60	13.91	17.17	16.55	16.31	16.00	15.94	15.73
	JJ	14.55	15.69	18.75	18.42	17.74	17.77	17.57	17.51
	JK	13.16	14.45	16.44	16.46	16.23	16.08	16.10	16.15
	JM	14.12	15.57	17.55	17.29	17.36	16.81	17.06	16.98
	JN	14.12	15.79	17.47	17.32	17.31	17.11	17.15	17.20
	JP	14.50	16.92	-	-	17.22	17.16	17.16	17.06
Y3	MB	14.16	13.76	13.68	13.65	13.84	13.74	13.66	13.69
	MC	13.85	13.46	13.26	13.41	13.24	13.25	13.20	13.34
	MD	13.61	13.63	13.65	13.58	13.45	13.22	13.40	13.47
	ME	12.80	12.81	12.73	12.71	12.68	12.48	12.56	12.70
	MF	13.58	13.25	13.24	13.15	13.36	13.43	-	13.34
	MG	14.75	14.63	14.55	14.65	14.71	14.65	14.56	14.67
	MH	15.68	15.56	15.77	15.47	15.59	15.38	15.58	15.56
	MJ	13.66	13.72	13.65	13.74	13.80	13.72	13.71	13.65
	MK	12.88	13.08	13.12	13.07	12.92	13.13	13.06	12.75
	MM	13.55	13.92	13.90	13.92	13.95	13.83	13.85	13.89
	MN	13.77	14.51	14.33	14.48	14.34	14.19	14.17	14.41
	MP	14.90	16.13	15.94	15.84	15.58	15.36	15.38	15.33
	MR	14.53	15.61	15.42	15.52	15.16	15.10	14.98	15.00
	MS	15.48	16.37	16.17	16.30	16.36	16.22	16.29	16.21
	MT	15.38	15.62	15.73	15.74	15.81	15.65	15.56	15.60
	MU	16.32	15.97	15.89	15.98	15.84	15.97	15.96	15.93

Table A13 (Continued)

		FIELD VOLUMETRIC WATER CONTENT (%)							
		- - - - - Julian Date from 1/1/87 - - - - -							
ID		41	236	255	279	372	406	448	505
Z1	PB	17.63	16.88	16.80	17.02	16.99	17.23	17.11	16.98
	PC	17.15	16.60	16.62	16.76	16.66	17.01	16.56	16.75
	PD	16.03	15.47	15.55	15.55	15.71	15.79	15.79	15.67
	PE	14.22	13.91	13.77	13.93	14.14	14.35	13.97	14.16
	PF	12.51	12.65	12.37	12.30	12.42	12.38	12.33	12.36
	PG	13.52	14.28	14.01	14.03	13.78	13.66	13.60	13.59
	PH	12.83	12.94	13.09	-	13.14	13.20	13.05	13.10
Z2	SB	12.80	12.63	12.73	12.77	13.00	13.23	12.96	13.01
	SC	12.25	12.60	12.47	12.62	12.66	12.80	12.95	12.91
	SD	11.95	12.34	12.12	12.41	12.37	12.28	12.53	12.89
	SE	13.33	13.15	13.15	13.34	13.28	13.35	13.27	13.58
	SF	14.73	14.81	14.67	14.61	14.56	14.44	14.49	14.48
	SG	17.35	17.29	17.37	17.25	17.07	17.23	17.15	16.86
	SH	13.93	14.05	14.15	13.85	13.97	13.75	13.81	13.75
	SJ	13.55	13.67	13.87	13.70	13.71	13.62	13.76	13.68
	SK	12.90	12.97	12.98	12.85	12.88	12.91	12.90	12.93
	SM	12.17	12.66	12.69	12.66	12.64	12.58	12.52	12.53
	SN	12.55	14.04	13.78	13.83	13.86	13.73	13.87	13.69
	SP	13.49	15.40	15.43	15.28	15.24	15.06	15.05	15.11
Z3	UW	12.17	11.66	11.60	11.49	12.45	12.42	12.35	12.44
	UC	11.18	10.85	11.05	10.78	10.14	10.69	10.79	10.93
	UD	10.91	11.01	10.91	11.13	9.99	10.18	10.51	10.54
	UE	10.19	10.94	10.89	10.77	10.06	9.53	9.85	10.14
	UF	11.98	11.41	11.28	11.29	11.38	11.28	11.33	11.18
	UG	12.74	12.86	12.86	12.90	12.72	12.68	12.79	12.60
	UH	14.04	14.22	14.19	14.06	14.04	14.04	14.01	13.94
	UJ	13.35	13.56	13.56	13.65	13.66	13.54	13.65	13.65
	UK	12.58	12.33	12.49	12.45	12.39	12.41	12.45	12.30
	UM	13.54	13.73	13.68	13.85	13.68	13.64	13.68	13.72
	UN	14.19	14.89	14.89	14.89	14.74	14.77	14.89	14.65
	UP	14.13	14.97	14.94	14.99	14.90	14.90	14.85	14.92
	UR	14.36	15.09	14.90	14.90	14.97	14.86	14.79	14.82
	US	14.48	15.16	15.19	15.23	14.95	15.07	15.00	15.04
	UT	14.88	14.91	14.94	14.84	14.84	14.66	14.69	14.64
	UU	14.03	14.80	14.56	14.70	14.50	14.45	14.40	14.39

Table A14: Laboratory unsaturated air permeability ($\text{m}^2 \times \text{E-16}$).

