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

PRESENTATION TO THE NUCLEAR WASTE TECHNICAL REVIEW BOARD

SUBJECT: IN SITU MONITORING - MEASURING FLUID-FLOW POTENTIAL FIELD

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DECEMBER 11-12, 1989

OVERVIEW OF PRESENTATION

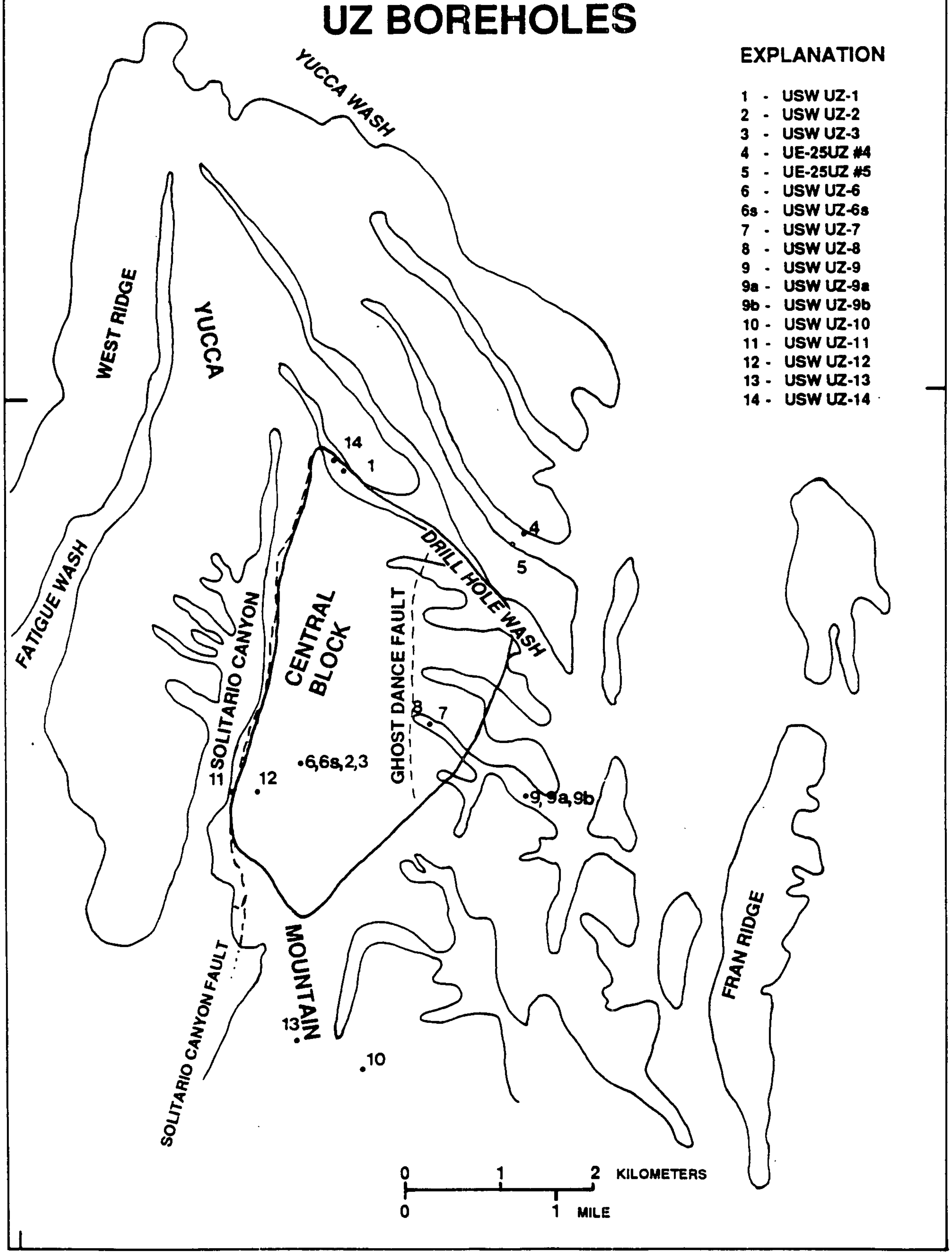
- PURPOSE/SCOPE/MEASUREMENTS - AN OVERVIEW
- UZ-1 EXPERIENCE - OBSERVATIONS
- G-TUNNEL EXPERIENCE - AN ANALOG SITE
- BENEFITS OF IN SITU MONITORING

PURPOSE OF IN SITU MONITORING

- DEFINE LIQUID AND VAPOR FLUX POTENTIALS
  - PNEUMATIC PRESSURE POTENTIAL (CONVECTION)
  - VAPOR PRESSURE POTENTIAL (DIFFUSION)
  - WATER POTENTIAL (MATRIC AND OSMOTIC)
  - THERMAL POTENTIAL

116°30'

LOCATIONS OF EXISTING AND PROPOSED UZ BOREHOLES



EXPLANATION

1 - USW UZ-1
2 - USW UZ-2
3 - USW UZ-3
4 - UE-25UZ #4
5 - UE-25UZ #5
6 - USW UZ-6
6s - USW UZ-6s
7 - USW UZ-7
8 - USW UZ-8
9 - USW UZ-9
9a - USW UZ-9a
9b - USW UZ-9b
10 - USW UZ-10
11 - USW UZ-11
12 - USW UZ-12
13 - USW UZ-13
14 - USW UZ-14

NMUZJR5P.A22/12-11-89 3

SCOPE

- INSTURMENT 16 VERTICAL BOREHOLES (12.25 in. diam.)
- SOLID STEMMING DESIGN (GROUT AND SAND FILLER)
- 16 INSTRUMENT STATIONS/BOREHOLE
  - 2 PRESSURE TRANSDUCERS/STATION
  - 2 THERMISTORS/STATION
  - 2 THERMOCOUPLE PSYCHROMETERS/STATION
  - 1 GAS SAMPLING "U" TUBE/STATION
  - 2 SOLENOID VALVES/STATION
- APPROXIMATELY 1600 SENSORS INVOLVED
- SENSORS READ EVERY FIVE HOURS
- DURATION OF MONITORING – 3 TO 5 YEARS

MEASUREMENTS

- **PRESSURE – (IN SITU RECALIBRATION OPTION)**
  - 0.005 PSIA ACCURACY (2 SIGMA)
  - 1 PSIA TOTAL RANGE/2,500 FT.
- **TEMPERATURE**
  - 0.005°C ACCURACY (2 SIGMA)
  - 25°C TOTAL RANGE (15 – 40°C)
- **WATER POTENTIAL (IN SITU VERIFICATION OPTION)**
  - ACCURACY RELATIVE (0.5 TO 1.0 BAR)
  - –0.5 to > –70 BARS MOISTURE SUCTION

