U.S. Department of Energy
Office of Civilian Radioactive Waste Management

YUCCA MOUNTAIN PROJECT

Science and Engineering Update

Presented to:
Nuclear Waste Technical Review Board

Presented by:
Mark T. Peters, Manager
Science and Technology Project
Los Alamos National Laboratory
Bechtel SAIC Company, LLC.

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Overview

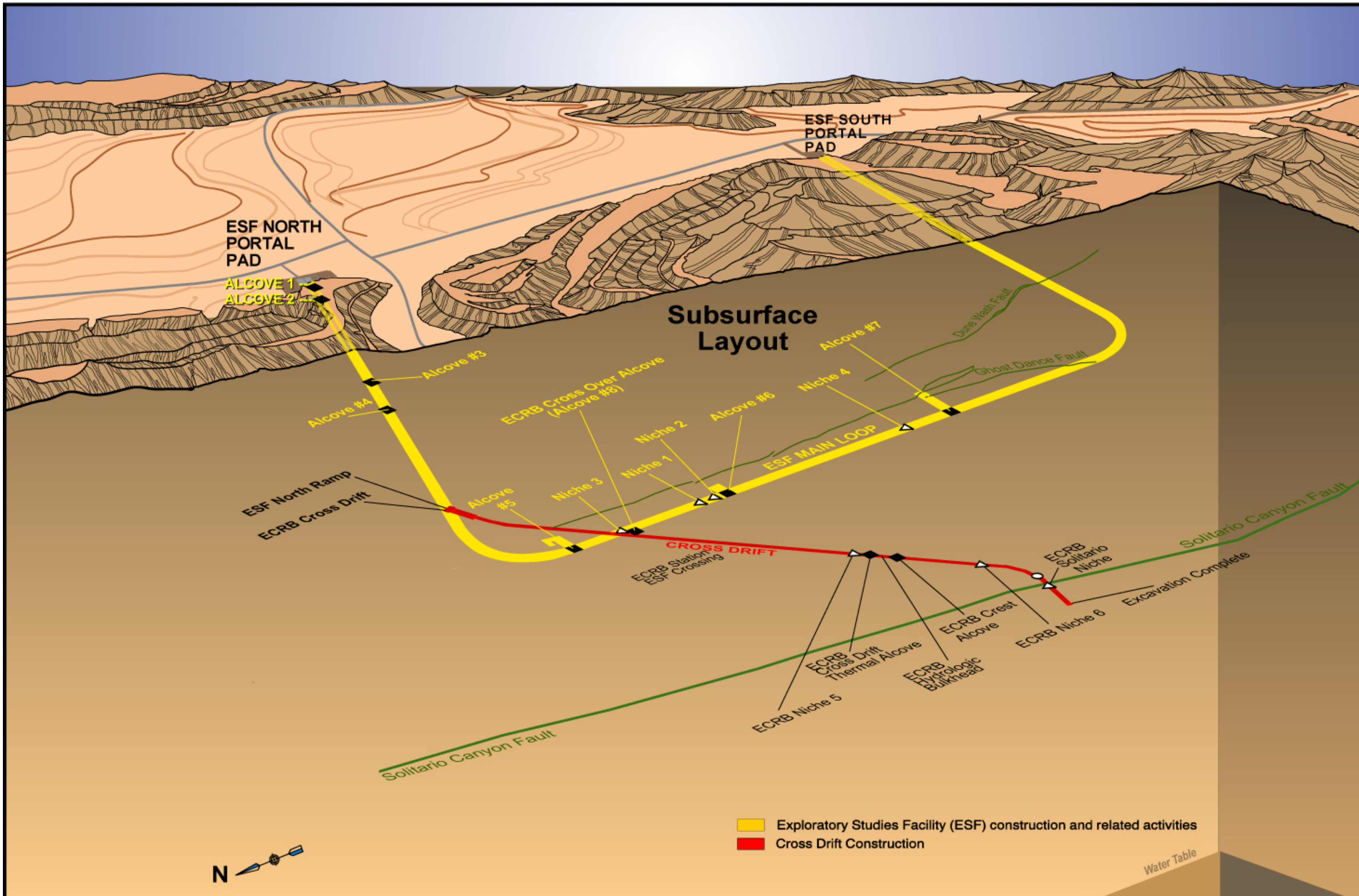
- Objective is to provide status on scientific and engineering data collection and testing program in support of natural and engineered systems process models and design
- Unsaturated Zone (UZ)
  - Exploratory Studies Facility (ESF) Studies
    - Drift Scale Test
    - 36Cl Validation
    - Secondary Fracture Minerals/Fluid Inclusions/Hydrochemistry
  - Cross Drift Studies
    - Lithophysal / Fracture Studies
    - Alcove 8 / Niche 3 (Crossover Alcove)
    - Niche 5 and Systematic Hydrologic Testing
    - Bulkhead Investigations
  - Busted Butte UZ Transport Test