		LABORATORY AIR-PERMEABILITY ($\text{m}^2 \times \text{E-16}$)					
		Suction (kPa)					
ID	k _{air}	10	25	50	100	300	500
X1 AA	84.27	10.53	37.55	35.34	40.65	45.57	49.57
AB	15.06	0.02	0.21	2.79	5.31	9.28	9.74
AC	13.62	0.04	0.06	0.61	2.31	4.73	5.22
AD	5.35	<0.01	0.02	0.32	0.91	2.17	2.34
AE	4.40	0.10	0.03	0.18	0.78	1.99	2.64
AF	4.17	0.03	0.07	0.22	1.08	2.38	2.79
AG	3.98	0.23	0.08	0.05	0.89	1.89	2.31
X2 CA	254.79	0.10	2.62	88.32	144.67	179.03	190.96
CB	17.08	0.05	0.05	0.05	0.80	2.59	4.03
CC	13.52	0.03	0.04	0.61	3.32	3.83	6.55
CD	8.19	0.02	0.05	0.03	0.44	1.62	1.99
CE	6.03	<0.01	0.66	2.16	2.36	3.87	4.44
CF	24.99	0.02	0.48	0.44	6.45	17.47	18.93
CG	20.37	0.11	0.70	2.95	10.10	14.87	16.27
CH	66.29	0.36	1.52	10.94	34.81	46.51	48.04
CJ	9.94	0.02	0.03	0.13	0.87	6.53	7.00
CK	13.51	<0.01	0.02	0.06	2.91	7.08	8.20
CM	15.16	0.05	0.07	1.41	6.19	12.18	12.41
CN	6.51	0.08	0.12	0.15	0.37	3.05	3.94
X3 EA	30.72	0.85	3.35	3.92	8.66	11.54	13.69
EB	12.73	0.03	0.23	1.14	4.69	8.10	9.38
EC	27.62	0.06	0.12	0.42	4.41	5.94	6.07
ED	16.26	0.02	0.06	0.14	2.19	2.62	2.78
EE	21.67	0.05	0.37	0.46	5.63	6.69	5.58
EF	14.79	0.10	0.08	0.15	2.11	5.13	4.88
EG	9.92	0.02	0.02	0.03	2.96	6.20	6.87
EH	9.51	0.03	0.04	0.10	3.08	5.62	6.44
EJ	6.30	0.03	0.02	0.08	0.82	2.47	3.34
EK	6.00	0.14	0.06	0.09	0.62	2.99	3.73
EM	5.27	0.02	0.02	0.02	0.63	1.97	2.77
EN	6.01	0.04	0.04	0.08	0.59	3.59	4.26
EP	9.04	0.03	0.04	0.19	0.71	6.31	6.67
ER	7.20	0.04	0.04	0.06	0.91	4.21	4.85
ES	8.50	0.08	0.10	0.07	0.25	4.70	6.09
ET	5.20	0.02	0.03	0.04	0.47	2.68	3.48

Table A14 (Continued)

		LABORATORY AIR-PERMEABILITY ($\text{m}^2 \times \text{E-16}$)					
		Suction (kPa)					
ID	k _{air}	10	25	50	100	300	500
Y1 GB	6.59	0.03	0.03	0.25	0.82	2.46	2.61
GC	35.16	4.37	12.00	12.21	17.81	13.44	17.81
GD	17.77	0.16	0.34	1.50	4.56	9.47	9.61
GA	6.02	0.02	<0.01	0.12	0.96	2.59	3.02
GF	6.56	0.03	0.04	0.07	0.37	3.55	3.98
GG	4.99	0.10	0.14	0.14	0.60	2.09	3.11
GH	6.18	0.11	0.19	0.51	1.27	2.28	4.05
Y2 JB	60.13	2.85	7.30	16.19	28.28	33.34	37.27
JC	141.74	30.95	42.35	41.16	61.81	77.26	118.86
JD	15.59	0.11	0.05	4.51	1.26	4.69	12.90
JE	25.10	0.09	0.53	2.00	1.94	10.82	12.99
JF	5.88	0.17	0.07	0.17	0.68	1.29	3.13
JG	20.97	0.03	0.03	0.50	9.89	13.47	14.72
JH	9.74	0.02	0.02	0.95	2.13	4.84	6.04
JJ	124.72	0.51	14.28	38.22	81.20	102.39	110.37
JK	8.39	0.05	0.16	0.17	2.49	5.23	5.99
JM	7.81	0.08	0.27	0.49	1.63	5.09	5.92
JN	7.26	0.05	0.06	0.21	1.37	4.38	5.19
JP	9.85	0.04	0.04	0.07	1.48	5.05	5.67
Y3 MB	27.16	<0.01	0.04	0.06	7.07	7.71	9.04
MC	88.44	0.05	6.49	7.19	23.51	36.90	33.40
MD	174.04	0.06	4.35	55.52	82.43	97.64	104.05
ME	740.22	0.06	333.08	212.48	339.44	531.79	490.88
MF	10.46	0.03	0.10	0.15	1.48	2.04	2.60
MG	1012.62	22.58	316.76	389.79	678.65	780.45	780.45
MH	42.02	0.04	0.08	3.14	13.16	20.38	22.57
MJ	6.91	0.12	0.06	0.07	1.48	2.12	4.21
MK	5.25	0.04	0.28	0.18	0.34	2.62	4.66
MM	6.30	0.38	0.28	0.46	0.49	2.26	2.52
MN	7.92	0.02	0.04	0.16	0.77	2.27	4.26
MP	8.49	0.07	0.09	0.10	1.11	4.04	4.94
MR	5.49	0.08	0.11	0.15	0.48	3.16	3.78
MS	9.95	0.03	0.10	0.39	1.26	5.80	6.57
MT	8.21	0.03	0.03	0.10	1.35	4.74	6.26
MU	3.81	0.06	0.13	0.39	0.46	1.98	2.55