MEASUREMENTS

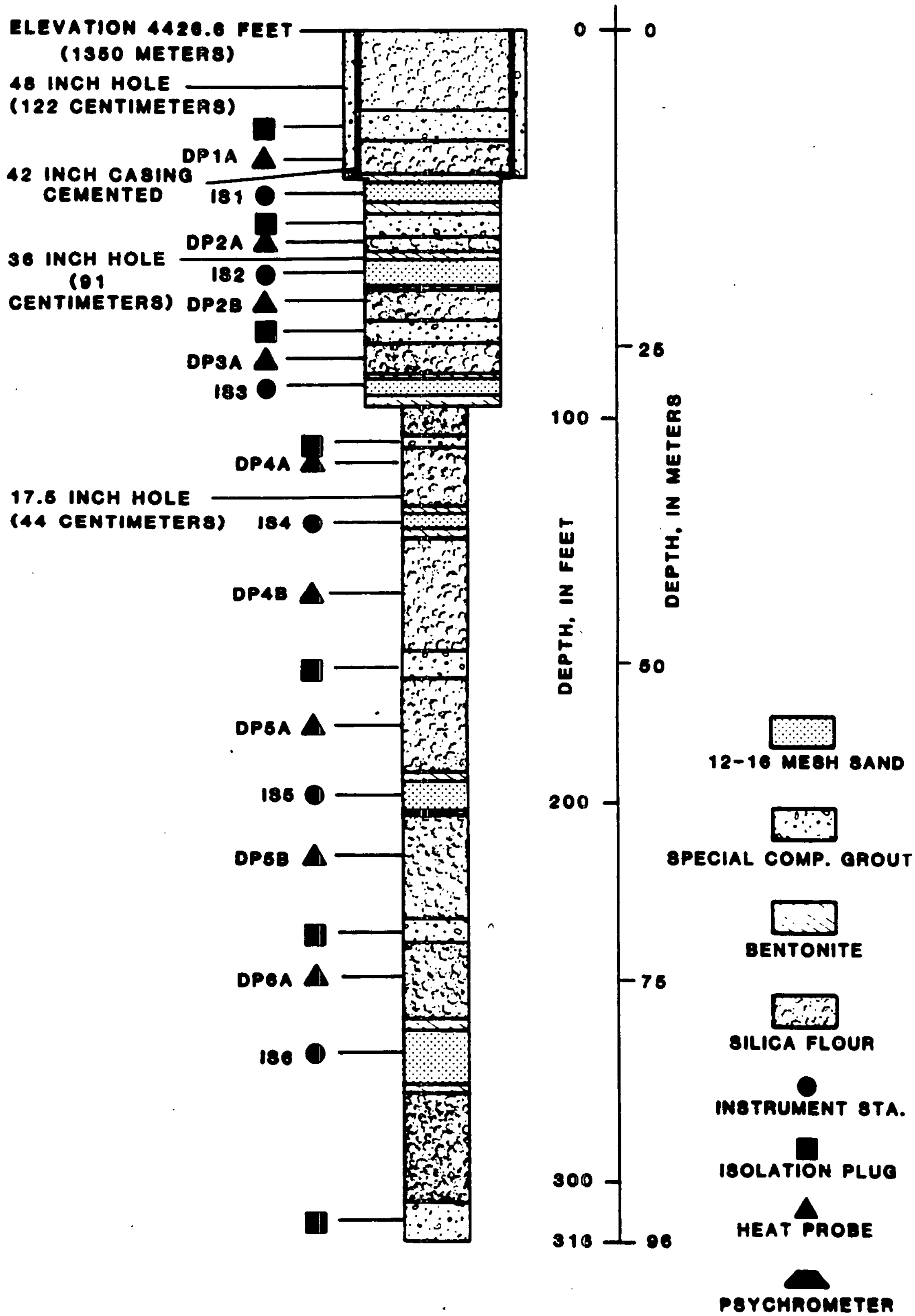
(CONTINUED)

- GAS SAMPLING
  - DESIGNED TO INHIBIT CONDENSATION DURING VACUUM WITHDRAWAL OF PORE GASES
  - DRY–CARRIER GAS (N_2) MIXED WITH SOURCE GAS
  - MASS FLOW OF DRY AND MIXED GASES MEASURED
  - DEW POINT TEMPERATURE OF MIXED GASES MEASURED
  - VAPOR PRESSURE OF SOURCE GAS CALCULATED

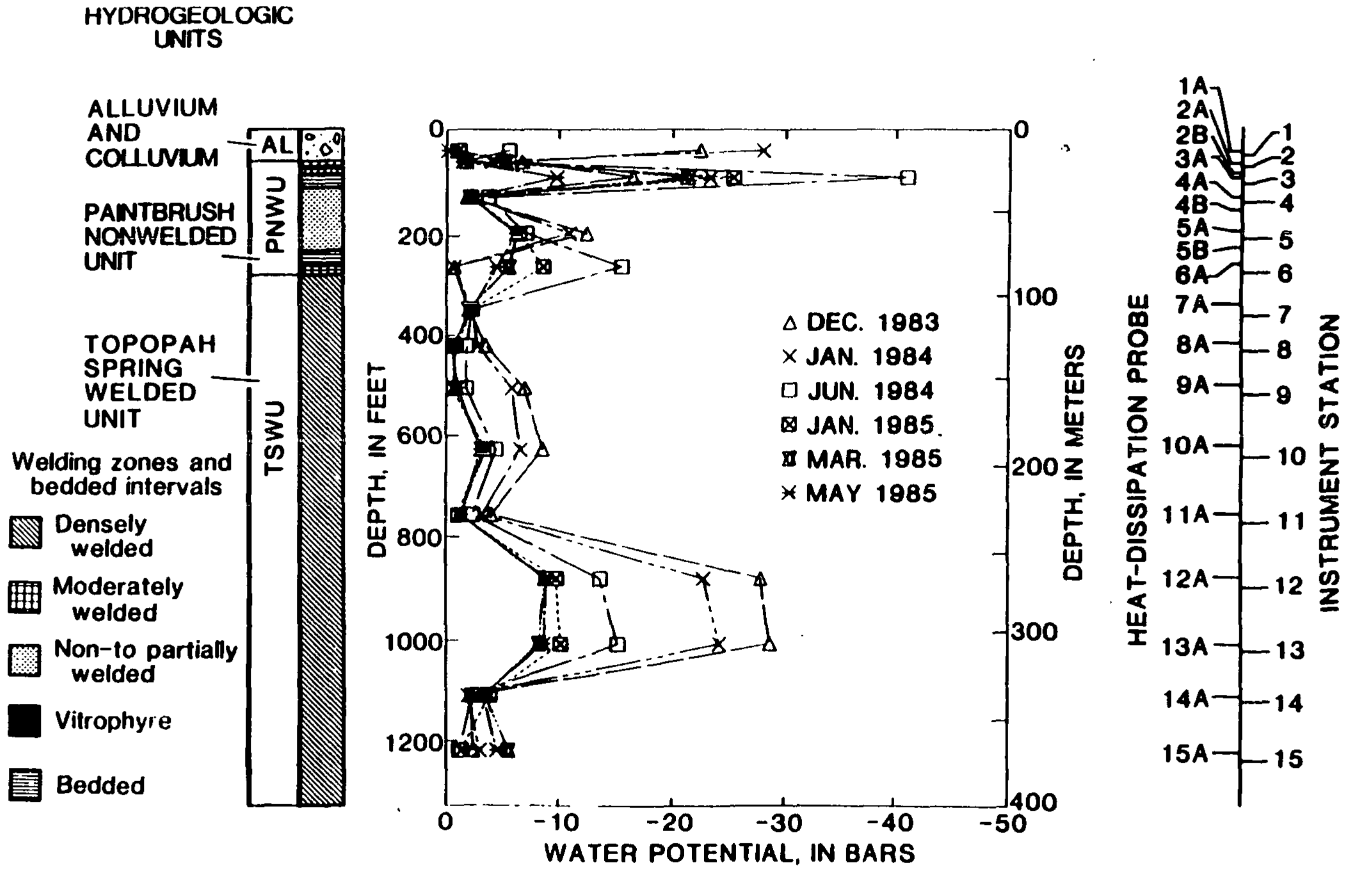
UZ–1 EXPERIENCE

- SIGNIFICANT REVERSALS IN WATER POTENTIAL GRADIENTS ACROSS HYDROGEOLOGIC BOUNDARIES AND WITHIN HYDROGEOLOGIC UNITS
- RELATIVELY HIGH THERMAL ACTIVITY AT DEPTHS GREATER THAN 100 FEET
- UNIT HYDRAULIC GRADIENT ASSUMPTION ACROSS THICK SECTION OF TOPOPAH SPRING WELDED UNIT NOT SUPPORTED BY IN SITU MEASUREMENTS
- EQUILIBRATION TIME ON THE ORDER OF 18 TO 24 MONTHS ON AVERAGE — SOME STATIONS ON THE ORDER OF A FEW MONTHS
- UZ-1 SERVED AS A USEFUL PROTOTYPE AND WILL HELP GUIDE IMPROVED INSTRUMENTATION OF FUTURE UZ BOREHOLES