Overview
(Continued)

- Saturated Zone
  - Lithostratigraphy / Hydrostratigraphy / Hydrochemistry
  - Alluvium Sorption Investigations
- Igneous Events Studies
- Engineered Barrier System
  - Thermal Properties Investigations
  - Thermal-Mechanical Rock Properties Investigations
  - Dust Investigations
  - Reactive Transport Studies
  - Waste Form Investigations
- Summary

The data and conclusions presented are preliminary, in various stages of Project review, and not yet all in controlled databases/reports.

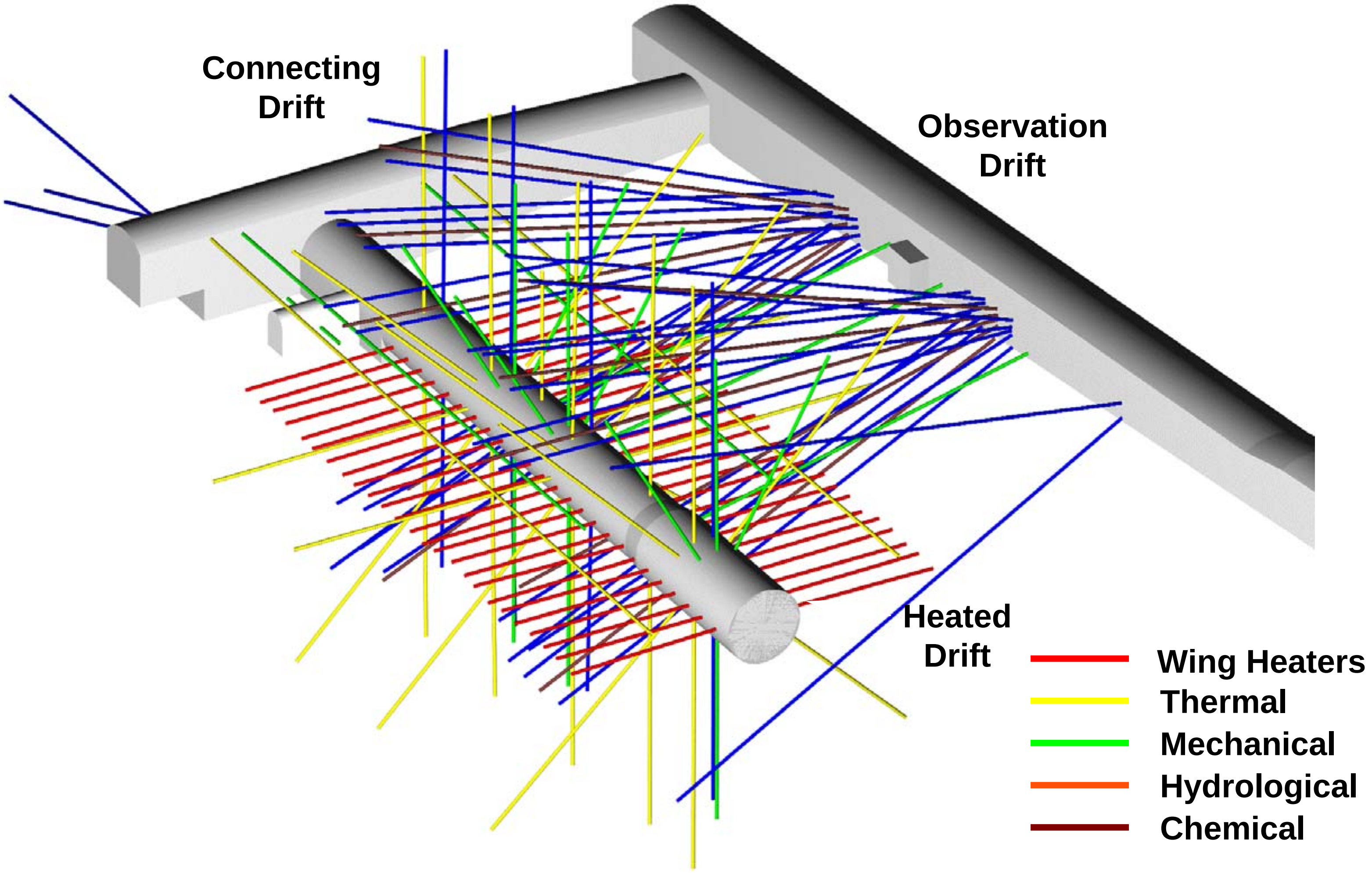
Exploratory Studies Facility and Alcoves