Table A14 (Continued)

		LABORATORY AIR-PERMEABILITY (m ² x E-16)					
		Suction (kPa)					
ID	k _{air}	10	25	50	100	300	500
Z1 PB	28.59	0.01	0.01	1.19	4.89	7.37	9.01
PC	19.53	0.19	0.07	1.40	2.57	6.60	7.15
PD	355.47	0.09	20.30	132.45	170.99	209.60	224.05
PE	53.07	0.01	0.04	1.01	10.09	8.83	8.71
PF	10.10	0.02	0.03	0.20	1.12	4.23	3.97
PG	120.28	0.03	0.97	21.92	48.12	68.00	62.56
PH	25.96	0.01	0.03	0.06	1.15	2.34	1.91
Z2 SB	8.56	0.01	0.02	0.28	0.92	2.01	3.64
SC	11.94	0.05	0.44	0.46	8.36	5.82	6.39
SD	51.61	0.46	10.08	11.30	15.14	25.38	67.49
SE	10.31	0.03	0.02	0.63	2.19	3.43	4.37
SF	101.68	0.03	0.56	25.00	61.25	74.79	76.57
SG	915.85	39.21	131.26	304.74	376.86	529.47	628.09
SH	89.69	<0.01	0.77	5.56	17.38	21.79	25.06
SJ	12.90	0.03	0.06	0.29	1.81	5.31	5.18
SK	11.77	0.12	0.08	0.09	2.21	3.08	4.20
SM	6.14	0.44	0.61	0.65	1.99	2.86	3.21
SN	12.26	0.05	0.02	0.44	1.31	5.93	5.98
SP	24.13	0.06	0.10	0.07	1.06	3.04	11.77
Z3 UW	10.21	0.06	0.07	0.17	1.09	2.59	2.99
UC	20.93	0.12	2.22	6.28	8.07	13.51	14.26
UD	338.40	1.47	168.06	239.00	260.78	250.75	284.69
UE	92.25	41.93	47.03	45.97	57.41	70.61	74.92
UF	7.92	0.06	0.16	0.44	2.33	3.35	4.43
UG	28.22	0.04	2.47	10.90	14.51	19.86	28.89
UH	55.00	0.02	0.26	16.65	36.71	41.95	45.01
UJ	10.76	0.09	0.19	0.78	2.10	4.70	5.75
UK	7.66	0.04	0.12	0.12	0.63	2.46	3.55
UM	8.24	0.05	0.10	0.05	0.43	1.30	3.95
UN	10.15	0.02	0.14	0.17	0.73	4.62	6.42
UP	9.14	0.06	0.03	0.05	0.90	1.29	2.08
UR	23.72	0.03	0.03	0.03	2.93	6.88	7.79
US	13.52	0.07	0.16	0.40	1.79	3.77	4.16
UT	18.28	0.10	0.06	0.21	1.20	6.95	6.59
UU	12.08	0.03	0.08	0.15	1.23	5.53	5.63

Table A15: Klinkenberg coefficients obtained from laboratory air/water permeability ratios for 105 large core segments.

ID	Klinkenberg Coef. (kPa)	ID	Klinkenberg Coef. (kPa)	ID	Klinkenberg Coef. (kPa)
X1 AA	575.	Y1 GB	335.	Z1 PB	497.
AB	264.	GC	777.	PC	541.
AC	613.	GD	468.	PD	290.
AD	408.	GA	521.	PE	1260.
AE	401.	GF	637.	PF	382.
AF	242.	GG	294.	PG	434.
AG	206.	GH	190.	PH	1047.
X2 CA	95.	Y2 JB	325.	Z2 SB	584.
CB	481.	JC	808.	SC	356.
CC	243.	JD	708.	SD	255.
CD	1277.	JE	904.	SE	142.
CE	176.	JF	234.	SF	108.
CF	76.	JG	114.	SG	174.
CG	104.	JH	204.	SH	967.
CH	97.	JJ	67.	SJ	242.
CJ	130.	JK	123.	SK	282.
CK	129.	JM	105.	SM	232.
CM	108.	JN	130.	SN	210.
CN	168.	JP	137.	SP	236.
X3 EA	409.	Y3 MB	439.	Z3 UW	774.
EB	213.	MC	865.	UC	262.
EC	765.	MD	538.	UD	99.
ED	577.	ME	250.	UE	98.
EE	831.	MF	757.	UF	281.
EF	445.	MG	160.	UG	101.
EG	139.	MH	257.	UH	213.
EH	89.	MJ	109.	UJ	199.
EJ	143.	MK	35.	UK	161.
EK	106.	MM	170.	UM	90.
EM	135.	MN	109.	UN	136.
EN	232.	MP	162.	UP	177.
EP	100.	MR	202.	UR	335.
ER	115.	MS	185.	US	168.
ES	119.	MT	130.	UT	237.
ET	176.	MU	199.	UU	217.

