U.S. DEPARTMENT OF ENERGY
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: MATRIX HYDROLOGIC PROPERTIES

PRESENTER: DR. ALAN FLINT

PRESENTER'S TITLE AND ORGANIZATION: HYDROLOGIST
U.S. GEOLOGICAL SURVEY
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REGISTRY HOTEL, DENVER, COLORADO
JUNE 25-27, 1991

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

- o 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

- o TO ESTIMATE, WITHIN DETERMINABLE UNCERTAINTIES, THE VALUES OF FLUX–RELATED, MATRIX HYDROLOGIC PROPERTIES FOR LARGE VOLUMES OF ROCK BENEATH YUCCA MOUNTIAN 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

- o WATER CONTENT
- o WATER POTENTIAL
- o PERMEABILITY (GAS AND LIQUID)
  - –SATURATED
  - –UNSATURATED
  - –MODELS (EQUATIONS)
- o MOISTURE CHARACTERISTIC CURVES
  - –HYSTERESIS
  - –MODELS (EQUATIONS)
- o 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

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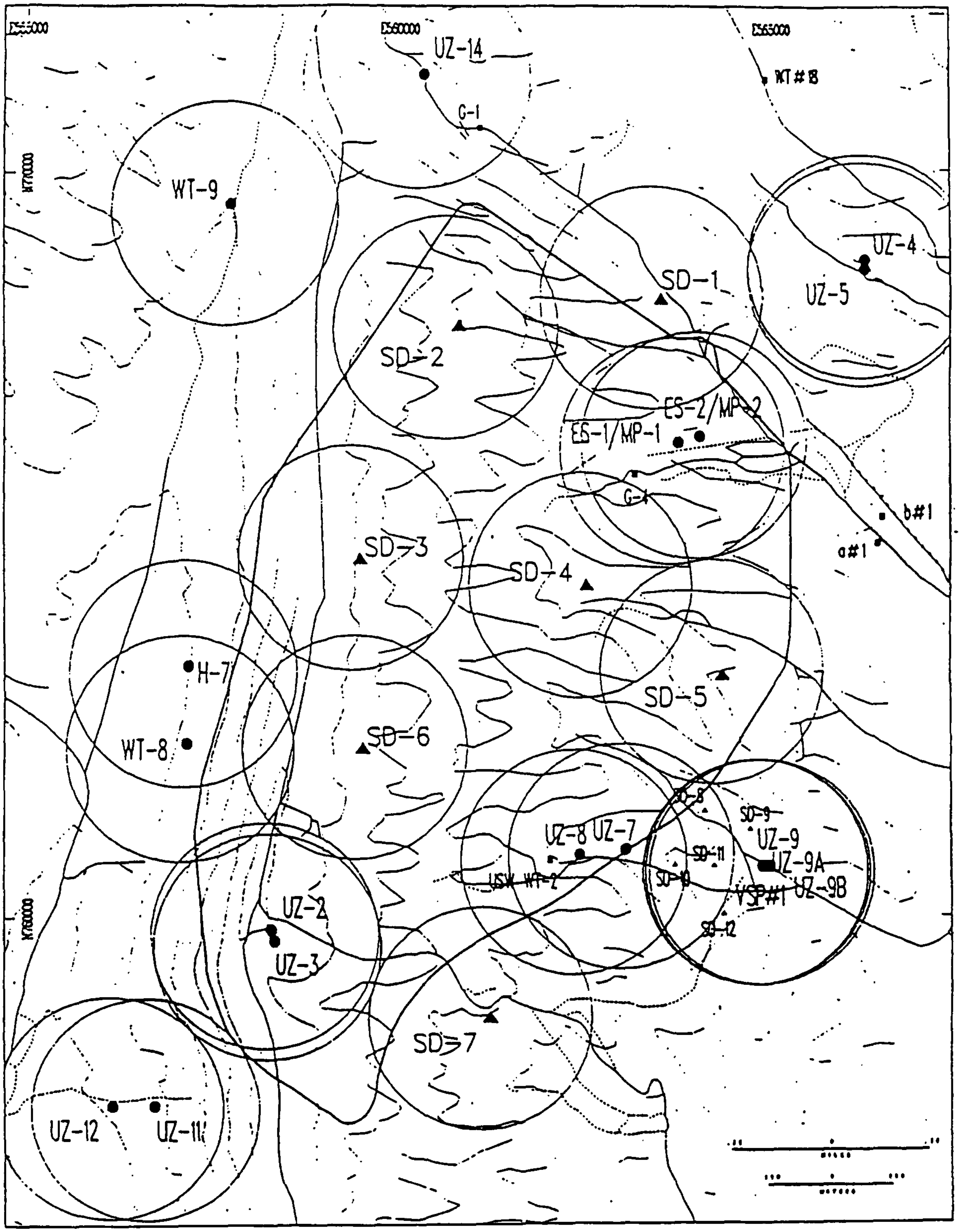
BOREHOLE CORE SAMPLES

- o FEATURE–BASED DRILLING
  - – FAULTS
- o SYSTEMATIC DRILLING
  - – AREAL COVERAGE
  - – ADDITIONAL DRILLING (PHASE II)
- o SAMPLE SELECTION

YUCCA MOUNTAIN SYSTEMATIC DRILLING PROGRAM AREAL COVERAGE SCHEME



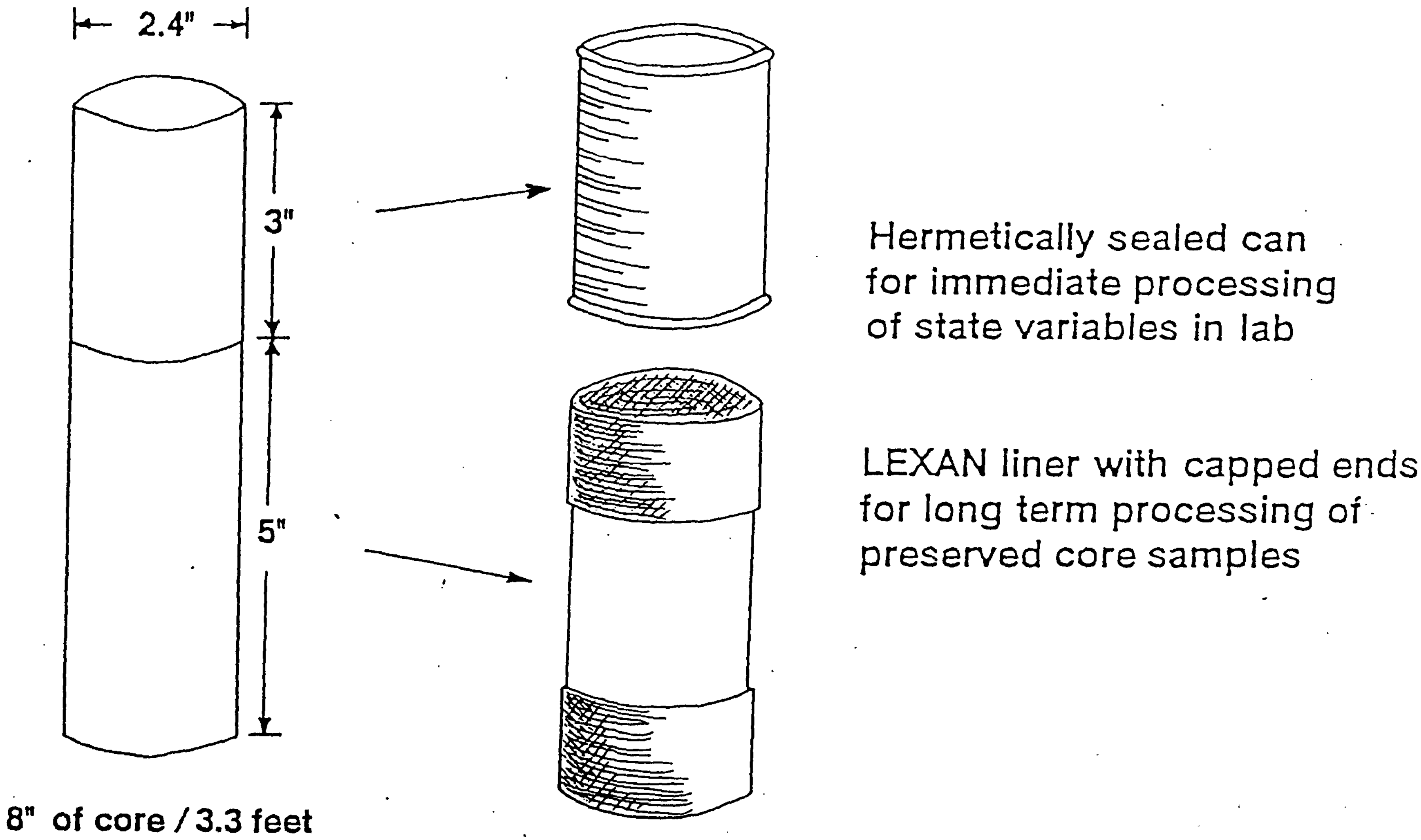

2.4"
3"
5"
8" of core / 3.3 feet
Hermetically sealed can for immediate processing of state variables in lab
LEXAN liner with capped ends for long term processing of preserved core samples

PHOTO OF CANNER AND CANS FOR PRESERVATION

PHOTO OF CORE SAMPLES IN LEXAN

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PHOTOS OF ROCK PREPARATION EQUIPMENT

PRELIMINARY PROCESSING OF ROCK OUTCROP SAMPLES

MEASUREMENT	METHOD
BULK DENSITY	ARCHIMEDES' METHOD
EFFECTIVE POROSITY[1]	WATER SATURATION
EFFECTIVE PARTICLE DENSITY[1]	WATER PYCNOMETRY
SORPTIVITY	1-D IMBIBITION

[1] OVEN DRY WEIGHTS ARE FROM RELATIVE HUMIDITY OVEN AT 60 C AND 40% RH

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IMMEDIATE PROCESSING OF CORE IN HERMETICALLY SEALED CANS

MEASUREMENT	METHOD
WATER CONTENT	GRAVIMETRIC
WATER POTENTIAL	>1.5 BARS, PSYCHROMETRY (SC10-A)
BULK DENSITY	ARCHIMEDES' METHOD BOYLE'S LAW
PARTICLE DENSITY	BOYLE'S LAW (GAS PYCNOMETRY) WATER PYCNOMETRY
POROSITY	WATER SATURATION BOYLE'S LAW (GAS PYCNOMETRY)
CHARACTERISTIC CURVES	PSYCHROMETRY (SC10-A) (EVAPORATION OR MICROWAVE)

PROCESSING OF CORE IN CAPPED LEXAN LINER

MEASUREMENT	METHOD
MEASUREMENT ON WHOLE CORE IN LINER:	
WATER POTENTIAL	<1.5 BARS, TENSIOMETRY, HEAT DISSIPATION
MEASUREMENT ON UNDERCORED SAMPLE:	
CHARACTERISTIC CURVES	PRESSURE PLATE, SPOC (HYSTERESIS) CENTRIFUGE MERCURY POROSIMETRY PORE SIZE DISTRIBUTION BY GAS INJECTION
HYDRAULIC CONDUCTIVITY	
SATURATED	PERMEAMETRY (GAS AND LIQUID)
UNSATURATED	CENTRIFUGE (STEADY AND NON–STEADY STATE) MULTI–STEP OUTFLOW GAS DRIVE (NON–STEADY STATE) HASSLER METHOD (STEADY STATE) IMBIBITION

