PURPOSE

TO COLLECT NECESSARY INFORMATION TO DETERMINE THE CHARACTER OF HYDROLOGIC PROPERTIES, BOTH PHYSICAL AND STATE HYDROLOGIC VARIABLES, WITH ENOUGH RESOLUTION FOR ADEQUATE USE IN HYDROLOGIC MODELS.
OBJECTIVES

- TO CHARACTERIZE THE FLUX-RELATED, MATRIX HYDROLOGIC PROPERTIES OF MAJOR UNSATURATED-ZONE GEOHYDROLOGIC UNITS THROUGH LABORATORY TESTING OF GEOLOGIC SAMPLES OBTAINED FROM BOREHOLES, EXCAVATIONS, AND SURFACE OUTCROPS

- TO ESTIMATE, WITHIN DETERMINABLE UNCERTAINTIES, THE VALUES OF FLUX-RELATED, MATRIX HYDROLOGIC PROPERTIES FOR LARGE VOLUMES OF ROCK BENEATH YUCCA MOUNTAIN USING STATISTICAL AND GEOSTATISTICAL METHODS
RICHARDS'-BASED EQUATIONS:

\[
\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[ K(\psi) \frac{\partial \psi_m}{\partial z} + K(\psi) \frac{\partial \psi_z}{\partial z} \right]
\]

\[
\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left[ K(\theta) \frac{\partial \psi}{\partial z} \left( \frac{\partial \theta}{\partial \psi} \right) + K(\theta) \right]
\]
MEASURING AND MODELING
MATRIX PROPERTIES

- WATER CONTENT
- WATER POTENTIAL
- PERMEABILITY (GAS AND LIQUID)
  - SATURATED
  - UNSATURATED
  - MODELS (EQUATIONS)
- MOISTURE CHARACTERISTIC CURVES
  - HYSTERESIS
  - MODELS (EQUATIONS)
- RELATED PROPERTIES
  - BULK DENSITY
  - PARTICLE DENSITY
  - POROSITY
  - HEAT CAPACITY
  - THERMAL CONDUCTIVITY
SAMPLING PROGRAM

- SURFACE OUTCROP SAMPLING
- BOREHOLE CORES

TESTING PROGRAM

- TESTING OF SURFACE OUTCROP SAMPLES
- TESTING OF BOREHOLE CORE SAMPLES
  - IMMEDIATE PROCESSING OF HERMETICALLY SEALED SAMPLES
  - LONG TERM TESTING OF PRESERVED SAMPLES
  - CONCERNS OF SAMPLE HANDLING
- METHODS SELECTION (MODELING)
- SIMPLIFYING RELATIONSHIPS

ANALYSIS

- STATISTICS
  - CLASSICAL
  - GEOSTATISTICS
- PRELIMINARY DATA ON ROCK OUTCROP SAMPLES
- PRELIMINARY DATA ON BOREHOLE CORE SAMPLES

SUMMARY
SURFACE OUTCROP SAMPLING

- PRELIMINARY CHARACTERIZATION OF DETERMINISTIC PROCESSES
- PRELIMINARY CHARACTERIZATION OF SPATIAL RELATIONSHIPS
- DETERMINE NUMBER AND LOCATION OF SAMPLES FOR TESTING WITHIN EACH LITHOLOGIC UNIT IN EACH BOREHOLE
PHOTO OF SOLITARIO CANYON OUTCROPS
SAMPLING PROGRAM

- SURFACE OUTCROP SAMPLING
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  - GEOSTATISTICS
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- PRELIMINARY DATA ON BOREHOLE CORE SAMPLES

SUMMARY
BOREHOLE CORE SAMPLES

- FEATURE-BASED DRILLING
  - FAULTS

- SYSTEMATIC DRILLING
  - AREAL COVERAGE
  - ADDITIONAL DRILLING (PHASE II)

- SAMPLE SELECTION
Hermetically sealed can for immediate processing of state variables in lab.

LEXAN liner with capped ends for long term processing of preserved core samples.