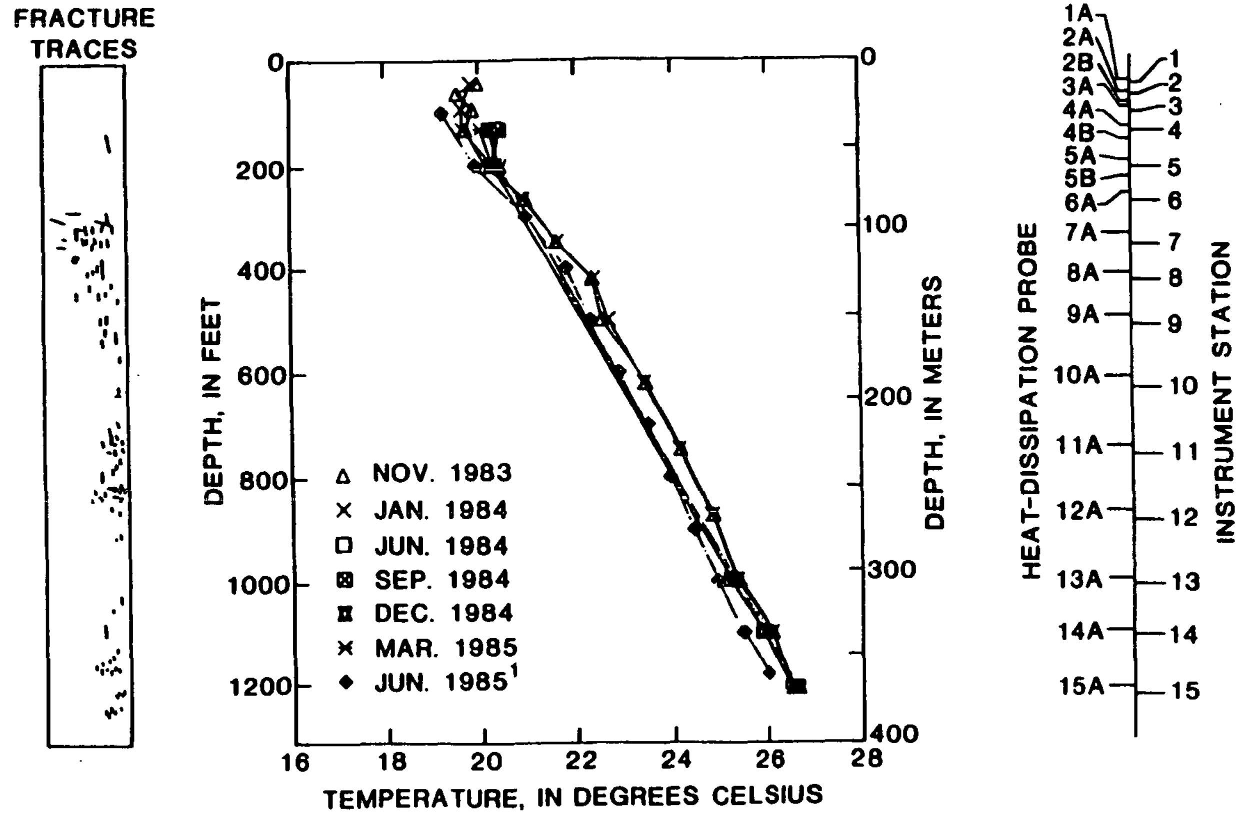
DETAILS OF THE STEMMING OF TEST BOREHOLE USW UZ-1



WATER POTENTIAL AT TEST BOREHOLE USW UZ-1 BASED ON DATA FROM THERMOCOUPLE PSYCHROMETERS



TEMPERATURE PROFILES AND DISTRIBUTION OF FRACTURE TRACES AT TEST BOREHOLE USW UZ-1



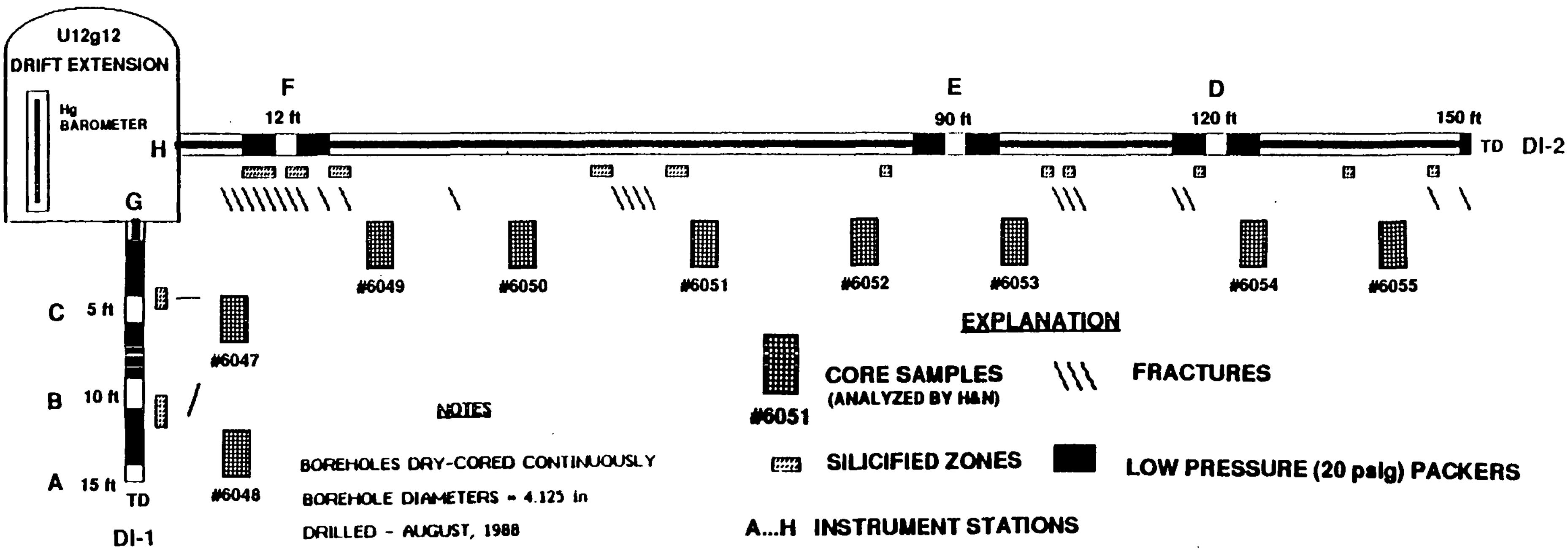
[1] DATA FOR JUNE 1985 FROM JOHN SASS (U.S. GEOLOGICAL SURVEY, WRITTEN COMMUN., 1985)

G TUNNEL EXPERIENCE

- 2 BOREHOLES INSTRUMENTED (3 STATIONS/ BOREHOLE)
- MONITORED FOR 1+ YEAR
- LIQUID AND VAPOR PHASES NOT IN "HYDRAULIC" EQUILIBRIUM WITHIN ZONE AFFECTED BY THE ANNUAL TEMPERATURE WAVE (WITHIN FIRST 20 FEET)
- CONVECTIVE TRANSPORT OF NEARLY VAPOR SATURATED AIR IS PREDOMINANT MECHANISM FOR DRYING OF NEAR–FIELD WALLROCK
- PRELIMINARY CALCULATIONS SUGGEST NEAR–FIELD DESATURATION AT THE RATE OF 0.1% PER YEAR

THERMODYNAMIC PROCESSES OF LIQUID AND VAPOR MOVEMENT IN THE U12g.12 DRIFT EXTENSION, GTUF, NTS

PROTOTYPE DRILLHOLE INSTRUMENTATION
G TUNNEL UNDERGROUND FACILITY, NTS



NOTES

BOREHOLES DRY-CORED CONTINUOUSLY

BOREHOLE DIAMETERS = 4.125 in

DRILLED - AUGUST, 1988

INSTRUMENTED - OCTOBER, 1988

VERTICAL SCALE = 2x HORIZONTAL

EXPLANATION

#6051 CORE SAMPLES (ANALYZED BY H&N)

FRACTURES

SILICIFIED ZONES

LOW PRESSURE (20 psig) PACKERS

A...H INSTRUMENT STATIONS

A,B,C,D,E,F - sensors
pressure transducers
thermistors
thermocouple psychrometers