Table A16: Field observed flow rates and interpreted air permeability.

ID	Date	Injection Pressure, kPa	Flow Rate m ³ /s x E-9	Permeability m ² x E-16
X1	AA	-	-	-
	AB	-	-	-
	AC	08/04/88	91.2	602.35
		07/21/88	91.4	516.62
	AD	07/21/88	91.6	219.40
		08/04/88	91.5	307.10
	AE	07/21/88	91.2	7615.4
		08/04/88	91.2	7677.3
	AF	08/04/88	150.6	1766.9
		09/01/88	91.2	124.64
	AG	09/08/88	90.9	78.40
		09/08/88	91.1	117.59
		09/13/88	90.9	77.27
				0.48
X2	CA	-	-	-
	CB	-	-	-
	CC	08/04/88	91.2	2806.9
		09/01/88	91.0	2881.8
	CD	07/13/88	91.3	77.83
		09/01/88	91.1	105.47
	CE	07/14/88	91.1	1854.9
		08/04/88	91.3	1799.5
	CF	07/14/88	87.2	15837.
		08/04/88	87.1	16274.
	CG	07/13/88	91.0	1463.7
		08/15/88	91.6	1737.6
	CH	07/13/88	91.5	1044.5
		08/15/88	91.4	1349.6
	CJ	07/13/88	91.0	2242.9
		07/13/88	90.9	2184.2
		08/15/88	91.0	2324.4
	CK	08/15/88	91.1	227.57
		08/25/88	148.3	2448.3
		09/01/88	91.1	166.38
	CM	07/13/88	91.2	200.50
		08/15/88	91.2	258.03
	CN	09/06/88	91.5	151.43
		09/08/88	91.5	127.75

Table A16 (Continued)

ID	Date	Injection Pressure, kPa	Flow Rate m3/s x E-9	Permeability m2 x E-16
X3	EA	-	-	-
	EB	-	-	-
	EC	08/15/88	91.4	4850.9
		08/25/88	90.7	3993.5
	ED	08/15/88	91.2	10562.
		09/06/88	91.0	9998.4
	EE	06/29/88	90.2	1333.3
		08/15/88	92.3	1995.1
	EF	08/15/88	91.6	229.27
		08/25/88	90.9	188.09
	EG	08/15/88	91.3	118.16
		09/01/88	91.2	113.08
	EH	08/15/88	138.3	950.90
		08/25/88	91.4	89.68
	EJ	08/15/88	93.6	140.15
		08/25/88	91.1	94.47
	EK	08/15/88	91.5	109.98
		08/25/88	90.9	82.63
	EM	08/25/88	91.3	82.63
		09/01/88	91.3	76.70
	EN	06/29/88	89.4	1343.1
		08/25/88	91.3	1195.4
		09/01/88	91.0	1392.5
	EP	06/29/88	89.5	217.99
		08/15/88	93.6	492.94
	ER	06/29/88	90.5	1460.5
		08/17/88	90.7	1933.2
	ES	08/17/88	90.8	201.35
		09/01/88	90.9	145.51
	ET	09/06/88	91.2	73.88
		09/08/88	91.2	101.52
Y1	GB	-	-	-
	GC	-	-	-
	GD	07/21/88	138.8	4221.7
		08/04/88	142.9	6513.5
	GA	07/21/88	90.6	325.15
		08/04/88	91.1	419.33
	GF	07/21/88	91.2	191.76
		08/04/88	91.4	315.28
	GG	07/13/88	91.8	225.88
		07/21/88	91.7	226.16
		08/04/88	91.2	262.82
	GH	09/08/88	90.9	137.62
		09/13/88	91.0	126.05

Table A16 (Continued)

