NUCLEAR WASTE TECHNICAL REVIEW BOARD
HYDROLOGY AND GEOCHEMISTRY PANEL

Subject: PROGRESS IN UNSATURATED ZONE STUDIES

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OUTLINE

- Summary of infiltration studies
- Pagany Wash simulations
- Block Experiment
- Fracture properties
- Matrix properties
- Permeability and fracture data from UZ-16
- Isotopic evidence for deep, transient fracture flow
- Gas flow model of Yucca Crest
- Perched Water
- Unsaturated zone-saturated zone interactions
- Summary

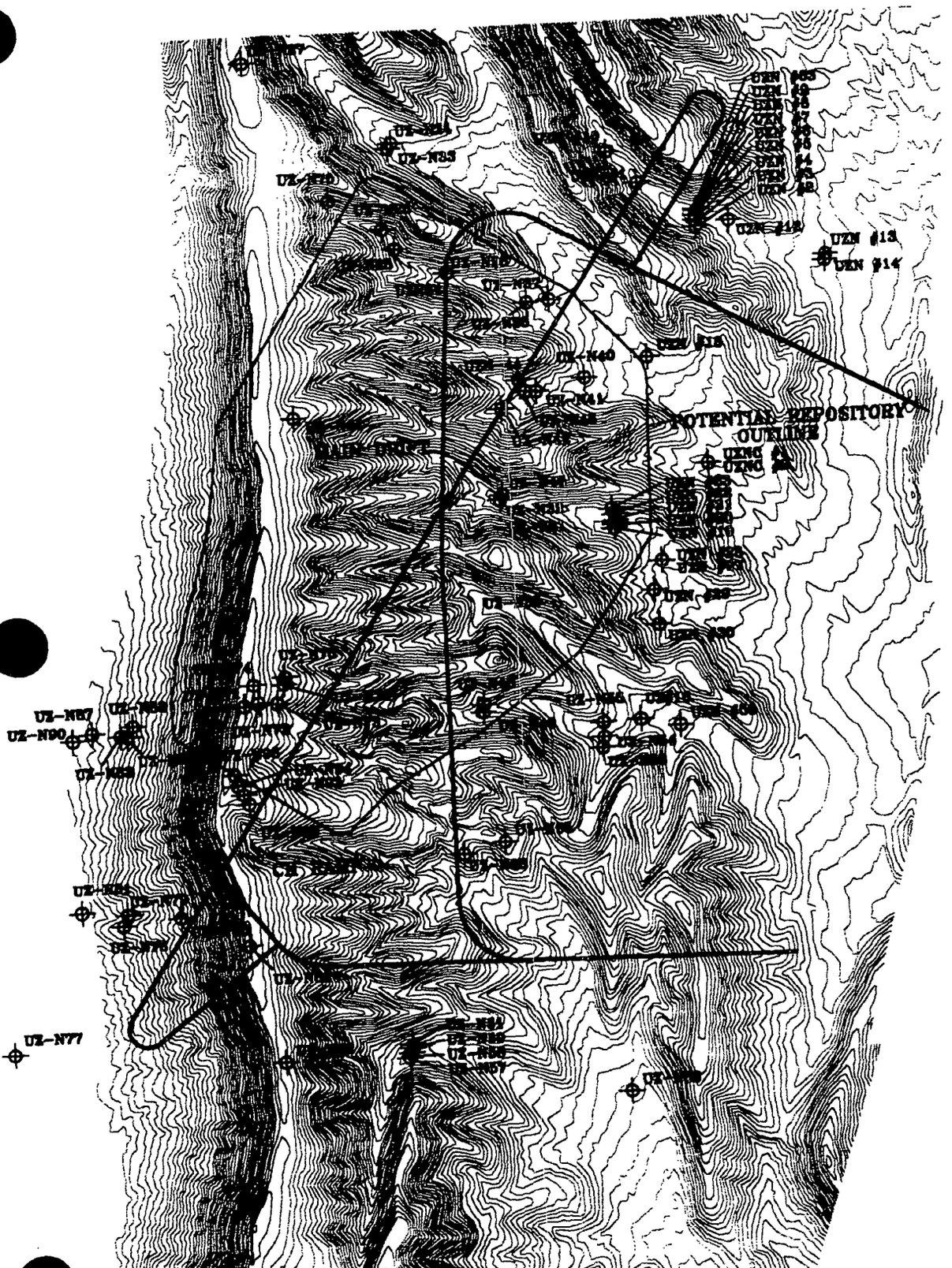
Neutron Hole Data

- Over 90 shallow boreholes in various topographic and geographic locations.

- Purpose is to identify those locations where infiltration is presently occurring and determine dominant controls on net infiltration, including:

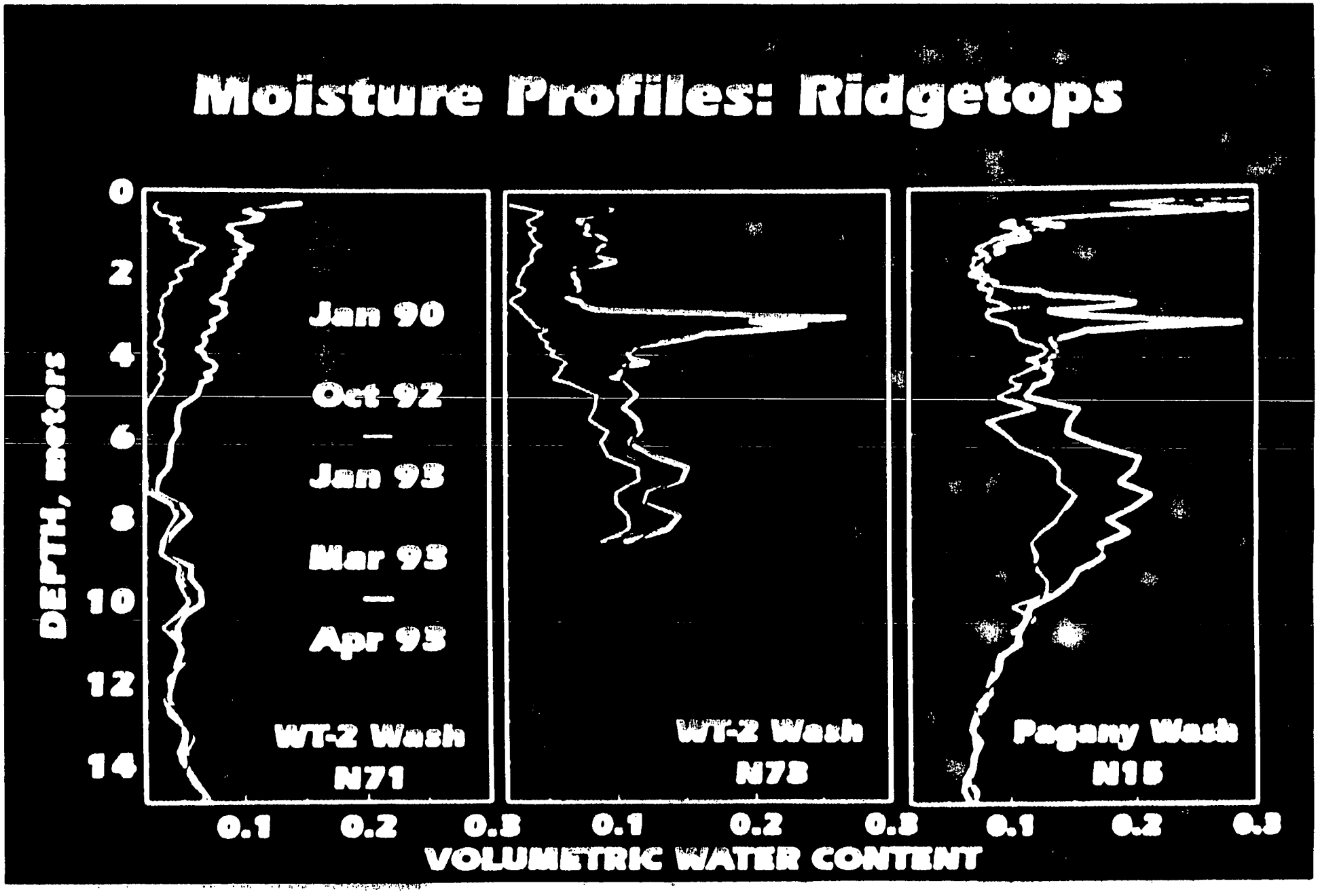
  - the type of outcropping geologic formation
  - topographic position
  - slope aspect
  - depth of alluvial cover.

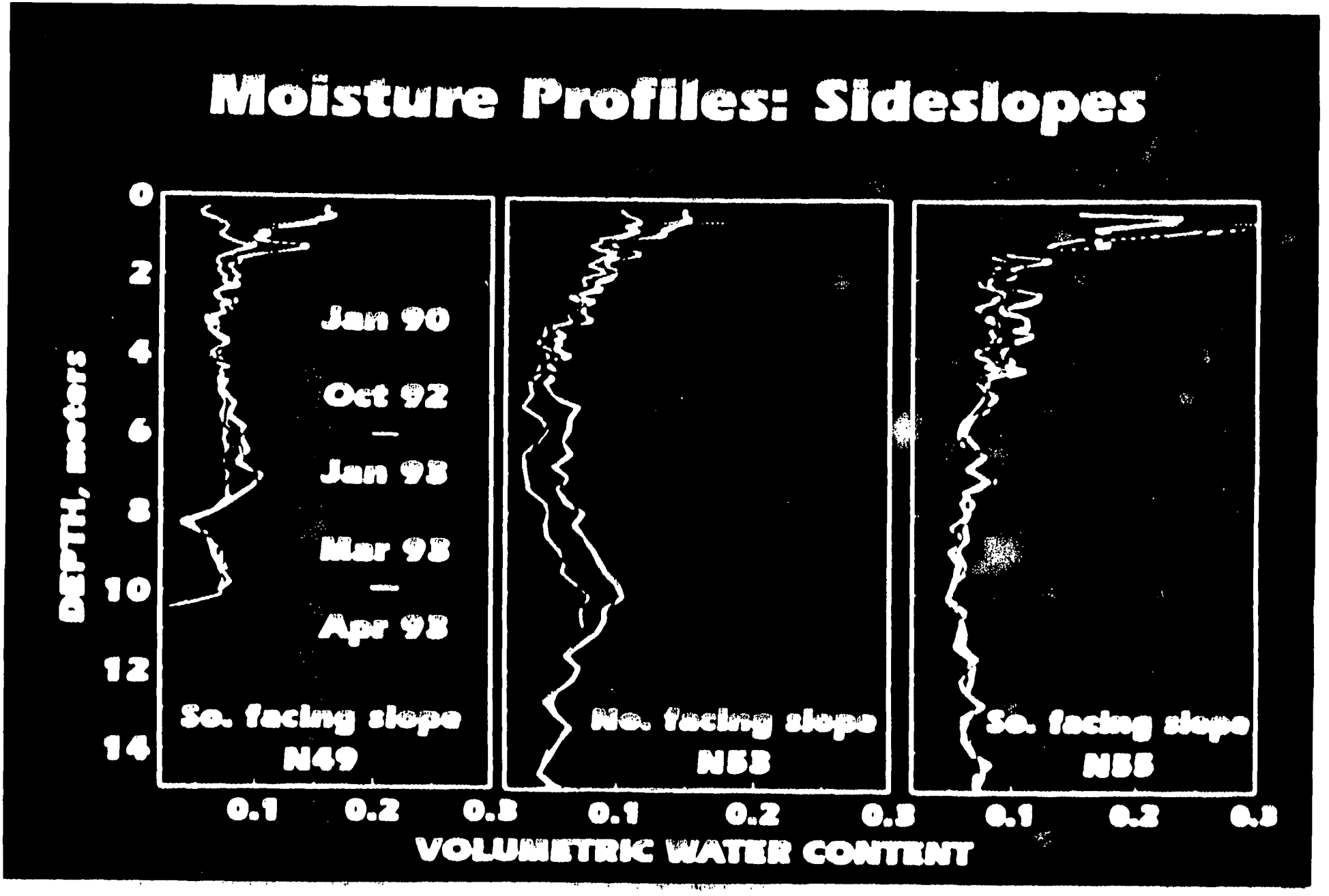
NEUTRON HOLE LOCATIONS

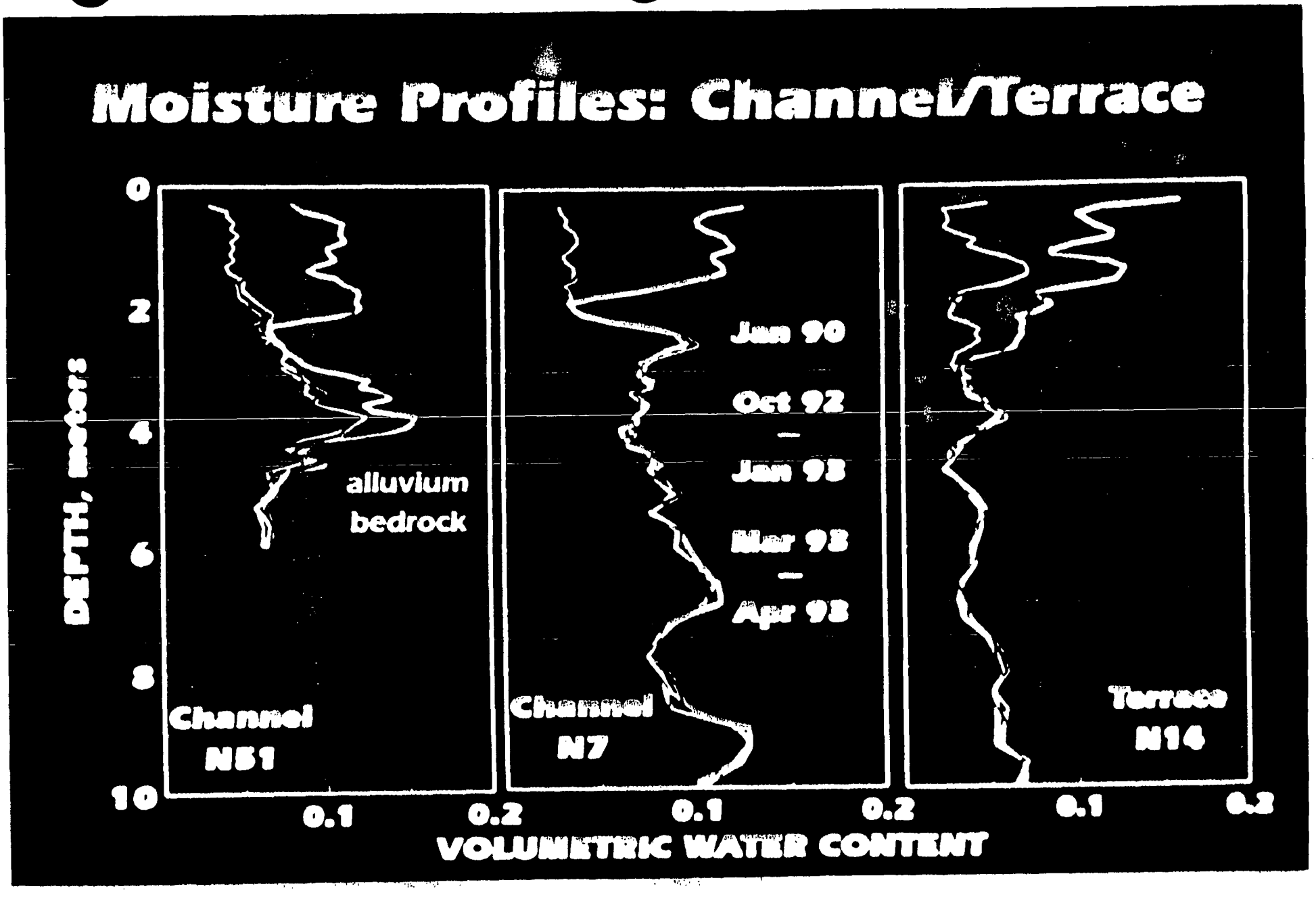


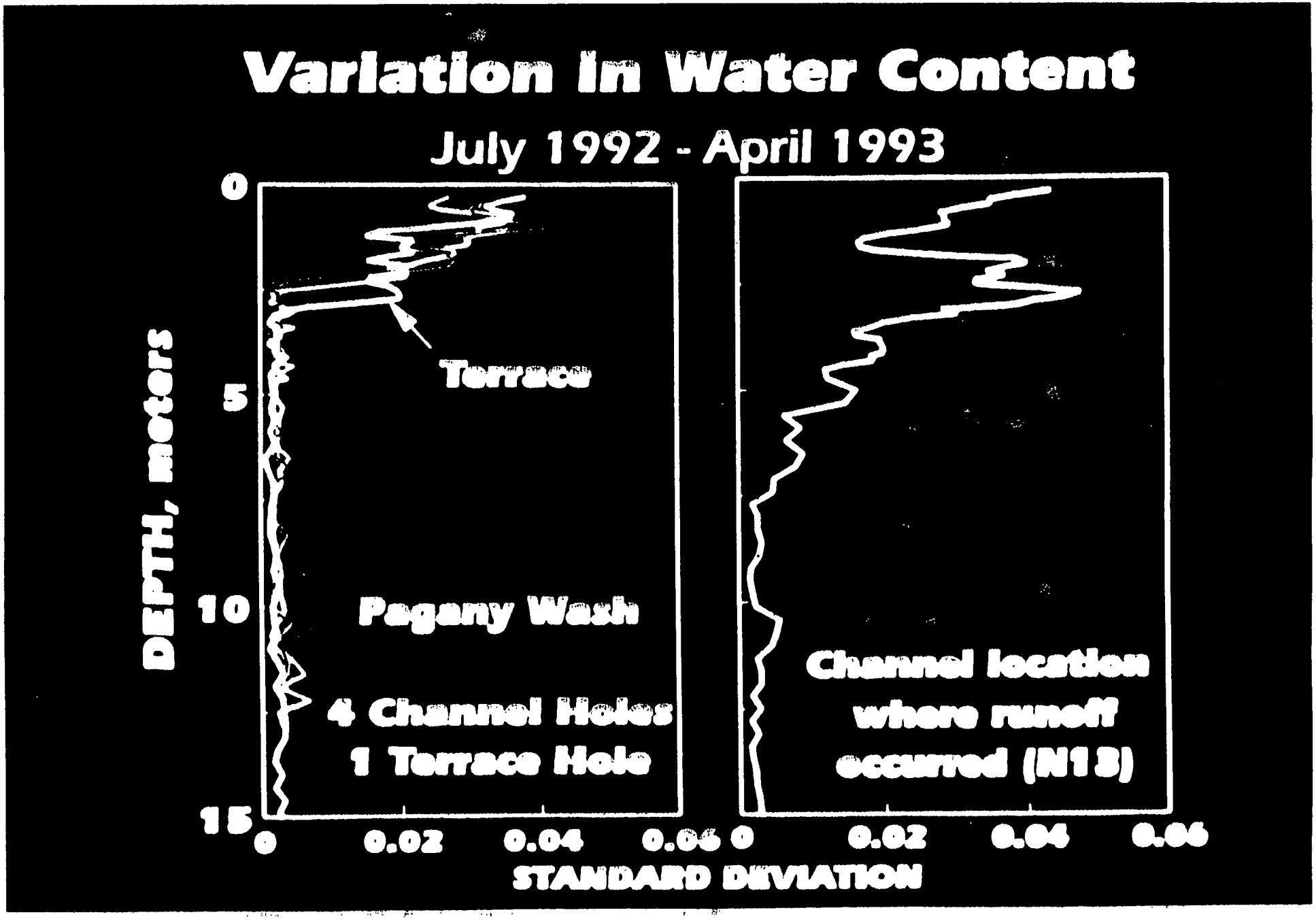
Saturated Conductivity (mm/yr)

Tiva Caprock	3.4
Tiva Mod Weld	122.0
Tiva Welded	0.9
PTn	16398.7
Topopah Weld	1.9
Rainier Mesa	133.7


Moisture Profiles: Ridgetops
DEPTH, meters
0
2
4
6
8
10
12
14
Jan 90
Oct 92
Jan 93
Mar 93
Apr 93
WT-2 Wash
N71
WT-2 Wash
N73
Pagany Wash
N15
0.1
0.2
0.3
VOLUMETRIC WATER CONTENT

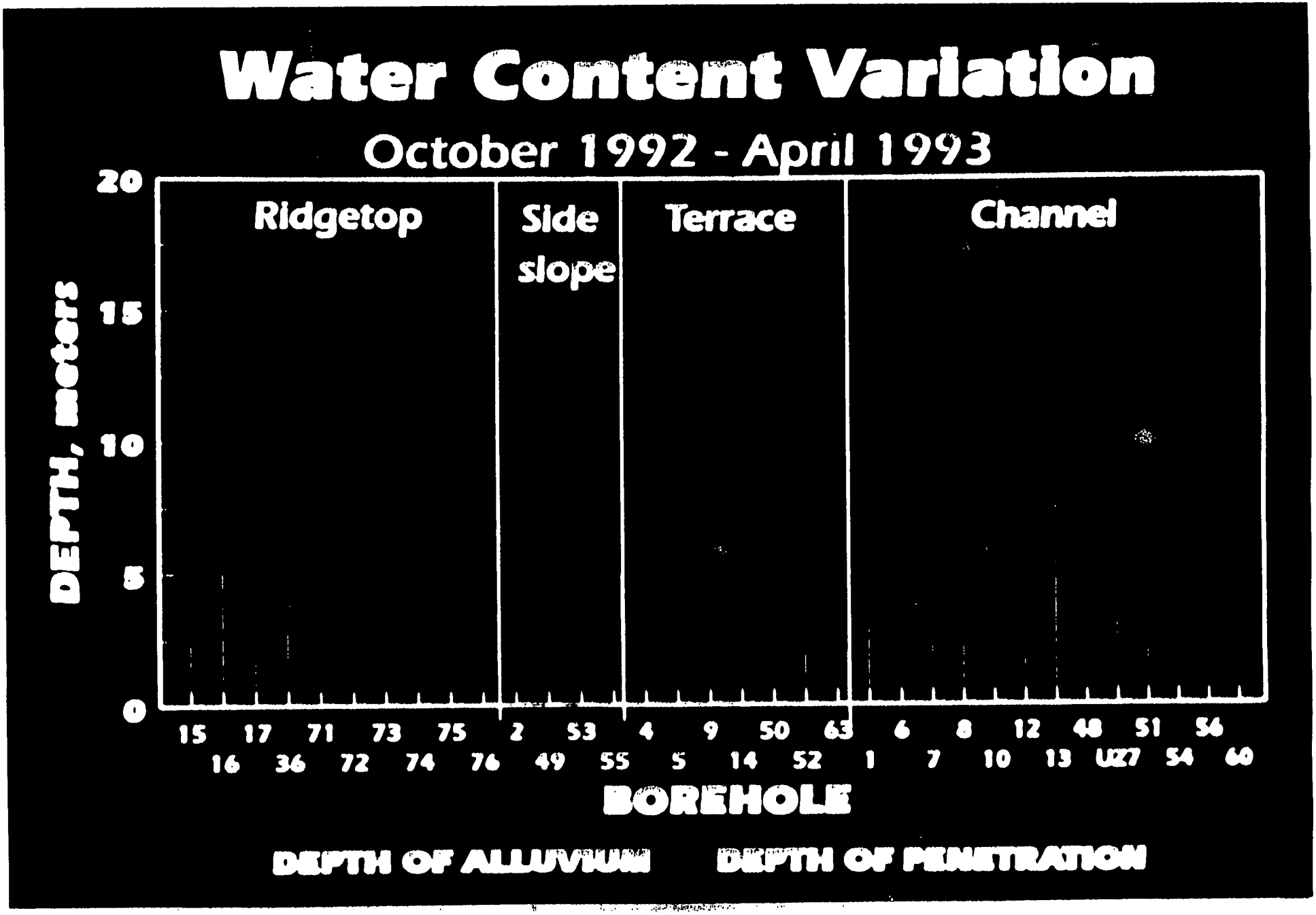

Moisture Profiles: Sideslopes
DEPTH, meters
0
2
4
6
8
10
12
14
Jan 90
Oct 92
Jun 93
Mar 93
Apr 93
So. facing slope
N49
No. facing slope
N53
So. facing slope
N55
0.1
0.2
0.3
VOLUMETRIC WATER CONTENT