G,H - sensors
pressure transducers
thermistors
mercury barometer

HYDROLOGIC-PHYSICAL-THERMODYNAMIC ROCK PROPERTIES

PHYSICAL AND MATRIX HYDROLOGIC ROCK PROPERTIES

Lab Sample No.	Depth Interval (ft)	Grain Density (gm/cc)	Bulk Density (gm/cc) Natural	Bulk Density (gm/cc) Dry	% Moisture Content by Weight (%)	Moisture Content by Volume (%)	Porosity (%)	Saturation (%)	Gas-Field Porosity (%)
DI-1									
6047	5.7-6.0	2.39	1.655	1.359	21.8	29.64	43.1	68.8	13.4
6048	12.4-12.9	2.50	1.830	1.639	11.7	19.12	34.4	55.6	15.3
DI-2									
6049	22.4-22.7	2.50	1.676	1.363	22.9	31.26	43.3	72.2	12.0
6050	39.3-39.6	2.44	1.670	1.340	24.6	32.99	45.1	73.2	12.1
6051	61.0-61.4	2.39	1.763	1.492	18.2	27.10	37.5	72.2	10.4
6052	79.4-79.8	2.61	1.630	1.284	26.9	34.55	50.7	68.1	16.2
6053	97.5-97.8	2.42	1.547	1.245	24.2	30.15	48.4	62.2	18.3
6054	124.9-125.5	2.40	1.514	1.243	21.8	27.06	48.1	56.2	21.0
6055	140.0-140.6	2.41	1.504	1.220	23.2	28.36	49.3	57.6	20.9

(Data from Holmes and Narver Materials Testing Laboratory, 1988)

THERMODYNAMIC ROCK PROPERTIES

Heat Capacity (C): 0.837 $\frac{KJ}{Kg\text{-}^{o}K}$ - dry, nonwelded tuff (porosity = 45%, density = 1.32 gm/cc)

4.18 $\frac{KJ}{Kg\text{-}^{o}K}$ - water

Thermal Conductivity (k): 0.59 - 1.24 W/m-°K - dry, nonwelded tuff (porosity 35 - 50%)

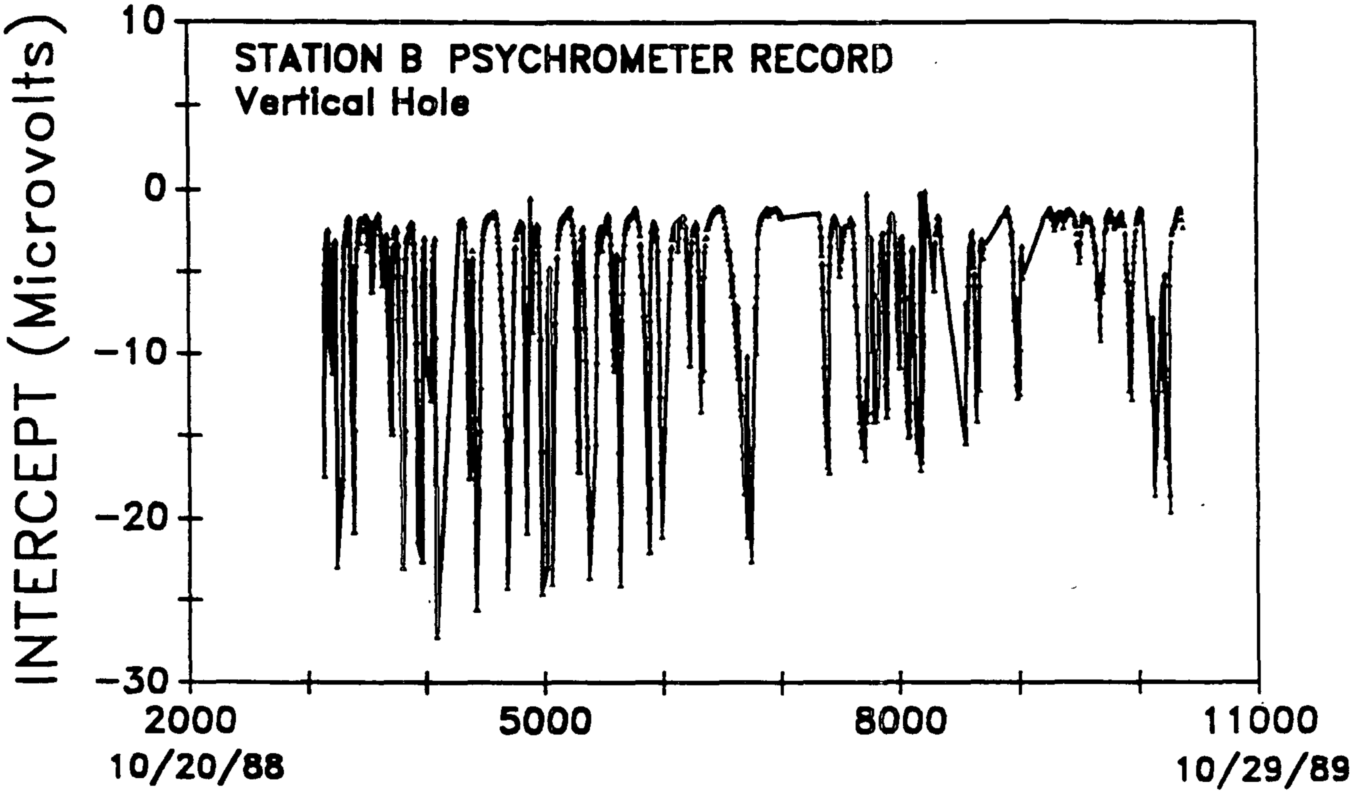
1.30 - 1.64 W/m-°K - 100% saturated nonwelded tuff (porosity 35 - 50%)

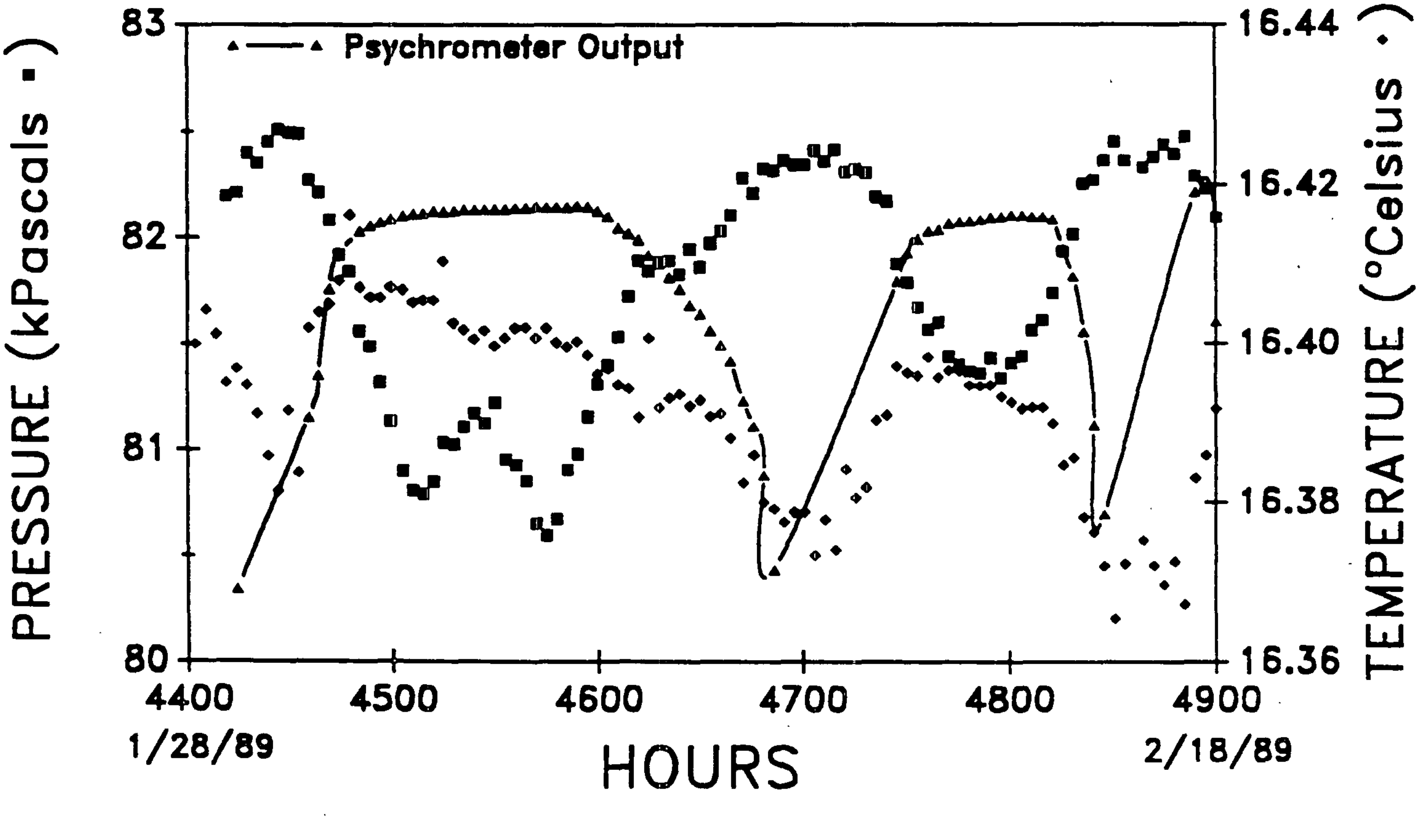
Thermal Diffusivity (D): 4.7×10^{-7} m^3/m - sec - nonwelded tuff (porosity - 46.8%, saturation - 62%) where $D = k/\rho C$