8" of core / 3.3 feet
PHOTO OF CANNER AND CANS FOR PRESERVATION
PHOTO OF CORE SAMPLES IN LEXAN
SAMPLING PROGRAM

- SURFACE OUTCROP SAMPLING
- BOREHOLE CORES

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- STATISTICS
  - CLASSICAL
  - GEOSTATISTICS
- PRELIMINARY DATA ON ROCK OUTCROP SAMPLES
- PRELIMINARY DATA ON BOREHOLE CORE SAMPLES

SUMMARY
PHOTOS OF ROCK PREPARATION EQUIPMENT
**PRELIMINARY PROCESSING OF ROCK OUTCROP SAMPLES**

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>BULK DENSITY</td>
<td>ARCHIMEDES' METHOD</td>
</tr>
<tr>
<td>EFFECTIVE POROSITY ¹</td>
<td>WATER SATURATION</td>
</tr>
<tr>
<td>EFFECTIVE PARTICLE DENSITY ¹</td>
<td>WATER PYCNOMETRY</td>
</tr>
<tr>
<td>SORPTIVITY</td>
<td>1-D IMBIBITION</td>
</tr>
</tbody>
</table>

¹ Oven dry weights are from relative humidity oven at 60°C and 40% RH
SAMPLING PROGRAM

- SURFACE OUTCROP SAMPLING
- BOREHOLE CORES

TESTING PROGRAM

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ANALYSIS

- STATISTICS
  - CLASSICAL
  - GEOSTATISTICS
- PRELIMINARY DATA ON ROCK OUTCROP SAMPLES
- PRELIMINARY DATA ON BOREHOLE CORE SAMPLES

SUMMARY
**IMMEDIATE PROCESSING OF CORE IN HERMETICALLY SEALED CANS**

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>WATER CONTENT</td>
<td>GRAVIMETRIC</td>
</tr>
<tr>
<td>WATER POTENTIAL</td>
<td>&gt;1.5 BARS, PSYCHROMETRY (SC10–A)</td>
</tr>
<tr>
<td>BULK DENSITY</td>
<td>ARCHIMEDES' METHOD</td>
</tr>
<tr>
<td></td>
<td>BOYLE'S LAW</td>
</tr>
<tr>
<td>PARTICLE DENSITY</td>
<td>BOYLE'S LAW (GAS PYCNOMETRY)</td>
</tr>
<tr>
<td></td>
<td>WATER PYCNOMETRY</td>
</tr>
<tr>
<td>POROSITY</td>
<td>WATER SATURATION</td>
</tr>
<tr>
<td></td>
<td>BOYLE'S LAW (GAS PYCNOMETRY)</td>
</tr>
<tr>
<td>CHARACTERISTIC CURVES</td>
<td>PSYCHROMETRY (SC10–A)</td>
</tr>
<tr>
<td></td>
<td>(EVAPORATION OR MICROWAVE)</td>
</tr>
</tbody>
</table>
### PROCESSING OF CORE IN CAPPED LEXAN LINER

<table>
<thead>
<tr>
<th>MEASUREMENT</th>
<th>METHOD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MEASUREMENT ON WHOLE CORE IN LINER:</strong></td>
<td></td>
</tr>
<tr>
<td>WATER POTENTIAL</td>
<td>&lt;1.5 BARS, TENSIOMETRY, HEAT DISSIPATION</td>
</tr>
<tr>
<td><strong>MEASUREMENT ON UNDERCORED SAMPLE:</strong></td>
<td></td>
</tr>
<tr>
<td>CHARACTERISTIC CURVES</td>
<td>PRESSURE PLATE, SPOC (HYSTERESIS)</td>
</tr>
<tr>
<td></td>
<td>CENTRIFUGE</td>
</tr>
<tr>
<td></td>
<td>MERCURY POROSIMETRY</td>
</tr>
<tr>
<td></td>
<td>PORE SIZE DISTRIBUTION BY GAS INJECTION</td>
</tr>
<tr>
<td>HYDRAULIC CONDUCTIVITY</td>
<td></td>
</tr>
<tr>
<td>SATURATED</td>
<td>PERMEAMETRY (GAS AND LIQUID)</td>
</tr>
<tr>
<td>UNSATURATED</td>
<td>CENTRIFUGE (STEADY AND NON-STEADY STATE)</td>
</tr>
<tr>
<td></td>
<td>MULTI-STEP OUTFLOW</td>
</tr>
<tr>
<td></td>
<td>GAS DRIVE (NON-STEADY STATE)</td>
</tr>
<tr>
<td></td>
<td>HASSLER METHOD (STEADY STATE)</td>
</tr>
<tr>
<td></td>
<td>IMBIBITION</td>
</tr>
</tbody>
</table>
PHOTOS OF LABORATORY MEASUREMENT EQUIPMENT
CONCERNS OF SAMPLE HANDLING