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

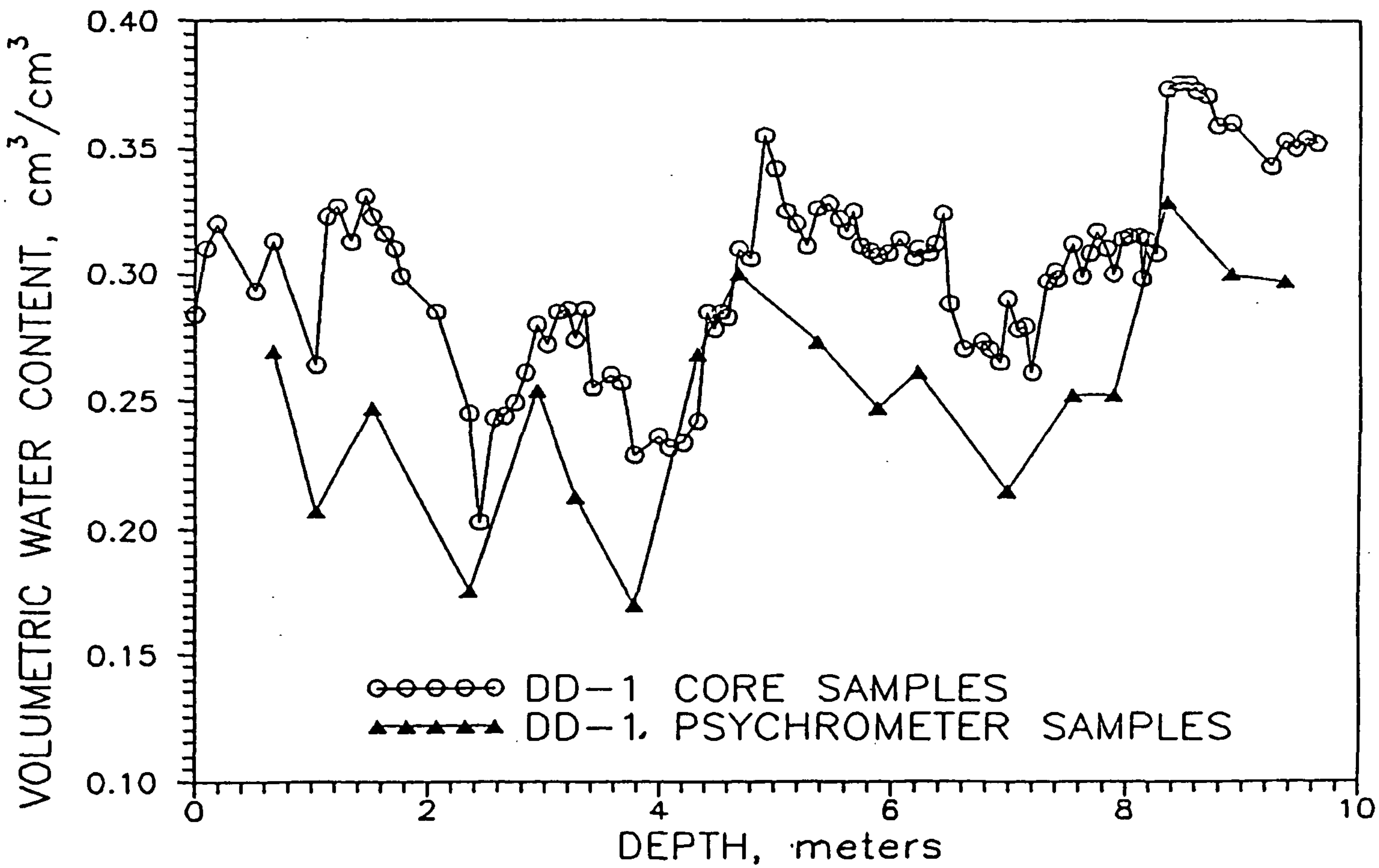

PHOTO OF RELATIVE HUMIDITY OVENS

EFFECT OF DRYING TECHNIQUE ON PERMEABILITY AND POROSITY

CORE SAMPLE	RELATIVE HUMIDITY 60 C, 40% RH		VACUUM 105 C	
	PERM	POROSITY	PERM	POROSITY
GROUSE CANYON (welded)	68.00 ud	18.7%	85.00 ud	18.9%
TOPOPAH SPRING (welded)	0.08 ud	6.5	<0.01 ud	7.6
TUNNEL BED 5 (nw, zeolitized)	0.13 ud	14.0	0.15 ud	37.0
CALICO HILLS (nw, zeolitized)	4.76 ud	22.2	14.10 ud	27.4
PAH CANYON (nw, vitric)	5.80 md	47.5	5.80 md	52.4
BASE OF TIVA CANYON (nw, vitric)	11.20 md	47.8	3.40 md	60.9

DO OUTCROP SAMPLES REPRESENT BOREHOLE SAMPLES?

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METHODS SELECTION

CONSIDERATIONS:

- o REPEATABILITY, ACCURACY
- o MULTI–MEASUREMENT METHODS
- o SPEED, COST VS. ERROR
- o CONCEPTUALLY ADEQUATE, MODELING

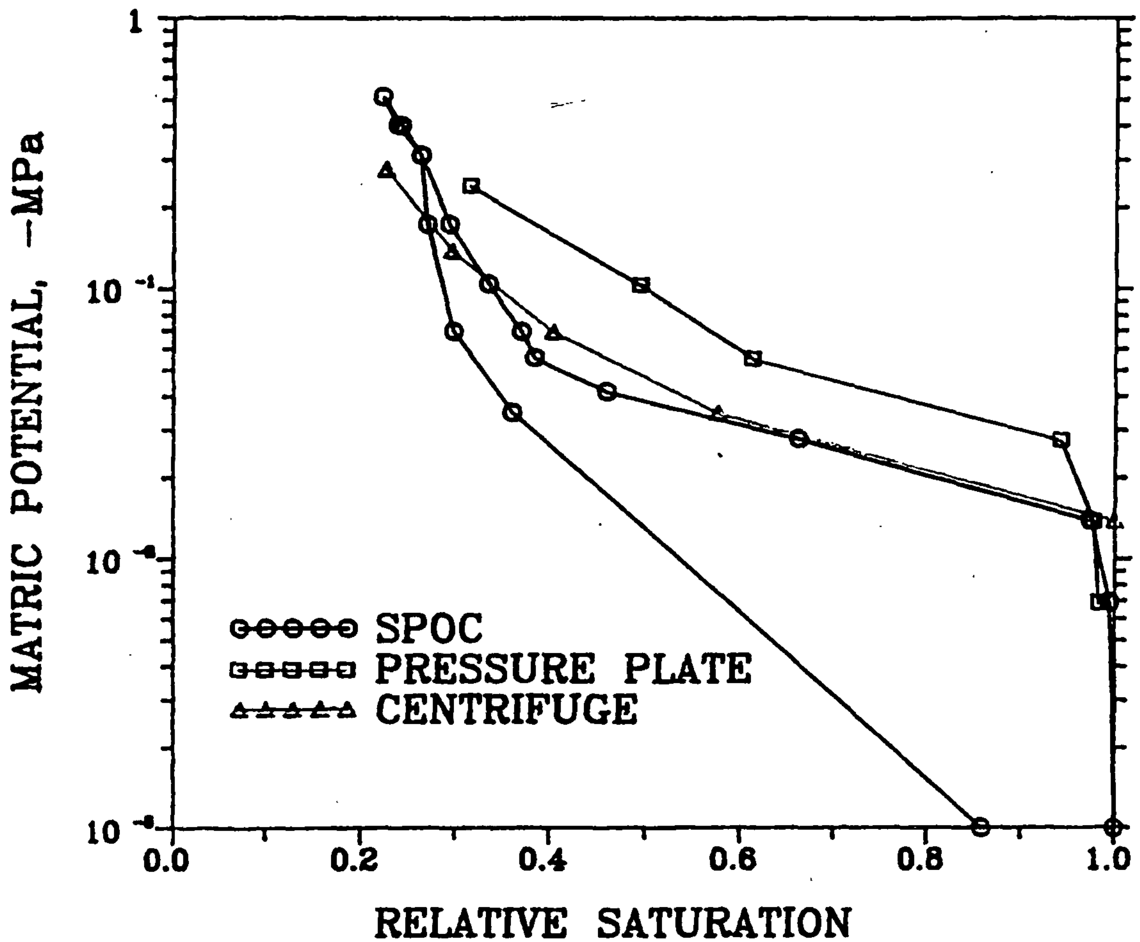
MOISTURE CHARACTERISTIC CURVES

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

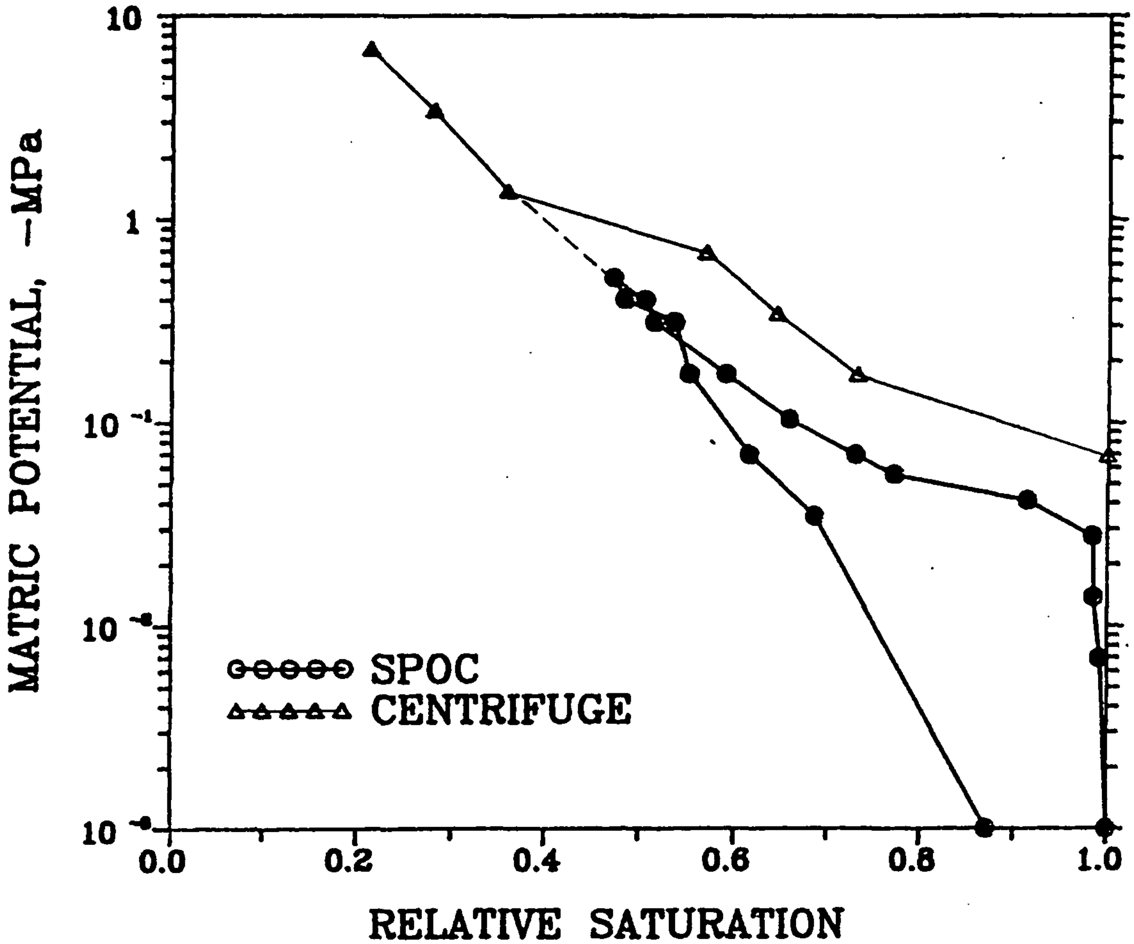
APPROACH TO METHODS SELECTION

- 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

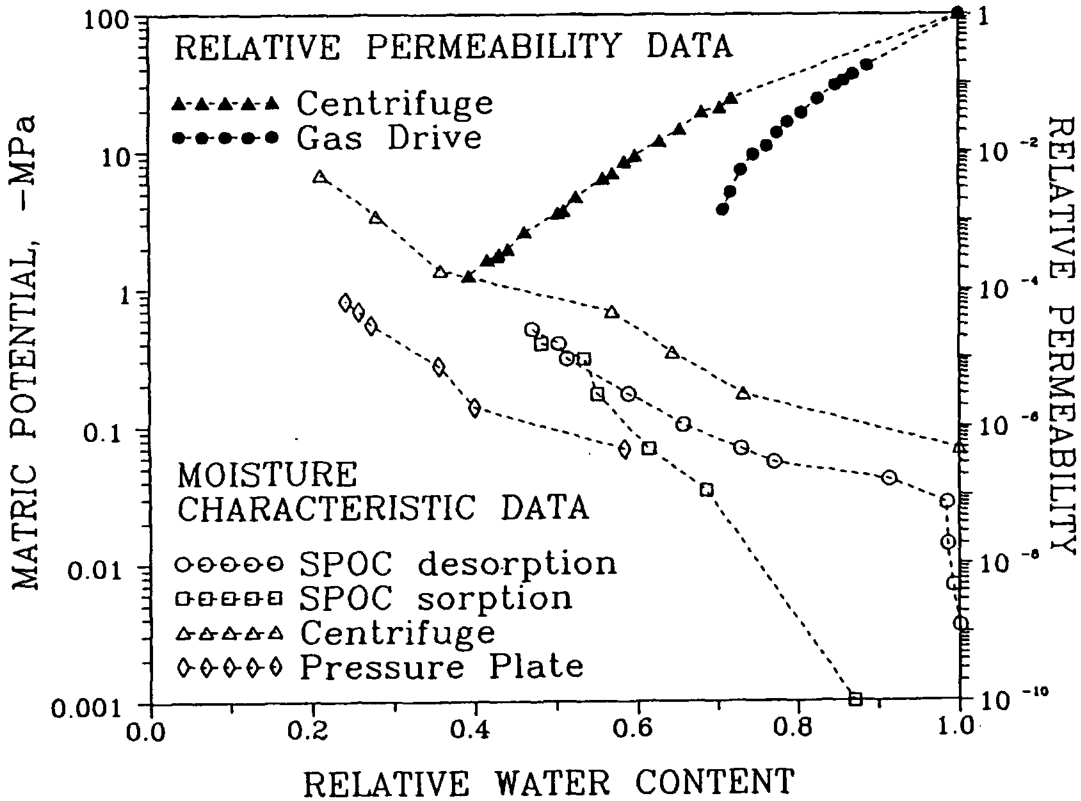
COMPOSITE MOISTURE CHARACTERISTIC CURVE USING SPOC AND CENTRIFUGE DATA



MOISTURE CHARACTERISTIC CURVES USING THREE METHODS



DATASETS USED FOR MODELING IMBIBITION



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:

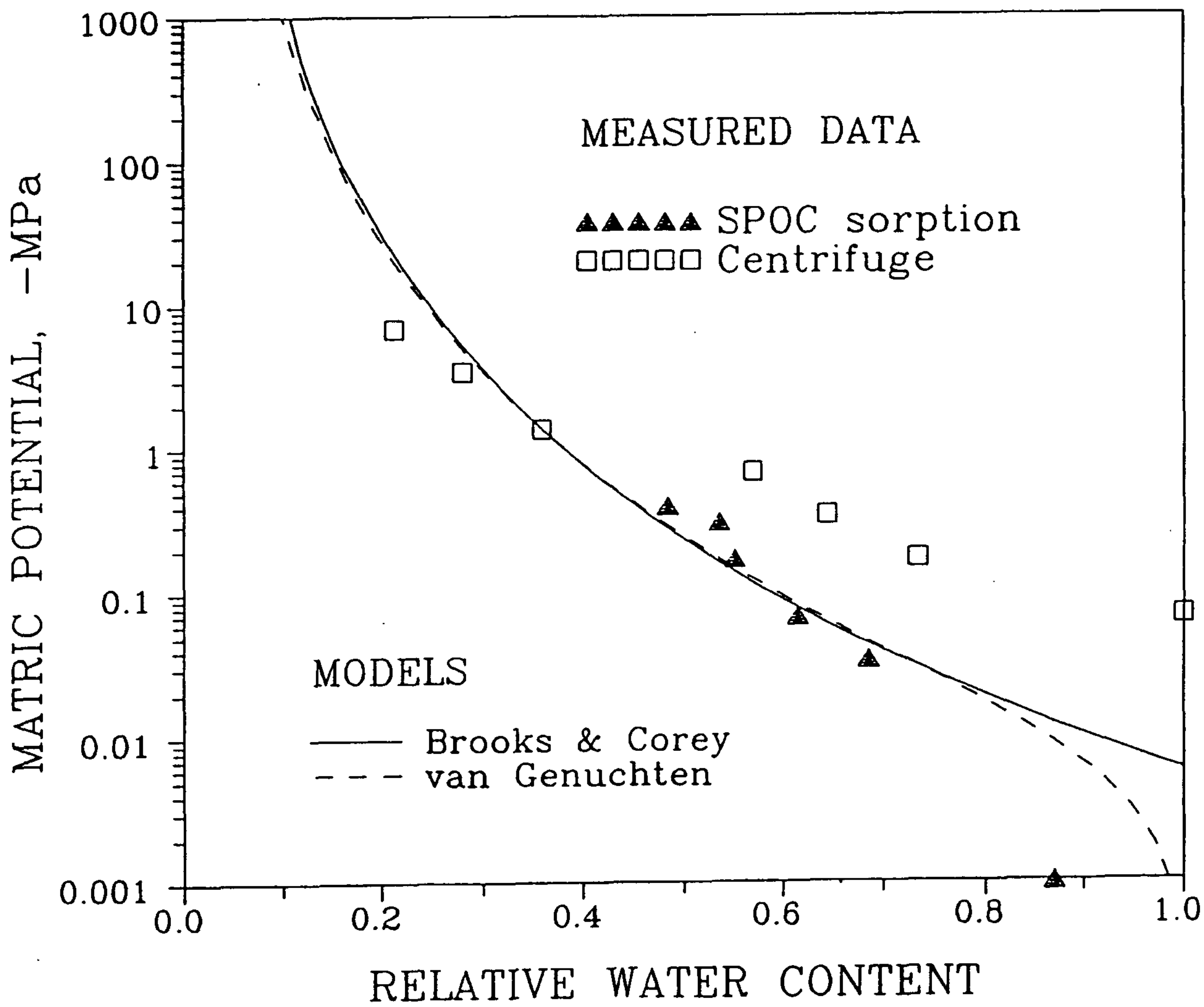
BROOKS AND COREY (1964)

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

VAN GENUCHTEN (1978)

$$k = \Theta^{1/2}[1-(1-\Theta^{1/m})^{m}]^{2}$$

CURVES FIT TO SPOC SORPTION/CENTRIFUGE COMPOSITE MOISTURE CHARACTERISTIC CURVE



PREDICTIONS OF RELATIVE PERMEABILITY USING COMPOSITE MOISTURE CHARACTERISTIC DATA

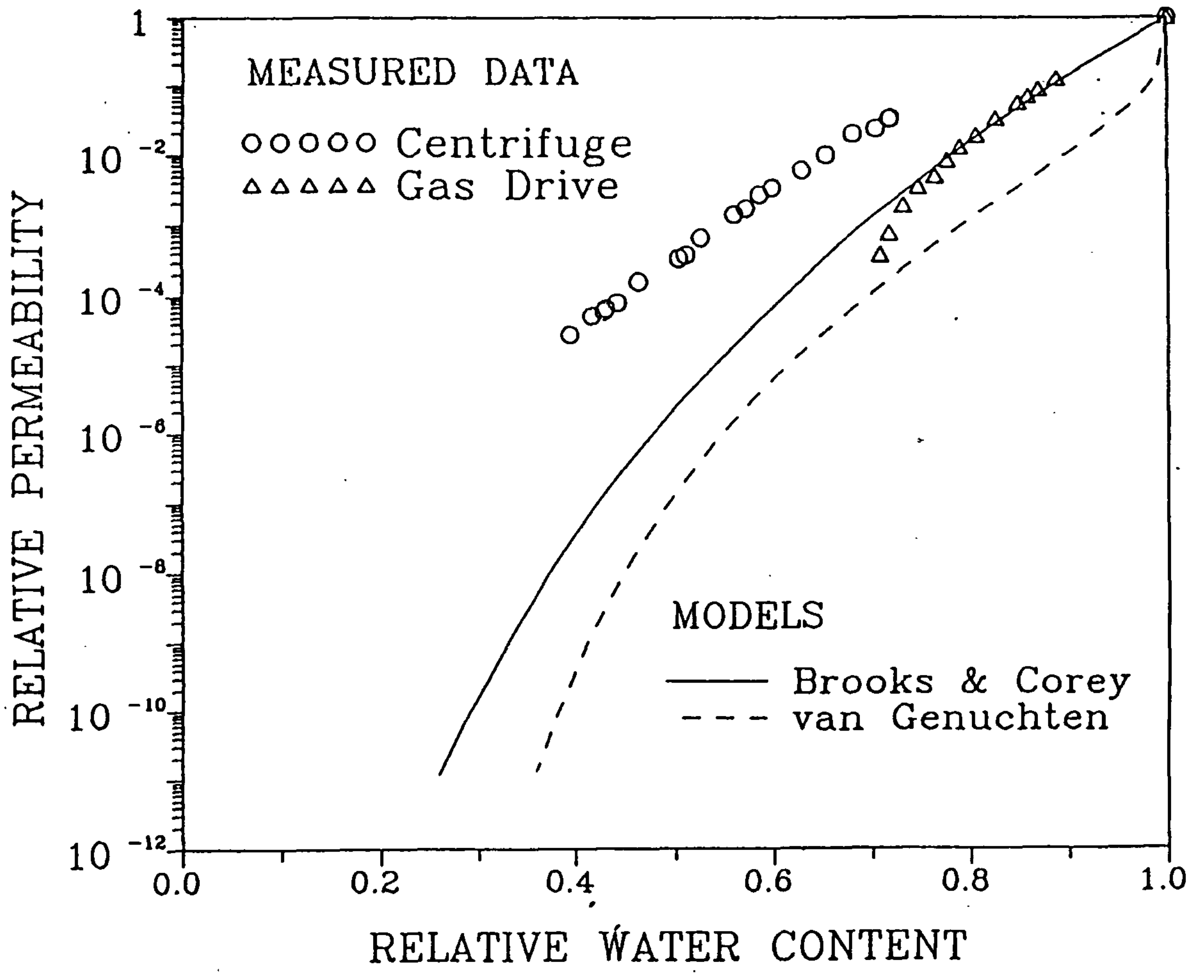
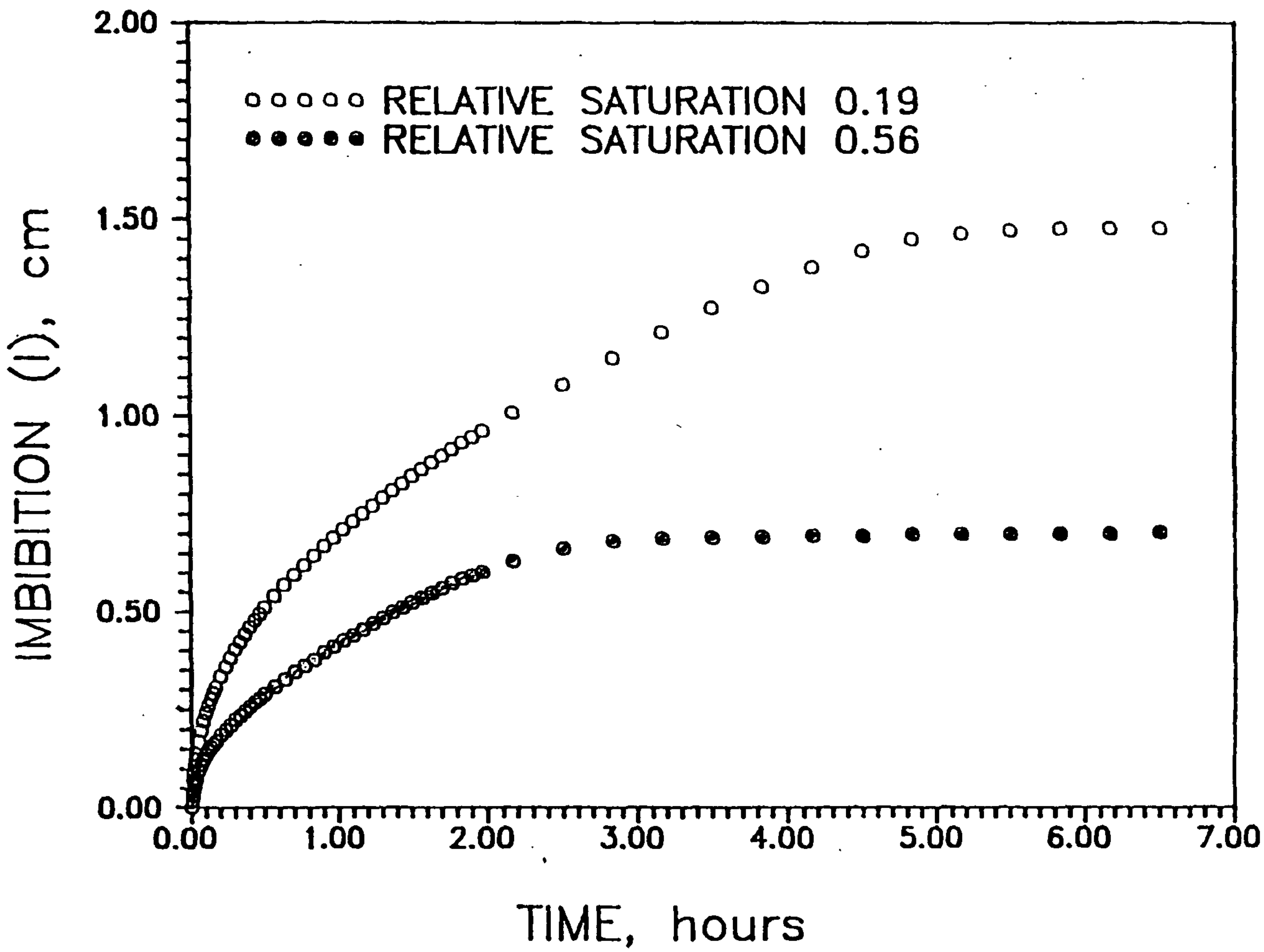
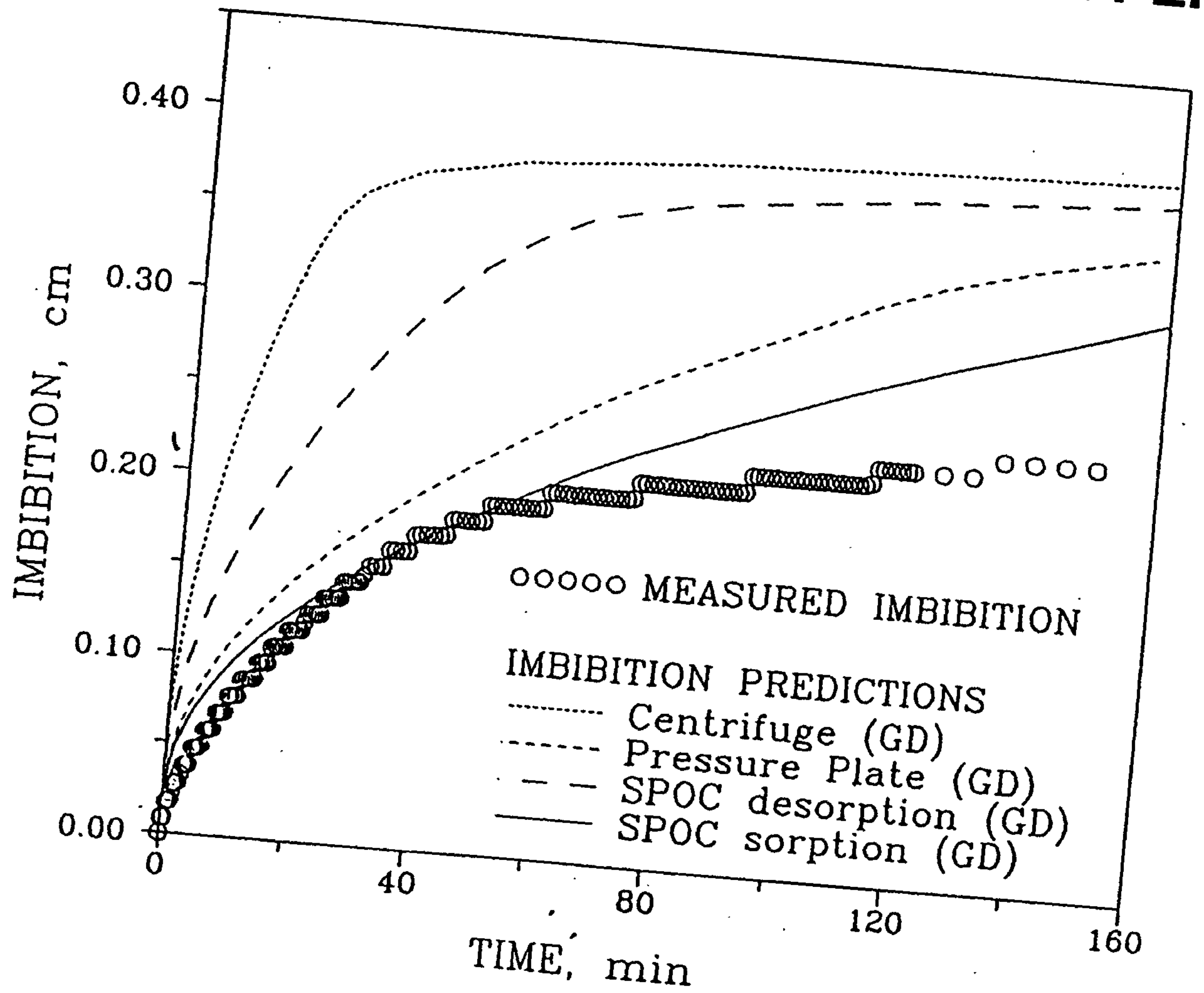