(Data from Blanford and Osnes, 1987; Hillel, 1971; Lappin and Nimick, 1985)

STATION B
FRACTURE INFLUENCED

BOREHOLE DI-1 STATION B





NMUZJR5P.A22/12-11-89 14

IN SITU TEMPERATURE

TEMPERATURE RECORD
BOREHOLE DI-1

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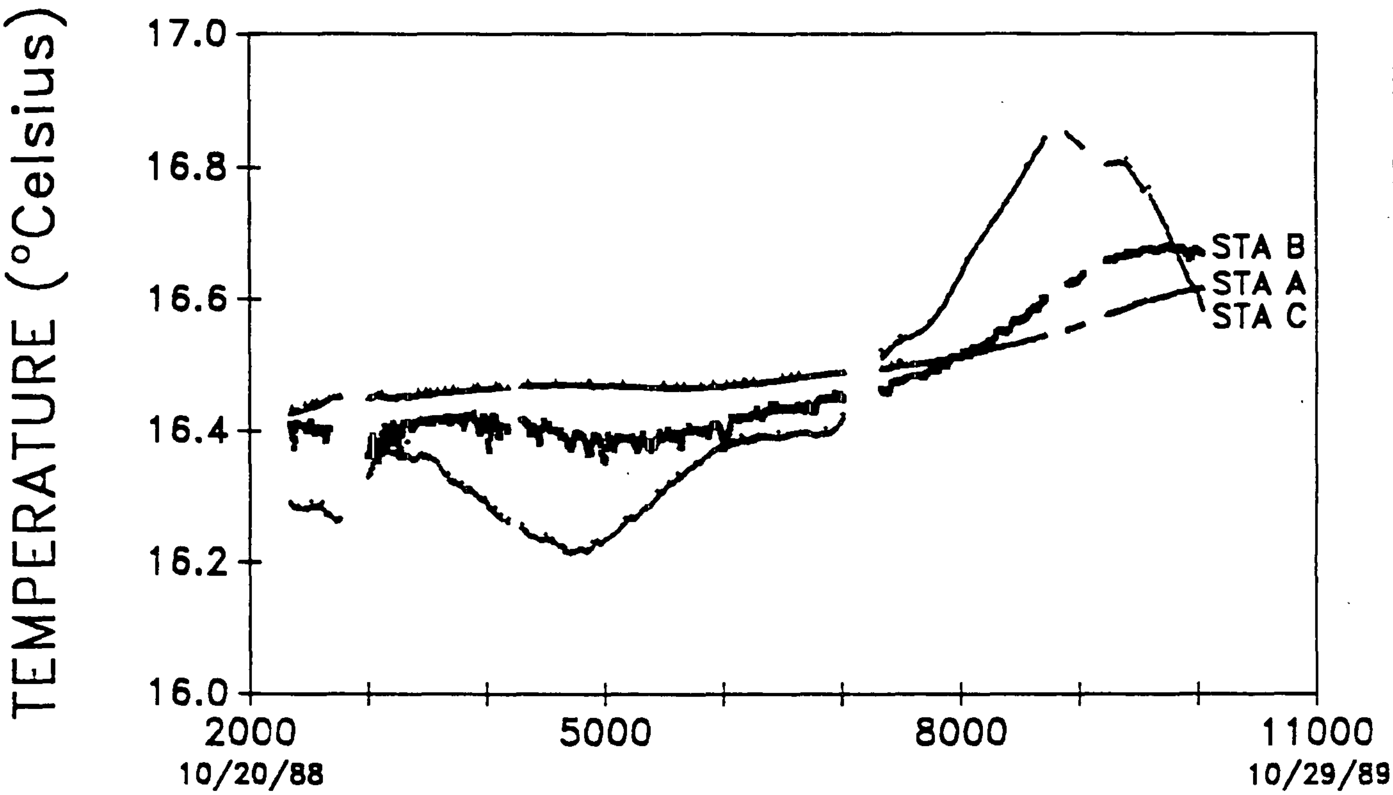
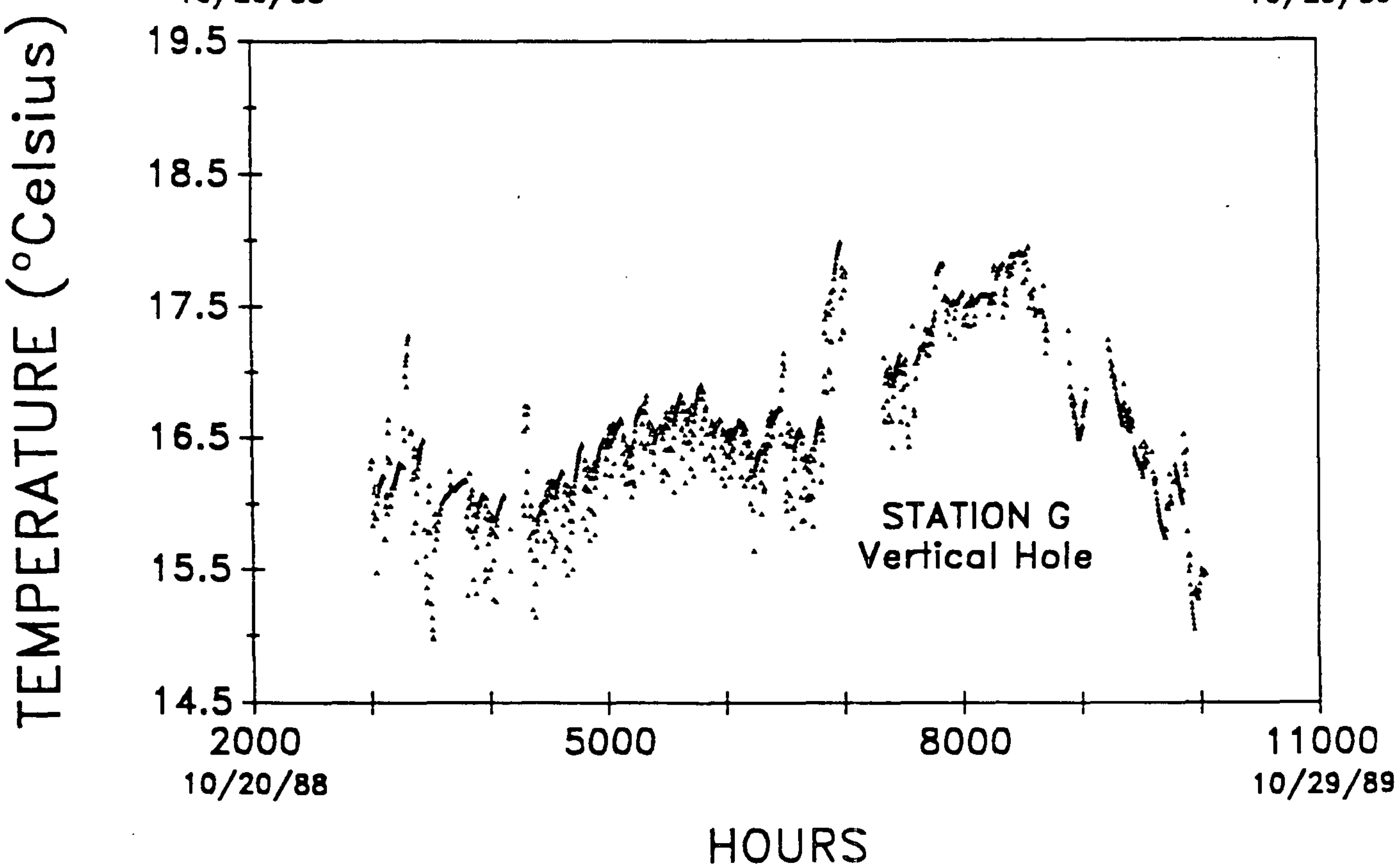
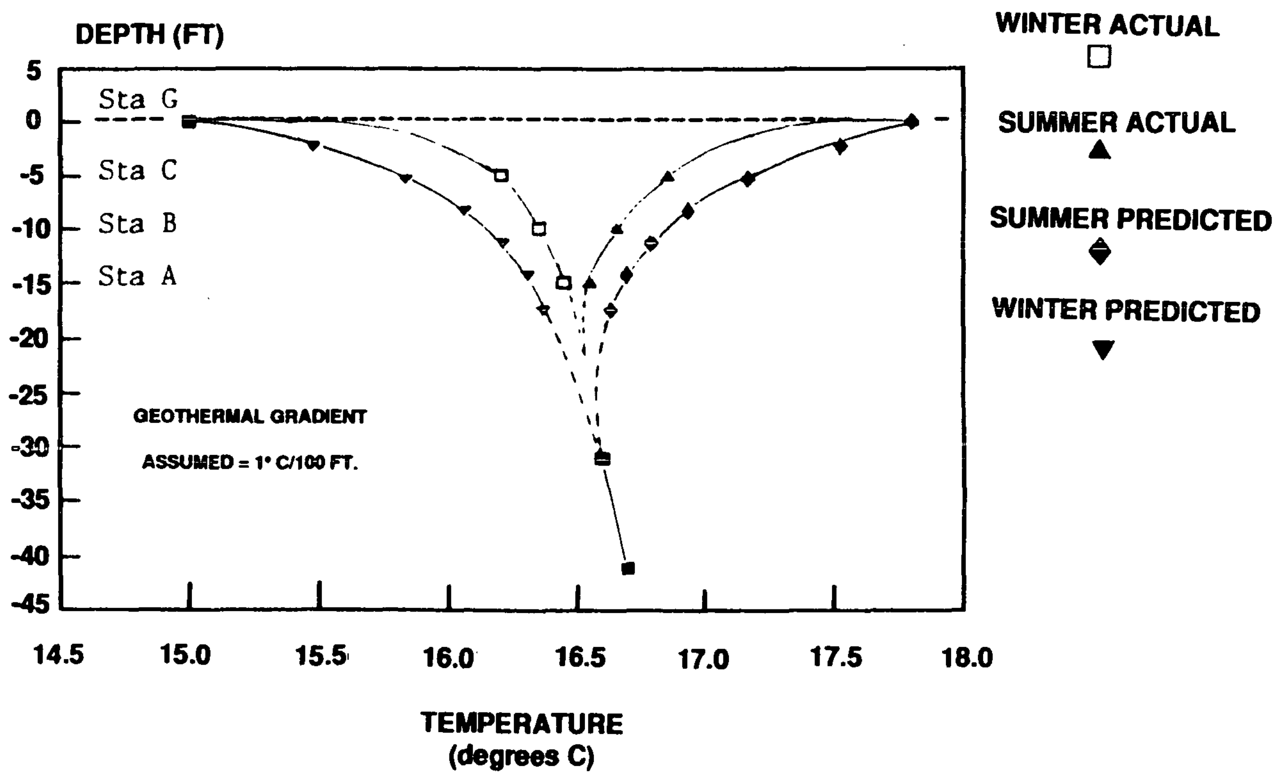