- PRESERVATION (MAINTAINING IN SITU WATER CONTENTS)
- SAMPLE DRYING
- OUTCROP VERSUS BOREHOLE
DIFFERENCES IN WATER CONTENT DUE TO SAMPLE HANDLING DURING WATER POTENTIAL MEASUREMENT

- Graph showing volumetric water content (cm$^3$/cm$^3$) against depth (meters)
- DD-1 CORE SAMPLES represented by circles
- DD-1, PSYCHROMETER SAMPLES represented by triangles

Depth range: 0 to 10 meters
Volumetric water content range: 0.10 to 0.40 cm$^3$/cm$^3$
PHOTO OF RELATIVE HUMIDITY OVENS
**EFFECT OF DRYING TECHNIQUE ON PERMEABILITY AND POROSITY**

<table>
<thead>
<tr>
<th>CORE SAMPLE</th>
<th>RELATIVE HUMIDITY 60 C, 40% RH</th>
<th>VACUUM 105 C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PERM</td>
<td>POROSITY</td>
</tr>
<tr>
<td>GROUSE CANYON (welded)</td>
<td>68.00 ud</td>
<td>18.7%</td>
</tr>
<tr>
<td>TOPOPAH SPRING (welded)</td>
<td>0.08 ud</td>
<td>6.5</td>
</tr>
<tr>
<td>TUNNEL BED 5 (nw, zeolitized)</td>
<td>0.13 ud</td>
<td>14.0</td>
</tr>
<tr>
<td>CALICO HILLS (nw, zeolitized)</td>
<td>4.76 ud</td>
<td>22.2</td>
</tr>
<tr>
<td>PAH CANYON (nw, vitric)</td>
<td>5.80 md</td>
<td>47.5</td>
</tr>
<tr>
<td>BASE OF TIVA CANYON (nw, vitric)</td>
<td>11.20 md</td>
<td>47.8</td>
</tr>
</tbody>
</table>
DO OUTCROP SAMPLES REPRESENT BOREHOLE SAMPLES?
SAMPLING PROGRAM

- SURFACE OUTCROP SAMPLING
- BOREHOLE CORES

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ANALYSIS

- STATISTICS
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  - GEOSTATISTICS
- PRELIMINARY DATA ON ROCK OUTCROP SAMPLES
- PRELIMINARY DATA ON BOREHOLE CORE SAMPLES

SUMMARY
METHODS SELECTION

CONSIDERATIONS:

- REPEATABILITY, ACCURACY
- MULTI-MEASUREMENT METHODS
- SPEED, COST VS. ERROR
- CONCEPTUALLY ADEQUATE, MODELING
# MOISTURE CHARACTERISTIC CURVES

<table>
<thead>
<tr>
<th>METHOD</th>
<th>PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRESSURE PLATE</td>
<td>ARTIFICIALLY HIGH WATER CONTENT, GOOD AT HIGH POTENTIALS, CANNOT MEASURE AT VERY LOW POTENTIALS, SPECIAL DESIGNS CAN MEASURE HYSTERESIS</td>
</tr>
<tr>
<td>CENTRIFUGE</td>
<td>FAST METHOD, NOT ACCURATE AT HIGH POTENTIALS, MAY MEASURE HYSTERESIS</td>
</tr>
<tr>
<td>MERCURY POROSIMETRY</td>
<td>INDIRECT, FAST MEASUREMENT, DESTRUCTIVE, ERROR PRODUCING ASSUMPTIONS</td>
</tr>
<tr>
<td>HANGING WATER COLUMN</td>
<td>ONLY GOOD TO −0.1 MPa, ACCURATE VOLUMETRIC OUTFLOW MEASUREMENT</td>
</tr>
<tr>
<td>PSYCHROMETER</td>
<td>FAIRLY FAST METHOD, INACCURATE ABOVE −0.2 MPa, TEDIOUS CALIBRATION</td>
</tr>
<tr>
<td>COMPOSITE PSYCHROMETRY</td>
<td>VERY FAST METHOD, REPRESENTS AVERAGE OF ALL SAMPLES USED, DESORPTION OR SORPTION?</td>
</tr>
</tbody>
</table>
APPROACH TO METHODS SELECTION