ID	Date	Injection Pressure, kPa	Flow Rate m3/s x E-9	Permeability m2 x E-16
Y2 JB	-	-	-	-
JC	-	-	-	-
JD	07/20/88	90.9	5564.8	51.43
	08/03/88	91.6	6242.9	50.63
JE	07/13/88	91.1	410.03	3.61
	07/20/88	90.9	436.54	4.01
	08/03/88	91.1	581.02	5.17
JF	07/13/88	92.2	1467.0	10.73
	07/20/88	90.3	964.72	10.28
	08/03/88	92.1	1610.4	11.95
JG	07/13/88	91.5	1724.5	14.14
	07/20/88	91.1	2004.9	17.98
	08/03/88	91.0	1956.0	17.79
JH	07/13/88	91.0	17604.	159.11
	07/20/88	90.2	16069.	172.00
	08/03/88	90.3	16277.	173.42
JJ	07/13/88	91.3	1701.7	14.62
	07/20/88	91.2	1776.7	15.47
	08/03/88	93.0	2679.7	17.24
JK	07/21/88	91.4	352.22	2.96
	08/03/88	92.2	550.46	4.02
JM	07/13/88	91.3	381.55	3.25
	07/21/88	91.6	504.22	4.05
	08/04/88	91.3	585.15	5.04
	08/17/88	91.2	685.54	5.99
JN	07/13/88	91.6	84.04	0.67
	07/21/88	145.4	1092.8	0.64
JP	09/06/88	91.0	89.96	1.00
	09/08/88	91.0	84.32	0.94
Y3 MB	-	-	-	-
MC	-	-	-	-
MD	08/03/88	91.7	9864.8	78.16
	08/17/88	91.2	9030.2	78.32
ME	07/07/88	90.5	1877.8	18.75
	08/03/88	90.9	1378.4	12.69
MF	07/07/88	91.2	2096.2	18.32
	08/03/88	91.4	2360.2	19.90
MG	07/07/88	90.9	1929.9	17.89
	08/03/88	91.3	2272.2	19.41
MH	07/07/88	91.3	576.13	4.88
	08/03/88	91.4	710.68	5.99
MJ	07/07/88	91.4	122.67	1.03
	08/03/88	91.6	144.38	1.16

Table A16 (Continued)

ID	Date	Injection Pressure, kPa	Flow Rate m ³ /s x E-9	Permeability m ² x E-16
MK	08/03/88	91.5	190.63	1.58
	08/17/88	90.9	236.88	2.17
MM	08/03/88	91.5	408.34	3.37
	08/17/88	91.7	263.39	2.11
	08/25/88	91.3	328.25	2.79
MN	08/03/88	91.4	170.89	1.43
	08/17/88	91.7	159.61	1.28
MP	08/03/88	91.0	328.25	2.98
	08/17/88	90.9	329.09	3.04
MR	08/03/88	91.4	195.71	1.64
	08/25/88	90.9	139.59	1.29
MS	08/03/88	91.1	154.25	1.38
	08/25/88	91.0	87.98	0.79
	09/01/88	91.2	118.44	1.04
MT	08/25/88	91.1	77.27	0.68
	09/01/88	90.9	80.65	0.74
MU	09/06/88	91.2	73.88	0.50
	09/08/88	91.2	61.76	0.42
Z1	PB	-	-	-
	PC	-	-	-
	PD	07/18/88	90.1	15834.
		08/17/88	90.0	13689.
	PE	07/18/88	89.8	15022.
		08/17/88	90.1	15899.
	PF	08/17/88	86.1	16307.
		09/01/88	86.1	16267.
	PG	07/18/88	90.7	11853.
		08/17/88	90.9	13663.
	PH	(Permeability exceeds measurement capability)		
Z2	SB	-	-	-
	SC	-	-	-
	SD	08/17/88	90.8	54.14
		09/01/88	91.3	50.20
	SE	08/17/88	91.3	92.78
		09/01/88	91.1	97.85
	SF	07/20/88	90.6	8736.8
		08/17/88	91.1	9916.9
	SG	07/20/88	88.9	16238.
		08/17/88	89.2	16297.
	SH	07/20/88	90.6	1871.2
		08/17/88	91.4	2402.6
	SJ	07/20/88	87.9	16277.
		08/17/88	88.1	16297.

Table A16 (Continued)

ID	Date	Injection Pressure, kPa	Flow Rate m ³ /s x E-9	Permeability m ² x E-16
SK	07/20/88	88.9	15371.	241.11
	08/17/88	89.2	16290.	232.58
SM	07/20/88	91.9	213.47	1.63
	08/17/88	91.1	299.20	2.68
	09/01/88	91.1	328.81	2.93
SN	07/20/88	90.6	5868.0	57.40
	08/17/88	91.6	8241.3	66.23
SP	09/08/88	91.2	4762.9	49.48
	09/13/88	90.9	404.39	4.45
Z3 UW	-	-	-	-
UC	-	-	-	-
UD	07/14/88	91.4	228.98	1.92
	09/06/88	91.4	256.90	2.15
UE	07/14/88	91.0	283.41	2.59
	08/17/88	90.7	347.42	3.36
UF	07/14/88	91.0	1489.8	13.49
	08/17/88	90.9	704.44	6.47
	09/06/88	90.9	188.38	1.73
	09/06/88	90.8	162.71	1.52
UG	07/14/88	92.5	590.79	4.10
	08/17/88	91.1	529.03	4.72
UH	07/14/88	91.1	6207.0	55.66
	08/17/88	91.2	7374.1	63.71
UJ	08/17/88	91.7	417.92	3.33
	09/06/88	91.7	455.99	3.63
UK	07/14/88	91.3	129.72	1.12
	08/17/88	91.0	178.22	1.61
UM	07/14/88	91.6	3687.1	29.87
	08/17/88	91.1	4381.4	39.21
UN	07/14/88	91.1	13249.1	117.97
	08/17/88	90.9	13725.	127.62
UP	07/14/88	91.3	1434.4	12.31
	08/17/88	90.9	1718.0	15.91
UR	07/14/88	91.3	832.18	7.17
	08/17/88	91.3	1013.5	8.71
US	07/14/88	91.7	209.24	1.67
	08/17/88	91.0	243.08	2.21
UT	08/17/88	86.0	16329.	13366.
UU	09/08/88	91.2	129.72	0.94
	09/13/88	91.0	132.54	0.98

Table A17: Laboratory-estimated thermal conductivity (J/m/s/°K) and dry rock specific heat (J/kg/°K) for saturated, variably saturated and oven-dried large core segments.