TEMPERATURE PROFILES

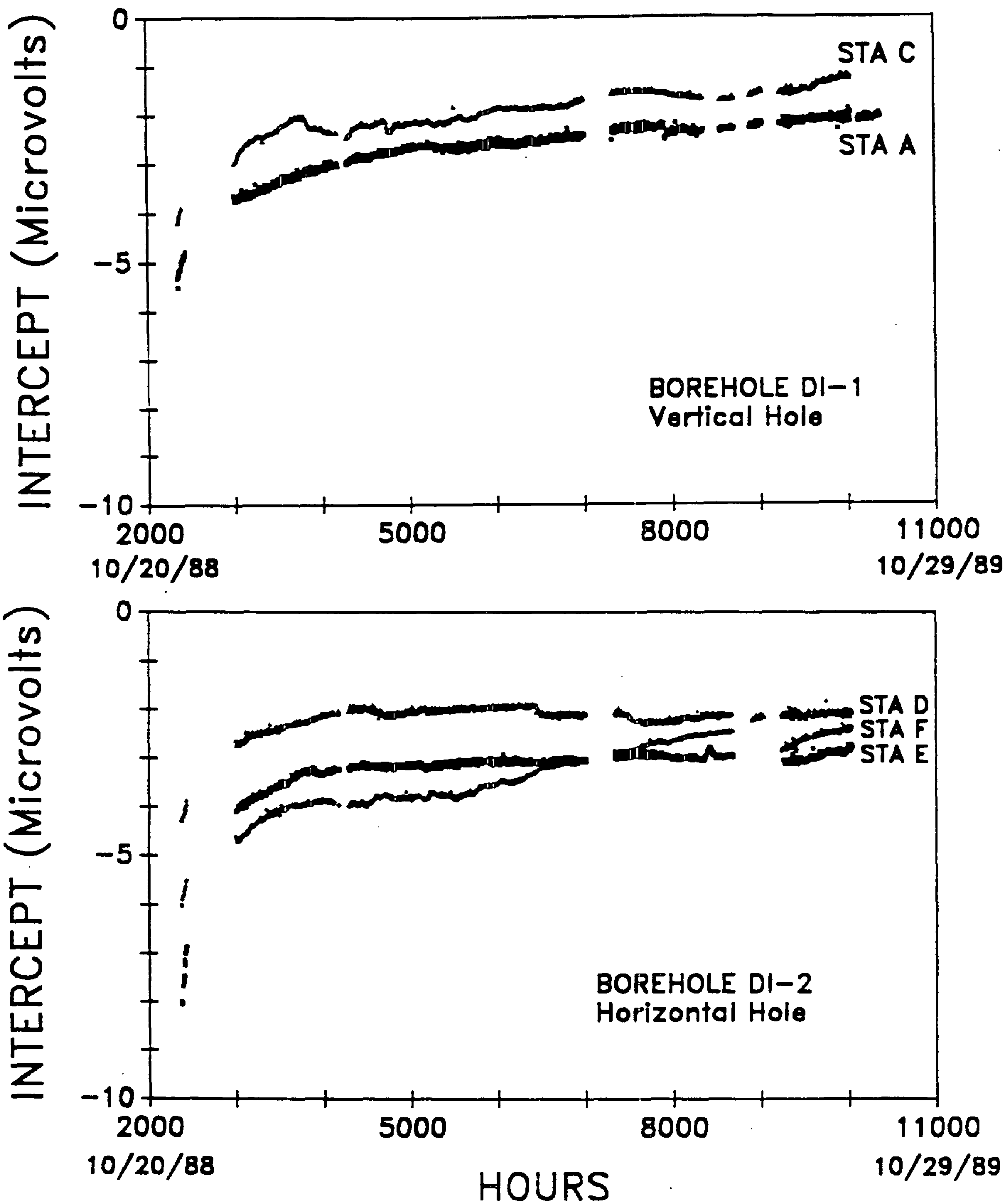
TEMPERATURE PROFILE

DI-1 (VERTICAL)