- To use method that measures necessary information, whether wet or dry region, hysteresis, ball park averages, according to application
- Use more than one method to cover whole range
- Verify accuracy of method with modeling
COMPOSITE MOISTURE CHARACTERISTIC CURVE
USING SPOC AND CENTRIFUGE DATA
MOISTURE CHARACTERISTIC CURVES USING THREE METHODS
DATASETS USED FOR MODELING IMBIBITION

RELATIVE PERMEABILITY DATA
- Centrifuge
- Gas Drive

MOISTURE CHARACTERISTIC DATA
- SPOC desorption
- SPOC sorption
- Centrifuge
- Pressure Plate
MOISTURE CHARACTERISTIC FUNCTIONS:

BROOKS AND COREY (1964)

\[ \Theta = \left( \frac{\psi_a}{\psi} \right)^\lambda \]

\[ \Theta = \left( \frac{\theta - \theta_r}{\theta_s - \theta_r} \right) \]

VAN GENUCHTEN (1978)

\[ \Theta = \left[ \frac{1}{1 + (\alpha \psi)^n} \right]^m, \quad m = 1 - \frac{1}{n} \]
RELATIVE PERMEABILITY FUNCTIONS:

BROOKS AND COREY (1964)

\[ k = \Theta^{\left(\frac{2}{\lambda + 3}\right)} \]

VAN GENUCHTEN (1978)

\[ k = \Theta^{1/2} \left[ 1 - (1 - \Theta^{1/m})^m \right]^2 \]
CURVES FIT TO SPOC SORPTION/CENTRIFUGE COMPOSITE MOISTURE CHARACTERISTIC CURVE

MEASURED DATA

- SPOC sorption
- Centrifuge

MODELS
- Brooks & Corey
- van Genuchten

MATRIC POTENTIAL, $-\text{MPa}$

RELATIVE WATER CONTENT
PREDICTIONS OF RELATIVE PERMEABILITY USING COMPOSITE MOISTURE CHARACTERISTIC DATA

MEASURED DATA
- Centrifuge
- Gas Drive

MODELS
- Brooks & Corey
- van Genuchten
PHOTO IMBIBITION LAB SET UP
IMBIBITION AT DIFFERENT WATER CONTENTS

- RELATIVE SATURATION 0.19
- RELATIVE SATURATION 0.56
IMBIBITION PREDICTED USING BROOKS AND COREY MODEL FIT TO MOISTURE CHAR. AND RELATIVE PERM. DATA
IMBIBITION PREDICTED USING VAN GENUCHTEN MODEL
FIT TO MOISTURE CHAR. AND RELATIVE PERM. DATA

IMBIBITION PREDICTIONS
- Centrifuge (Cent)
- Pressure Plate (GD)
- SPOC desorption
- SPOC sorption

MEASURED IMBIBITION

TIME, min

IMBIBITION, cm
SAMPLING PROGRAM

- SURFACE OUTCROP SAMPLING
- BOREHOLE CORES

TESTING PROGRAM

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- STATISTICS
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- PRELIMINARY DATA ON BOREHOLE CORE SAMPLES

SUMMARY
SIMPLIFYING RELATIONSHIPS OR MODELS

- INVERSE MODELING
- $S = f(\text{WATER CONTENT, POROSITY})$ WHERE $S = l/t^{0.5}$
- NEED MECHANISTIC MODEL TO EVALUATE SCALE EFFECTS
- $K(\theta) = f(S)$?
- $\psi(\theta) = f(\text{PORE STRUCTURE})$? $\rightarrow$ THIN SECTION ANALYSIS
BROOKS AND COREY ANALYTICAL SOLUTION