PHOTO IMBIBITION LAB SET UP

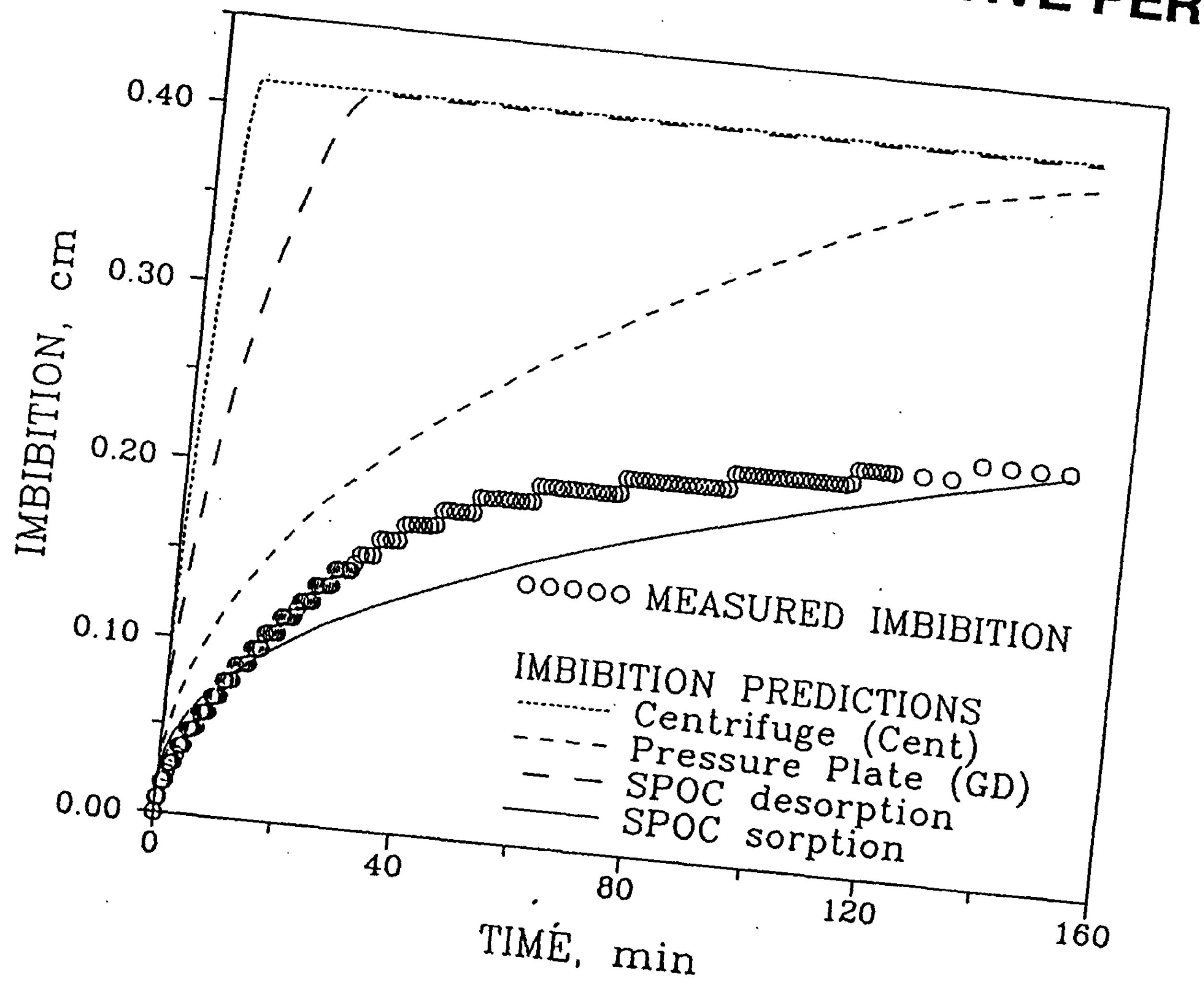
IMBIBITION AT DIFFERENT WATER CONTENTS



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



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SUMMARY

SIMPLIFYING RELATIONSHIPS OR MODELS

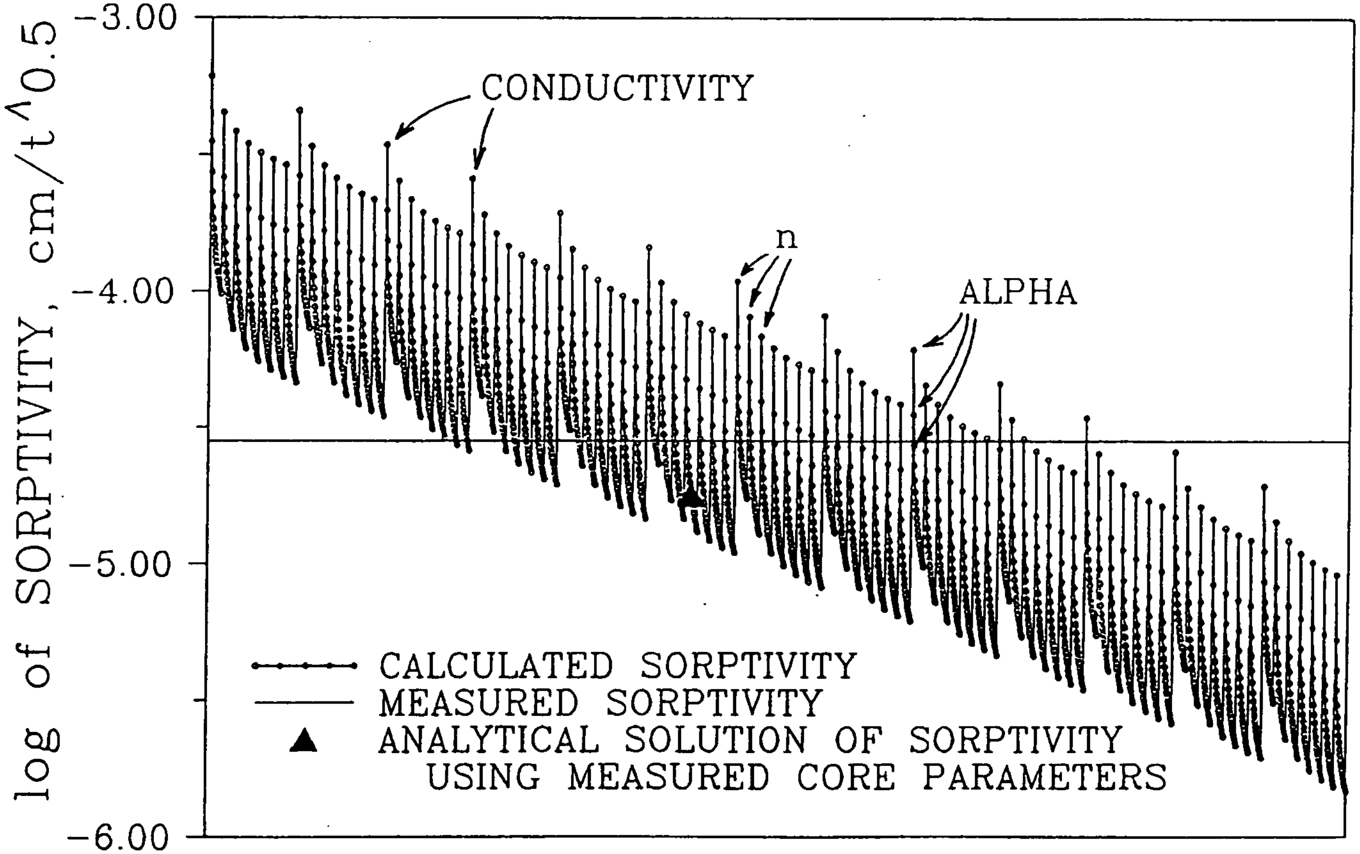
- INVERSE MODELING
- $S = f$(WATER CONTENT, POROSITY) WHERE $S = I/t^{0.5}$
- NEED MECHANISTIC MODEL TO EVALUATE SCALE EFFECTS
- $K(\theta) = f(S)$?
- $\psi(\theta) = f$(PORE STRUCTURE)? –> THIN SECTION ANALYSIS