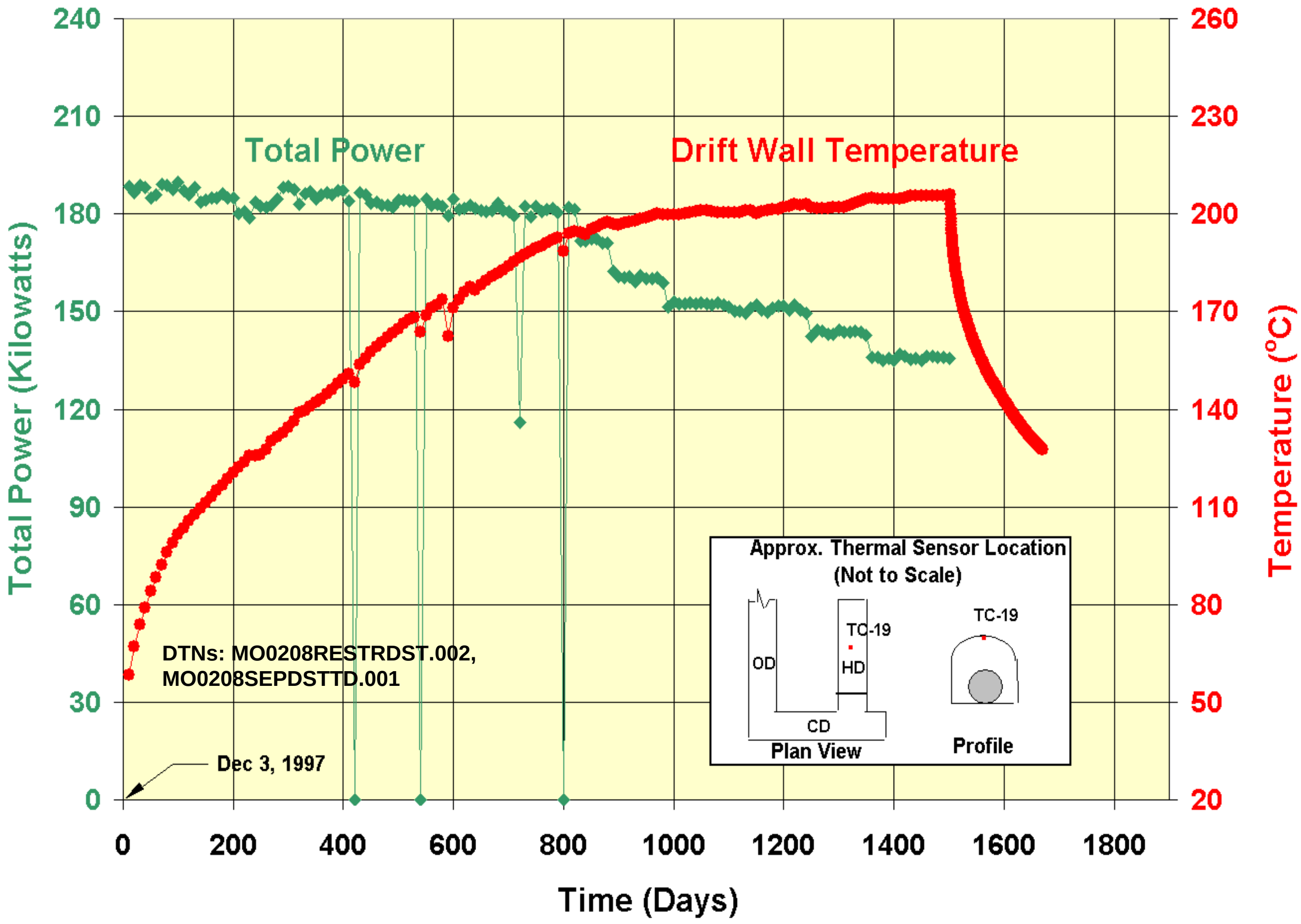
ESF_subsurface_01_03a.ai

Drift Scale Test

Evaluate thermally-coupled processes in potential repository horizon rocks at the field-scale