ZIMMERMAN AND BODVARSSON (1989)

\[ S = \left[ \frac{2k \phi (S_s - S_i)}{\alpha \mu} \left( 1 + \frac{(S_s - S_i)}{2n(S_s - S_i)} \right) \right]^{1/2} \]
USING THE INVERSE SOLUTION TO THE Analytical Equation FOR Sorptivity TO ESTIMATE Rock Properties

CONDUCTIVITY

n

ALPHA

log of Sorptivity, cm/t^0.5

CALCULATED Sorptivity

MEASURED Sorptivity

ANALYTICAL SOLUTION OF Sorptivity USING MEASURED CORE PARAMETERS
TABLE 1: SUMMARY OF PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorptivity</td>
<td>0.9709</td>
</tr>
<tr>
<td>Total Porosity</td>
<td>0.9354</td>
</tr>
</tbody>
</table>

The relationship between sorptivity and total porosity is shown in the graph. The sorptivity increases with increasing total porosity. The graph includes data points for large and small cores, with different symbols for each. The correlation coefficient for 20% saturation is 0.9709, and for 80% saturation is 0.9354.
PHOTOS OF WELDED AND NONWELDED MICROGRAPHS
SAMPLING PROGRAM

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- PRELIMINARY DATA ON BOREHOLE CORE SAMPLES

SUMMARY
STATISTICS

- CLASSICAL
  - MEAN
  - VARIANCE
  - DISTRIBUTION (NORMAL, LOG)
  - REGRESSION

- GEOSTATISTICS
  - 3-DIMENSIONAL
  - MULTIVARIATE
  - STRUCTURAL ANALYSIS (VARIOGRAPHY)
  - PREDICTION (KRIGING, COKRIGING)
  - SIMULATION
<table>
<thead>
<tr>
<th>Formation member</th>
<th>Core matrix description</th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calico Hills</td>
<td>Vitric</td>
<td>2</td>
<td>0.291</td>
<td>0.290</td>
<td>0.997</td>
</tr>
<tr>
<td></td>
<td>Devitrified, zeolitized</td>
<td>4</td>
<td>0.030</td>
<td>0.021</td>
<td>0.690</td>
</tr>
<tr>
<td></td>
<td>Zeolitized</td>
<td>8</td>
<td>0.016</td>
<td>0.007</td>
<td>0.428</td>
</tr>
<tr>
<td></td>
<td>Zeolitized, part. arg.</td>
<td>4</td>
<td>0.006</td>
<td>0.005</td>
<td>0.818</td>
</tr>
<tr>
<td></td>
<td>Bedded tuff</td>
<td>1</td>
<td>0.010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base of Tiva</td>
<td>Vitric</td>
<td>2</td>
<td>50.01</td>
<td>49.99</td>
<td>1.00</td>
</tr>
<tr>
<td>Canyon</td>
<td>Vitric, part. argillic</td>
<td>1</td>
<td>145.90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yucca Mountain</td>
<td>Vitric</td>
<td>5</td>
<td>92.20</td>
<td>105.64</td>
<td>1.15</td>
</tr>
<tr>
<td>Pah Canyon</td>
<td>Vitric</td>
<td>4</td>
<td>17.59</td>
<td>19.35</td>
<td>1.10</td>
</tr>
<tr>
<td>Bedded Tuff</td>
<td></td>
<td>5</td>
<td>5.89</td>
<td>7.09</td>
<td>1.20</td>
</tr>
<tr>
<td>Topopah Spring</td>
<td>Vitric</td>
<td>1</td>
<td>162.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Classification of Data to Be Used for Site Characterization

<table>
<thead>
<tr>
<th>Category</th>
<th>Hard Data</th>
<th>Soft Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exact</td>
<td>Measurements provide estimate of expected value and variance</td>
<td>Guess for expected value</td>
</tr>
<tr>
<td>Inequality</td>
<td>Measurements provide estimate for minimum or maximum value</td>
<td>Guess for minimum or maximum value</td>
</tr>
<tr>
<td>Interval</td>
<td>Measurements provide estimates for minimum and maximum value</td>
<td>Guess for minimum and maximum value</td>
</tr>
</tbody>
</table>
## DATA CATEGORIES USED BY SELECTED KRIGING METHODS