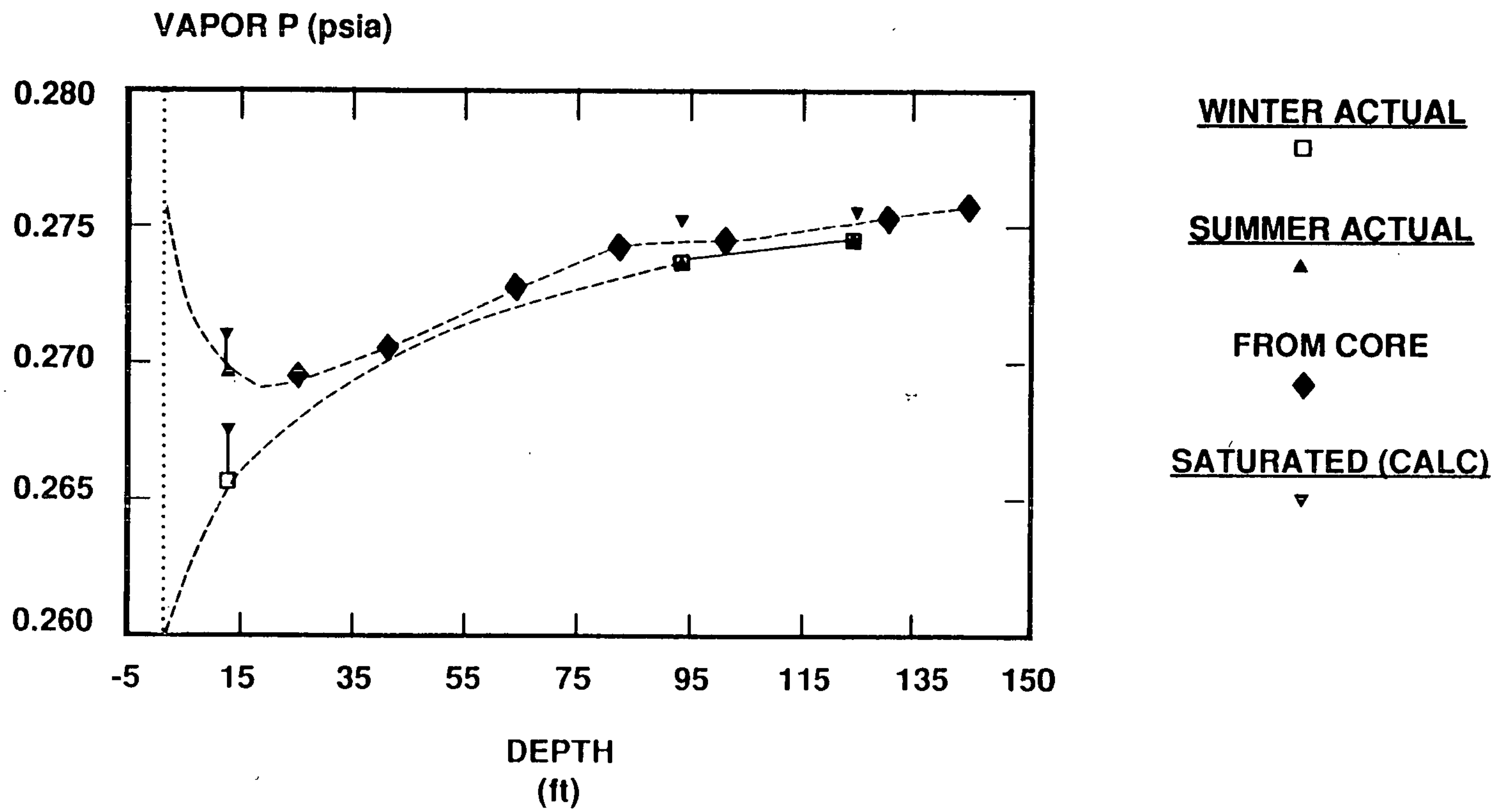
IN SITU WATER POTENTIAL - ψ

PSYCHROMETER RECORD



VAPOR PRESSURE PROFILES

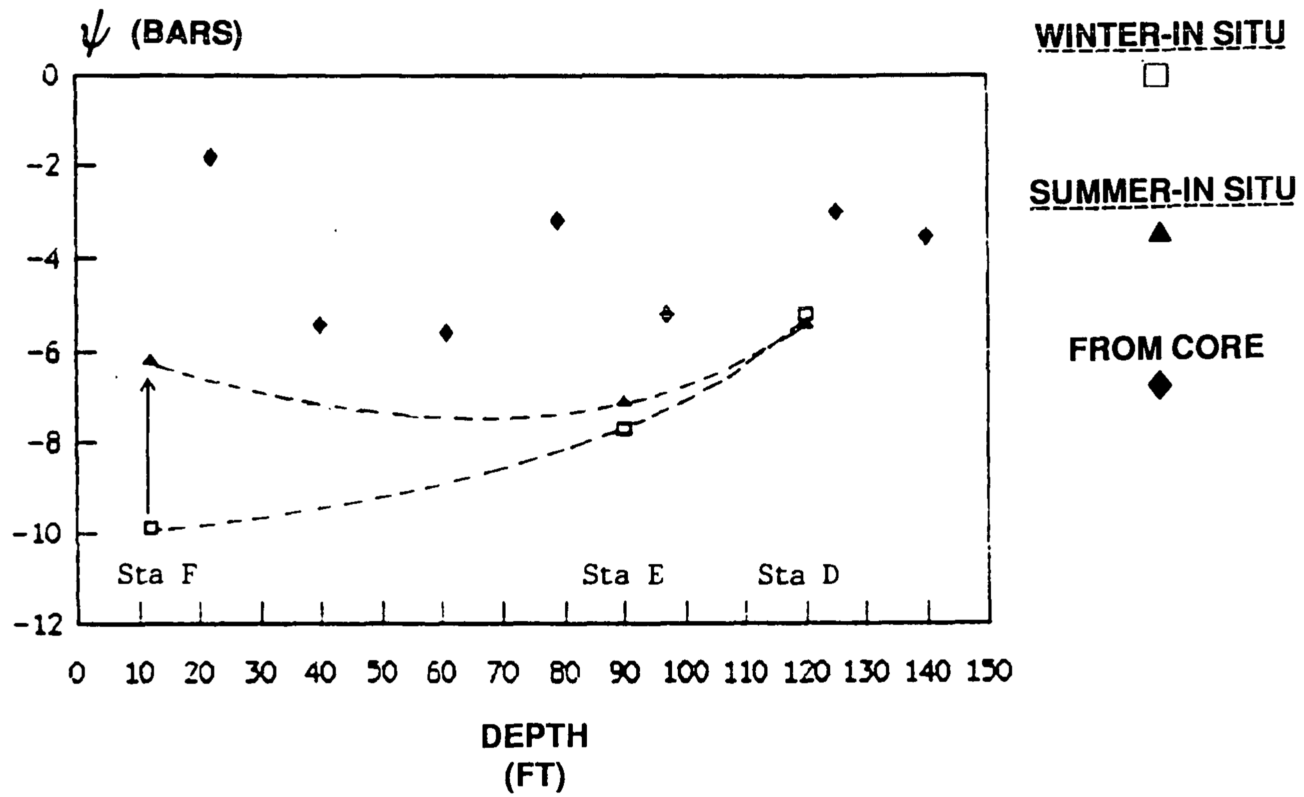
VAPOR PRESSURE PROFILE
DI-2 (HORIZ)