Moisture Profiles: Channel/Terrace
DEPTH, meters
0
2
4
6
8
10
alluvium
bedrock
Channel
N51
Jun 90
Oct 92
Jun 93
Mar 93
Apr 93
Channel
N7
Terrace
N14
0.1
0.2
0.1
0.2
0.1
0.2
VOLUMETRIC WATER CONTENT

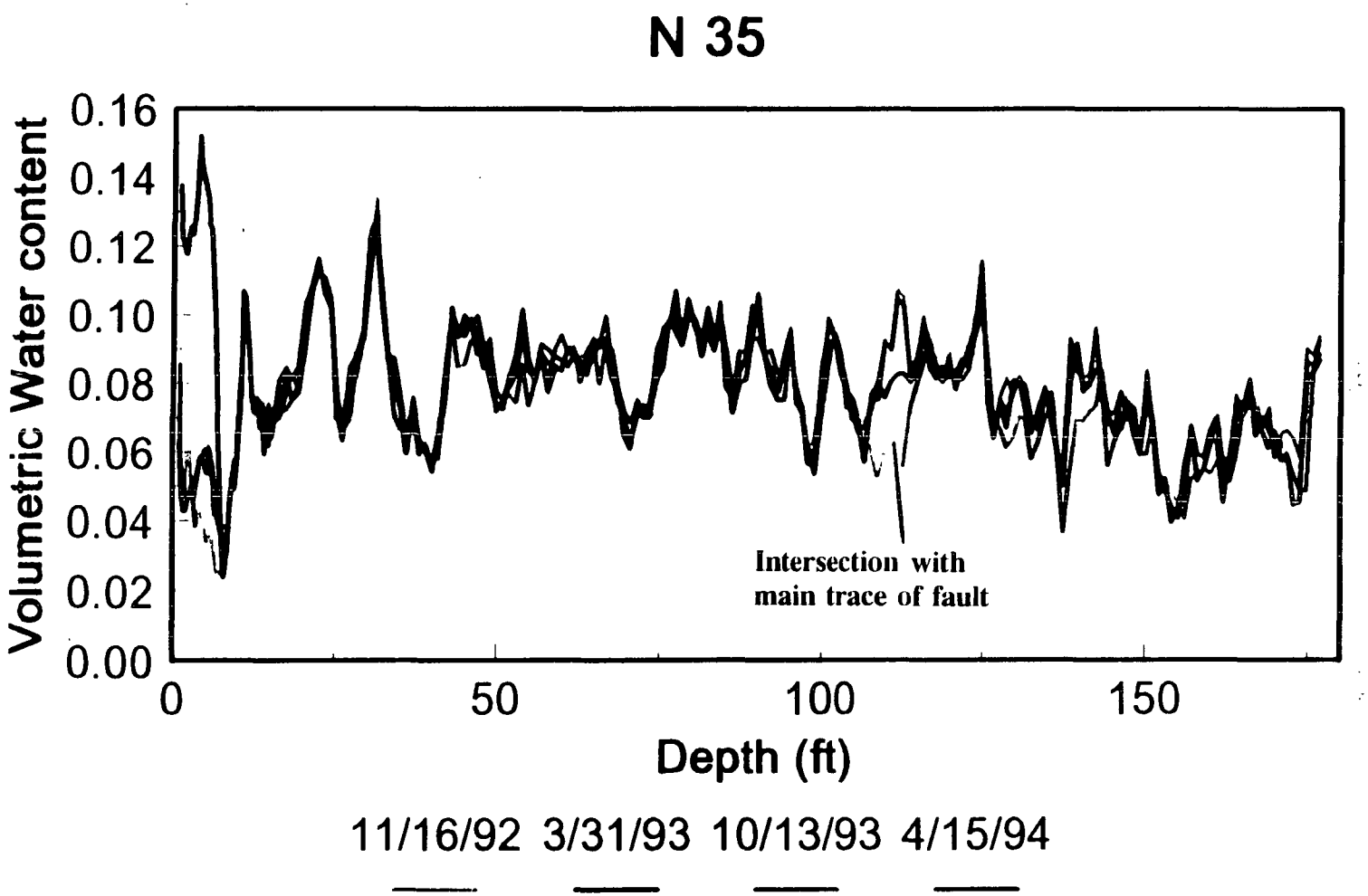

Variation in Water Content
July 1992 - April 1993
DEPTH, meters
0
5
10
15
Terrace
Pagany Wash
4 Channel Holes
1 Terrace Hole
Channel location
where runoff
occurred (N13)
0
0.02
0.04
0.06
0
0.02
0.04
0.06
STANDARD DEVIATION

Deep Penetration of Moisture Following Runoff in Upper Fortymile Wash (Savard, 1994)

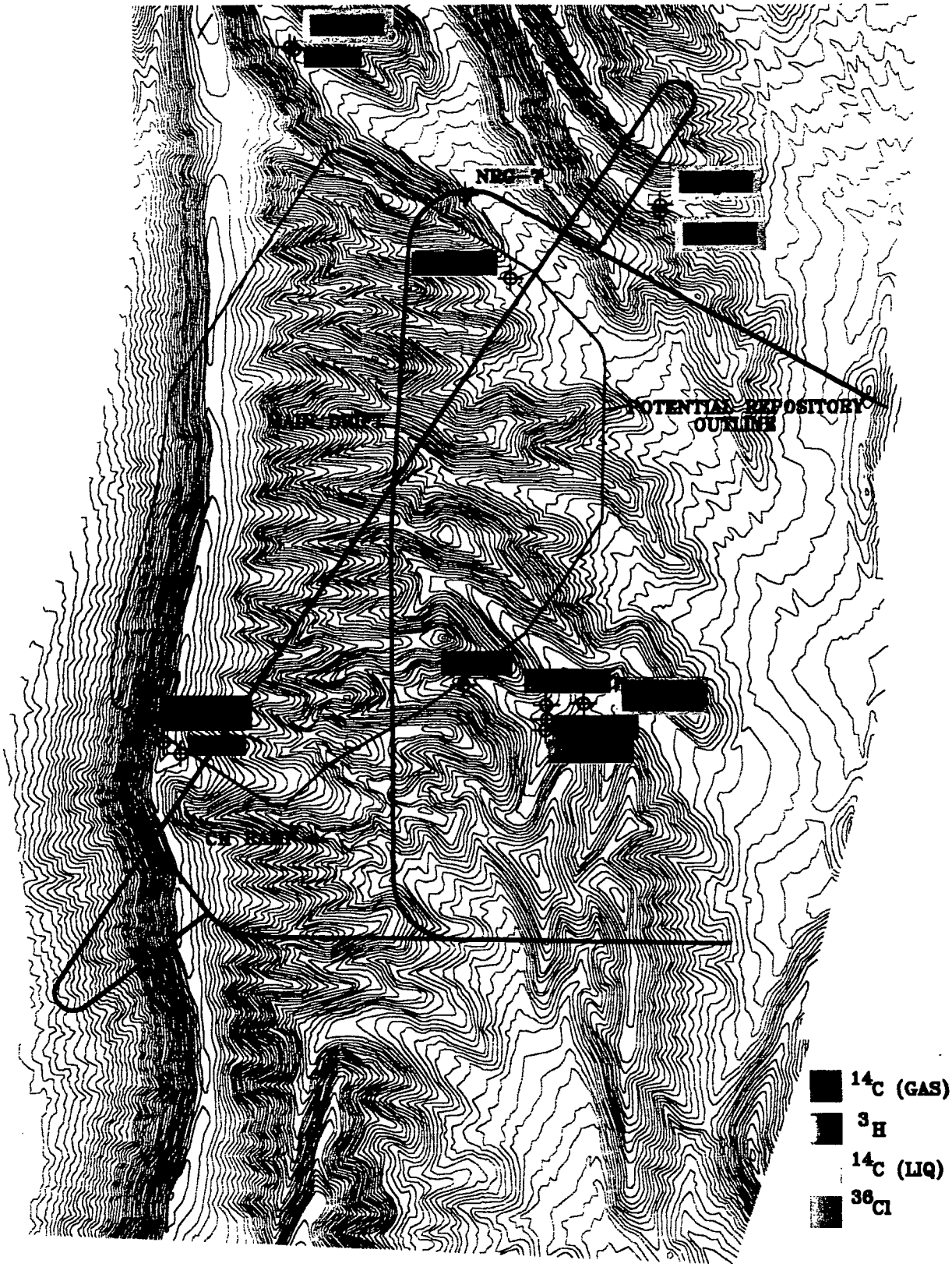
- Infiltration and redistribution from runoff events in winters of 1992 and 1993 monitored with neutron logging tool at N91, 10km north-northeast of Yucca Mountain.
- Smaller runoff event of 1992 filled only part of channel and moisture content changes at N91 did not occur beneath a depth of 5m.
- Larger runoff event of 1993, which filled the entire width of the channel, resulted in moisture content changes all the way to the water table at an 18m depth.
- Concluded that first wetting pulse stopped after satisfying a preexisting moisture deficit in the upper 5m, but wetter antecedent conditions and greater width of runoff can allow moisture to penetrate channel alluvium to considerable depths.
- Extrapolation of results to Yucca Mountain uncertain because carbonate layers (at least in older alluvium) may impede infiltration.


Water Content Variation
October 1992 - April 1993
Ridgetop
Side slope
Terrace
Channel
DEPTH, meters
20
15
10
5
0
15 17 71 73 75 2 53 4 9 50 63 6 8 12 48 51 56
16 36 72 74 76 49 55 5 14 52 1 7 10 13 UZ7 54 60
BOREHOLE
DEPTH OF ALLUVIUM
DEPTH OF PENETRATION

Evidence from neutron moisture logs for water flow in the Ghost Dance Fault



BOREHOLES WITH AVAILABLE ISOTOPIC DATA



^{36}Cl and ^{3}H data - isotopic evidence for near surface, transient fracture flow (above and within PTn)

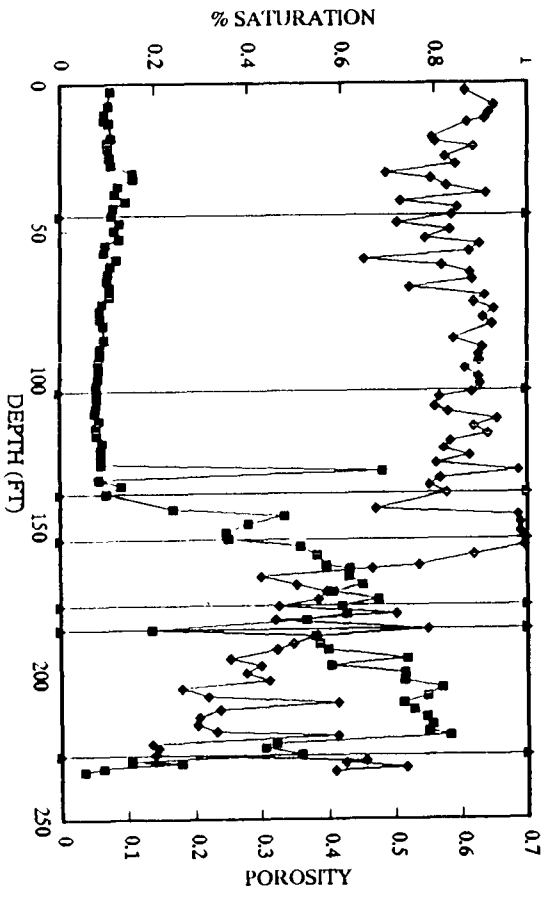
- Bomb pulse ^{36}Cl in the PTn unit in N11 (65 and 80 feet depths), and N53 (144 and 183 feet depths).
- Bomb pulse ^{3}H in similar stratigraphic positions in UZ#4 and UZ #5 in Pagany Wash.
- Bomb pulse ^{3}H throughout the Tiva Canyon Member, and within bedded tuffs as deep as 42m in the Pah Canyon Member at UZ7 in WT-2 Wash (near trace of Ghost Dance Fault).
- Bomb pulse ^{3}H found in UZ6s at depths of 20-30 m in the densely welded Tiva Canyon Member, in a bedded unit at about 133m depth, and in the upper nonwelded part of the Topopah Spring Member at a depth of about 145m.
- Bomb pulse ^{3}H found within the PTn (tentatively) at UZ#16.

^{36}Cl and ^{3}H data - isotopic evidence for deep penetration in alluvium

- Bomb pulse ^{36}Cl to depths of 8m at N37
- Bomb pulse ^{36}Cl at the alluvium-TCw contact (13m depth) at UZ#16 (probably occurred as a result of flow along contact from sideslopes).

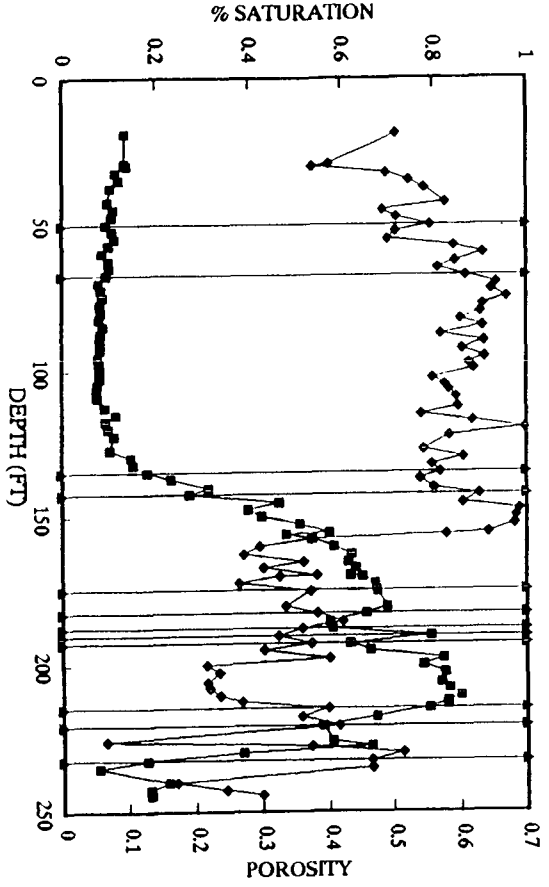
USW UZN-53, WT-2 WASH

760,096N 564,237E 4060 ft elevation



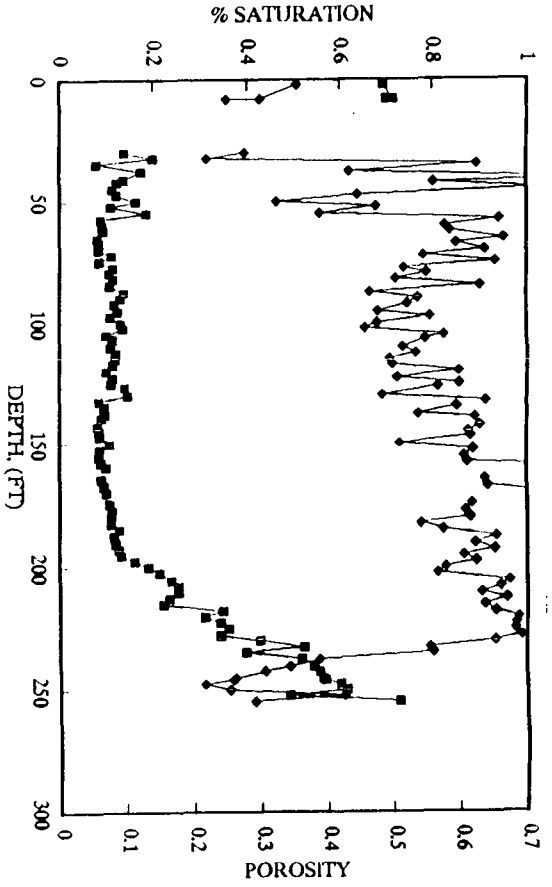
USW UZN-54, WT-2 WASH

760,273N 564,262E 4090 ft elevation



USW UZN-55, WT-2 WASH

760,503N 564,248E 4130 ft elevation



POROSITY % SATURATION

Stochastic Rainfall-Runoff Models

- Characterization of surficial materials (through physical measurements and model calibration) allows determination of what combination of climatic events - for instance, how many successive "wet" years, are necessary to produce recharge of a certain magnitude.

- Climate record allows the creation of stochastic climate models that indicate the liklihood of that combination of climatic events occurring.

Summary of Infiltration Studies

- Thick alluvial cover, in the absence of runoff or ponding, appears to be effective in storing infiltration until it can be removed by evapotranspiration (ET).
- During and following runoff, water can penetrate alluvium to depths beyond which it would be expected to be removed by ET.
- Where alluvial cover is thin or absent, water can enter fracture and move to depths of many tens of meters over periods of weeks.
- Net solar radiation is strongly influenced by slope aspect, so that deep infiltration appears more likely on north facing slopes.
- At this time, no topopgraphic setting or outcropping rock type can be eliminated as being a potentially significant location for infiltration.

Pagany Wash Simulations

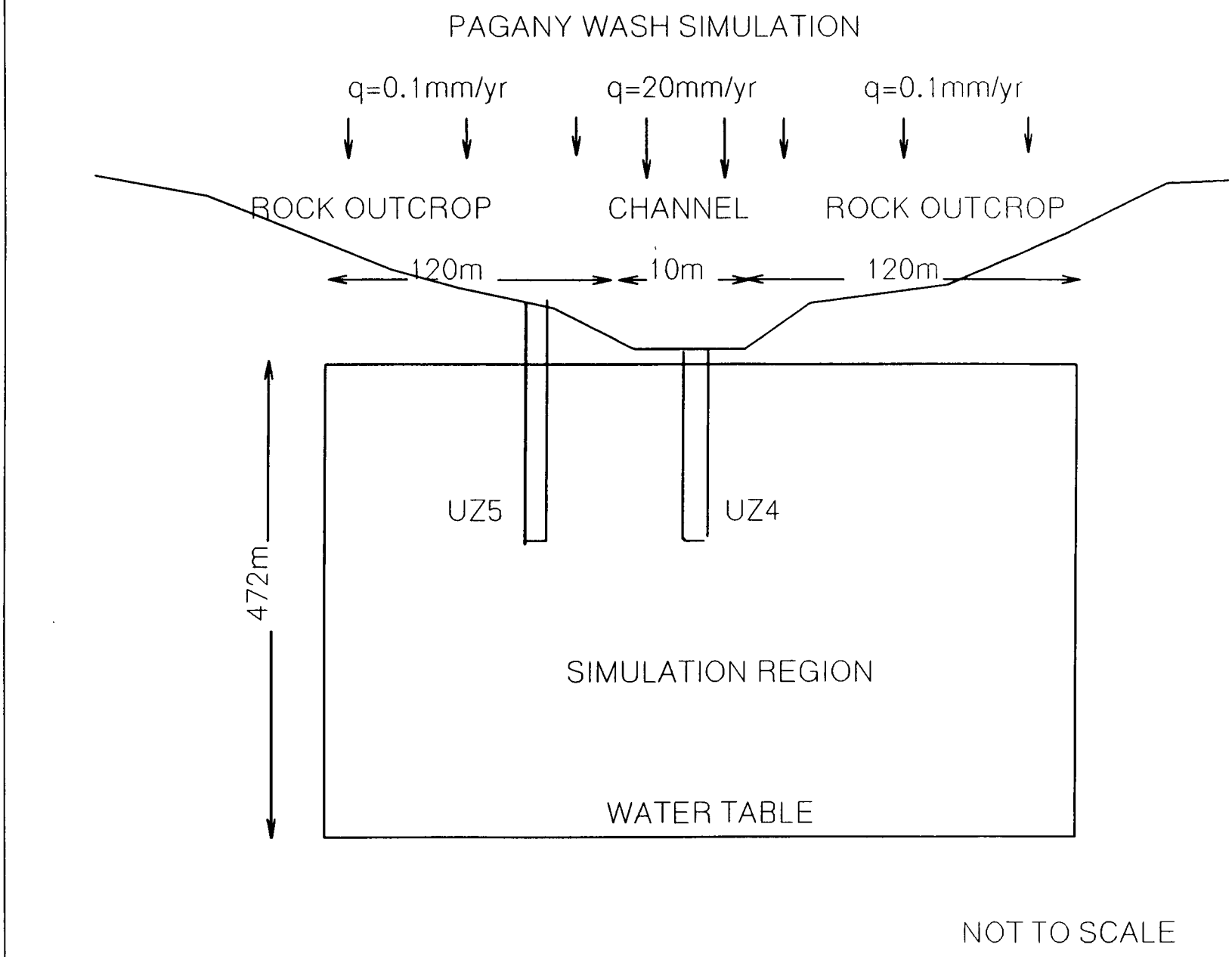
- Estimate percolation rates from saturation, water potential and isotope data from UZ4 and UZ5.
  - establish the long-term role of the wash in infiltration processes.

- Identify important processes and stratigraphic intervals controlling the vertical and lateral movement of water within and through the nonwelded and bedded intervals overlying the Topopah Spring.