BROOKS AND COREY ANALYTICAL SOLUTION

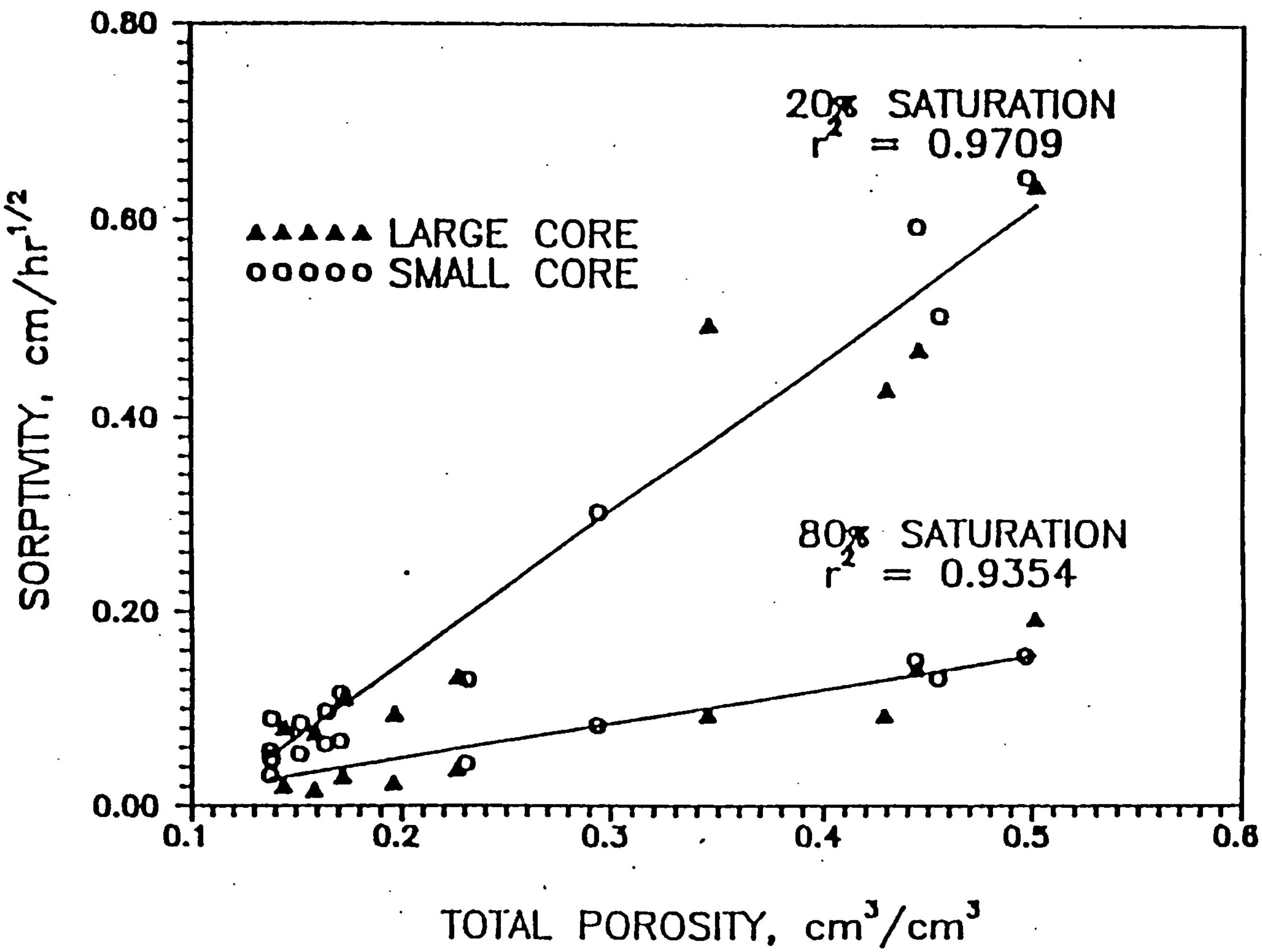
ZIMMERMAN AND BODVARSSON (1989)

$$S = \left[\frac{2k\phi(S_s - S_i)}{\alpha\mu} \left(1 + \frac{(S_s - S_i)}{2n(S_s - S_r)} \right) \right]^{1/2}$$

USING THE INVERSE SOLUTION TO THE ANALYTICAL EQUATION FOR SORPTIVITY TO ESTIMATE ROCK PROPERTIES



RELATIONSHIP OF SORPTIVITY TO POROSITY



PHOTOS OF WELDED AND NONWELDED MICROGRAPHS

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SUMMARY

STATISTICS

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

- o GEOSTATISTICS
  - 3-DIMENSIONAL
  - MULTIVARIATE
  - STRUCTURAL ANALYSIS (VARIOGRAPHY)
  - PREDICTION (KRIGING, COKRIGING)
  - SIMULATION

Formation member	Core matrix description	Specific permeability to water (md)			
		n	Mean	SD	CV
Calico Hills	Vitric	2	0.291	0.290	0.997
	Devitrified, zeolitized	4	0.030	0.021	0.690
	Zeolitized	8	0.016	0.007	0.428
	Zeolitized, part. arg.	4	0.006	0.005	0.818
	Bedded tuff	1	0.010		
Base of Tiva Canyon	Vitric	2	50.01	49.99	1.00
	Vitric, part. argillic	1	145.90		
Yucca Mountain	Vitric	5	92.20	105.64	1.15
Pah Canyon	Vitric	4	17.59	19.35	1.10
Bedded Tuff		5	5.89	7.09	1.20
Topopah Spring	Vitric	1	162.00		

CLASSIFICATION OF DATA TO BE USED FOR SITE CHARACTERIZATION

Category	Hard Data	Soft Data
Exact	Measurements provide estimate of expected value and variance	Guess for expected value
Inequality	Measurements provide estimate for minimum or maximum value	Guess for minimum or maximum value
Interval	Measurements provide estmates for minimum and maximum value	Guess for minimum and maximum value

DATA CATEGORIES USED BY SELECTED KRIGING METHODS

Kriging	Hard Data			Soft Data		
Method	Exact	Ineq	Inter	Exact	Ineq	Inter
Simple	yes (r)	no	no	no	no	no
Ordinary	yes (r)	no	no	no	no	no
Universal	yes (r)	no	no	no	no	no
Disjunctive	yes (r)	yes (o)	yes (o)	no	no	no
Indicator	yes (o)	yes (o)	yes (o)	no	no	no
Bayesian	yes (r)	no	no	yes (r)	no	no
Soft	yes (o)	yes (o)	yes (o)	yes (o)	yes (o)	yes (o)
Interval	yes (o)	no	yes (o)	no	no	no
Dual	yes (o)	yes (o)	yes (o)	no	no	no

(r) required
(o) optional

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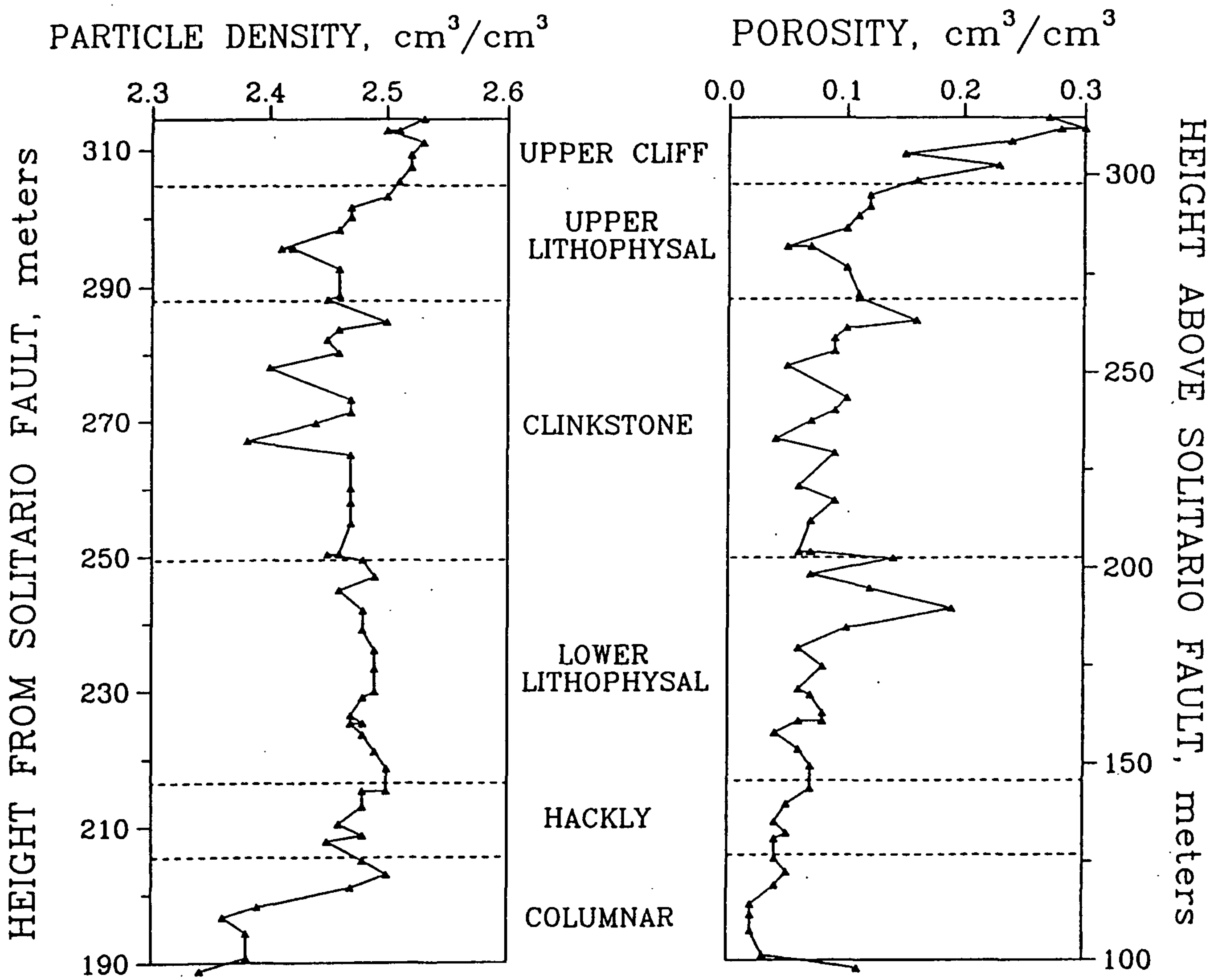
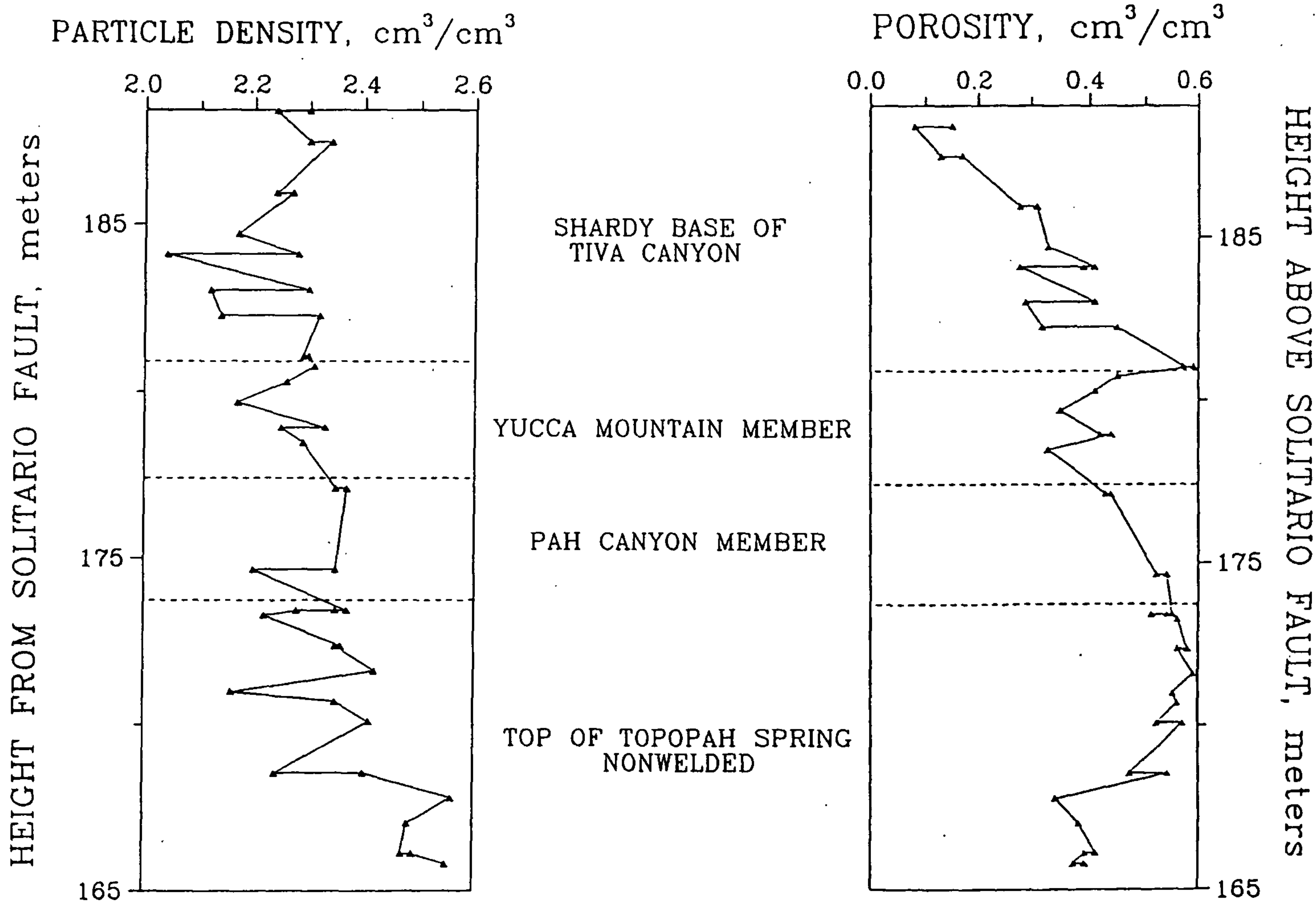
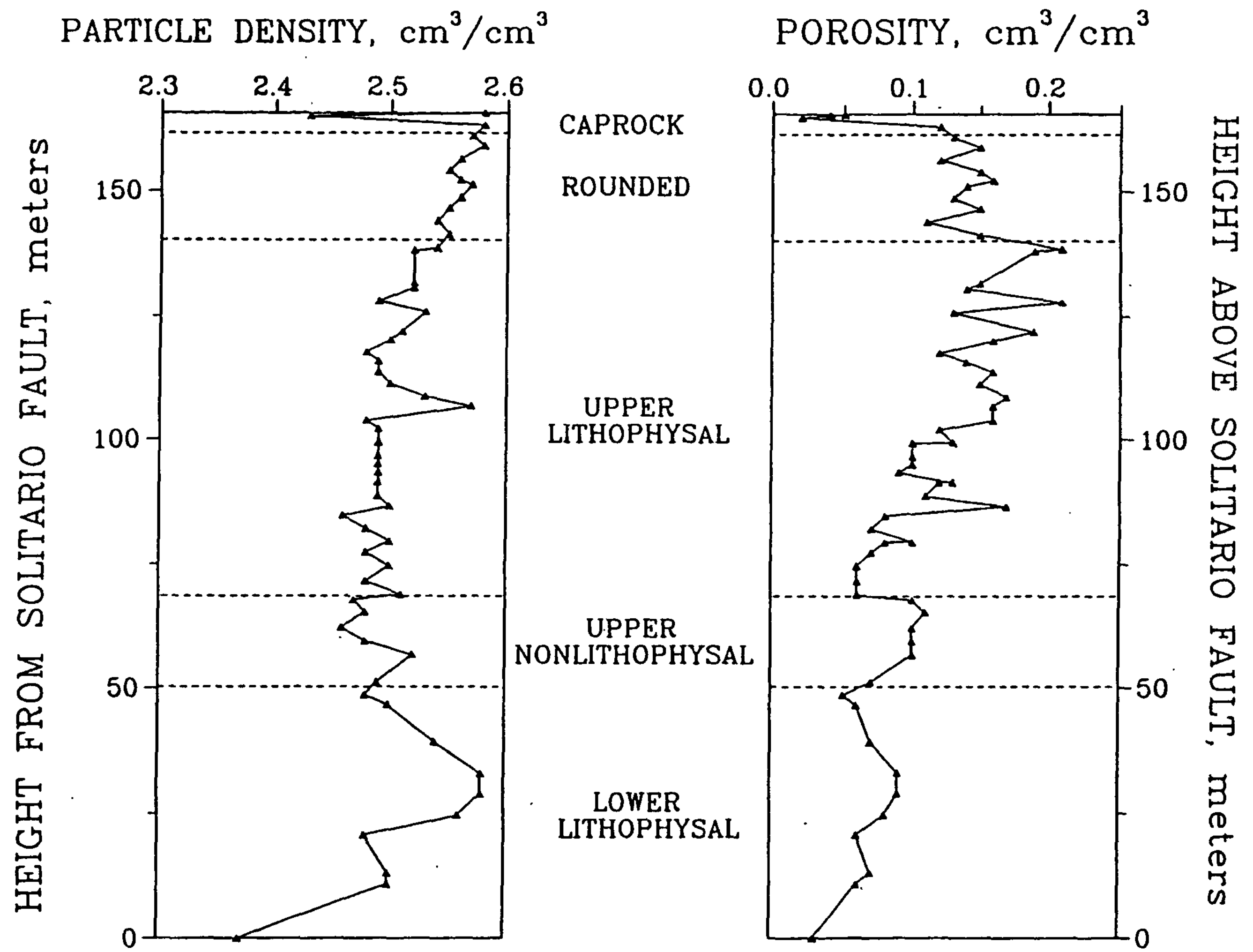
MICROUNITS OF THE TIVA CANYON WELDED