ID	THERMAL CONDUCTIVITY (J/m/s/°K)								Dry Rock	
	Suction (kPa)								Specific Heat	
	0	10	25	50	100	300	500	dry (J/kg/°K)		
X1	AA	1.875	1.780	1.913	1.691	1.670	1.568	1.683	1.197	595.09
	AB	1.621	1.986	1.767	1.956	2.242	1.650	1.982	1.487	822.37
	AC	1.989	1.565	1.640	1.603	1.835	2.066	1.796	1.388	692.02
	AD	2.135	1.666	1.733	1.664	1.938	1.863	1.797	1.491	604.79
	AE	1.938	1.736	1.936	1.908	2.239	1.876	1.775	1.596	795.11
	AF	2.075	2.005	2.089	2.063	2.313	1.837	1.958	1.347	680.09
	AG	1.994	1.651	1.727	1.685	1.964	1.885	1.890	1.469	637.67
X2	CA	1.853	1.871	1.572	1.552	1.651	1.527	1.663	1.064	1168.3
	CB	1.922	2.013	1.813	1.990	1.814	1.572	2.084	1.198	1125.2
	CC	2.174	1.937	1.989	2.568	1.881	1.845	1.610	1.430	748.75
	CD	1.707	1.868	2.287	2.030	2.785	2.040	1.939	1.335	770.39
	CE	1.894	1.829	1.857	1.815	1.796	1.704	1.762	1.279	498.71
	CF	2.017	2.107	1.947	1.925	1.871	1.632	1.841	1.319	748.78
	CG	1.637	1.597	1.737	1.912	1.517	1.719	1.349	1.333	915.32
	CH	2.025	2.026	1.964	1.720	1.676	1.651	1.591	1.189	837.35
	CJ	2.019	2.204	2.114	2.038	2.037	1.847	2.030	1.200	694.59
	CK	1.898	1.839	1.647	1.907	1.857	2.575	1.634	1.268	511.14
	CM	1.660	1.678	1.840	1.797	1.694	1.797	1.752	1.401	756.31
	CN	1.603	1.689	1.742	1.356	1.814	1.506	1.338	.987	468.52
X3	EA	1.839	1.883	1.855	1.734	1.785	1.685	1.844	1.088	447.99
	EB	1.983	1.771	1.722	1.654	1.745	1.749	1.809	1.223	583.80
	EC	1.901	1.844	2.000	1.678	1.951	1.615	1.708	1.149	578.51
	ED	1.835	1.978	2.377	2.017	2.194	2.333	2.065	1.311	512.15
	EE	1.908	1.742	1.752	1.718	1.948	1.754	1.838	1.328	626.39
	EF	1.912	1.904	1.827	1.944	2.036	1.515	2.127	1.343	345.18
	EG	2.237	1.886	1.968	2.136	1.972	1.910	1.822	1.443	726.25
	EH	2.202	1.747	2.580	2.459	2.116	1.896	2.138	1.280	976.70
	EJ	1.877	1.779	1.814	1.811	1.804	1.810	1.698	1.290	482.28
	EK	1.773	1.828	1.917	1.983	1.797	1.687	1.884	1.126	548.81
	EM	1.746	1.757	2.000	1.810	2.030	1.726	1.681	1.212	726.72
	EN	1.853	2.021	1.832	1.758	1.835	1.911	1.986	1.111	580.79
	EP	1.767	1.883	1.801	1.793	1.586	1.614	1.957	1.141	724.15
	ER	1.615	1.570	1.695	1.591	1.540	1.560	1.688	1.343	668.97
	ES	1.757	1.518	1.590	1.586	1.686	2.080	1.631	1.232	683.57
	ET	1.825	1.920	2.216	1.924	1.806	1.530	1.848	1.966	517.48

Table A17 (Continued)