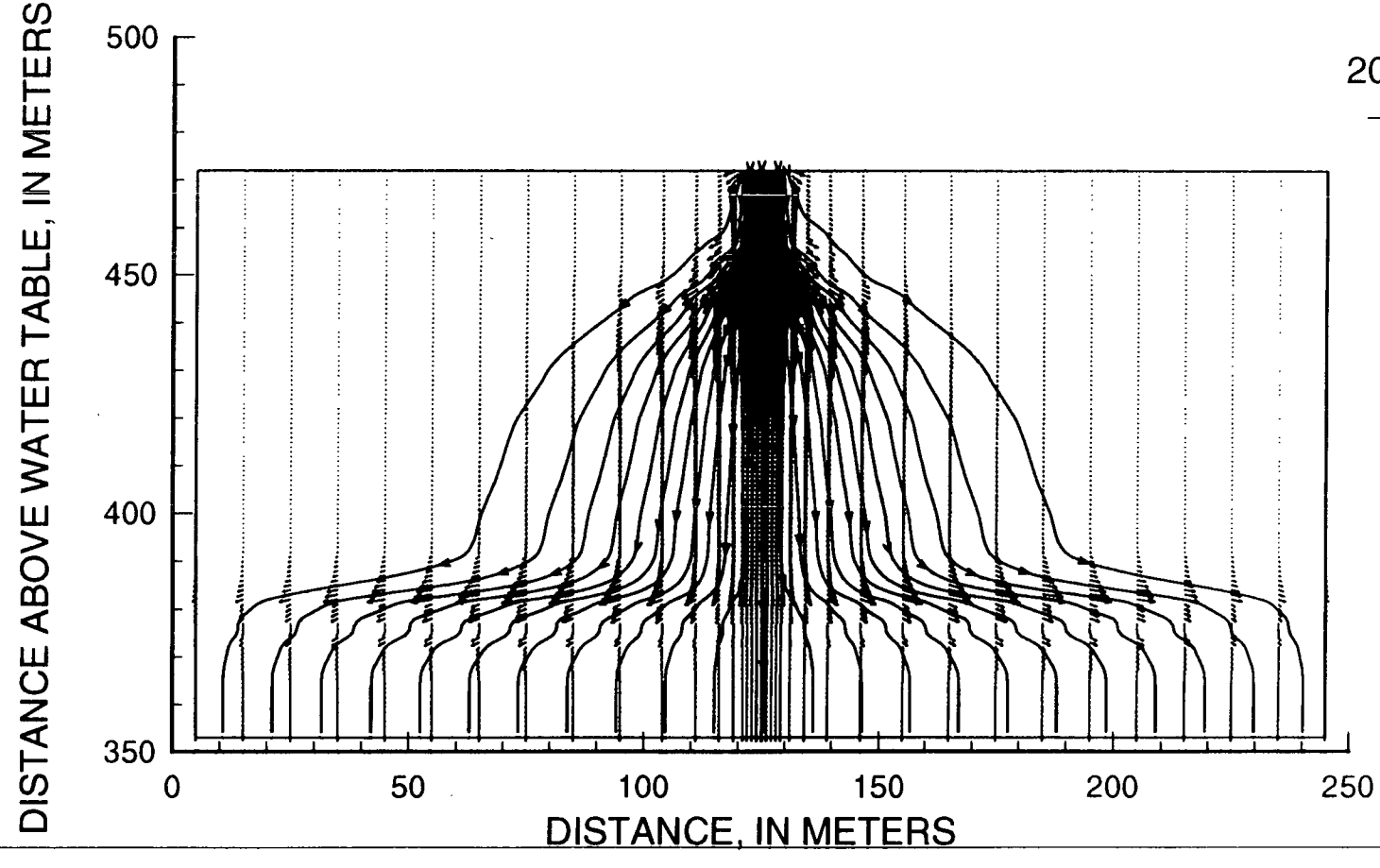
- Establish a sense of the time scales required for penetration of the PTn of infiltrating moisture.

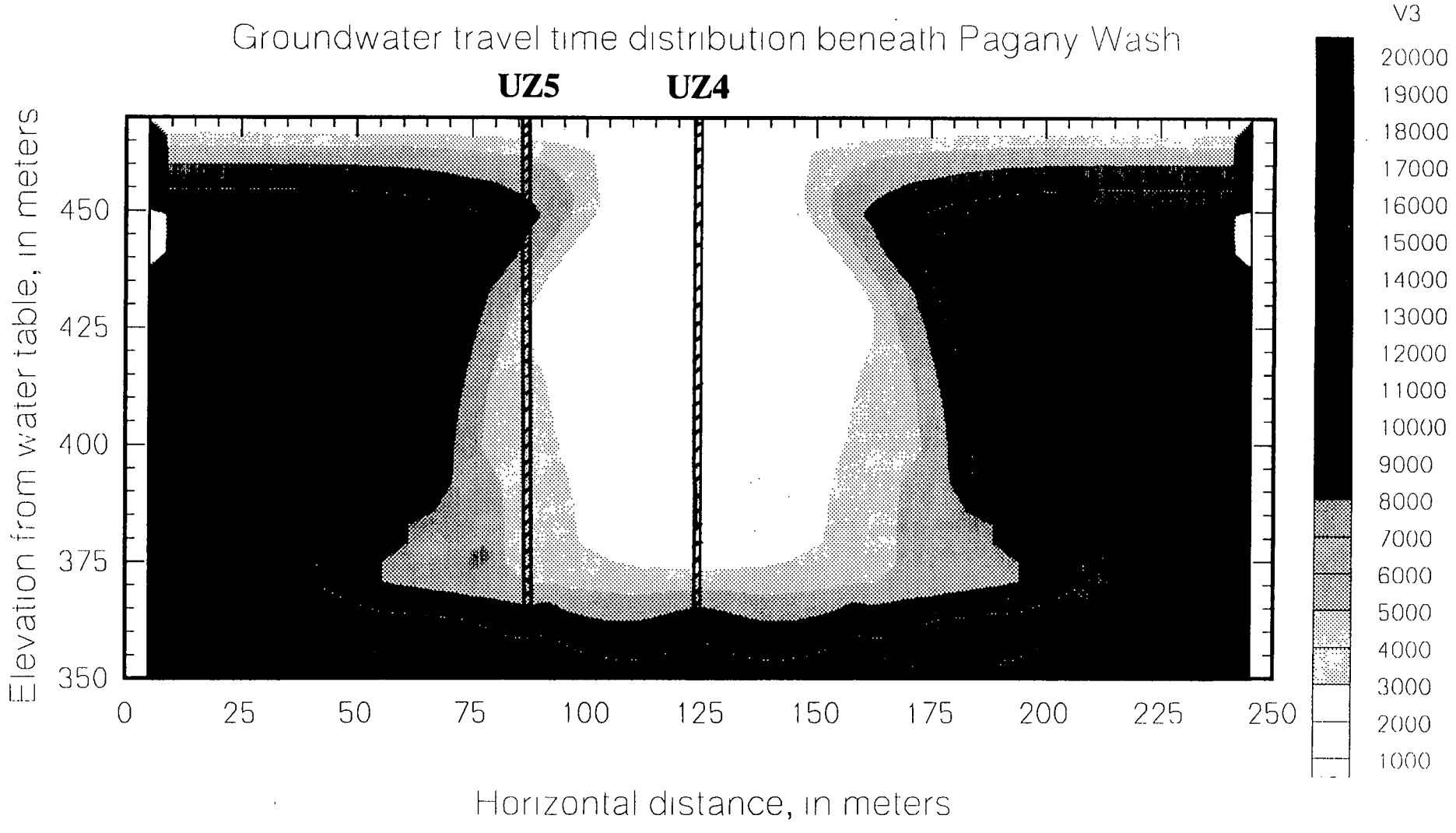
Available Data

- Porosity, saturation and water potential measurements for boreholes UZ#4 and UZ#5.
- ^{3}H and ^{14}C data from UZ4 and UZ5
  - ^{3}H data suggested the occurrence of lateral flow and entry of water along multiple flowpaths.
  - ^{14}C data were obtained from water squeezed from core sampled at approximately 100m depths in both UZ4 and UZ5.
- Matrix properties estimated from statistical correlations between hydrologic variables determined by analysis of SANDIA (1984) data set.
- Fracture property estimates based on a aperture-scale fracture flow model.


PAGANY WASH SIMULATION
q=0.1mm/yr
q=20mm/yr
q=0.1mm/yr
ROCK OUTCROP
CHANNEL
ROCK OUTCROP
120m
10m
120m
UZ5
UZ4
472m
SIMULATION REGION
WATER TABLE
NOT TO SCALE

Steady-state flux vectors and streamlines




Groundwater travel time distribution beneath Pagany Wash
UZ5
UZ4
Elevation from water table, in meters
450
425
400
375
350
0
25
50
75
100
125
150
175
200
225
250
Horizontal distance, in meters
V3
20000
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000

Simulation Results

- Indicate that in spite of evidence that the wash has not been a significant source of recharge over time-scales of a few decades, the wash appears to be a significant source of recharge over millennia-long time scales.
- Capillary barrier effects at the interface between the pores of the nonwelded tuffs and the fractures of the underlying densely welded tuffs, particularly the low-porosity vitric caprock of the Topopah Spring Member, promote lateral flow in the overlying intervals.
  - decreases the flux rates entering the potential repository unit considerably from peak values at the ground surface.
  - significantly delays (perhaps by thousands of years) the entry of surface derived moisture into the potential repository unit.
- Illustrates the processes by which depth-inversion of groundwater ages may be accomplished.

Near-static water potential equilibrium profile in the 20m above the TSw vitric caprock at UZ7 suggests a capillary barrier effect.

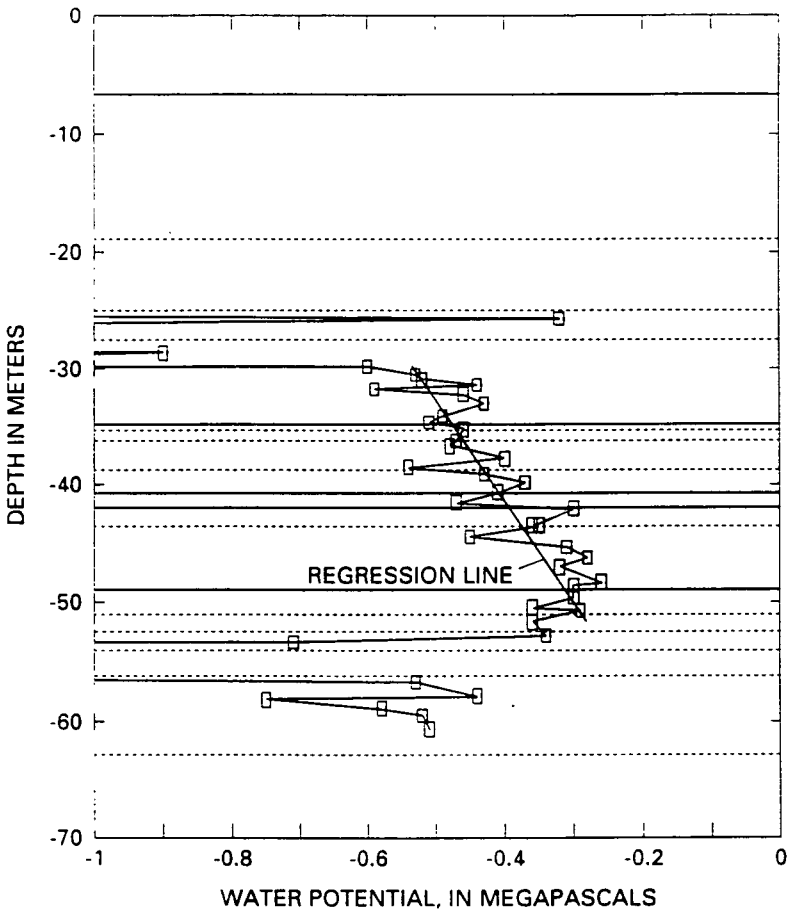


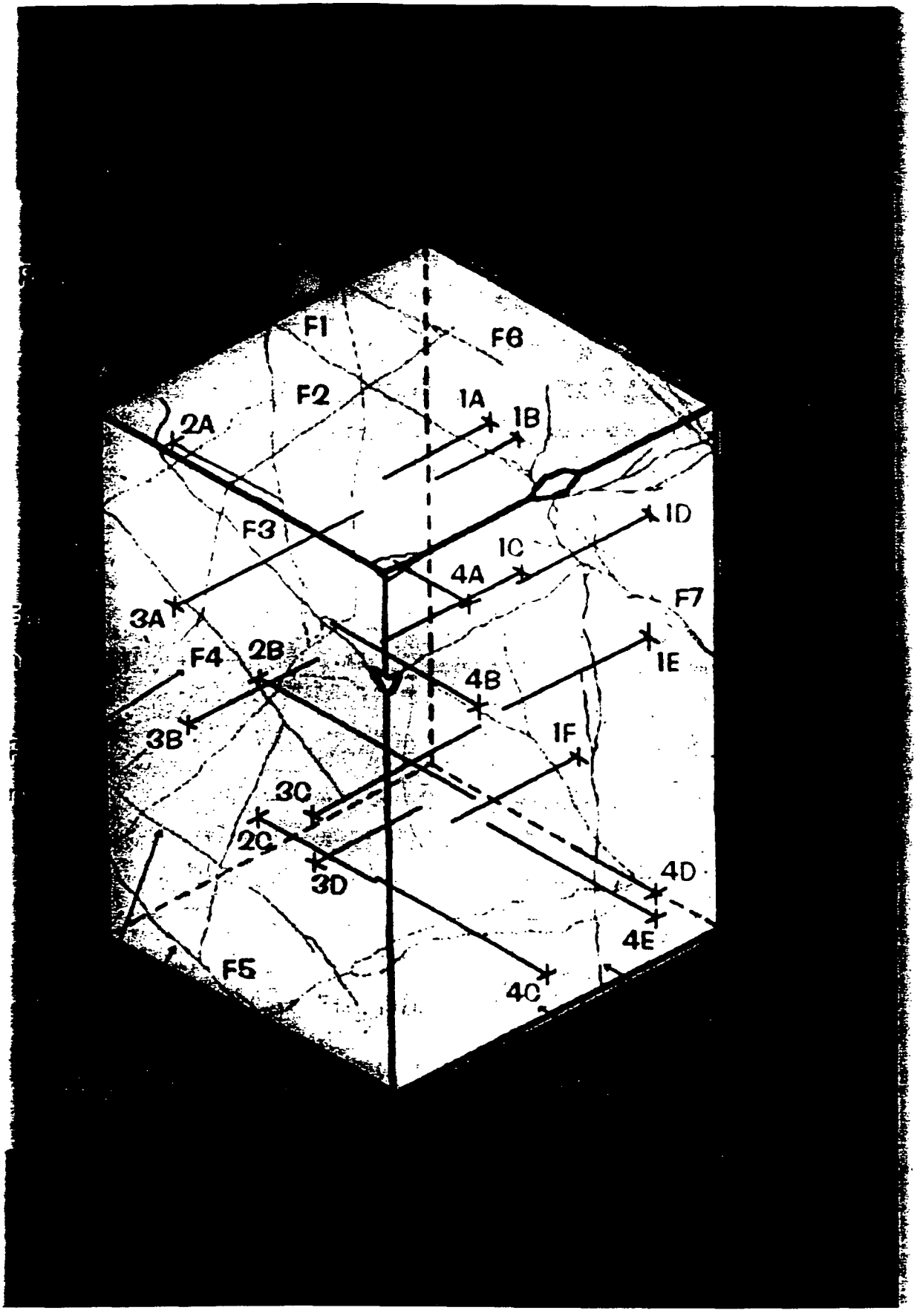
FIG 14 - RW14FIG.AI

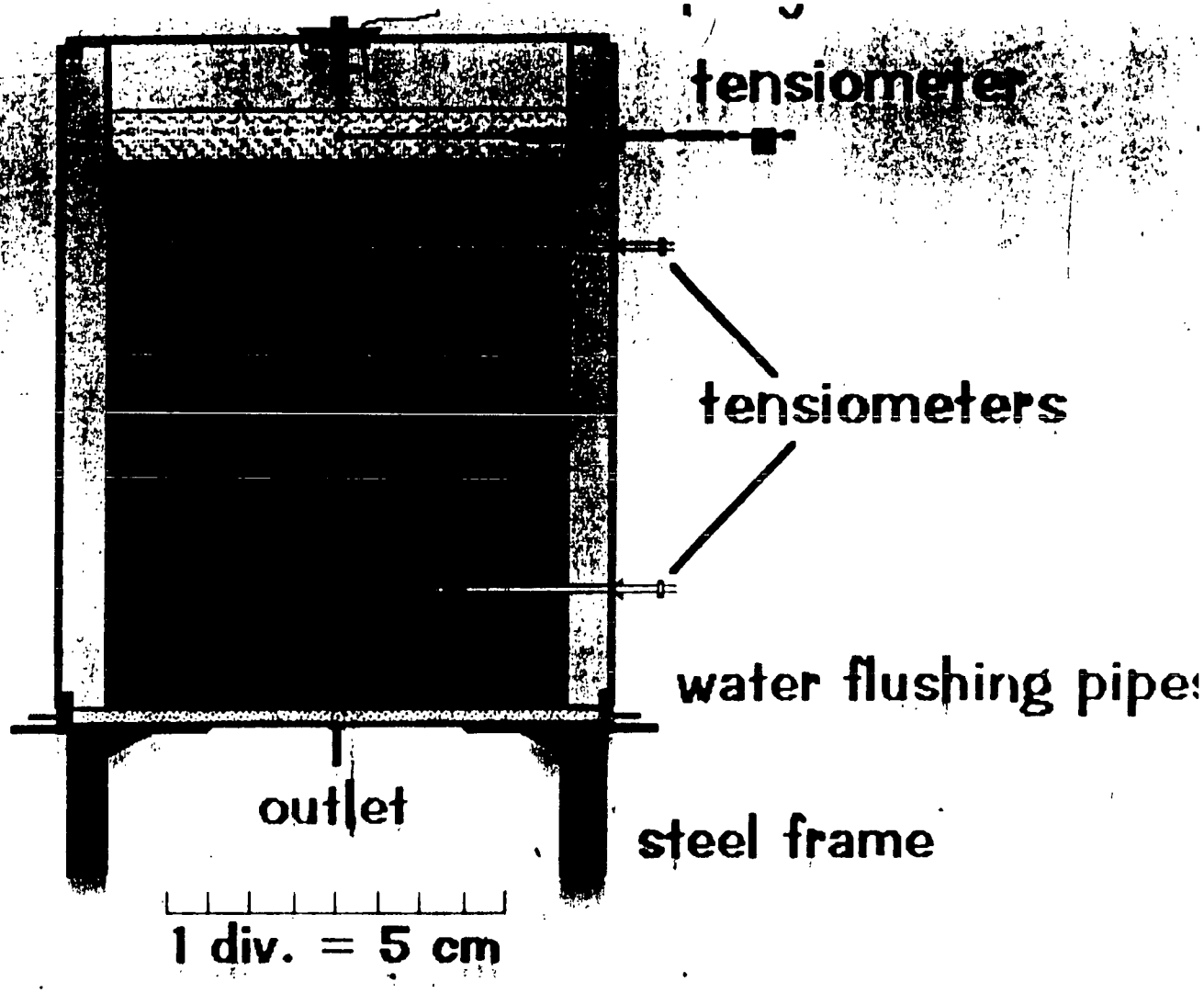
Block Experiment

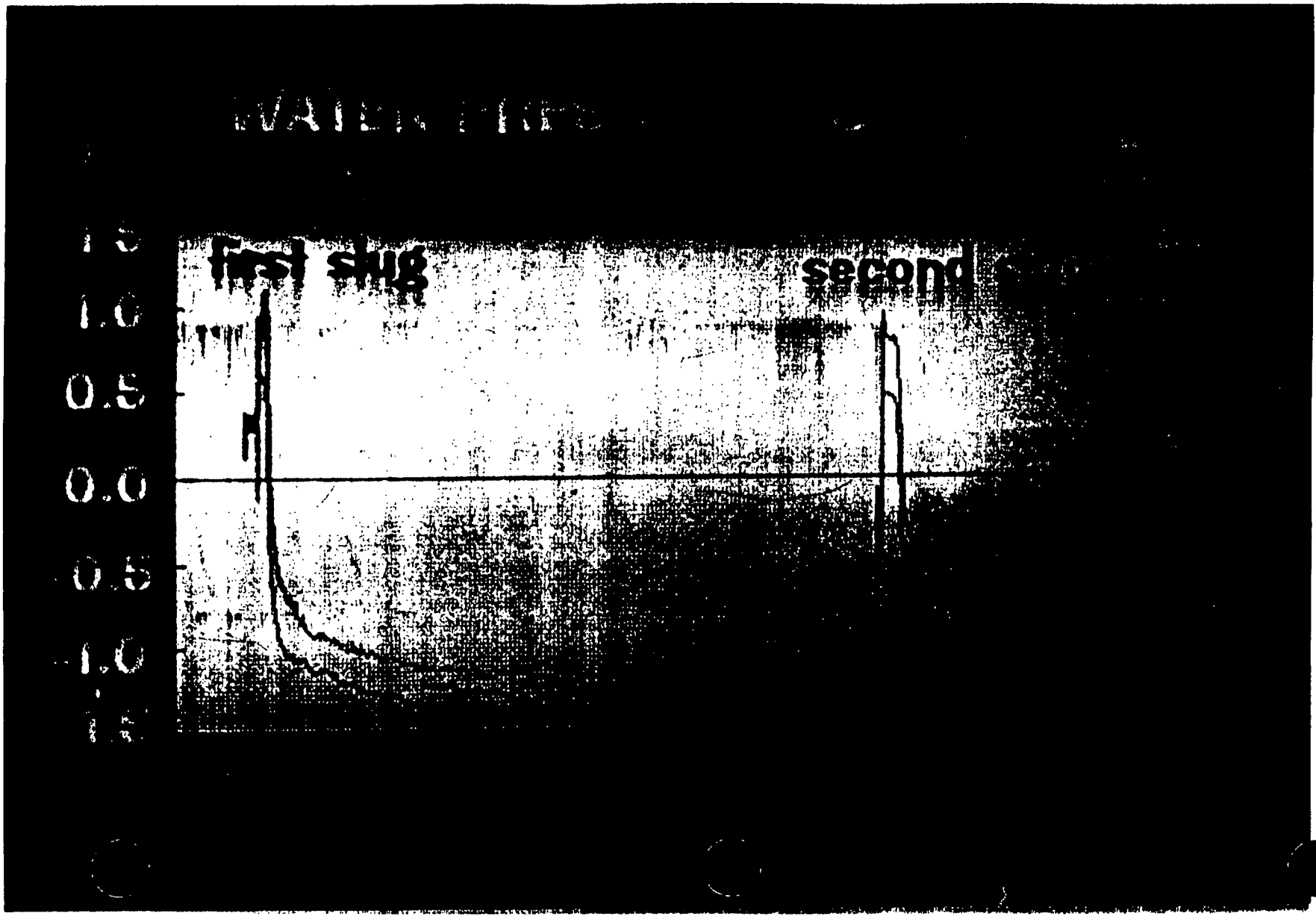
- Need for experimental basis for underlying assumptions in numerical models, particularly, that fractures become nontransmissive at small water tensions.