in support of Coupled Process Models, Near-Field Environment Models, and Design



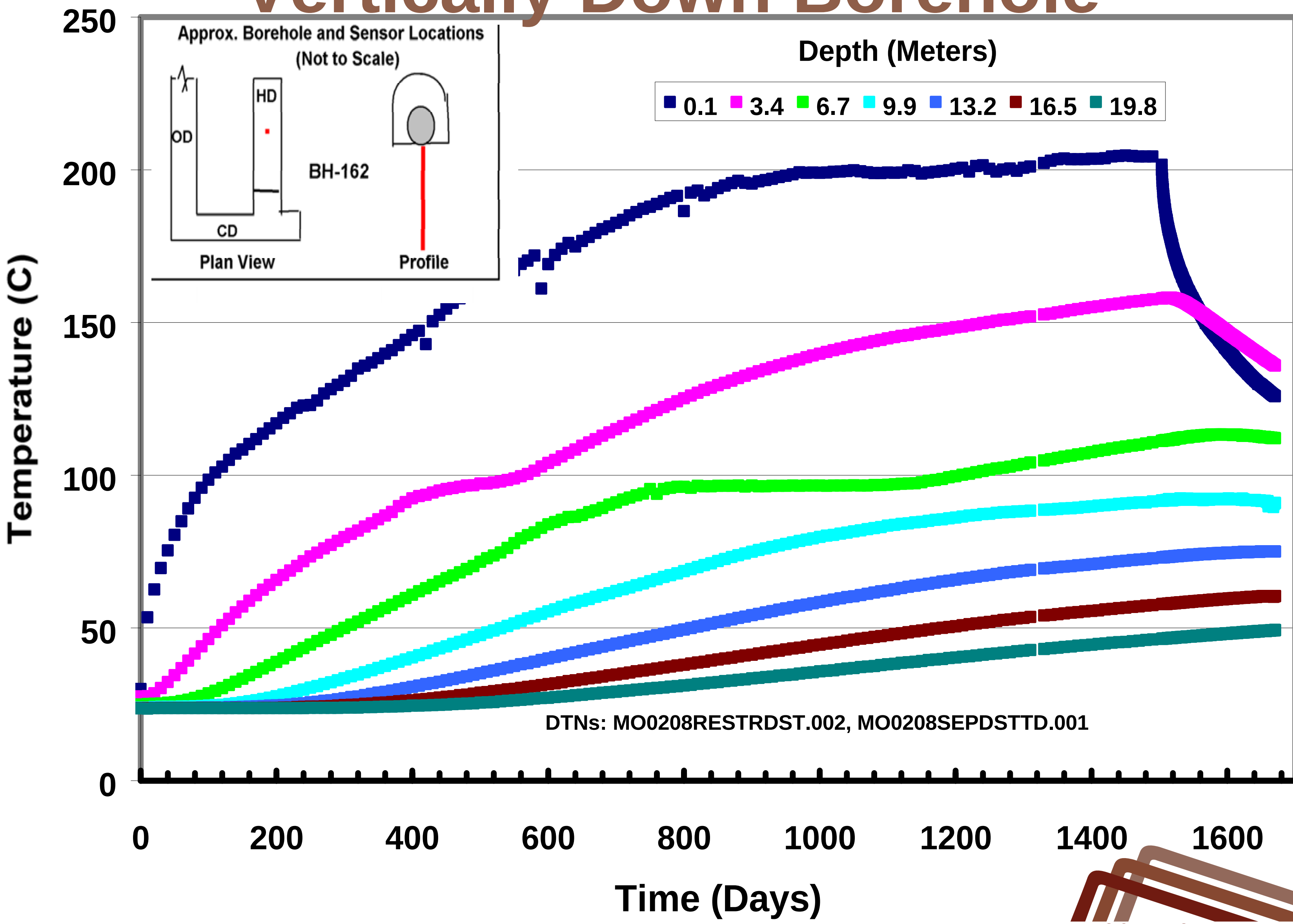
Drift Scale Test:
Power and Temperature History