ID	THERMAL CONDUCTIVITY (J/m/s/°K)								Dry Rock	
	Suction (kPa)								Specific Heat	
	0	10	25	50	100	300	500	dry	(J/kg/°K)	
Y1	GB	1.837	1.691	2.115	1.914	2.336	1.685	1.846	1.164	447.65
	GC	1.818	1.695	1.922	2.088	1.948	1.782	1.725	1.288	556.68
	GD	1.607	1.782	1.578	1.701	1.844	1.494	1.626	1.147	463.63
	GA	1.811	1.931	1.955	1.945	1.937	2.282	1.717	1.434	698.21
	GF	2.491	2.024	1.715	1.717	1.713	1.714	1.883	1.108	920.67
	GG	1.865	2.484	2.102	2.057	2.165	1.829	2.006	1.262	831.53
	GH	1.945	1.883	1.742	1.806	1.718	1.667	1.972	1.546	757.09
Y2	JB	1.866	1.914	1.673	1.452	1.701	1.677	1.749	.924	832.36
	JC	1.803	1.812	1.657	1.656	1.700	1.445	1.734	1.193	703.04
	JD	1.937	1.758	1.637	1.663	1.613	1.623	1.577	1.179	762.28
	JE	1.942	1.653	1.844	1.740	1.894	1.715	1.633	1.288	732.48
	JF	2.010	1.665	1.722	1.768	1.558	1.593	1.862	1.227	927.96
	JG	1.968	1.744	1.768	1.701	1.534	1.455	1.434	1.043	874.61
	JH	1.695	1.862	1.800	1.723	1.730	1.456	1.642	1.282	807.99
	JJ	1.768	1.814	1.689	1.755	1.632	1.595	1.520	1.305	463.54
	JK	1.859	1.775	1.723	1.822	1.674	1.702	1.788	1.431	583.58
	JM	1.314	1.514	1.665	1.474	1.491	1.484	1.783	1.308	511.87
	JN	1.437	1.780	1.748	1.534	1.625	1.531	1.701	1.429	814.70
	JP	1.670	1.635	1.533	1.684	1.623	1.802	1.591	1.282	676.75
Y3	MB	1.852	1.508	1.642	1.462	1.761	1.909	1.731	1.358	710.29
	MC	1.668	1.733	1.642	1.602	1.573	1.728	1.556	1.020	632.48
	MD	1.806	1.592	1.536	1.359	1.732	1.541	1.516	1.121	881.11
	ME	1.765	1.824	1.653	1.642	1.717	1.521	1.560	1.078	603.27
	MF	1.701	2.172	2.098	1.997	2.030	2.293	1.937	1.294	587.53
	MG	1.553	1.766	1.734	1.730	1.543	1.626	1.341	1.108	609.91
	MH	1.921	2.030	1.926	1.866	1.832	1.681	1.637	1.283	680.03
	MJ	2.239	1.921	1.937	1.882	1.893	2.012	1.702	1.451	812.99
	MK	1.806	1.992	1.851	1.881	1.754	1.642	1.887	1.307	755.20
	MM	1.983	1.967	1.776	1.842	1.694	1.645	1.770	1.240	708.60
	MN	1.635	1.723	1.680	1.715	1.691	1.474	1.323	1.186	587.56
	MP	1.500	1.647	1.618	1.525	1.521	1.582	1.645	1.318	663.59
	MR	2.035	1.766	1.575	1.689	1.763	1.792	1.917	1.229	764.81
	MS	1.762	1.884	1.994	1.740	1.671	1.721	1.870	1.330	635.28
	MT	1.607	1.502	1.736	1.787	1.763	1.671	1.661	1.318	616.55
	MU	1.896	1.974	2.018	1.759	2.059	1.773	2.007	1.278	783.01

Table A17 (Continued)

ID	THERMAL CONDUCTIVITY (J/m/s/°K)							Dry Rock	
	Suction (kPa)							Specific Heat	
	0	10	25	50	100	300	500	dry	(J/kg/°K)
Z1 PB	1.932	1.588	1.703	1.400	1.854	1.934	1.819	1.368	813.14
PC	1.836	1.818	1.923	1.917	1.788	1.647	1.714	1.199	962.41
PD	1.775	1.661	1.623	1.473	1.658	1.944	1.736	1.160	893.94
PE	1.901	1.626	1.938	1.650	2.184	1.672	1.715	1.321	797.72
PF	1.859	1.381	1.681	1.631	1.932	1.757	1.730	1.301	1043.5
PG	1.600	1.622	1.609	1.545	1.722	1.546	1.591	1.127	1037.7
PH	1.774	1.960	1.995	1.983	1.828	2.030	1.794	1.064	728.54
Z2 SB	1.820	1.949	1.663	1.868	1.836	1.785	1.881	1.313	832.19
SC	1.929	1.724	1.608	1.559	1.779	1.788	1.699	1.364	588.45
SD	2.033	1.887	1.816	1.890	1.893	1.676	1.684	1.338	683.39
SE	1.819	1.657	1.471	1.364	1.667	1.864	1.575	1.207	793.15
SF	1.955	1.944	1.797	1.749	1.761	1.606	1.843	1.151	713.16
SG	1.291	1.583	1.464	1.569	1.382	1.488	1.095	.829	600.20
SH	1.659	1.890	2.443	2.261	1.639	1.692	1.684	1.145	501.12
SJ	1.763	1.607	1.792	1.961	1.766	1.722	1.772	1.256	903.52
SK	1.991	1.792	1.897	1.730	1.945	1.744	1.627	1.330	511.48
SM	1.885	1.679	1.578	1.494	1.704	2.020	1.596	1.392	946.67
SN	1.841	1.854	1.890	1.941	2.028	1.783	1.807	1.248	820.72
SP	1.595	1.741	1.737	1.782	1.672	1.628	1.284	1.178	757.07
Z3 UW	1.552	1.843	1.814	1.611	1.608	1.640	1.697	1.451	684.52
UC	1.886	1.653	1.817	1.697	1.900	1.704	1.569	1.281	714.16
UD	1.539	1.770	1.754	1.505	1.578	1.491	1.680	1.386	437.31
UE	1.847	1.893	1.858	1.677	1.730	1.604	1.705	1.235	662.24
UF	1.926	1.957	1.740	1.570	1.687	1.710	1.841	1.192	851.96
UG	1.577	1.809	1.802	1.961	1.704	1.572	1.579	1.167	538.89
UH	1.603	1.591	1.874	1.649	1.813	1.521	1.504	1.100	469.63
UJ	1.782	1.733	1.809	1.816	1.863	1.749	1.643	1.333	917.89
UK	2.014	1.935	1.911	1.949	2.057	1.714	1.637	1.304	921.40
UM	1.940	1.809	1.719	1.780	1.704	1.578	1.742	1.304	619.63
UN	1.618	1.808	1.815	1.913	1.977	1.696	1.669	1.402	535.86
UP	1.611	1.747	1.819	1.899	1.808	1.905	1.410	1.350	823.33
UR	1.362	1.584	1.606	1.510	1.594	1.515	1.494	1.166	531.63
US	1.571	1.713	1.960	1.870	1.755	1.941	1.759	1.185	529.64
UT	1.741	1.830	2.036	1.941	1.720	1.634	1.615	1.217	853.37
UU	1.902	1.844	1.824	1.766	2.402	1.551	2.044	1.287	500.82