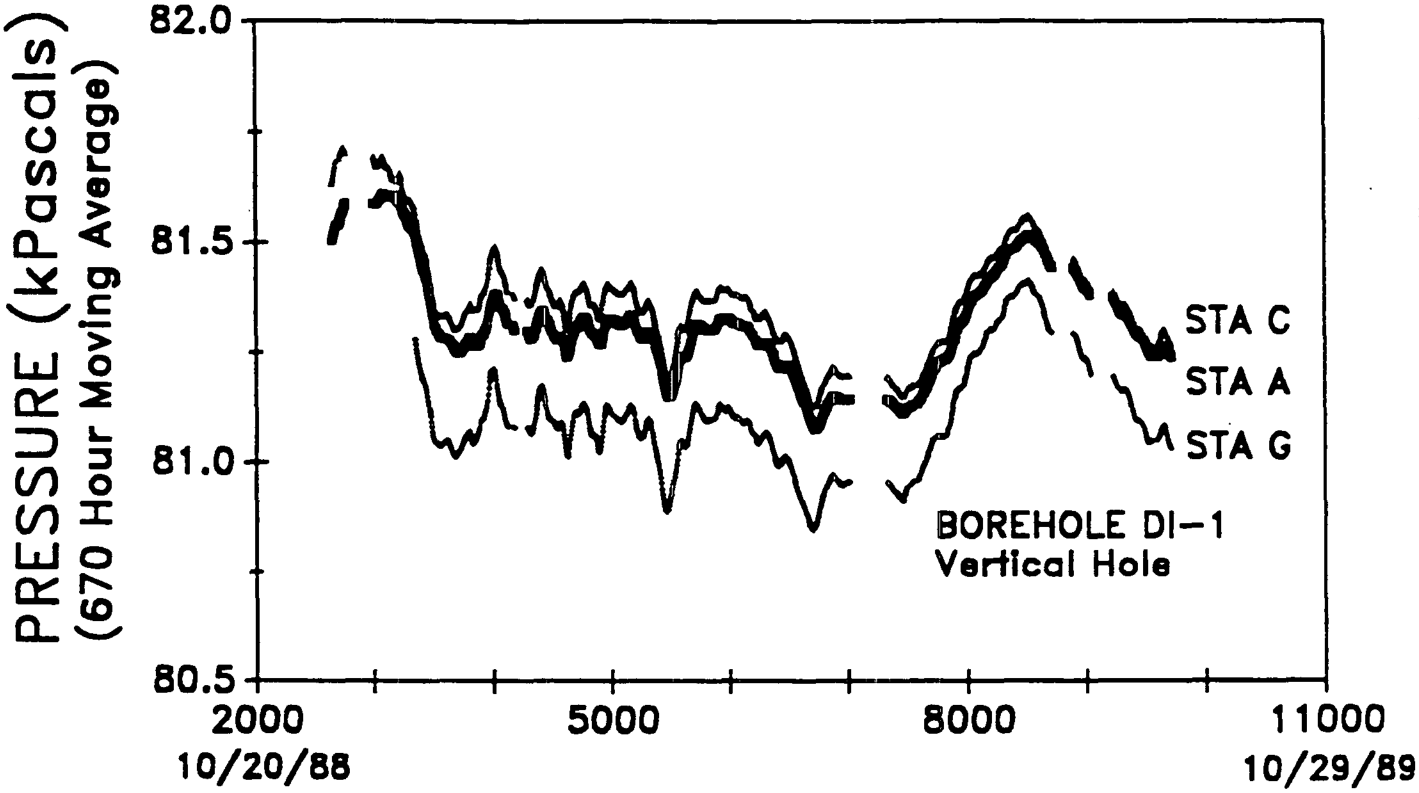
WATER POTENTIAL PROFILES

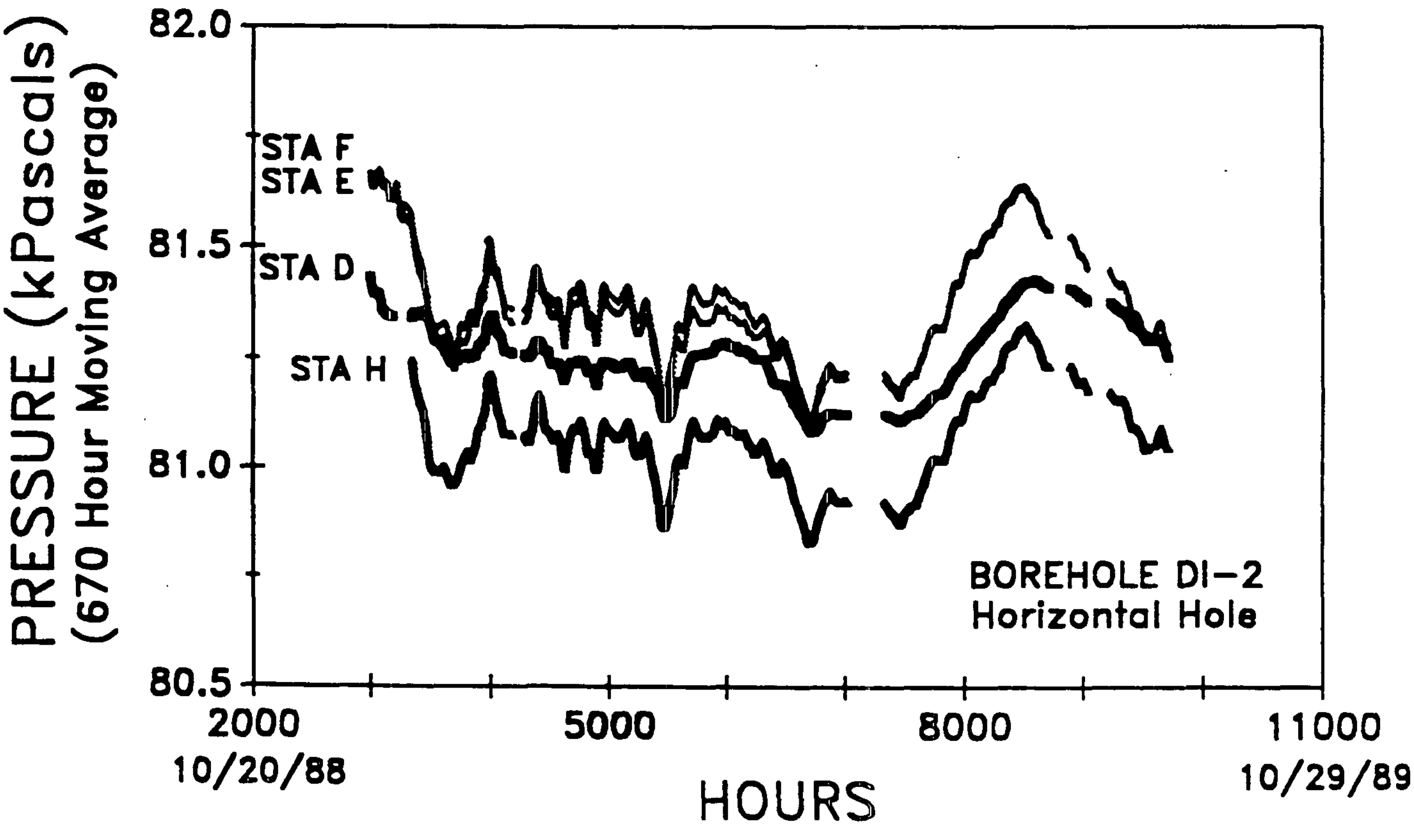
WATER POTENTIAL

DI-2 (HORIZONTAL)



PRESSURE TRANSDUCER RECORD





SUMMARY

- PNEUMATIC PRESSURE GRADIENTS INDICATE THAT CONVECTIVE FLOW OF INTERSTITIAL PORE GASES OCCURS CONTINUALLY BETWEEN THE NEAR–FIELD WALL ROCK AND THE DRIFT

- MEASURED TEMPERATURE CHANGES IN THE NEAR–FIELD WALL ROCK (WITHIN THE FIRST 15+ FEET OF THE DRIFT) ARE LESS THAN PREDICTED TEMPERATURE CHANGES

  - IN SUMMER THE WALL ROCK IS COOLER AND IN THE WINTER WARMER THAN PREDICTED

  - DIFFERENCES BETWEEN PREDICTED AND MEASURED TEMPERATURES ARE BELIEVED TO BE DUE TO EVAPORATION OF INTERSTITIAL PORE WATER IN THE SUMMER, AND TO CONDENSATION OF INTERSTITIAL WATER VAPOR IN THE WINTER DRIVEN BY SEASONAL TEMPERATURE CHANGES IN THE OPEN DRIFT

SUMMARY

(CONTINUED)

- CHANGES IN "APPARENT" WATER POTENTIAL BETWEEN WINTER AND SUMMER (AS MEASURED WITHIN THE FIRST 15 FEET OF THE WALL ROCK) CAN BE ATTRIBUTED TO AN INCREASE IN VAPOR PRESSURE DUE TO EVAPORATION OF LIQUID WATER COUPLED WITH THE CONVECTIVE FLOW OF NEARLY VAPOR SATURATED GASES FROM DEEPER WITHIN THE WALL ROCK

BENEFITS OF IN SITU MONITORING

- OBSERVE THE DYNAMICS OF THE SYSTEM
  - IMPACT OF EPISODIC EVENTS
  - IMPACT OF DIURNAL, SEASONAL, AND ANNUAL HARMONICS
- OBTAIN PNEUMATIC PRESSURE AND TEMPERATURE MEASUREMENTS
- EVALUATE EQUILIBRIUM PROCESSES
- ISOLATE DISCRETE INTERVALS OF INTEREST
  - FRACTURE ZONES
  - STRATIGRAPHIC AND STRUCTURAL CONTACTS
  - HYDROGEOLOGIC BOUNDARIES
- PROVIDE A PLATFORM FOR ISOLATION OF ROCK GASES FOR GEOCHEMICAL SAMPLING