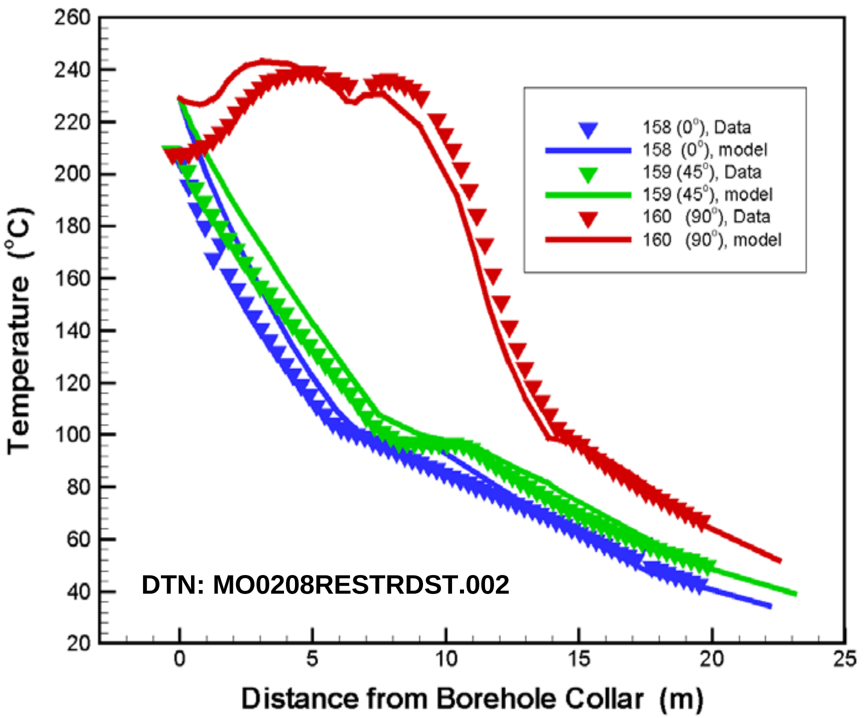
Drift Scale Test:
TH, THC, and THM Model Predictions

- **Temperature in the test block away from the Heated Drift and the wing heaters continues to rise**
- **Heat-pipe signatures are not expected as temperature cools from above to below boiling**
- **CO2 concentrations continue to change gradually in the rock during cooling phase - consistent with modeling**
- **Modeled fracture saturations indicate that little water is likely to be collected in boreholes during cooling - consistent with observations**
- **Air-permeability measurements confirm modeled predictions of TH processes (drying and wetting in fractures) and THM processes (closing and opening of fractures)**