Table A18: Field observed temperatures, °C, in Borehole Y3 for various dates.

Borehole ID		OBSERVED TEMPERATURES (°C)				
		Date				
		2/11/87	4/22/87	7/28/87	8/18/87	12/18/87
Y3	MB	-	-	-	-	11.097
	MC	-	-	-	-	18.866
	MD	-	-	-	-	-
	ME	16.574	16.361	34.533	26.559	22.036
	MF	18.953	17.748	25.792	21.552	21.227
	MG	19.422	18.695	20.814	19.192	20.052
	MH	19.257	19.053	18.784	18.549	19.348
	MJ	19.106	19.189	18.460	18.627	19.086
	MK	19.098	19.269	18.686	18.819	19.043
	MM	19.135	19.223	18.927	18.968	19.087
	MN	19.180	19.237	19.062	19.063	19.145
	MP	19.297	19.329	19.147	19.136	19.215
	MR	19.580	19.387	19.224	19.207	19.283
	MS	19.394	19.468	19.287	19.276	19.351
	MT	19.491	19.559	19.360	19.343	19.416
	MU	19.586	19.508	19.430	19.430	19.496

Borehole ID		OBSERVED TEMPERATURES (°C)				
		Date				
		2/10/88	3/23/88	5/19/88	7/13/88	9/20/88
Y3	MB	16.029	28.932	32.862	31.876	28.818
	MC	15.772	17.143	20.837	25.422	28.165
	MD	-	-	-	-	-
	ME	19.149	18.520	19.176	21.272	24.283
	MF	20.761	19.833	19.369	19.816	21.471
	MG	20.507	20.198	19.744	19.631	20.211
	MH	19.983	20.024	19.868	19.687	19.811
	MJ	19.630	19.755	19.792	19.707	19.673
	MK	19.491	19.590	19.685	19.665	19.663
	MM	19.463	19.527	19.611	19.613	19.649
	MN	19.503	19.537	19.591	19.599	19.627
	MP	19.575	19.596	19.628	19.615	19.661
	MR	19.642	19.659	19.683	19.660	19.684
	MS	19.710	19.735	19.759	19.727	19.737
	MT	19.781	19.822	19.842	19.791	19.818
	MU	19.815	19.881	19.947	19.850	19.863

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER
(Assigned by NRC. Add Vol., Supp., Rev.,
and Addendum Numbers, if any.)

NUREG/CR-5596

2. TITLE AND SUBTITLE

Unsaturated Fractured Rock Characterization Methods
and Data Sets at the Apache Leap Tuff Site

3. DATE REPORT PUBLISHED

MONTH YEAR

August 1990

4. FIN OR GRANT NUMBER

D1662

5. AUTHOR(S)

T.C. Rasmussen, D.D. Evans, P.J. Sheets and J.H. Blanford

6. TYPE OF REPORT

7. PERIOD COVERED (Inclusive Dates)

8. PERFORMING ORGANIZATION - NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)

Department of Hydrology and Water Resources
College of Engineering and Mines
University of Arizona
Tucson, AZ 85721

9. SPONSORING ORGANIZATION - NAME AND ADDRESS (If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)

Division of Engineering
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

Performance assessment of high-level nuclear waste containment feasibility requires representative values of parameters as input, including parameter moments, distributional characteristics, and covariance structures between parameters. To meet this need, characterization methods and data sets for interstitial, hydraulic, pneumatic and thermal parameters for a slightly welded fractured tuff at the Apache Leap Tuff Site situated in central Arizona are reported in this document. The data sets include the influence of matric suction on measured parameters. Spatial variability is investigated by sampling along nine boreholes at regular distances. Laboratory parameter estimates for 105 core segments are provided, as well as field estimates centered on the intervals where the core segments were collected. Measurement uncertainty is estimated by repetitively testing control samples.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

Apache Leap Tuff Site

13. AVAILABILITY STATEMENT

Unlimited

14. SECURITY CLASSIFICATION

(This Page)

Unclassified

(This Report)

Unclassified

15. NUMBER OF PAGES

16. PRICE