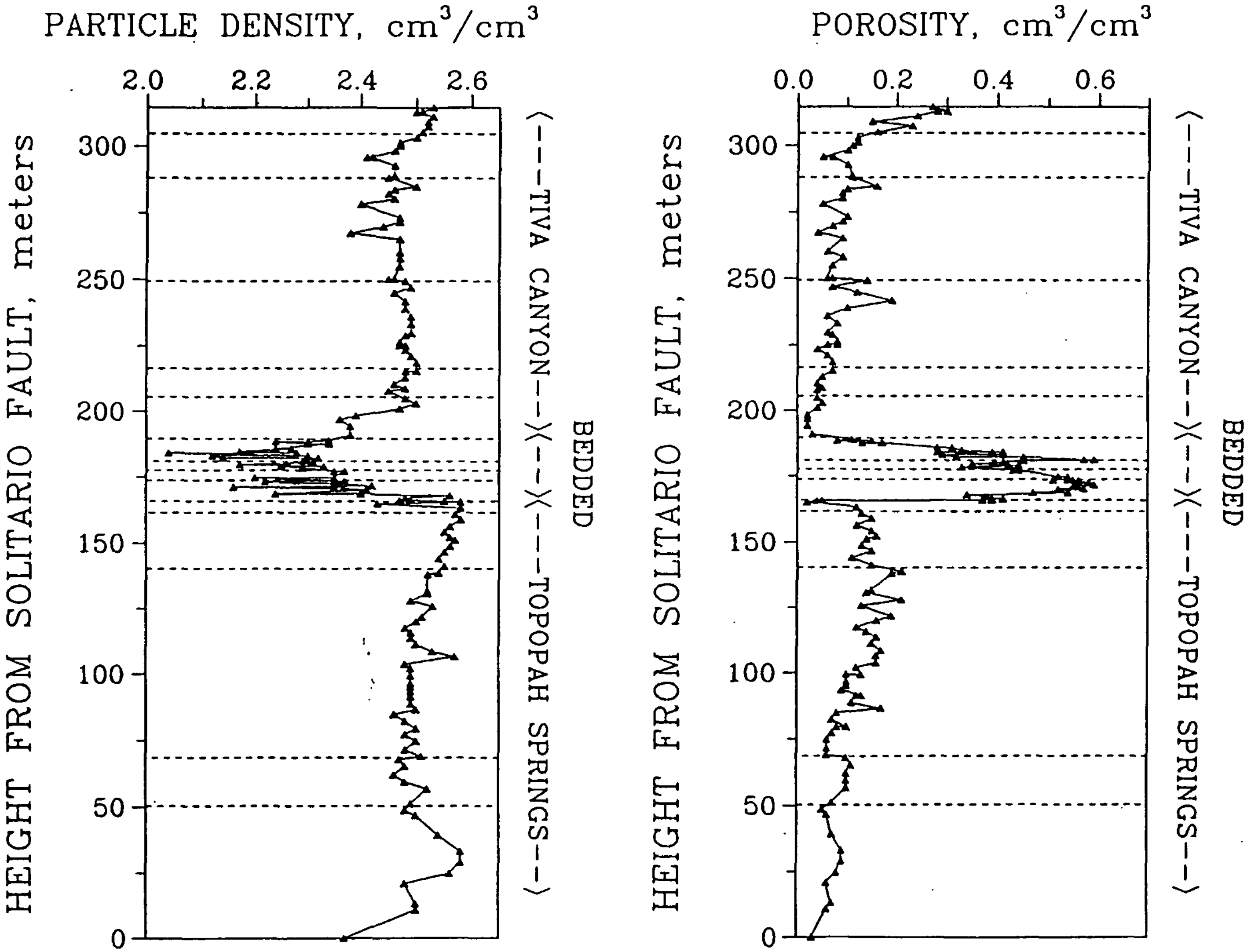
MICROUNITS OF THE BEDDED TUFFS



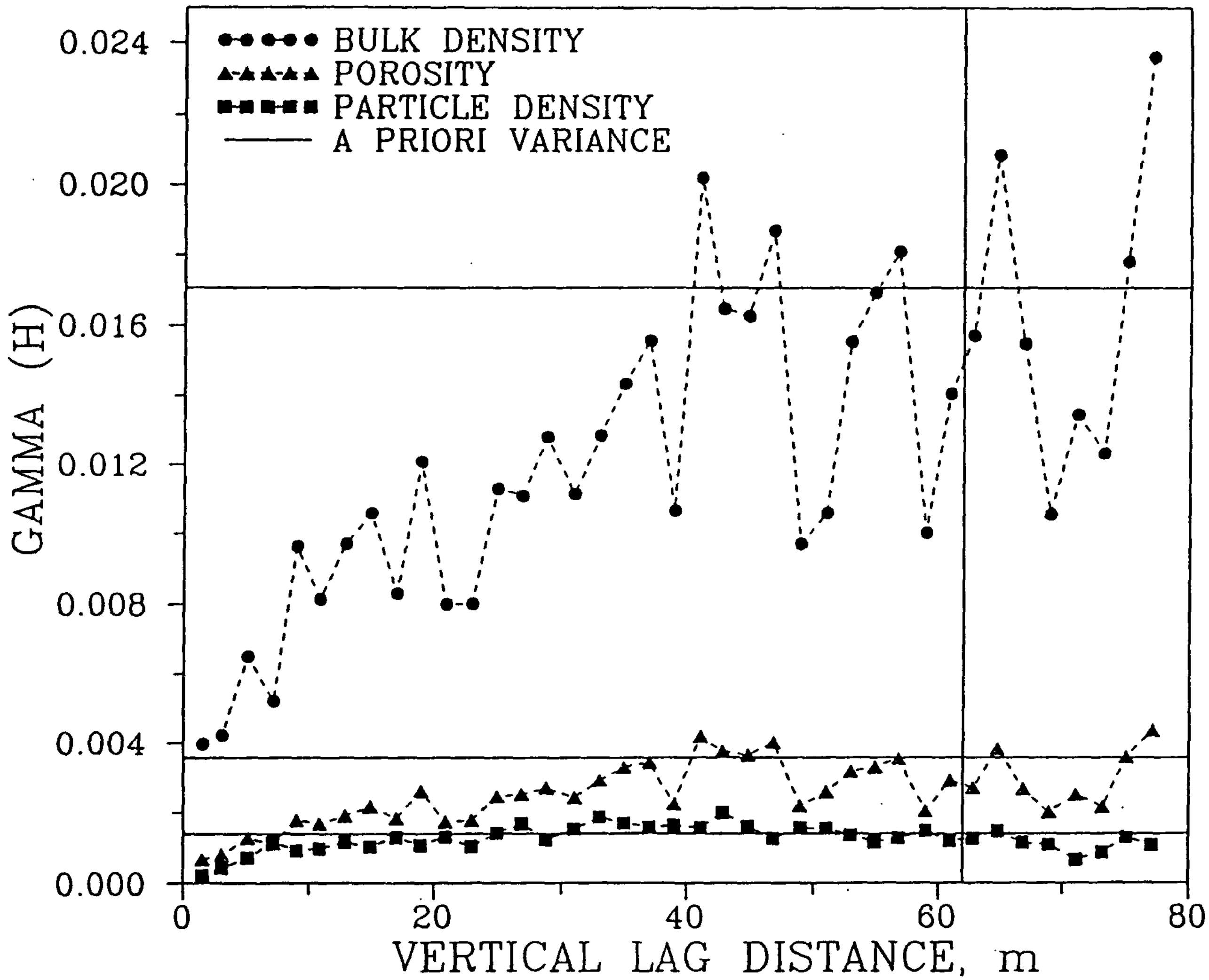
MICROUNITS OF THE TOPOPAH SPRING



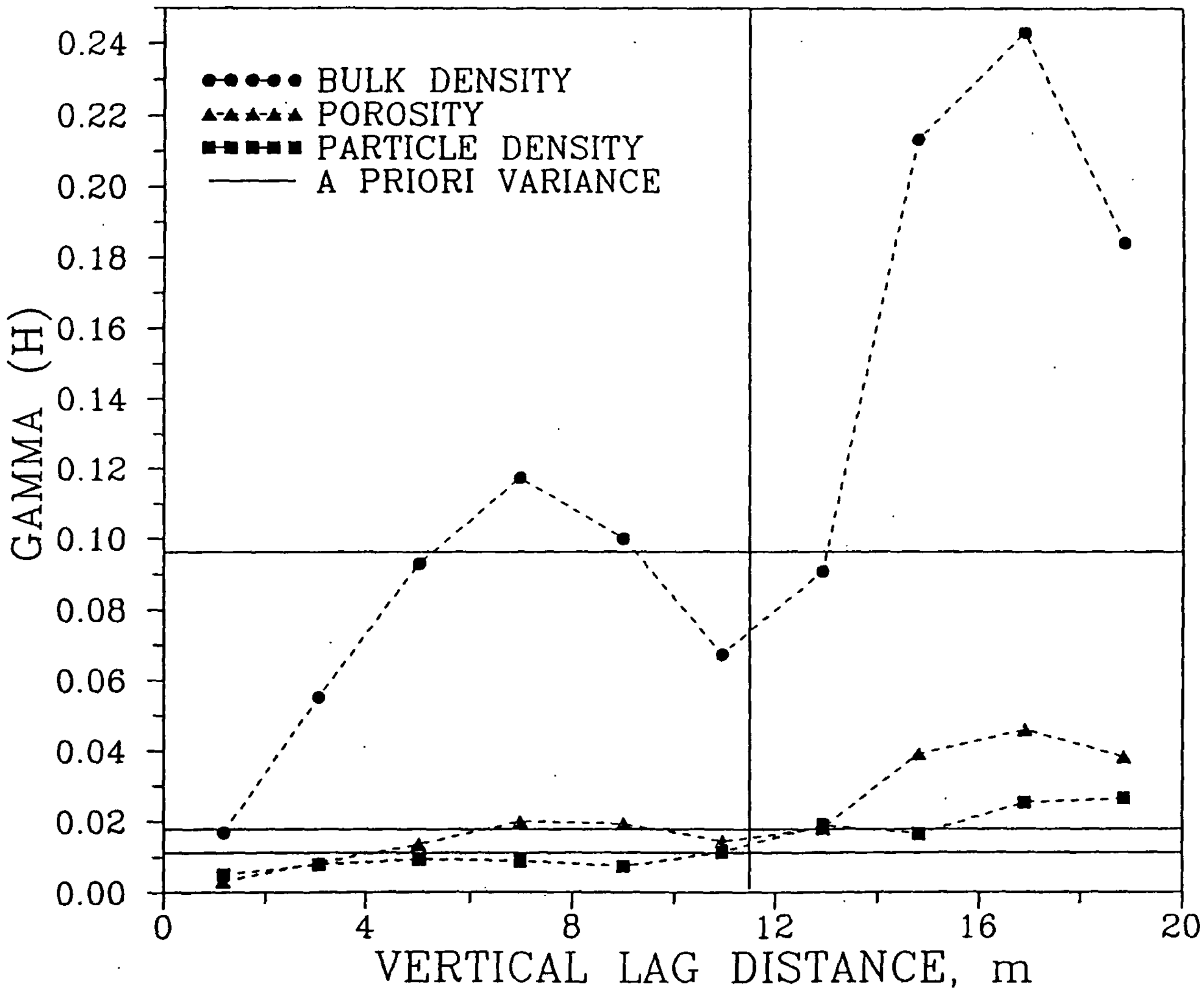
VERTICAL TRANSECT IN SOLITARIO CANYON AT UZ-6



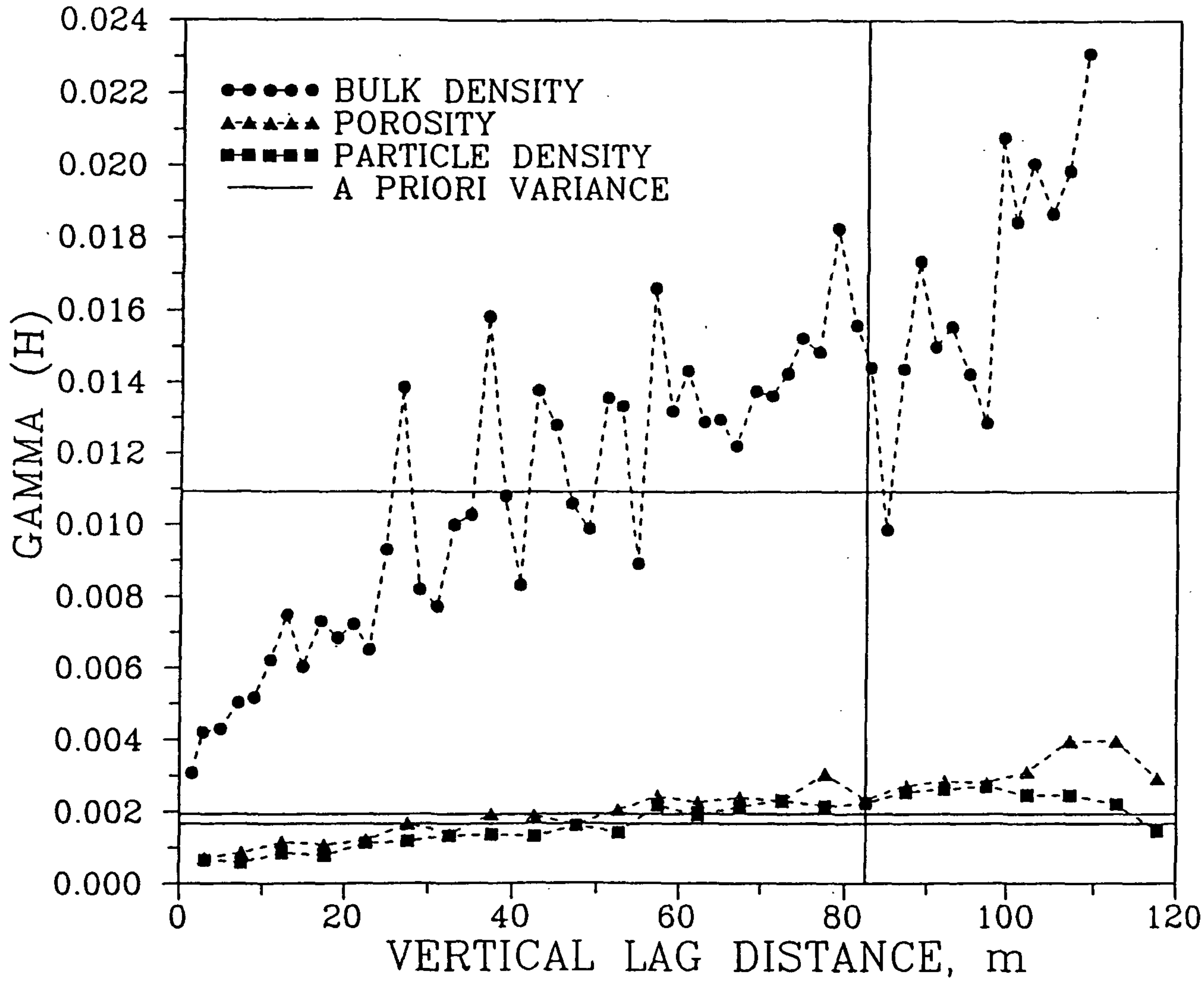
TIVA CANYON VARIOGRAMS



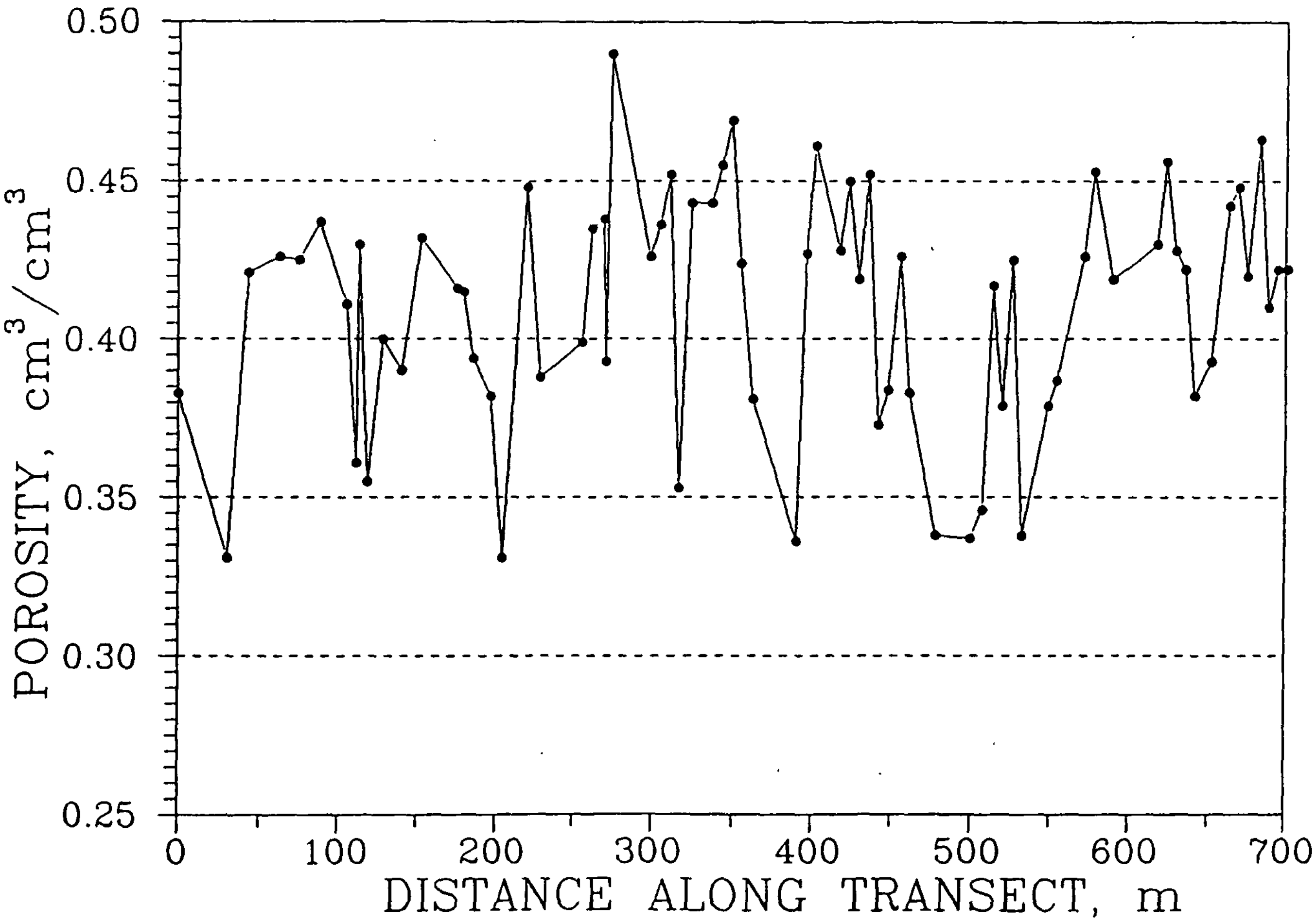
BEDDED TUFF VARIOGRAMS



TOPOPAH SPRING VARIOGRAMS



SURFACE OUTCROP SAMPLING
TRANSECT: SHARDY BASE OF TIVA CANYON NONWELDED



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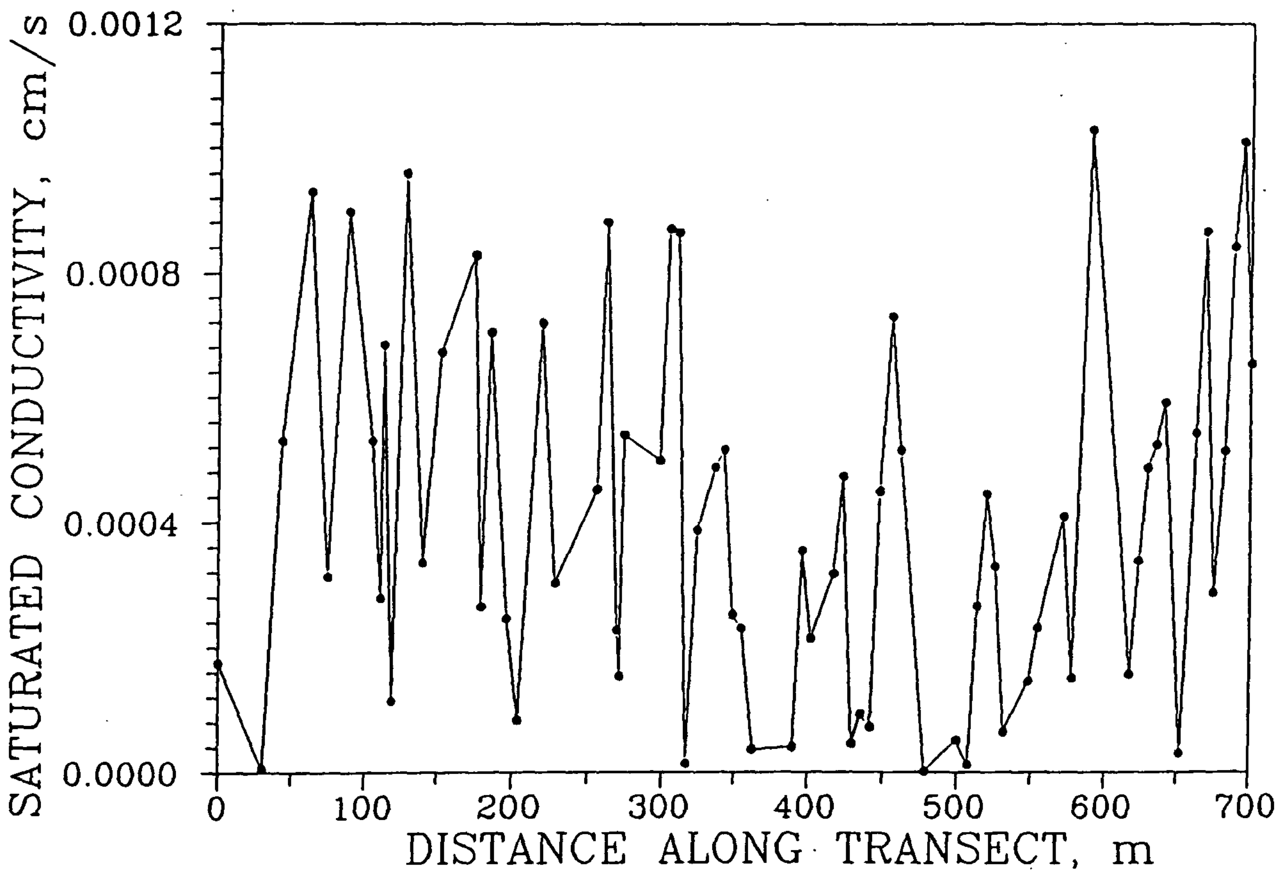
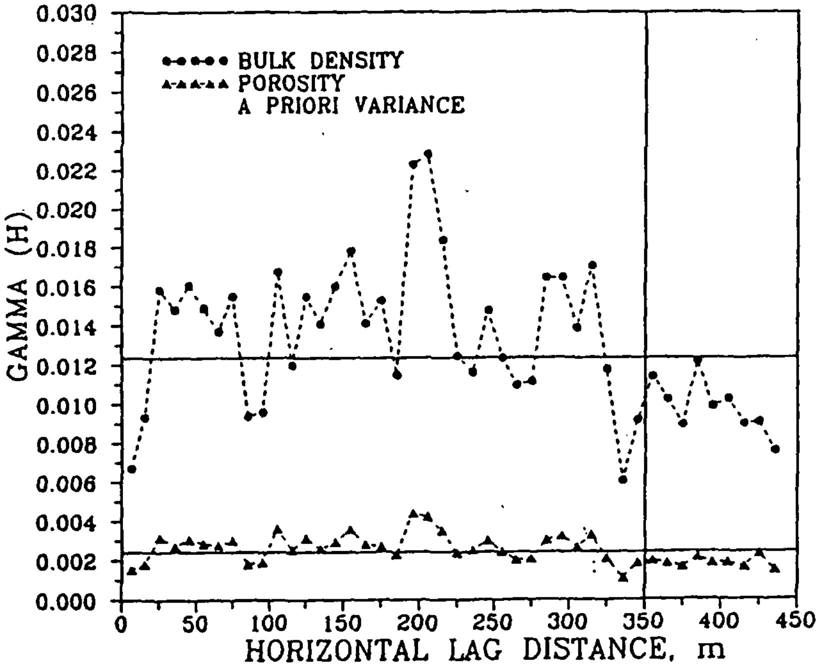
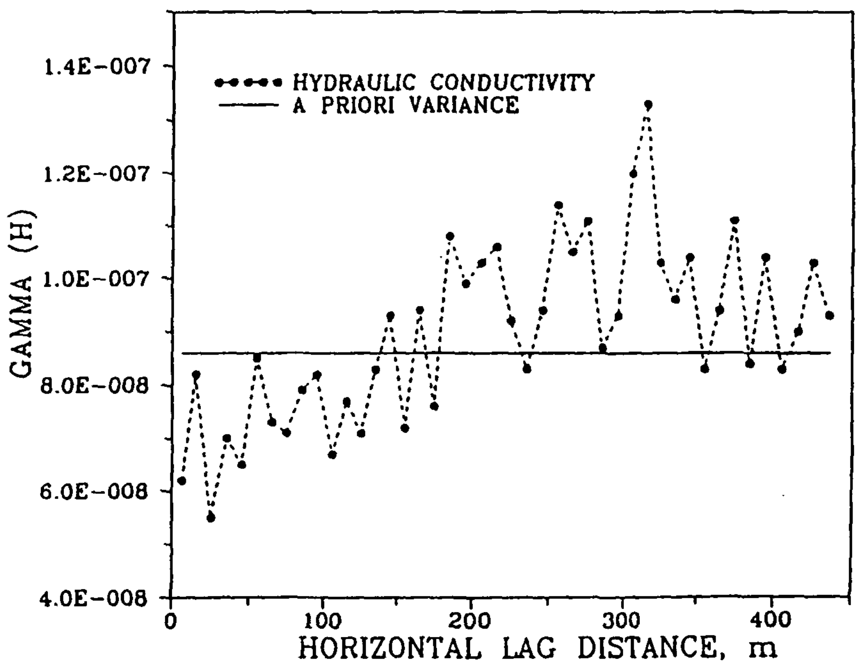
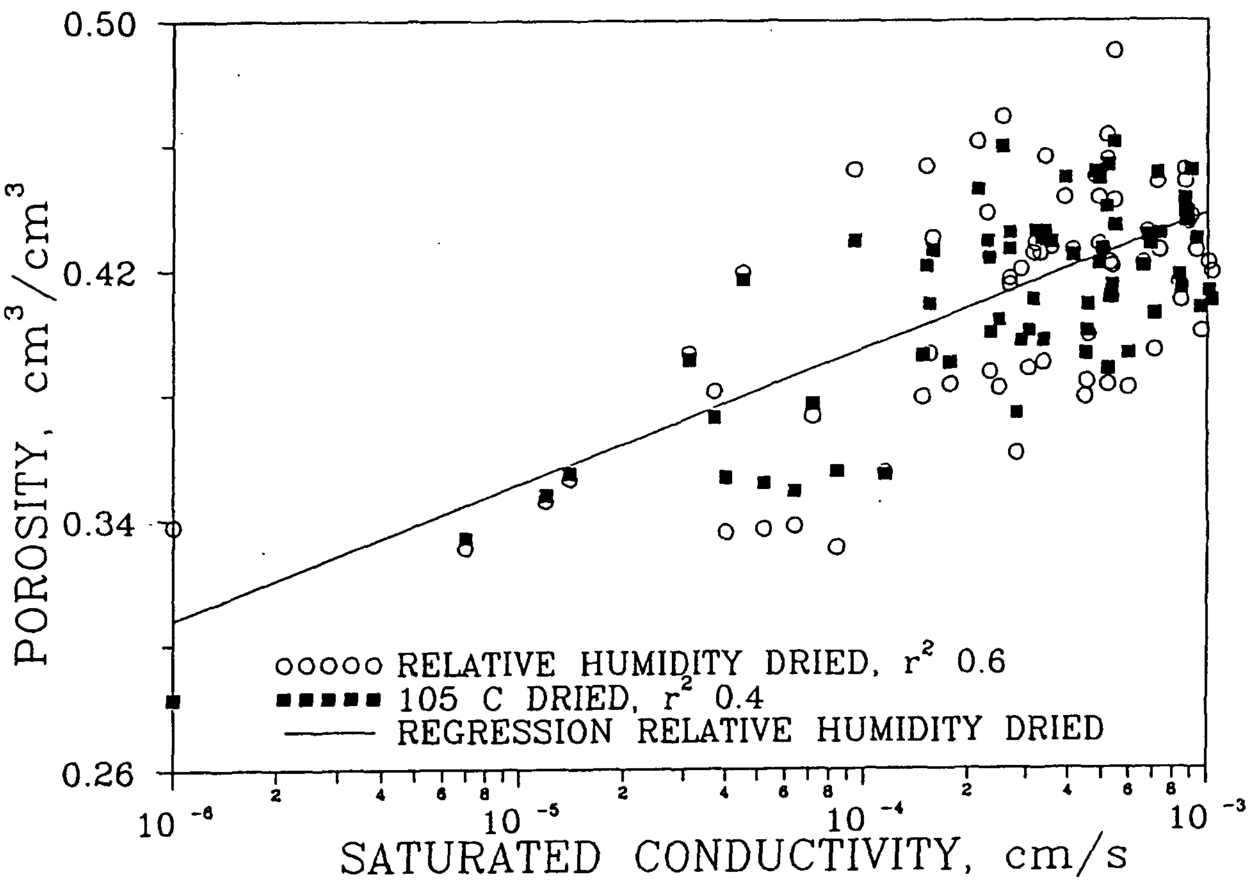