<table>
<thead>
<tr>
<th>Kriging Method</th>
<th>Hard Data</th>
<th>Soft Data</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exact</td>
<td>Ineq</td>
<td>Inter</td>
</tr>
<tr>
<td>Simple</td>
<td>yes (r)</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Ordinary</td>
<td>yes (r)</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Universal</td>
<td>yes (r)</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Disjunctive</td>
<td>yes (r)</td>
<td>yes (o)</td>
<td>yes (o)</td>
</tr>
<tr>
<td>Indicator</td>
<td>yes (o)</td>
<td>yes (o)</td>
<td>yes (o)</td>
</tr>
<tr>
<td>Bayesian</td>
<td>yes (r)</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Soft</td>
<td>yes (o)</td>
<td>yes (o)</td>
<td>yes (o)</td>
</tr>
<tr>
<td>Interval</td>
<td>yes (o)</td>
<td>no</td>
<td>yes (o)</td>
</tr>
<tr>
<td>Dual</td>
<td>yes (o)</td>
<td>yes (o)</td>
<td>yes (o)</td>
</tr>
</tbody>
</table>

(r) required
(o) optional
SAMPLING PROGRAM

- SURFACE OUTCROP SAMPLING
- BOREHOLE CORES

TESTING PROGRAM

- TESTING OF SURFACE OUTCROP SAMPLES
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  - GEOSTATISTICS
- PRELIMINARY DATA ON ROCK OUTCROP SAMPLES
- PRELIMINARY DATA ON BOREHOLE CORE SAMPLES

SUMMARY
MICROUNITS OF THE TIVA CANYON WELDED

PARTICLE DENSITY, cm$^3$/cm$^3$

POROSITY, cm$^3$/cm$^3$

HEIGHT FROM SOLITARIO FAULT, meters

HEIGHT ABOVE SOLITARIO FAULT, meters

UPPER CLIFF
UPPER LITHOPHYSAL
CLINKSTONE
LOWER LITHOPHYSAL
HACKLY
COLUMNAR

I I

I I
MICROUNITS OF THE BEDDED TUFFS

PARTICLE DENSITY, cm$^3$/cm$^3$

POROSITY, cm$^3$/cm$^3$

HEIGHT FROM SOLITARIO FAULT, meters

SHARDY BASE OF TIVA CANYON

YUCCA MOUNTAIN MEMBER

PAH CANYON MEMBER

TOP OF TOPOPAH SPRING NONWELDED

HEIGHT ABOVE SOLITARIO FAULT, meters
MICROUNITS OF THE TOPOPAH SPRING

PARTICLE DENSITY, cm³/cm³

POROSITY, cm³/cm³

HEIGHT FROM SOLITARIO FAULT, meters

HEIGHT ABOVE SOLITARIO FAULT, meters

CAPROCK

ROUNDED

UPPER LITHOPHYSAL

UPPER NONLITHOPHYSAL

LOWER LITHOPHYSAL

0.0 0.1 0.2

0 0.1 0.2 0.3

0 50 100 150

2.3 2.4 2.5 2.6

0 50 100 150
VERTICAL TRANSECT IN SOLITARIO CANYON AT UZ-6

PARTICLE DENSITY, cm$^3$/cm$^3$

POROSITY, cm$^3$/cm$^3$

HEIGHT FROM SOLITARIO FAULT, meters

(-- TIVRA CANYON --) X -- X -- TOPOPAH SPRINGS --)
BEDDED TUFF VARIOGRAMS

0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00

VERTICAL LAG DISTANCE, m

BULK DENSITY
POROSITY
PARTICLE DENSITY
A PRIORI VARIANCE
TOPOPAH SPRING VARIOGRAMS

![Graph showing variograms for different properties with vertical lag distance on the x-axis and gamma (H) on the y-axis. The properties include bulk density, porosity, particle density, and a priori variance.]
SURFACE OUTCROP SAMPLING
TRANSECT: SHARDY BASE OF TIVA CANYON NONWELDED

POROSITY, cm$^3$/cm$^3$

DISTANCE ALONG TRANSECT, m
SURFACE OUTCROP SAMPLING
TRANSECT: SHARDY BASE OF TIVA CANYON NONWELDED

![Graph showing saturated conductivity vs. distance along transect]
HORIZONTAL VARIOGRAM, SHARDY BASE OF TIVA CANYON