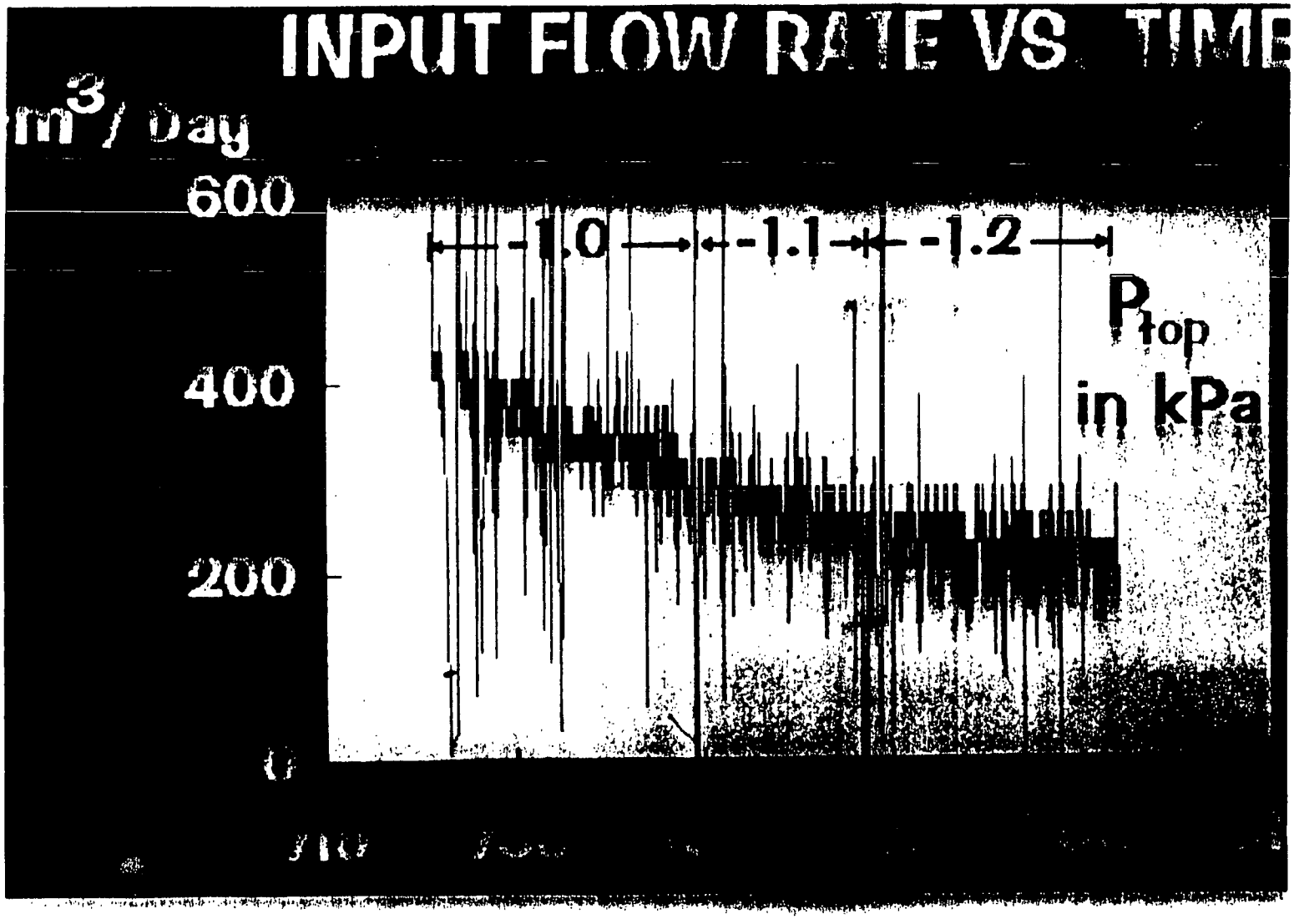
- Provide experimental support for modeling results (for example, that capillary barrier effects between unfractured and underlying fractured formations inhibit the entry of water into the lower interval).

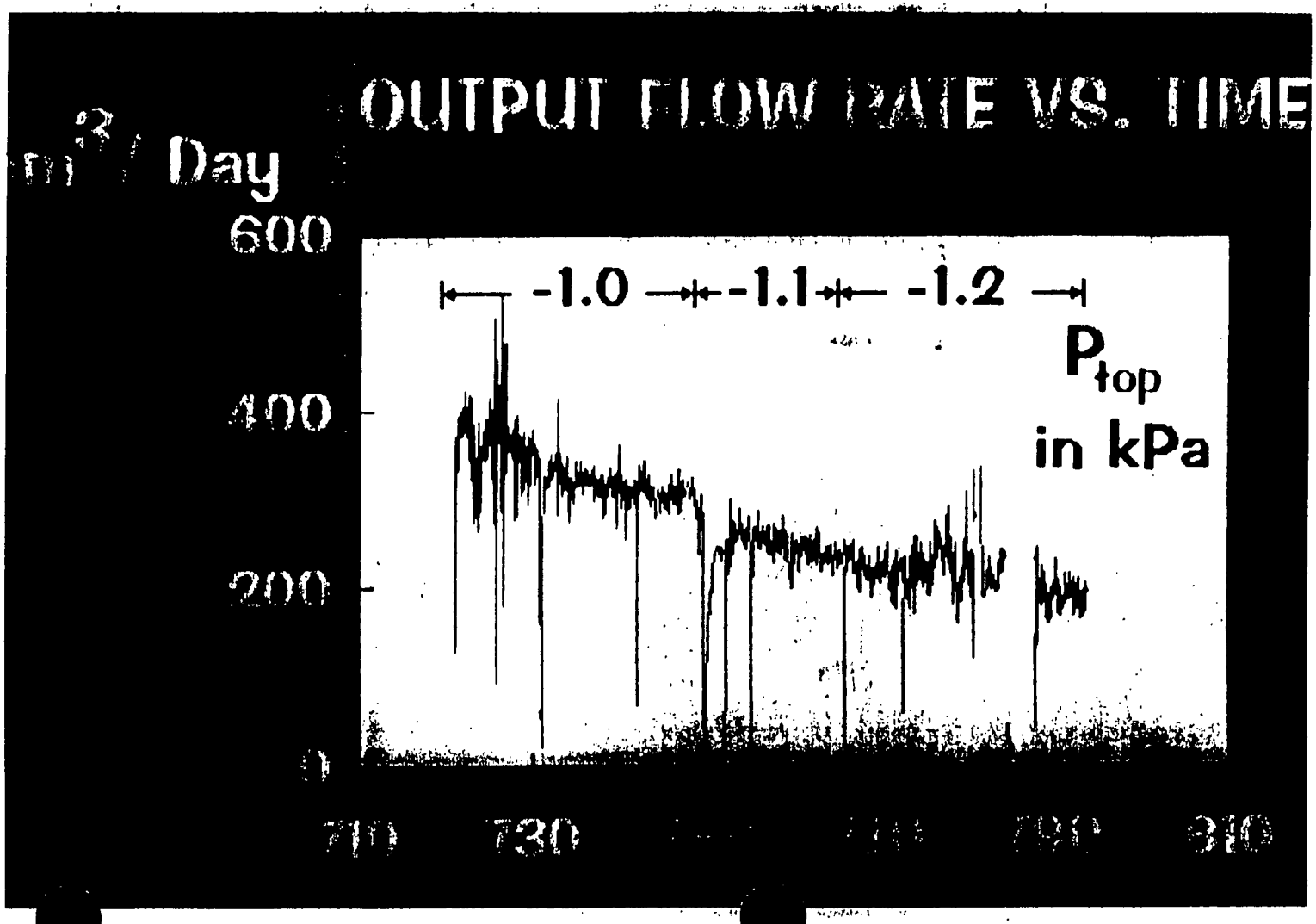
- Allows estimates of water percolation rates made on the basis of pneumatic testing, water potential monitoring and fracture mapping to be compared with applied percolation rates.


F1
F6
F2
1A
1B
2A
F3
1D
1C
4A
F7
3A
F4
2B
1E
4B
3B
1F
3C
2C
3D
4D
4E
F5
4C


tensiometer
tensiometers
water flushing pipes
outlet
steel frame
1 div. = 5 cm


1.0
0.5
0.0
0.5
1.0
second

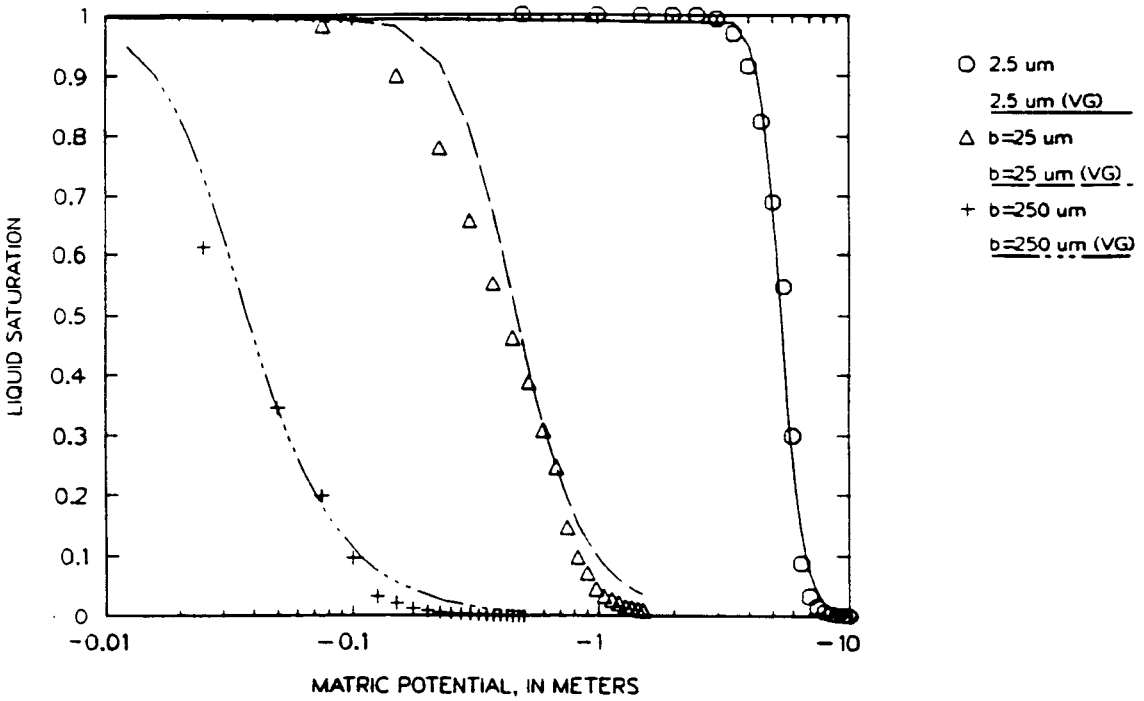

INPUT FLOW RATE VS. TIME
m3/ Day
600
400
200
-1.0
-1.1
-1.2
Ptop
in kPa

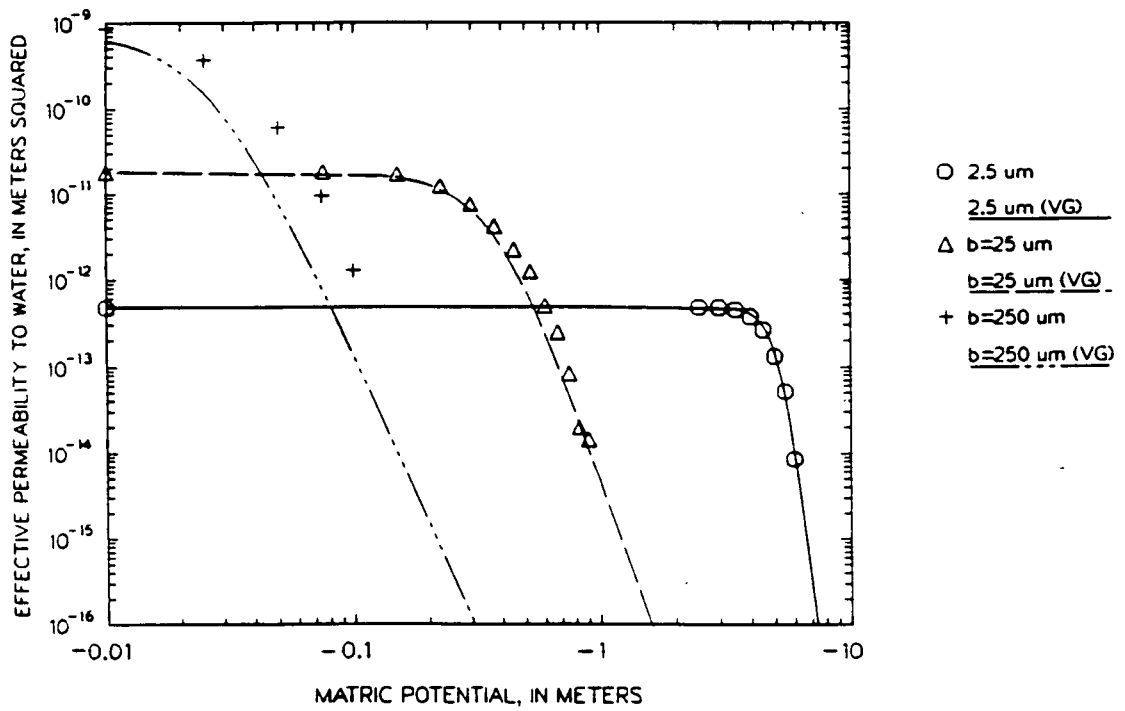

OUTPUT FLOW RATE VS. TIME
Day
600
400
200
-1.0
-1.1
-1.2
P_{top}
in kPa
730

Fracture Properties

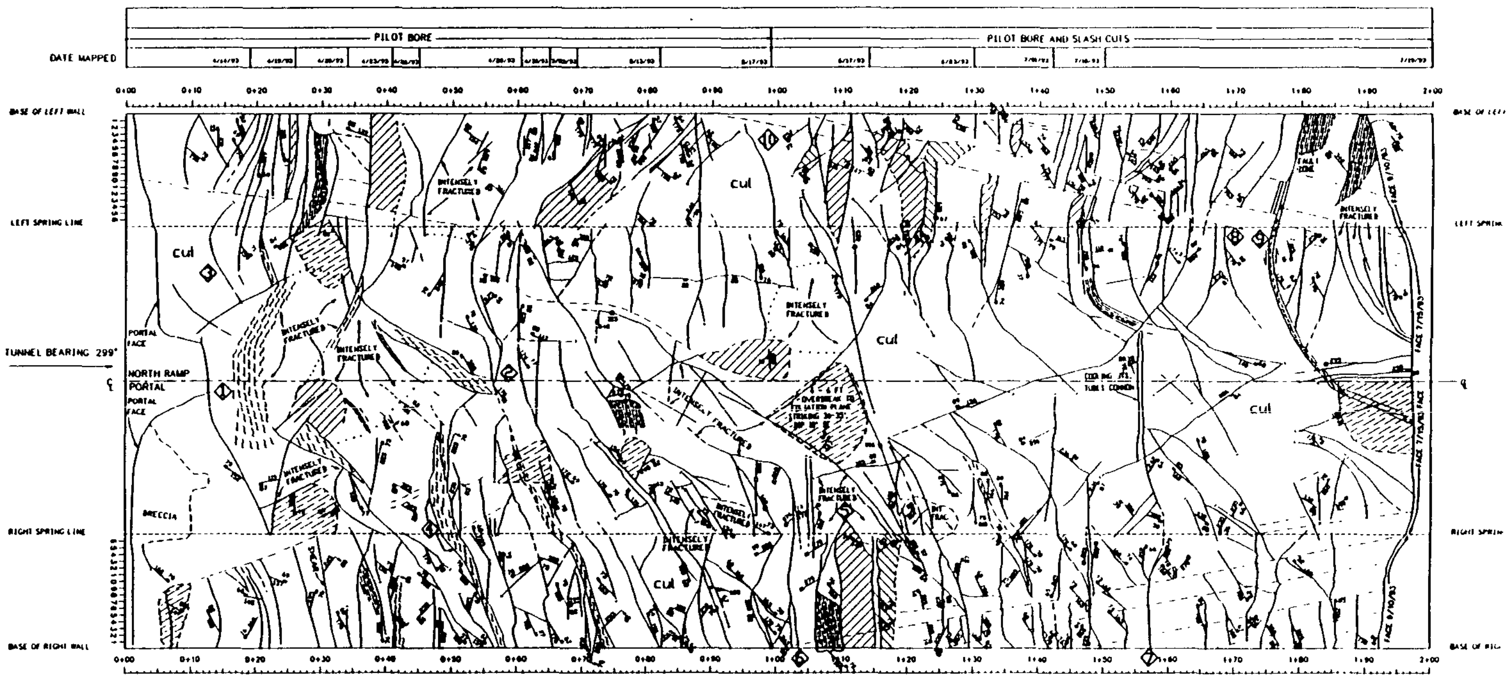
- Assumptions about behavior at the pore-scale can influence model results at the site-scale.
- Capillary theory and application of a pore-scale accessibility criteria form the basis for numerical models which consider aperture variability in thin, rough-walled fractures to calculated moisture retention and unsaturated flow properties.
- A large body of experimental data supporting the use of these models does not exist.
- Fracture mapping of the ESF suggests that conceptual model of fracture flow behavior needs to be expanded to consider wide (noncapillary fractures) fractures, mineralized or otherwise filled fractures, and fractures with obvious controls on flow such as gas tubes ("wormtubes").

Estimated fracture properties





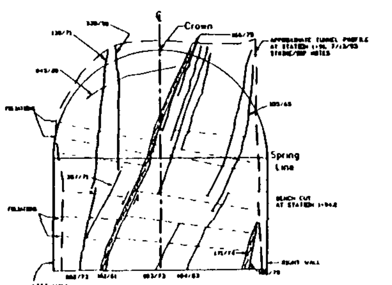
Fracture Map from ESF Starter Tunnel



NOTES

1. Distinct shear zone intersects crown centerline at Sta 0+17 and continues into right wall as intensely fractured zone Fracture surfaces coated with up to 3 cm of opal and calcite
2. Shear zone with breccia, no observed displacement near crown, terminates in possible cooling fracture Sta 0+57
3. Sta 0+05 to 0+20: Lithophysae aspect ratios range from 1:4 (L:H) to 3:1 in upper half of tunnel
4. Cooling fracture with bedded sand infilling, exhibits decorations on fracture surfaces consisting of elongate, anastomosing to subparallel channels extending 5mm into the wall rock The fracture bounds a shear zone striking 235°, dipping 70-83° SW
5. Shear zone with crushed rock and breccia
6. Zone of intensely fractured rock intersecting tunnel at Sta 0+50 in the left wall and Sta 1+15 in the right wall
7. Brownish gray to gray, densely welded, rhyolitic, ash-flow tuff Lithophysae comprise approximately 5-10% of the rock by volume; average diameter 7-20 cm; lithophysae less than 15 cm are typically filled with drusy quartz and opal
8. Foliation more prominent in crown, and combined with high-angle fracture causes fallout resulting in small wedge-shaped casts in the crown
9. Fault with crushed wall rock and sandy infilling Foliation trace is offset approximately 15 ft
10. Lithophysae: oblate to spheroidal; average size 5 cm diameter from Sta 0+92 to Sta 1+00; from Sta 1+00 to 1+05 average size is 20 cm, maximum size is 45 cm

SKETCH OF TUNNEL FACE STATION 1+96



EXPLANATION

STRIKE OF VERTICAL FRACTURE

FRACTURE TRACE WITH SYMBOL SHOWING STRIKE AND DIP; DASHED WHERE APPROXIMATE; CAPPED WHERE TERMINATION OBSERVED UNCAPPED WHERE TERMINATION NOT OBSERVED

STRIKE AND DIP OF FRACTURE, ARROW SHOWING PLUNGE OF FRACTURE DECORATIONS

STRIKE AND DIP OF BEDDING OR FOLIATION

FRACTURE TRACE, ORIENTATION NOT RECORDED (DASHED WHERE INDISTINCT)

FAULT OR SHEAR - SHOWING STRIKE AND DIP, ARROWS INDICATE DISPLACEMENT

SHEAR ZONE, LIMITS SHOWN BY LINES WHERE BOUNDED BY FRACTURES. SHEAR ZONE FILLINGS ARE COMPOSED OF BOTH CLAST- AND MATRIX-SUPPORTED BRECCIAS. WHERE THE ZONES WIDEN TO 30 CM (1 FT) OR MORE, THE BRECCIA IS USUALLY CLAST-SUPPORTED WITH THE MATRIX COMPOSED OF CLAY TO GRAVEL-SIZE MATERIALS, AND CLAST SIZES TO >30CM (1 FT). WHERE THE ZONES ARE LESS THAN 30 CM (1FT) THICK, THE SHEARS ARE TYPICALLY MATRIX-SUPPORTED, WITH SMALL LENTICULAR AND TABULAR CLASTS (<15 CM) IN A MATRIX OF CLAY TO SAND-SIZE MATERIALS. SOME SHEARS DISPLAY THIN FILLINGS OF GOUGE PROBABLY DERIVED FROM THE ADJACENT WALL ROCK. ALL MATERIALS OBSERVED IN THE SHEAR ZONES ARE SIMILAR IN APPEARANCE TO THE WALL ROCK IN COLOR AND COMPOSITION. THE BRECCIAS ARE UNCEMENTED AND FREQUENTLY DISPLAY OPEN VOIDS ALONG THE CLAST BOUNDARIES. THE SHEAR ZONES ARE COMMONLY BOUNDED BY DISTINCT FRACTURE PLANES.

TRACE OF VAPOR PHASE PARTING

LOCATION OF NOTES.

Tcl — UPPER LITHOPHYSAL ZONE OF THE TIVA CANYON MEMBER OF THE PAINTBRUSH TUFF. THE ROCK IS A RHYOLITIC, DENSELY WELDED ASH-FLOW TUFF. THE ROCK IS BROWNISH-GRAY TO GRAY, DEVITRIFIED WITH LIGHT-GRAY FLATTENED PUMICE FRAGMENTS TO 6 CM IN SIZE. LITHOPHYSAE ARE PRESENT THROUGHOUT THE ROCK IN THIS SECTION OF TUNNEL. THE LITHOPHYSAE VARY IN SIZE AND PERCENT VOLUME OF THE ROCK MASS, HAVING BOTH THE HIGHEST PERCENT VOLUME AND LARGEST SIZE NEAR THE PORTAL IN THE UPPER HALF OF THE TUNNEL.

FRACTURE FACES: OCCURS WHERE TUNNEL WALL HAS BROKEN TO A FRACTURE SURFACE OVER A LARGE AREA (GREATER THAN 1 SQUARE METER). WHERE FACES ABJOIN, HATCHING IS REVERSED. LIMITS DASHED WHERE APPROXIMATE.

CLOSELY SPACED FRACTURES SHOWING APPROXIMATE TRACES WHERE NUMEROUS FRACTURES HAVE SIMILAR ORIENTATIONS

FALLOUT OR OVERBREAK BOUNDARY, DASHED WHERE APPROXIMATE

APPROXIMATE LIMITS OF INTENSELY FRACTURED ZONE

DEFINITIONS

INTENSELY FRACTURED - CEMENTED OR UNCEMENTED, PREDOMINATELY ANGULAR (MAY BE PLATY) ROCK FRAGMENTS CREATED BY MULTI-INTERSECTING FRACTURES. APPROXIMATE LIMITS OF INTENSELY FRACTURED AREAS ARE INDICATED BY DOTTED LINES AND/OR FRACTURE TRACES

FOLIATION - 0.5 TO 15 CM THICK, PLANAR STRUCTURES THAT RESULT FROM FLATTENING OF CONCENTRATIONS OF PUMICE FRAGMENTS

BRECCIA - AT THIS LOCATION ONLY - A CLAST-SUPPORTED BRECCIA, WITH SLIGHT CEMENTATION. MATRIX IS A PRIMARILY SAND SIZE, NOT ASSOCIATED WITH A DISTINCT SHEAR

6/6/94 D-3610	MINOR REVISIONS TO EXPLANATION AND LOCATED NOTE #2

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
FOR
DEPARTMENT OF ENERGY

YUCCA MOUNTAIN PROJEC
STARTER TUNNEL-EXPLORATORY STUDIES FAC
FULL-PERIPHERY GEOLOGY M

GEOLOGY — USBR Mapping Team — PRINCIPAL INVESTIGATOR — J. Beason
DRAWN — D. L. Jardine — T.P.O. — J. Kyle
CHECKED — C. Sullivan — ADMIN. APPROVED — R. Thomas, CHIEF GEOLOGY BR.