HORIZONTAL VARIOGRAM, SHARDY BASE OF TIVA CANYON





RELATIONSHIP BETWEEN CONDUCTIVITY AND POROSITY



SAMPLING PROGRAM

- o SURFACE OUTCROP SAMPLING
- o BOREHOLE CORES

TESTING PROGRAM

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

ANALYSIS

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

SUMMARY

RANGE IN CORE PROPERTY VALUES FOR YUCCA MOUNTAIN GEOHYDROLOGIC UNITS

GEOHYDROLOGIC UNIT	POROSITY (cm^3/cm^3)	GRAIN DENSITY (g/cm^3)	DRY BULK DENSITY (g/cm^3)	SATURATED CONDUCTIVITY (cm/s)
TIVA CANYON w	.08-.12	2.3-2.8	1.4-2.4	1.5E-10-9.7E-10
PAINTBRUSH TUFF nw	.06-.54	2.2-2.6	1.1-2.4	2.3E-9 -2.4E-4
TOPOPAH SPRING w	.04-.33	2.4-2.6	1.8-2.4	1.2E-10-2.3E-7
CALICO HILLS nw	.14-.46	2.2-2.6	1.3-2.0	5.2E-10-2.9E-5
CRATER FLAT	.19-.38	2.5-2.6	1.6-2.1	2.0E-9 -6.9E-7

References
Anderson (1981)
Rush, Thordarson and Bruckheimer (1983)
Thordarson (1983)
Montazer and Wilson (1984)
Weeks and Wilson (1987)
Klavetter and Peters (1987)
Flint and Flint (1989)

COMPARISON OF CORE PROPERTIES FROM OUTCROP AND BOREHOLE CORE SAMPLES

GEOHYDROLOGIC UNIT	POROSITY CORE	POROSITY OUTCROP	BULK DENSITY CORE	BULK DENSITY OUTCROP
TIVA CANYON	0.08–0.12	0.02–0.30	1.4–2.4	1.8–2.4
PAINTBRUSH TUFF	0.06–0.54	0.04–0.59	1.1–2.4	0.9–2.5
TOPOPAH SPRING	0.04–0.33	0.02–0.21	1.8–2.4	1.9–2.4

SUMMARY

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