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**Graph 1:**
- **Bulk Density**
- **Porosity**
- **A Priori Variance**

**Graph 2:**
- **Hydraulic Conductivity**
- **A Priori Variance**

**Axes:**
- **Gamma (H)**
- **Horizontal Lag Distance, m**
RELATIONSHIP BETWEEN CONDUCTIVITY AND POROSITY

![Graph showing the relationship between conductivity and porosity.](image-url)
SAMPLING PROGRAM

- SURFACE OUTCROP SAMPLING
- BOREHOLE CORES

TESTING PROGRAM

- TESTING OF SURFACE OUTCROP SAMPLES
- TESTING OF BOREHOLE CORE SAMPLES
  - IMMEDIATE PROCESSING OF HERMETICALLY SEALED SAMPLES
  - LONG TERM TESTING OF PRESERVED SAMPLES
  - CONCERNS OF SAMPLE HANDLING
- METHODS SELECTION (MODELING)
- SIMPLIFYING RELATIONSHIPS

ANALYSIS

- STATISTICS
  - CLASSICAL
  - GEOSTATISTICS
- PRELIMINARY DATA ON ROCK OUTCROP SAMPLES
- PRELIMINARY DATA ON BOREHOLE CORE SAMPLES

SUMMARY
### RANGE IN CORE PROPERTY VALUES FOR YUCCA MOUNTAIN GEOHYDROLOGIC UNITS

<table>
<thead>
<tr>
<th>GEOHYDROLOGIC UNIT</th>
<th>POROSITY (cm³/cm³)</th>
<th>GRAIN DENSITY (g/cm³)</th>
<th>DRY BULK DENSITY (g/cm³)</th>
<th>SATURATED CONDUCTIVITY (cm/s)</th>
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</thead>
<tbody>
<tr>
<td>TIVA CANYON w</td>
<td>.08-.12</td>
<td>2.3-2.8</td>
<td>1.4-2.4</td>
<td>1.5E-10-9.7E-10</td>
</tr>
<tr>
<td>PAINTBRUSH TUFF nw</td>
<td>.06-.54</td>
<td>2.2-2.6</td>
<td>1.1-2.4</td>
<td>2.3E-9-2.4E-4</td>
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<tr>
<td>TOPOPAH SPRING w</td>
<td>.04-.33</td>
<td>2.4-2.6</td>
<td>1.8-2.4</td>
<td>1.2E-10-2.3E-7</td>
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<tr>
<td>CALICO HILLS nw</td>
<td>.14-.46</td>
<td>2.2-2.6</td>
<td>1.3-2.0</td>
<td>5.2E-10-2.9E-5</td>
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<tr>
<td>CRATER FLAT</td>
<td>.19-.38</td>
<td>2.5-2.6</td>
<td>1.6-2.1</td>
<td>2.0E-9-6.9E-7</td>
</tr>
</tbody>
</table>

**References**
- Anderson (1981)
- Rush, Thordarson and Bruckheimer (1983)
- Thordarson (1983)
- Weeks and Wilson (1987)
- Klavetter and Peters (1987)
- Flint and Flint (1989)
COMPARISON OF CORE PROPERTIES FROM OUTCROP AND BOREHOLE CORE SAMPLES

<table>
<thead>
<tr>
<th>GEOHYDROLOGIC UNIT</th>
<th>POROSITY</th>
<th>BULK DENSITY</th>
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<tr>
<td></td>
<td>CORE</td>
<td>OUTCROP</td>
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<tr>
<td>TIVA CANYON</td>
<td>0.08–0.12</td>
<td>0.02–0.30</td>
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<tr>
<td>PAINTBRUSH TUFF</td>
<td>0.06–0.54</td>
<td>0.04–0.59</td>
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<tr>
<td>TOPOPAH SPRING</td>
<td>0.04–0.33</td>
<td>0.02–0.21</td>
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</tbody>
</table>
SUMMARY

- SAMPLE
- TEST AND ANALYSIS
- MODEL (UZ, PA)
- ITERATE