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DENVER COLORADO	JANUARY 21, 1994	0A-46

Calcite-Silica Study

- Frequently, only a small percentage of fractures in drill core wll contain calcite, implying that flow pathways may occupy only a small percentage of a fracture network.
- Fracture flow has been episodic but repetative. Dissolution surfaces on fracture coatings may represent periods of greatest recharge, when waters are undersaturated with respect to calcite.
- The observation that calcite rarely occurs in fractures within the PTn suggests flow has occurred primarily through the matrix in that unit.
- ^{14}C ages of 14 samples from the unsaturated zone yielded 3 values greater than 51ky, 1 value as young as 20.9ky, and 10 values between 33.4-45.3ky, indicating calcite formation as recently as the last glacial period.

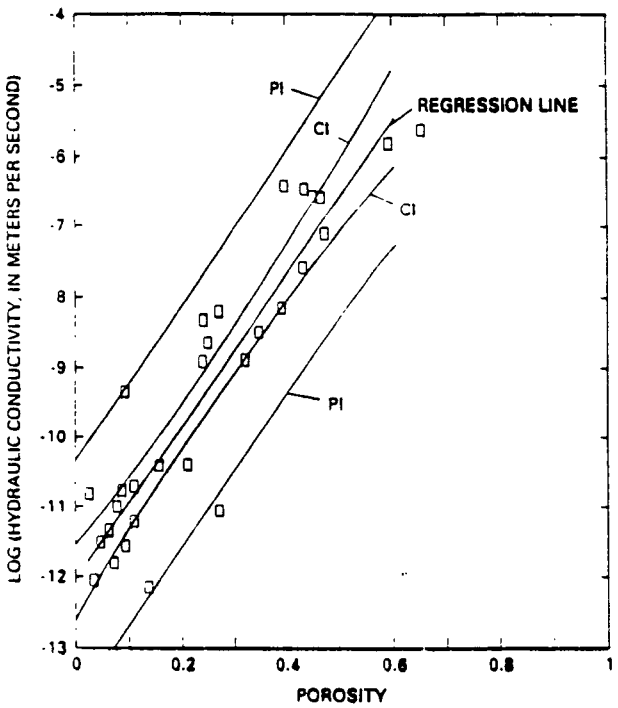
Matrix Properties

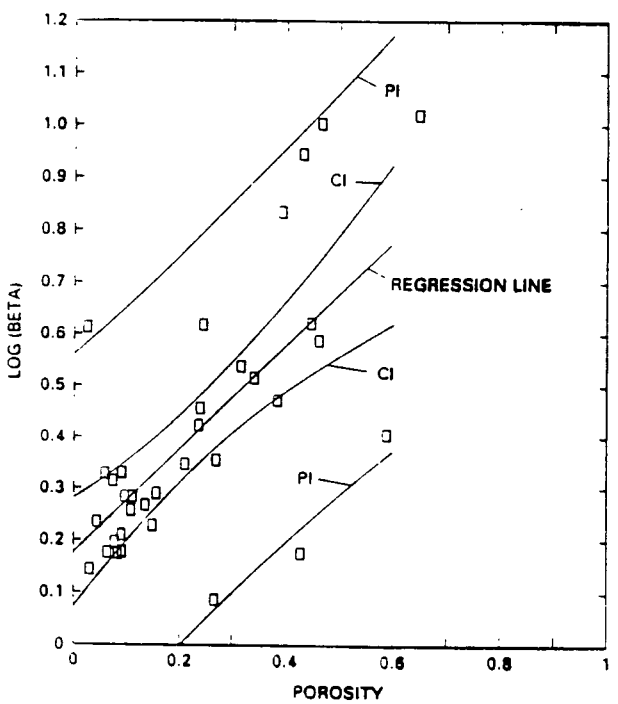
- Properties measured or assumed at the pore scale affect model results and their interpretation.

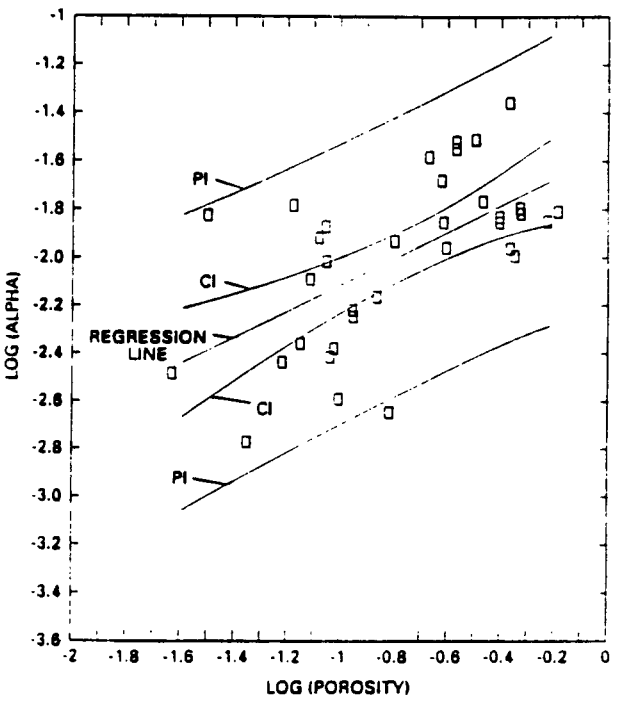
- A large data set for porosity, saturated hydraulic conductivity, and moisture retention characteristics is emerging both from drilling and sampling along horizontal and vertical transects.

- Analysis of older data sets allowed identification of significant correlations between hydrologic varables important in constraining parameter space in stochastic models.

- Hydrologic data collected by procedures that reflect field conditions remain scarce, particularly concerning hysteretic behavior.

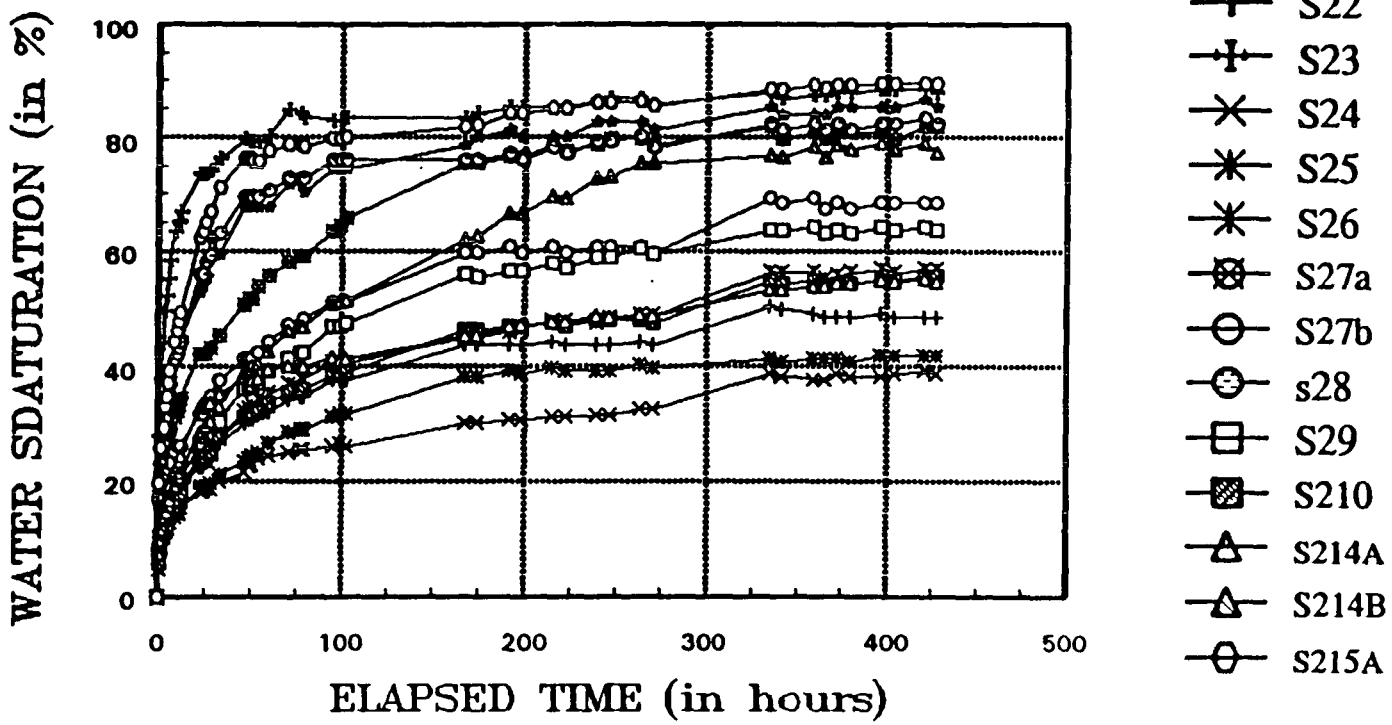

LOG (HYDRAULIC CONDUCTIVITY, IN METERS PER SECOND)
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
0
0.2
0.4
0.6
0.8
1
POROSITY
PI
CI
REGRESSION LINE
CI
PI


LOG (BETA)
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
POROSITY
PI
CI
REGRESSION LINE
CI
PI

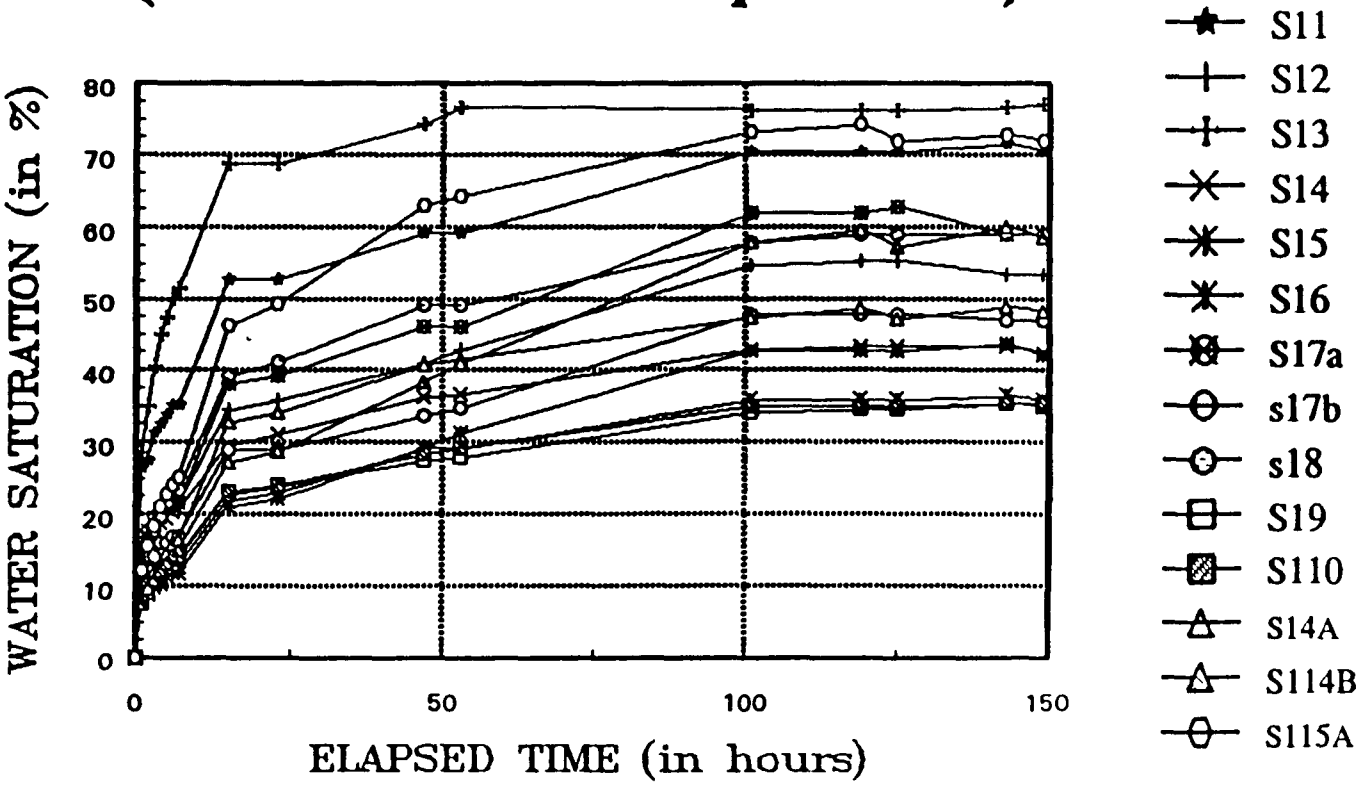

LOG (ALPHA)
-1
-1.2
-1.4
-1.6
-1.8
-2.0
-2.2
-2.4
-2.6
-2.8
-3.0
-3.2
-3.4
-3.6
-2
-1.8
-1.6
-1.4
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
LOG (POROSITY)
PI
CI
REGRESSION LINE
CI
PI

IMBIBITION THROUGH THE BASE

(2nd series of experiments)



IMBIBITION THROUGH THE BASE
(First series of the experiments)



UZ16 Air Permeability, Fracture and Isotope Data

- UZ16 unique in that permeability, fracture and several different types of isotope data exist.

  - ^{36}Cl and ^{14}C data are in apparent conflict.

- UZ16 is in the process of being instrumented for VSP imaging of nearby fault structures, which may help resolve some remaining uncertainties.

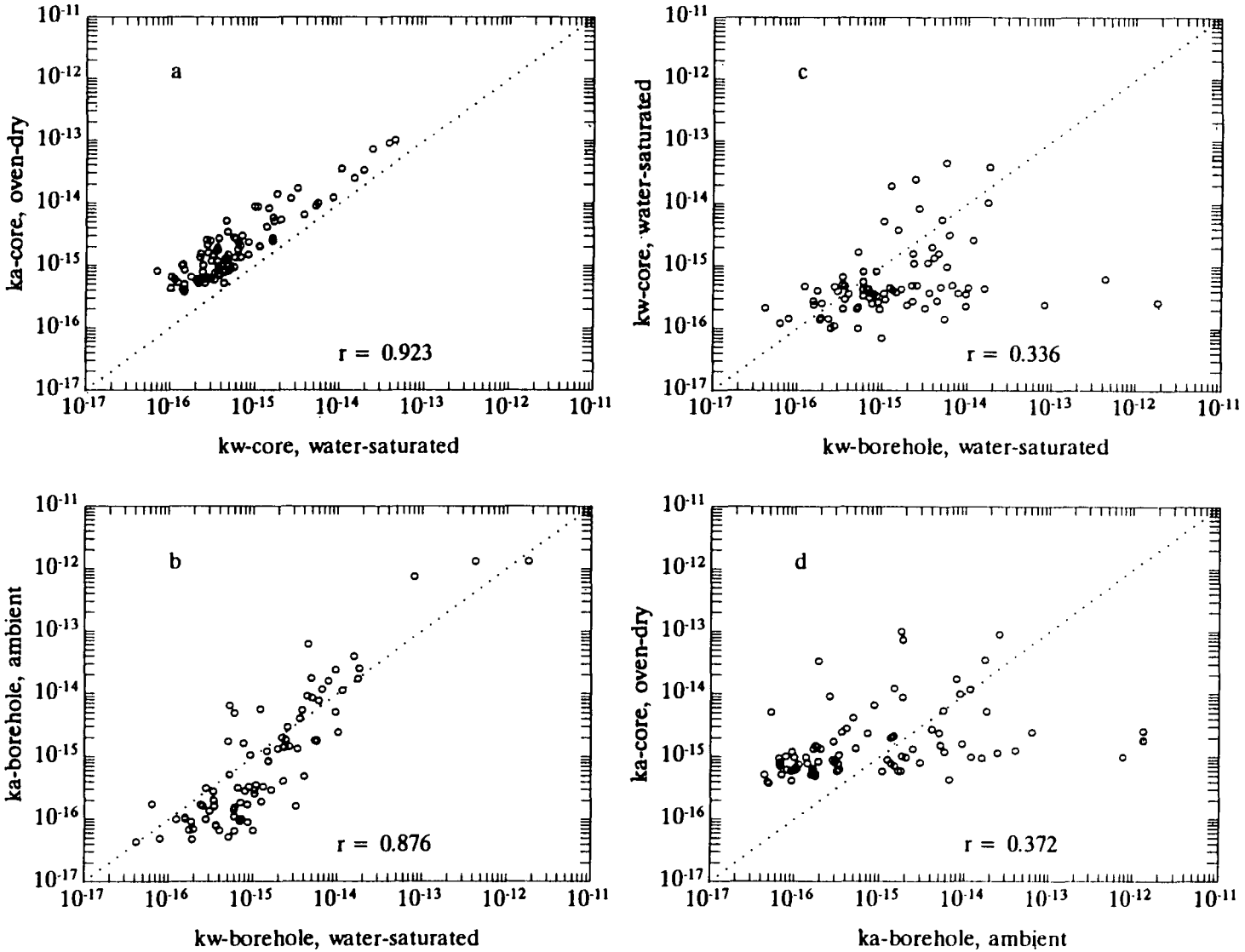
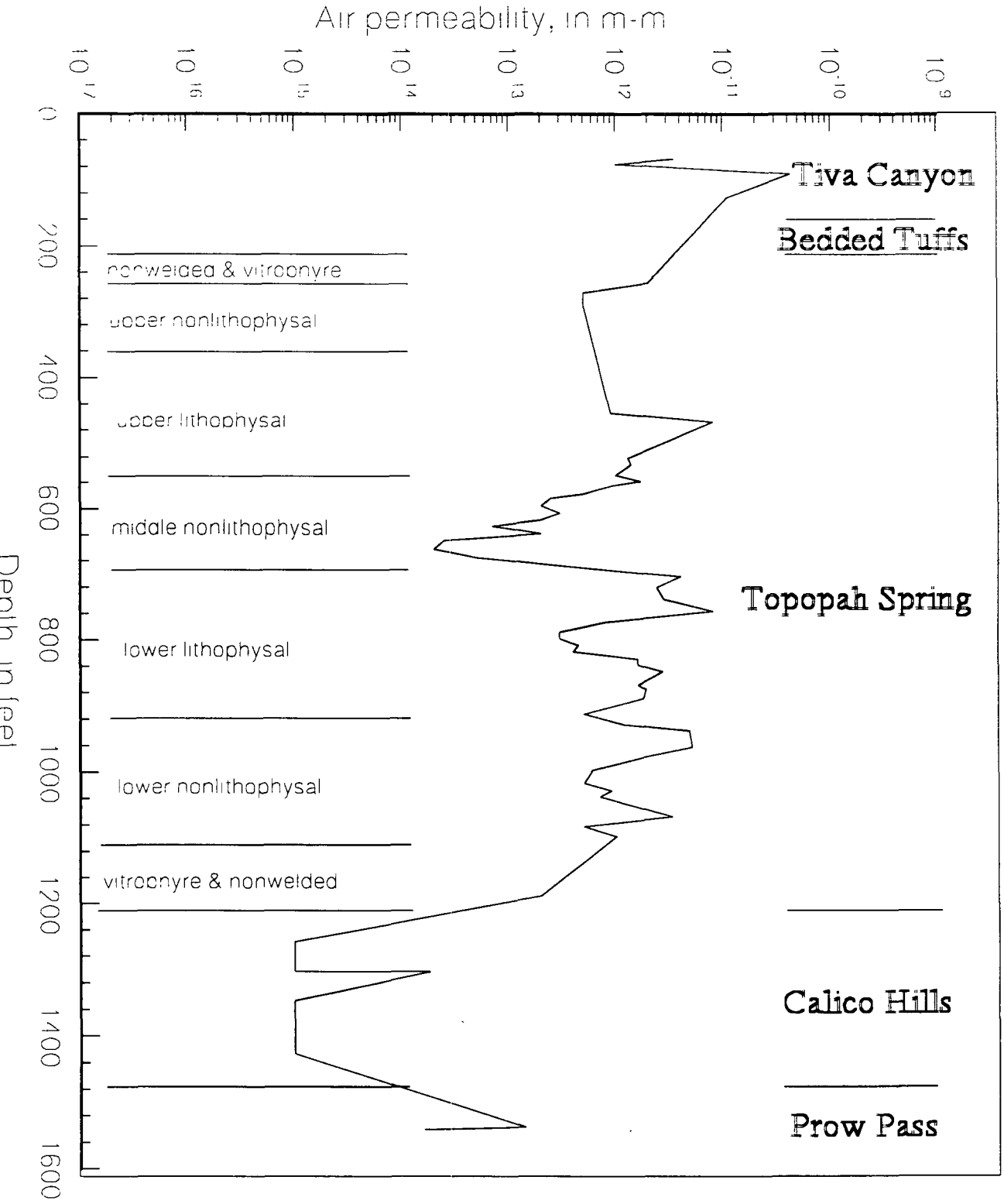
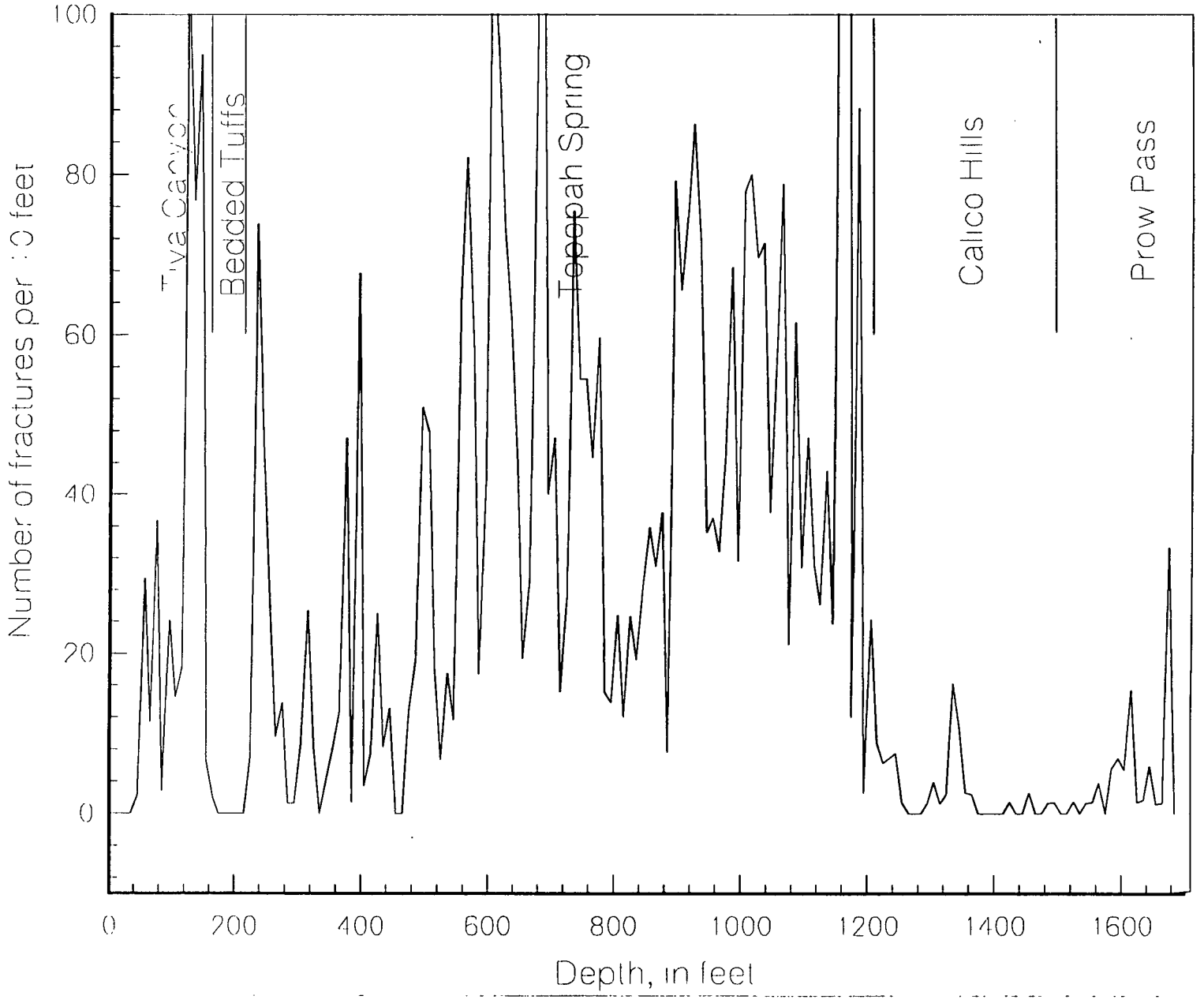
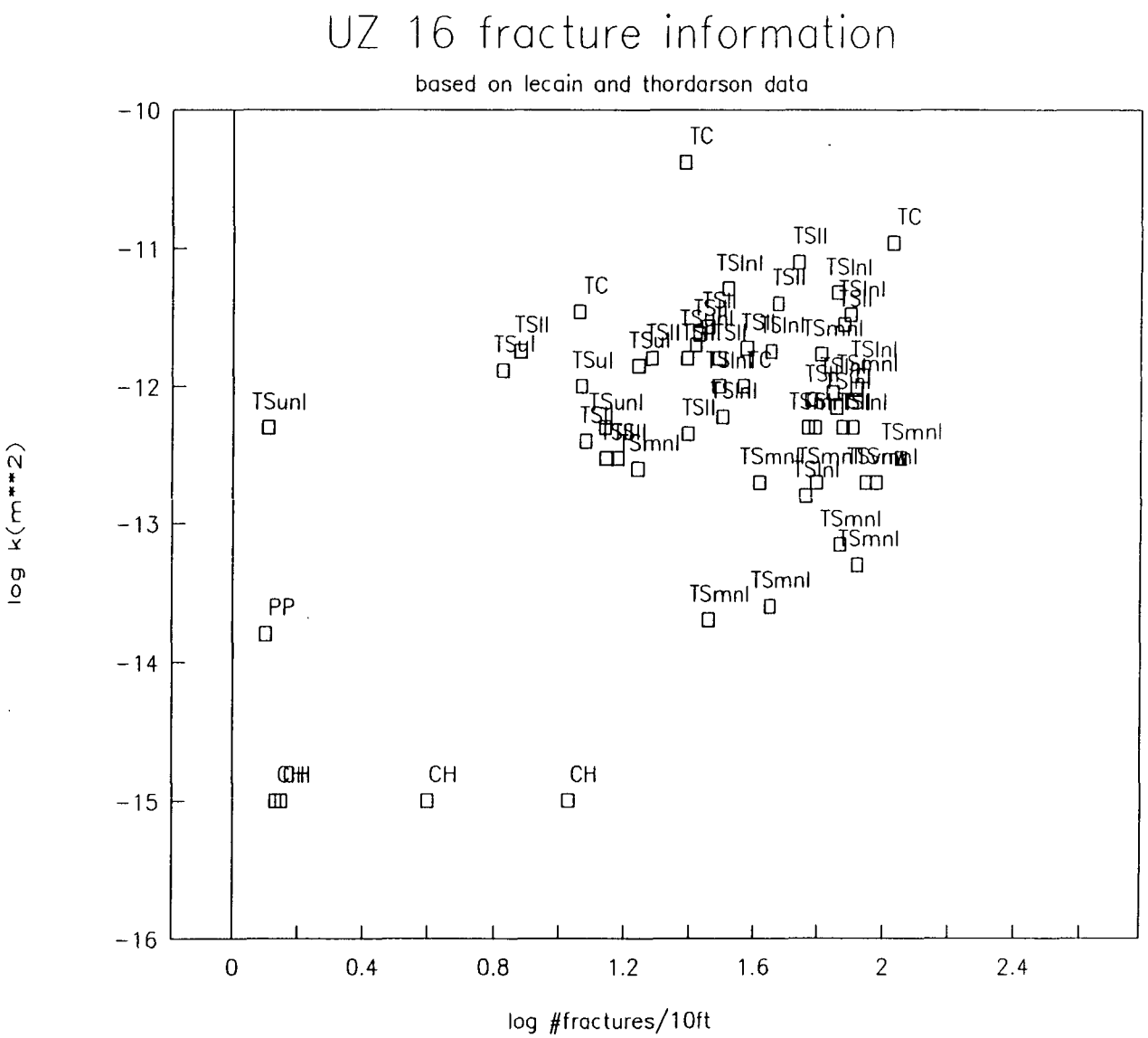


Fig. 5. Permeability scatterdiagrams including simple correlation coefficients and lines of equal permeabilities for the core and borehole data.




Number of fractures per 10 feet
100
80
60
40
20
0
Tiva Canyon
Bedded Tuffs
Topopah Spring
Calico Hills
Prow Pass
0
200
400
600
800
1000
1200
1400
1600
Depth, in feet



Scatterplot of permeability versus fracture frequency

UZ16 LILF

Summary of UZ16 Studies

- Permeabilities determined from air-injection tests in the Topopah Spring Member appear vary over a very limited range over depth intervals of many hundreds of feet, suggesting porous media type behavior, at least for air flow.
- The intermittent appearance of ^{3}H throughout the Topopah Spring Member suggests that only a few of the many fractures are conducting water (understandable, given the permeability.)
- The effective permeabilities determined for the Calico Hills suggest that matrix permeability is locally augmented by fracture contributions.
- The apparent discrepancy between the ^{36}Cl and ^{14} data may be resolved by considering the relative stratigraphic positions and fracture densities in their respective sampling locations, and the relative liklihood of sampling fast paths in structured (fractured) and unstructured (unfractured) media.

Isotopic Evidence for Deep, Transient Fracture Flow (below PTn)

- Bomb pulse ^{3}H (20+ tritium units) occur sporadically throughout the densely welded Topopah Spring Member at UZ16.

- Nine ^{14}C age dates of 1000 to 5000 years for pore water in the Calico Hills at UZ16 between depths of 1200 to 1500 feet. (Water with a ^{14}C concentration 97% modern was associated with a water sample having 44 tritium units).

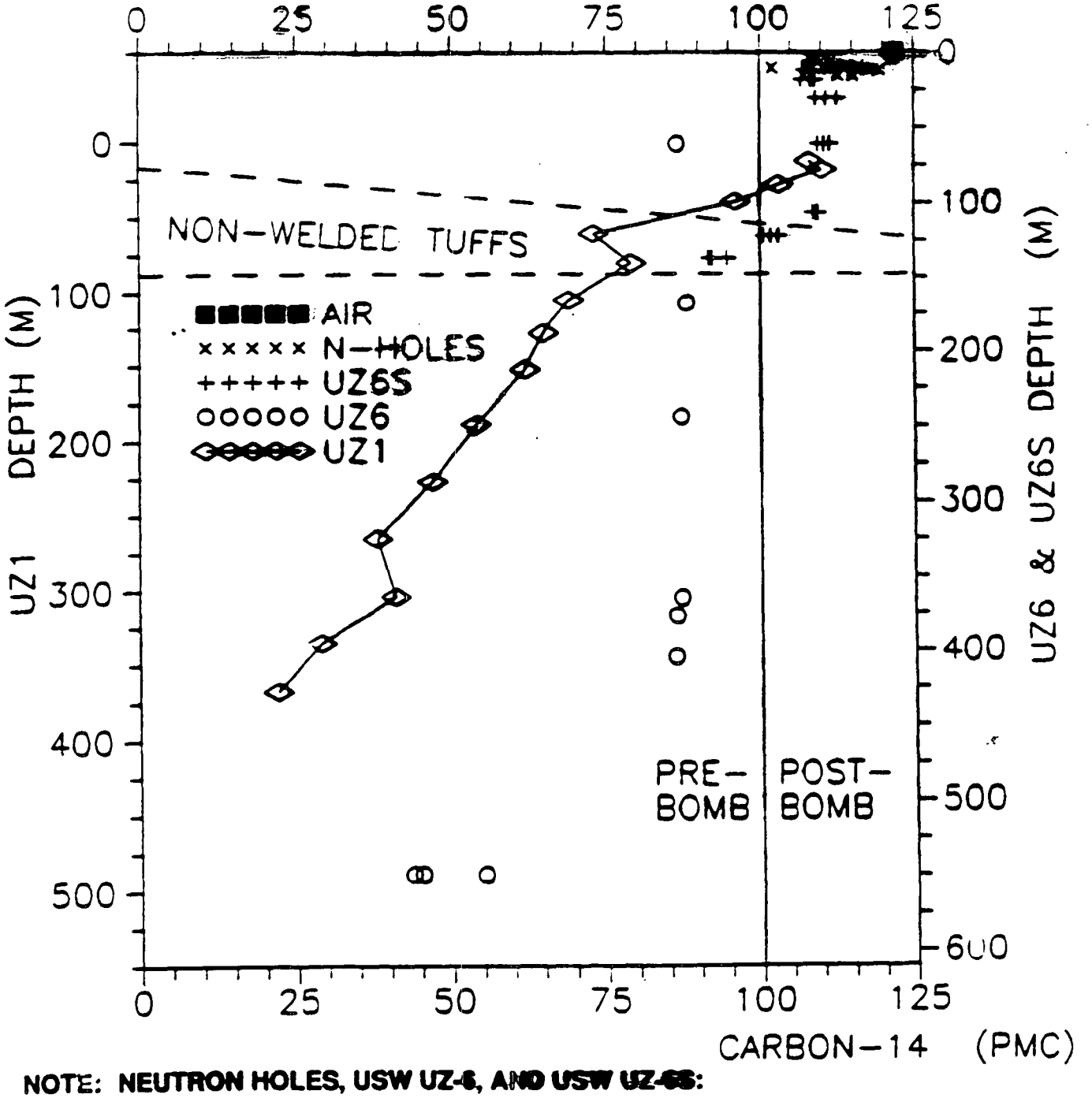
- ^{14}C age date of 3500 years for a water sample from the perched water encountered at NRG-7 within the Calico Hills at approximately 1500 feet.

- ^{36}Cl values from the saturated zone at UZ14 give $^{36}Cl/Cl$ ratios of $675+\-\ 12 \times 10^{-15}$, indicating possible bomb pulse contributions.

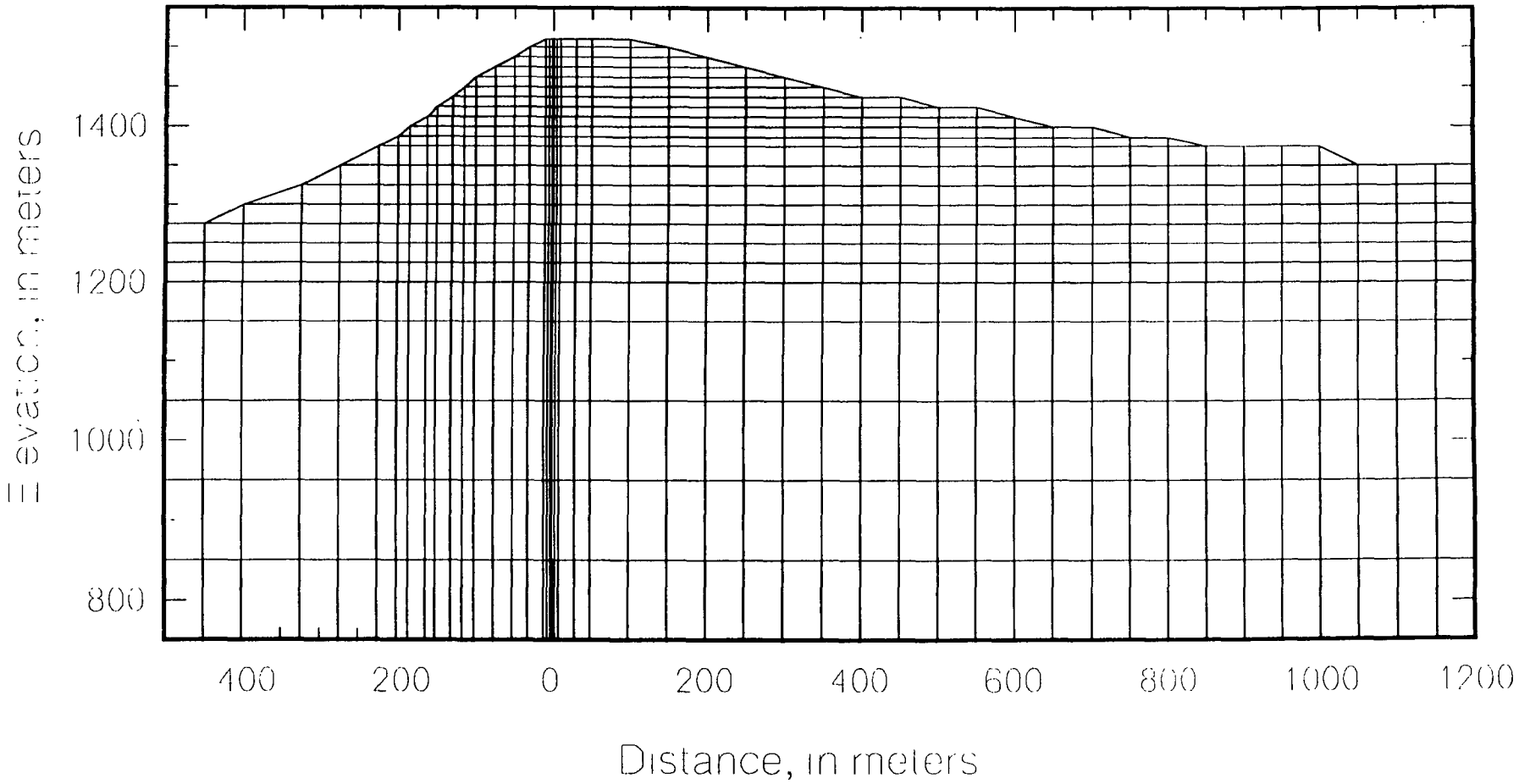
Summary of Gas Isotope Data

- All gas samples at depths <100m at Yucca Crest (UZ6s, neutron holes) have ^{14}C activities >100 percent modern, suggesting that the shallow flow system within the Tiva Canyon Member operates on time scales of decades or less.
- Fractured tuffs of the Topopah Spring Member at UZ1 and UZ6 show pre-bomb activities of ^{14}C.
- ^{14}C data at UZ1 appears to be consistent with a simple diffusion model whose estimated parameters appear to be reasonable for geologic media.
- Estimates of the size of the CO_2 reservoir necessary to contribute to the outflow of CO_2 indicate that flow from the east side of Yucca Mountain is a major source. (Also consistent with estimates based on methane consumption rates).
- An averaged downward advective velocity of v=50 m/yr is necessary to capture soil CO_2 along the east slope at rates observed from UZ6s.

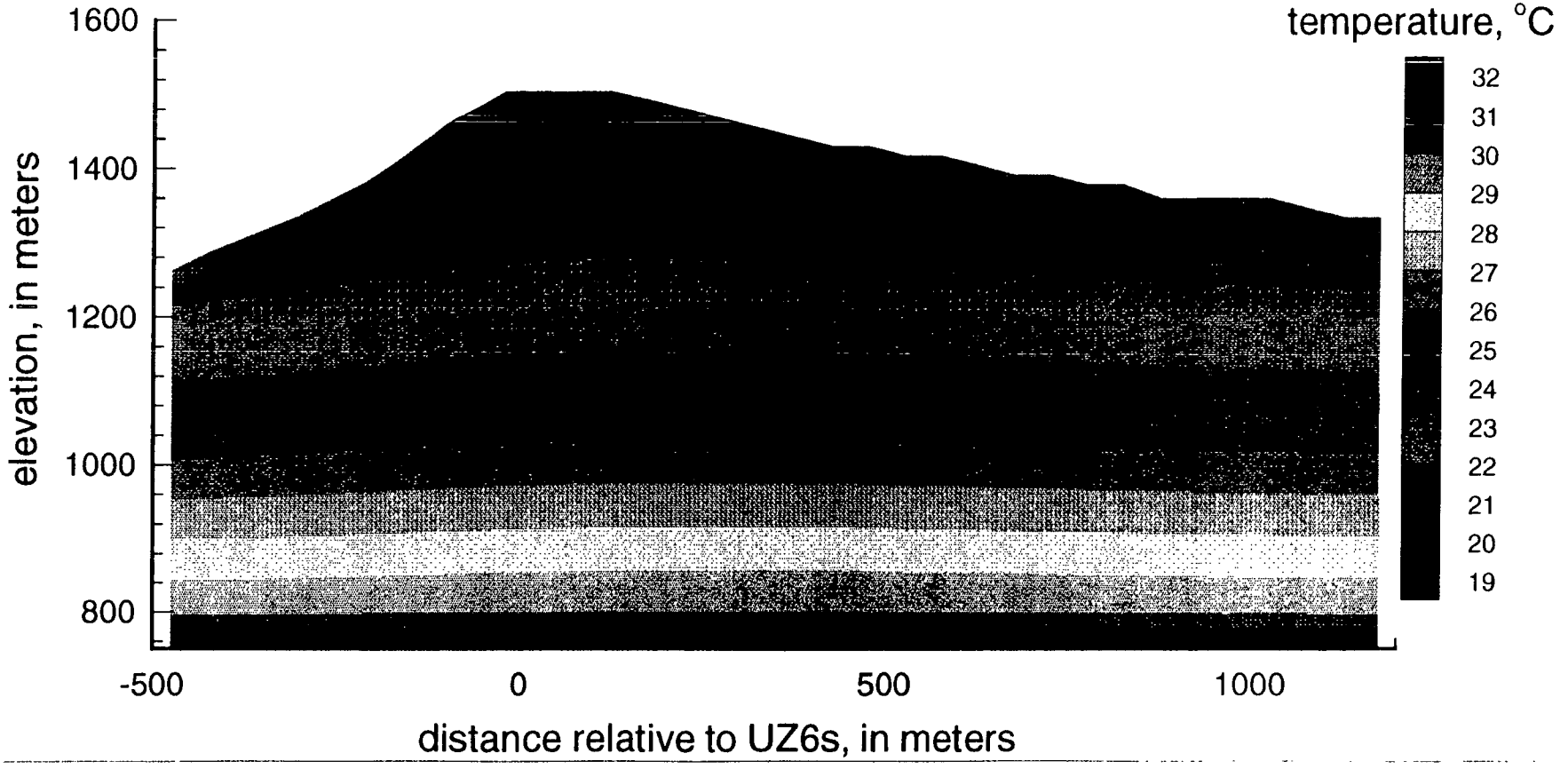
CARBON-14 vs DEPTH



NOTE: NEUTRON HOLES, USW UZ-6, AND USW UZ-6S: ALL DATA THROUGH SPRING, 1988; USW UZ-1: 1990 DATA (PETERS AND OTHERS, IN PRESS).

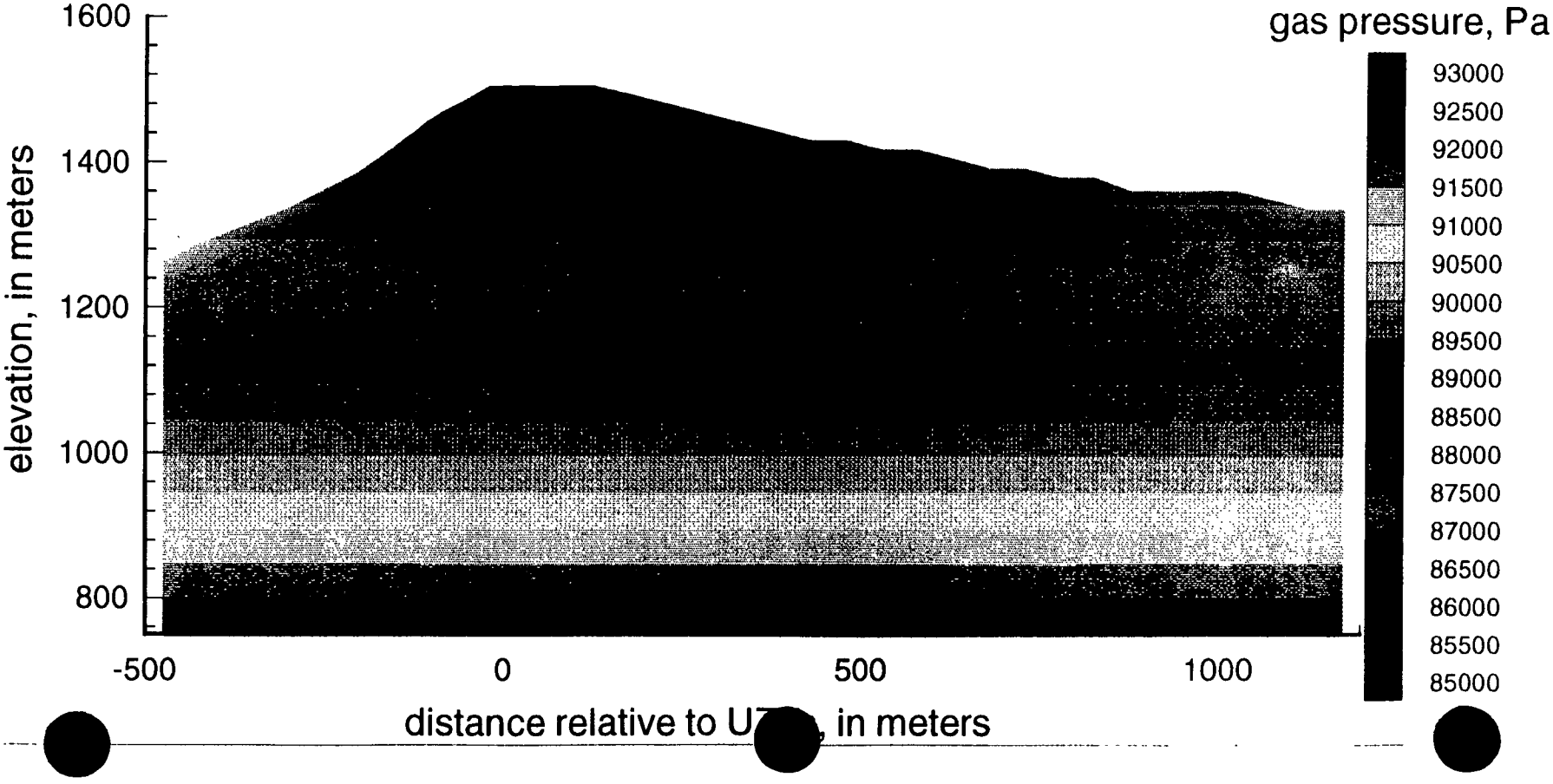

Elevation, in meters
1400
1200
1000
800
400
200
0
200
400
600
800
1000
1200
Distance, in meters

Temperature contours for average annual temperature conditions
uniformly fractured rock



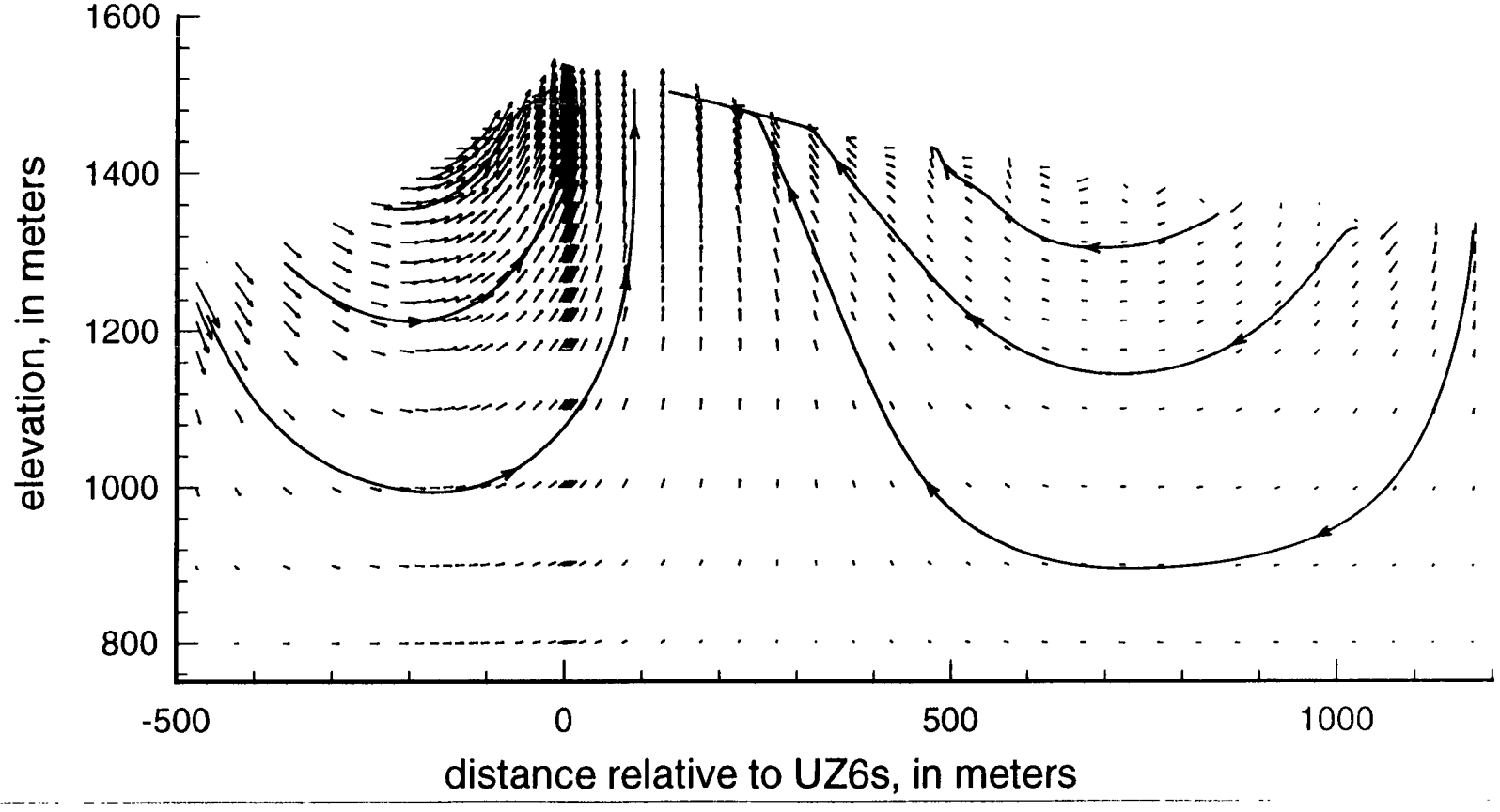
(2D) II Print II 12 Sep 1994 II anntmpa.dat II

Gas pressure contours for average annual temperature conditions
uniformly fractured rock



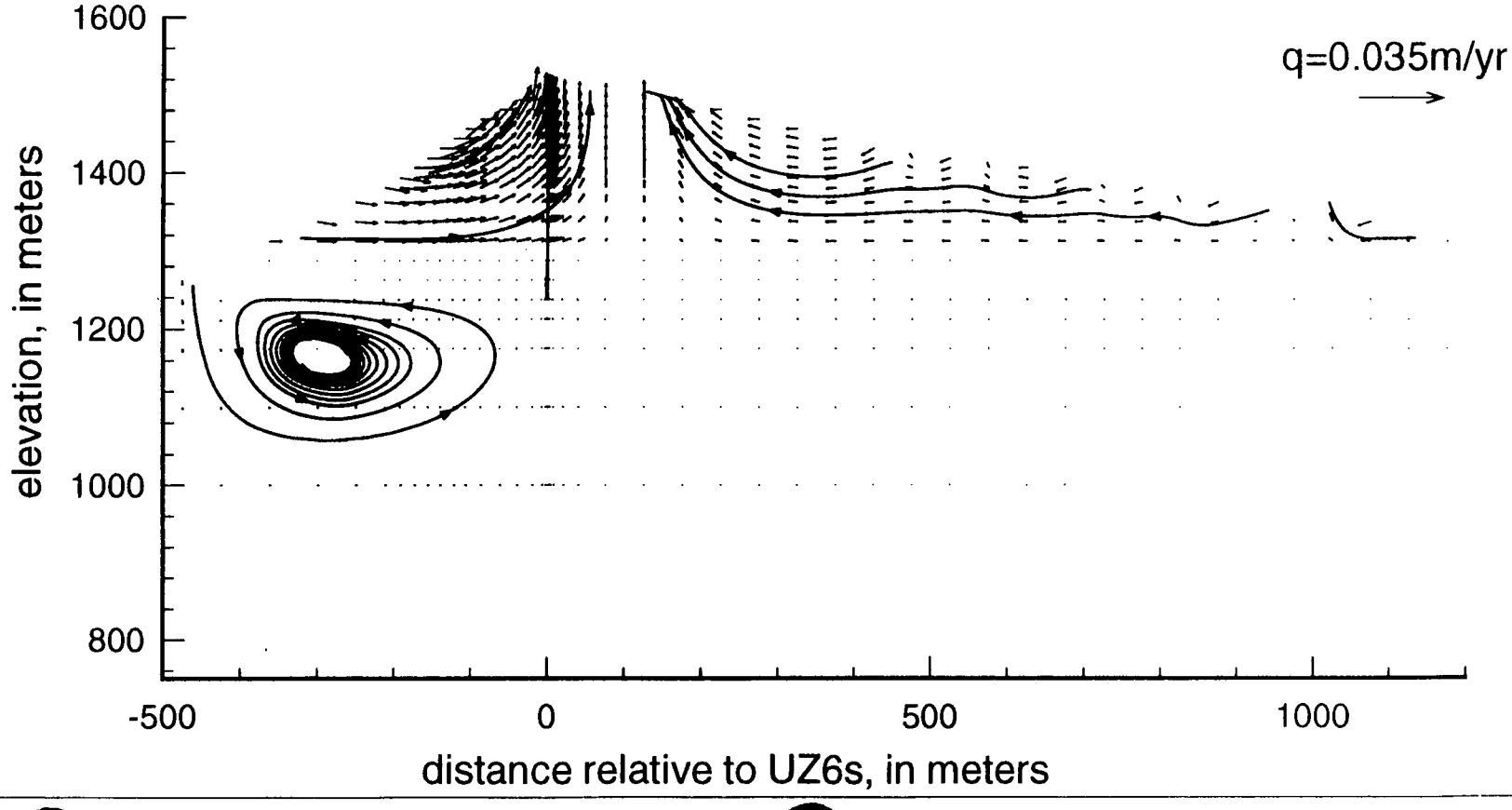
Streamlines and gas flux vectors for average annual temperature conditions

Uniformly fractured rock



Streamlines and gas flux vectors for average annual temperature conditions

nonwelded units included but assumed to have no fracture permeability



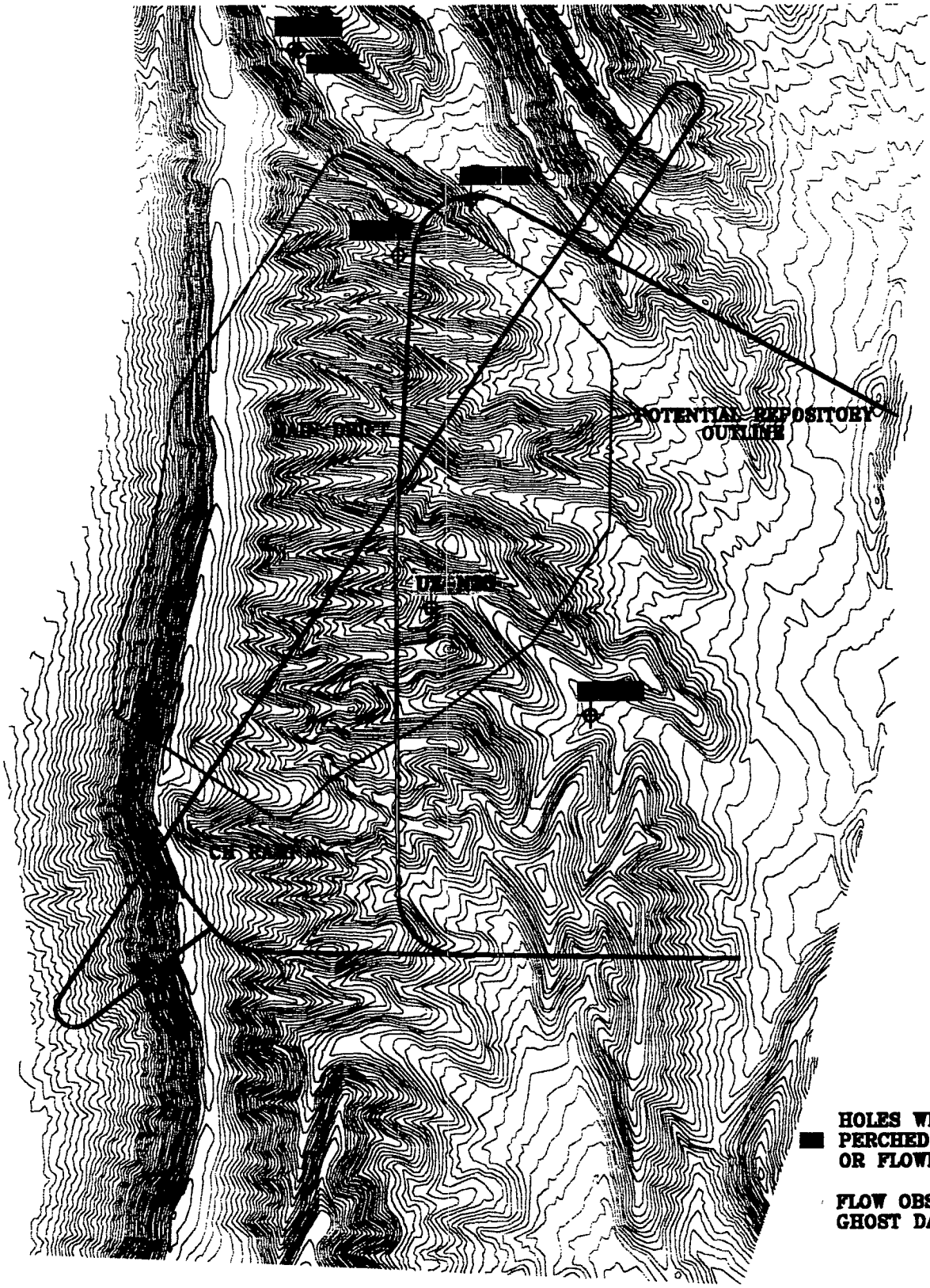
Gas isotope data and modeling of the gas flow system.

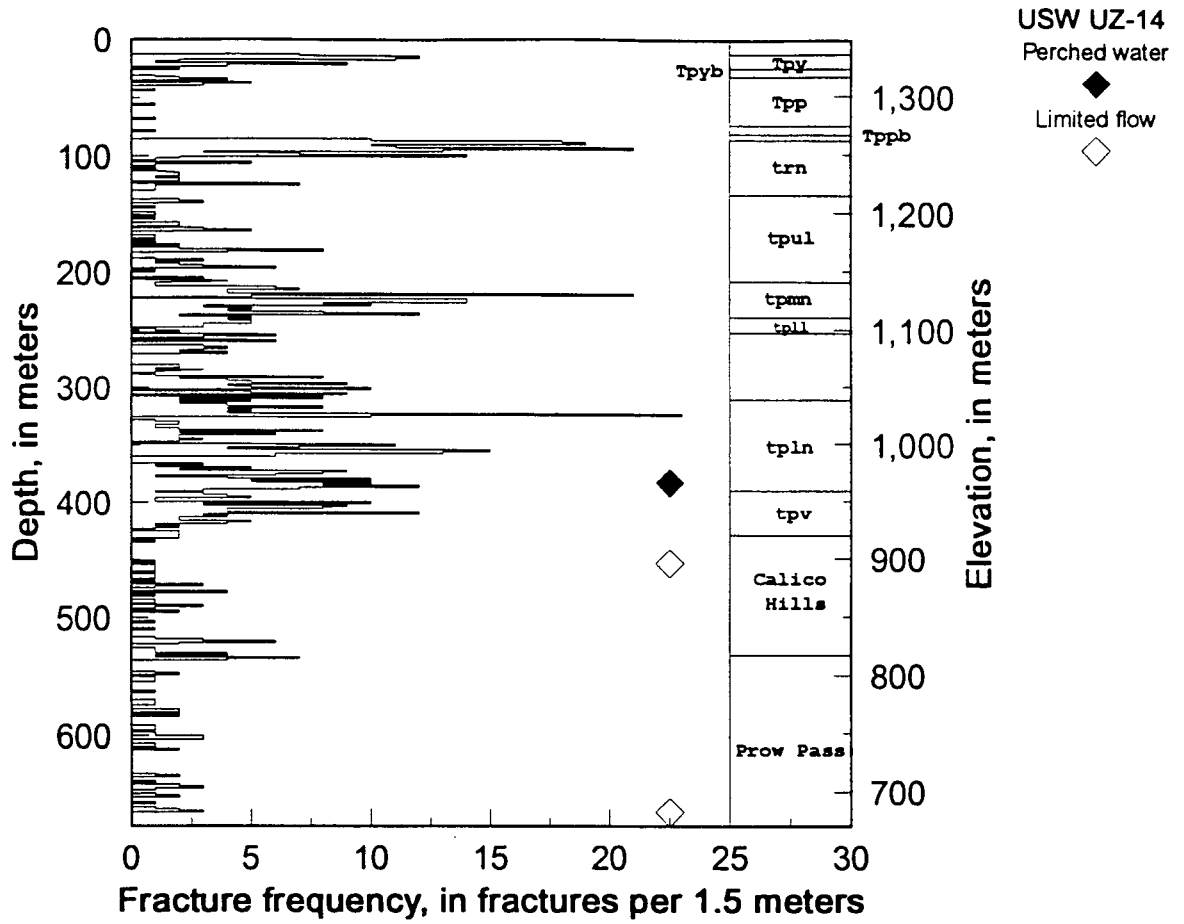
- The model is extremely preliminary.
- As indicated by the isotope data, the numerical model suggests considerable segregation of the shallow and deep gas flow system occurs when the PTn is assumed not to be fractured.
- The numerical model suggests a considerable amount of flow originates from the east slope of the mountain, as indicated by calculations for the size of the reservoir necessary to produce the observed CO_2 at borehole UZ6s.
- The model suggests considerable downward advective gas flow on the east slope of the mountain, consistent with calculations of advective velocities necessary to produce the observed CO_2 at UZ6s.

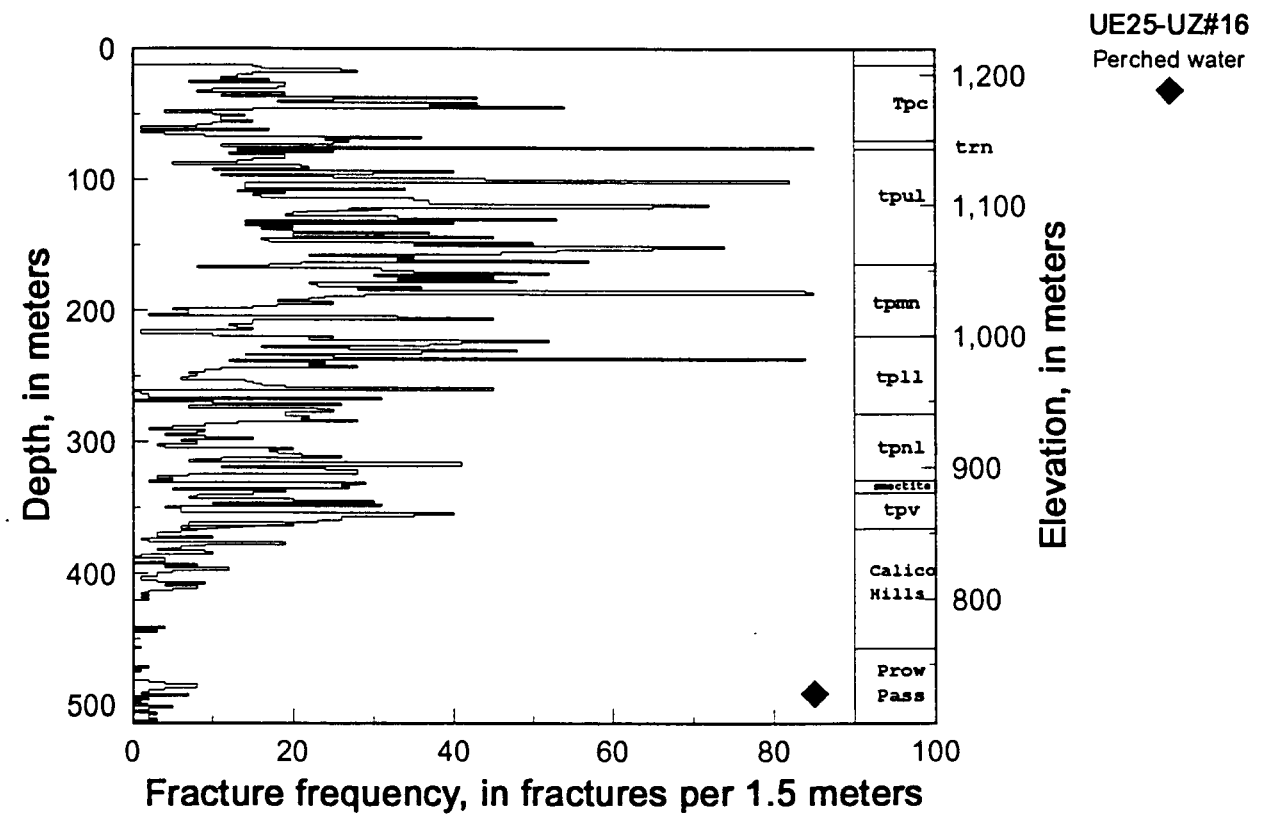
Perched Water

- Perched water was observed at boreholes UZ1, UZ14, UZ16, NRG-7/7a and SD-9.
- All occurrences of perched water occurred where a zone of fracturing was underlain by an interval of low matrix permeability and either low fracture frequency or filled fractures.
- Response to pump tests appears to be a good method for determining the magnitude of the perched zone.
- All encounters with perched water or freely-draining fractures noted so far have occurred below the stratigraphic levels expected to be penetrated by the North Ramp or the Main Test Level of the ESF.
- Should drifting proceed to the Calico Hills, encounters with perched water are more likely.

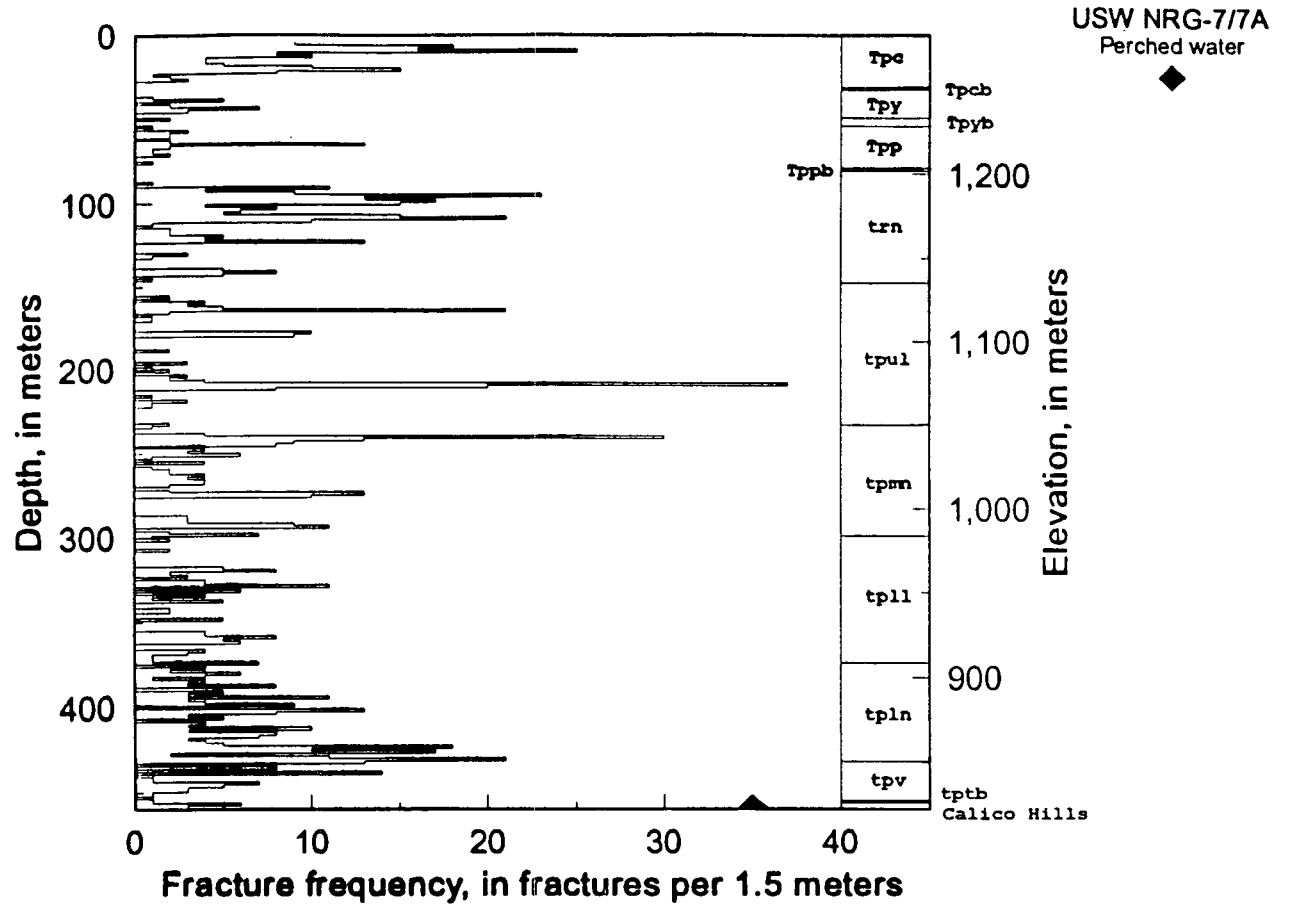
BOREHOLES WITH PERCHED WATER OR FLOWING FRACTURES

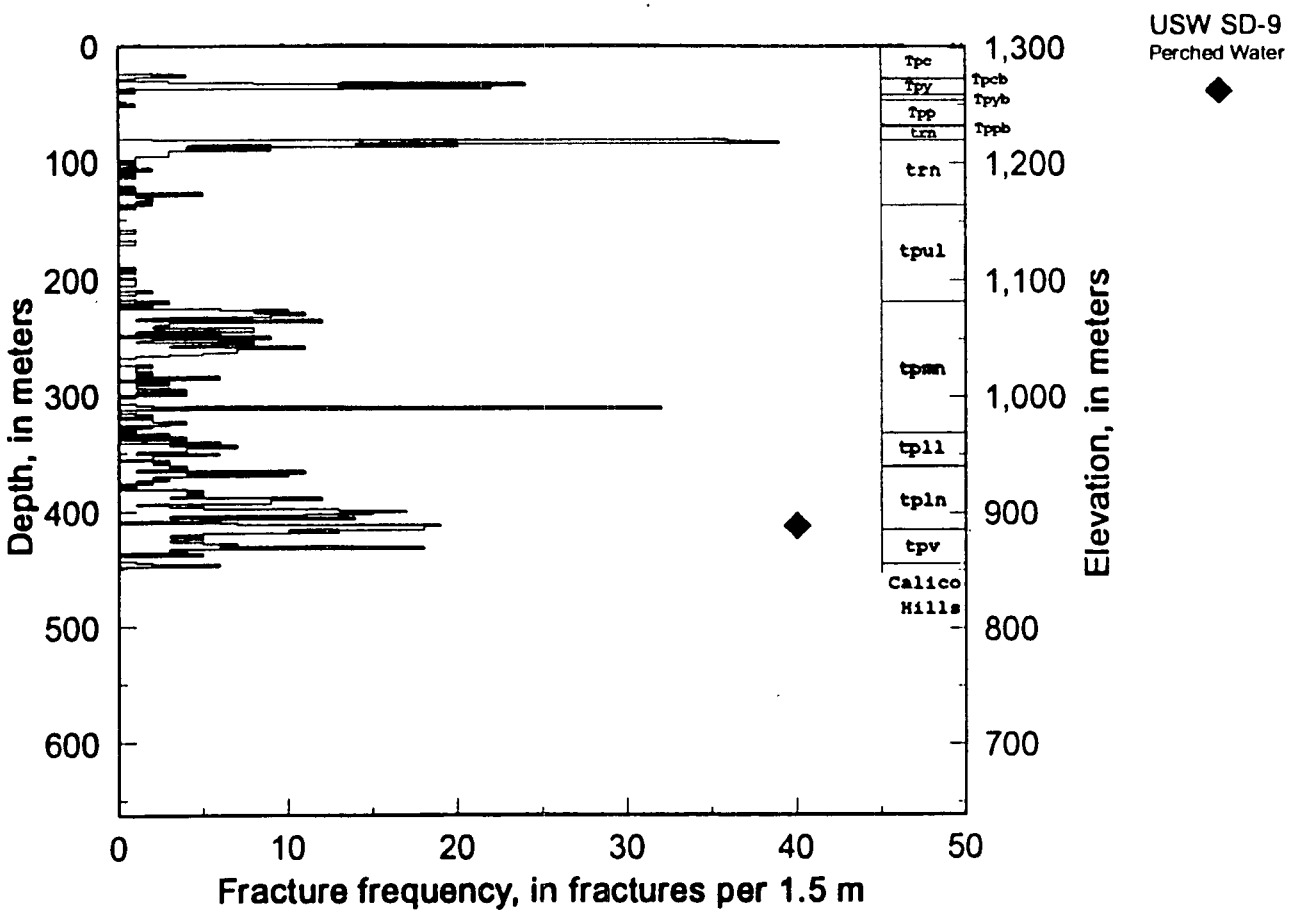






From Burger and Scofield (in progress, 1994)





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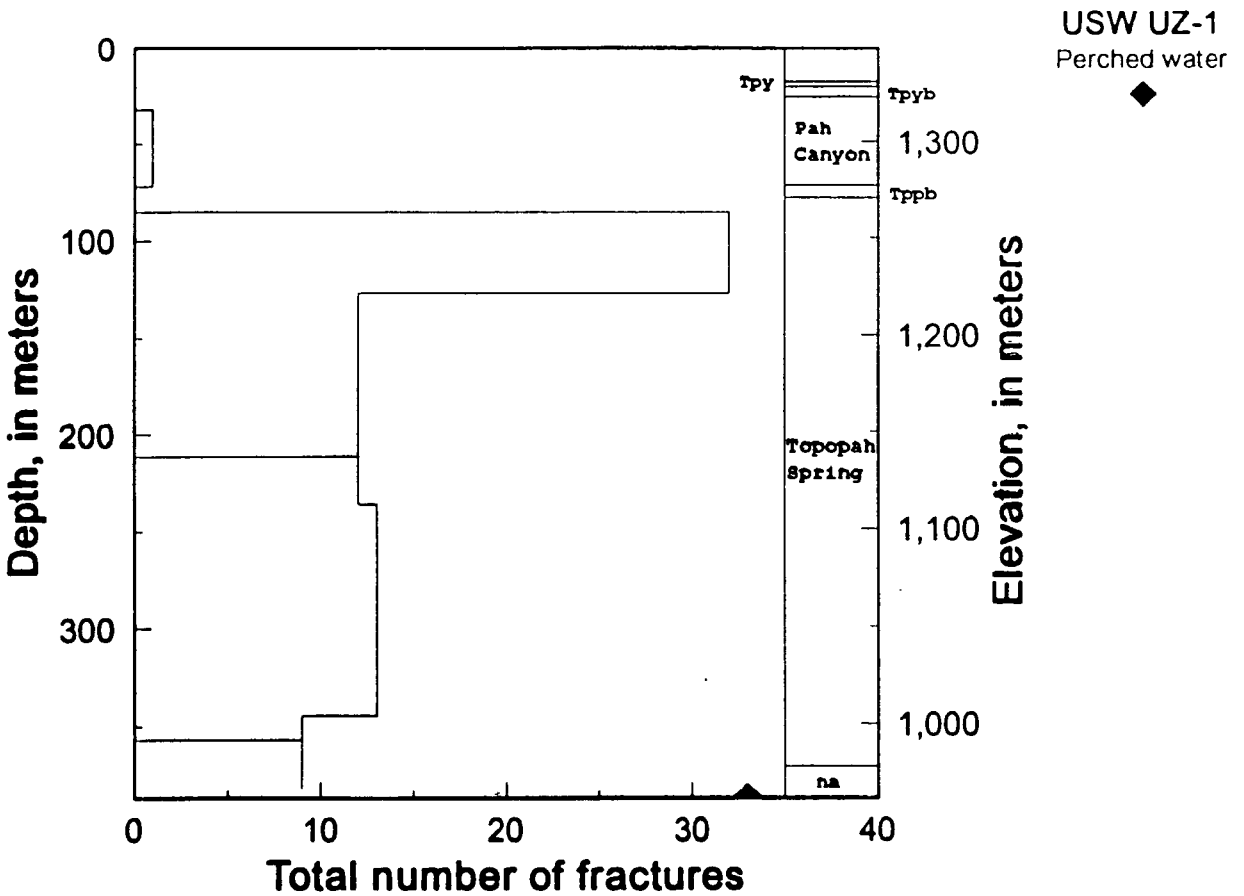
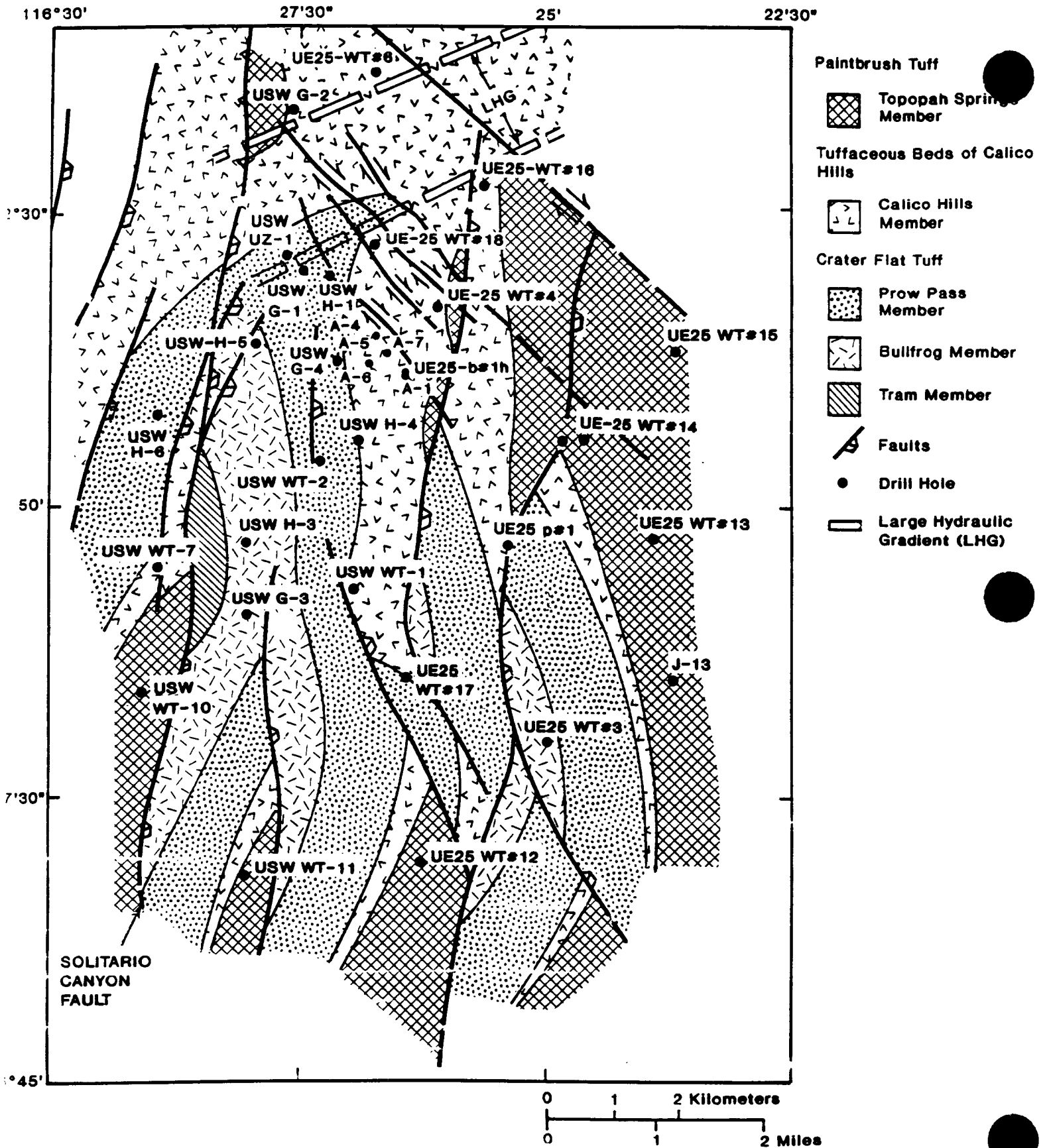


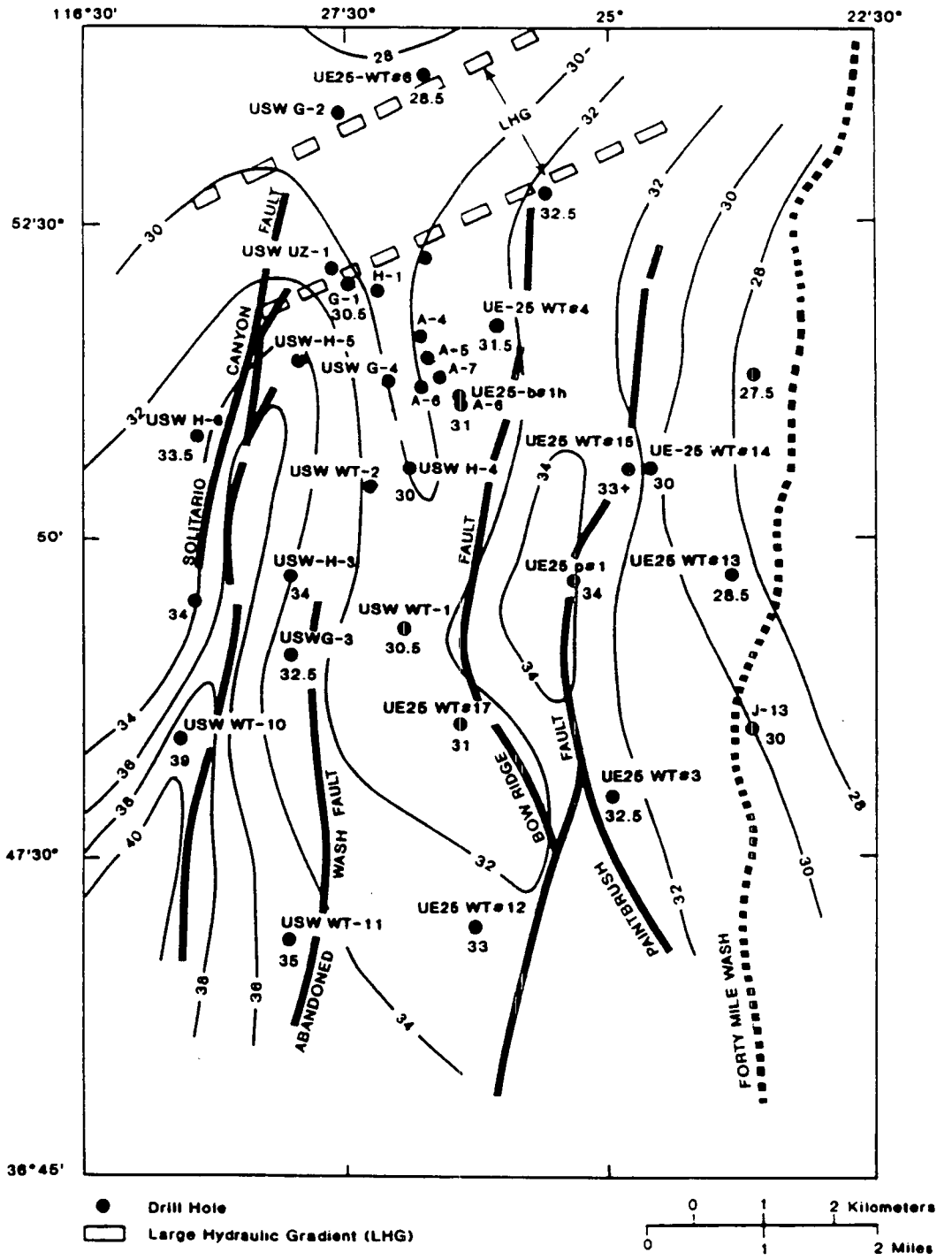
From Burger and Scofield (in progress, 1994)

Unsaturated Zone-Saturated Zone Interactions

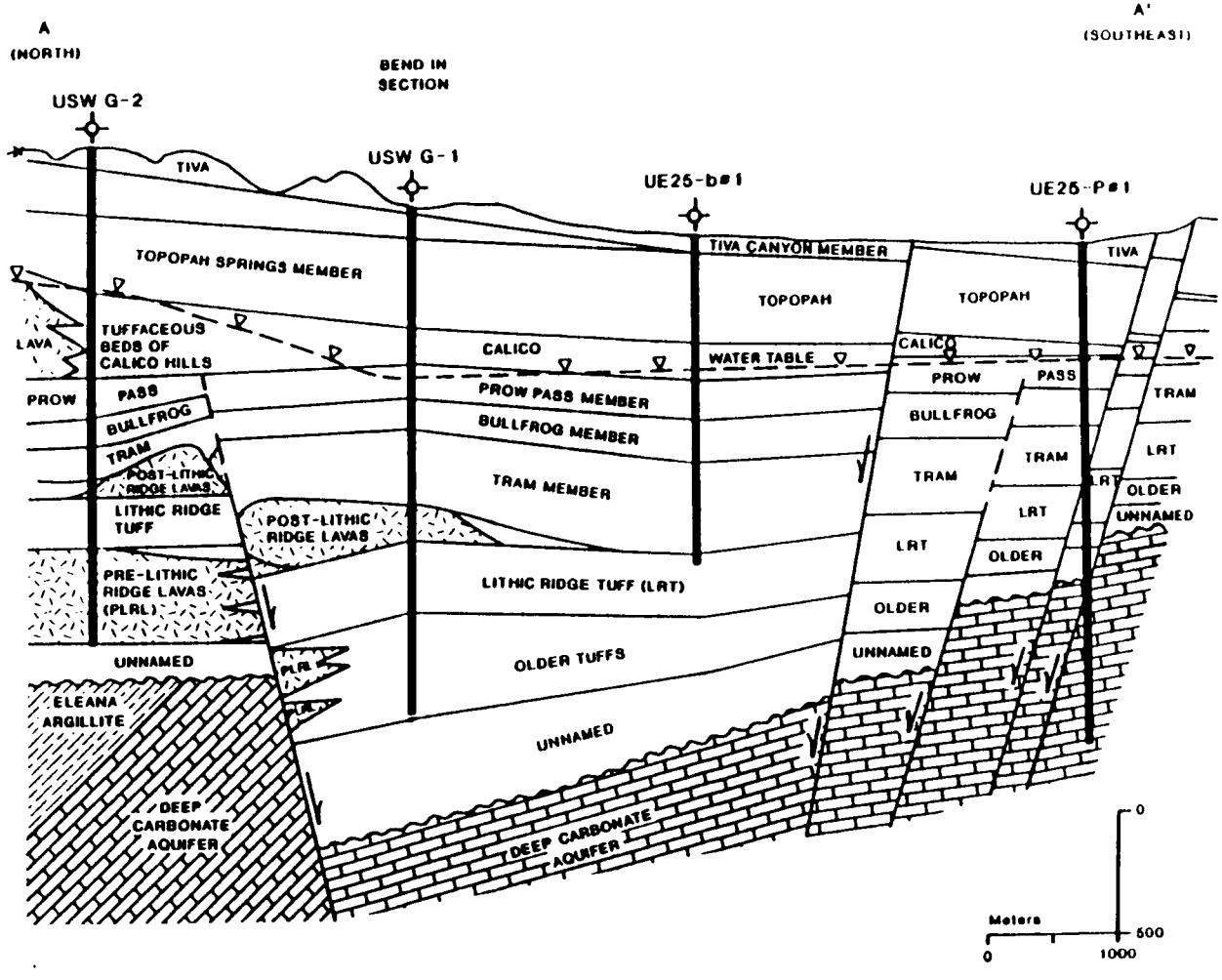
- Physical interactions
- Information transfer
- Numerical model coupling



Geologic formations intersected by the water table.



Temperature contours at the water table.



Structural cross-section through northern Yucca Mountain.

Summary of Physical Interactions

- A cross-section of the geology across the northern part of Yucca Mountain suggests it is not implausible that perched water beneath Drill Hole Wash is saturated zone water that has been diverted along impermeable beds as the water table elevation drops 300m.

- A map of geologic units intersected by the water table shows that, because of the low primary and secondary permeability of many of the units, hydraulic connections between the unsaturated and saturated zones may be localized and restricted to the Topopah Spring Member and major faults.

Information Transfer

- Formation permeabilities from well-testing unsaturated zone hydrologic units where submerged.
- Estimation of fault properties and behavior from calibration of saturated zone site model.
- Additional information on fault behavior from heat flow data.
- Tracer tests at the C-wells may provide values for effective porosities and diffusion coefficients for aqueous species (only gas tracers are currently planned in UZ).
- Sampling of groundwater chemistry in the shallow saturated zone may provide an additional means of identifying fast paths through the unsaturated zone if dilution is not too great.

Coupling of Saturated and Unsaturated Zone Models

- Physical coupling of the saturated and unsaturated zones, although more complex that previously assumed, may not require a fully coupled model to capture interactions, at least for modeling of ambient conditions.
  - Yucca Mountain not assumed to be a major source of recharge for the regional ground water system.
  - Water table location a relatively minor source of uncertainty.
- Past numerical simulations using the site 3d unsaturated zone model have not considered variations in water table elevations.
- Weak coupling can be accomplished through "maps" (physical or digital) with contours describing intensity of recharge or nuclide concentration or arrival times.
- In the future, consideration of repository generated heat may necessitate the use of a more strongly coupled unsaturated-saturated zone flow model.

SUMMARY AND CONCLUSIONS

- Neutron logging and isotope data suggest that near-surface fracture flow is a relatively common occurrence.
- At this time, no topographic setting or outcropping rock type can be eliminated as being a potentially significant location for infiltration.
- Capillary barrier effects in the PTn may significantly reduce peak surface fluxes from peak values at the ground surface and significantly delay their entry into the potential repository horizon.
- Although much has been learned about fracture and matrix properties, significant gaps exist for certain types of data.
- UZ16 data permeability and fracture data suggest gas flow may be described by porous media models, but isotope data suggest that water may be moving along a much smaller subset of available pathways.

SUMMARY AND CONCLUSIONS (continued)

- ^{14}C and ^{3}H data for UZ16 indicate relatively short (<1000 years) travel times as a result of fault or fracture flow near that borehole.
- Although relatively few locations have been studied, available gas isotope data indicate the PTn effectively separates the shallow and deep gas flow systems, suggesting little fracture permeability for the PTn.
- The perched water detected in the northern part of Yucca Mountain may be due to the steep decline of the potentiometric surface between G2 and G1, and lateral diversion of water into the UZ along low permeability beds.
- Direct connections between the unsaturated and saturated zones may be localized and restricted to the Topopah Spring Member and major faults.