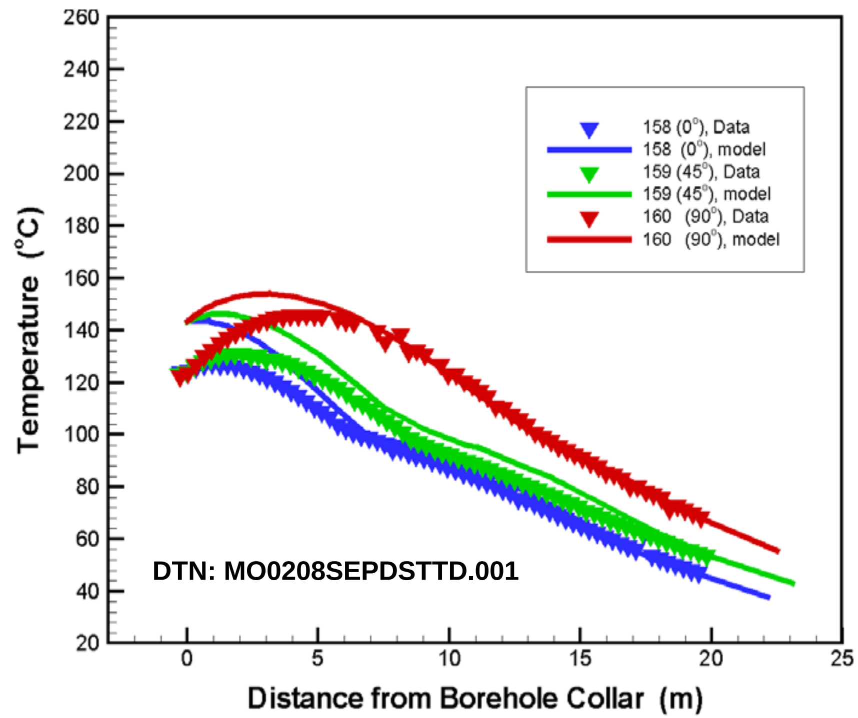
Drift Scale Test: Temperature Histories for Vertically Down Borehole



Drift Scale Test: Disappearance of Heat-Pipe Signature During Cooling Phase as Water Drained and Vapor Diminished

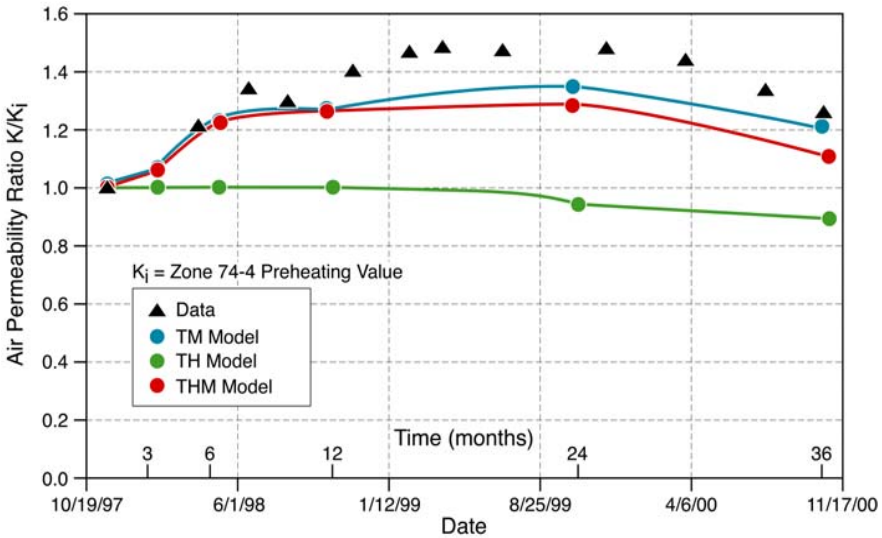


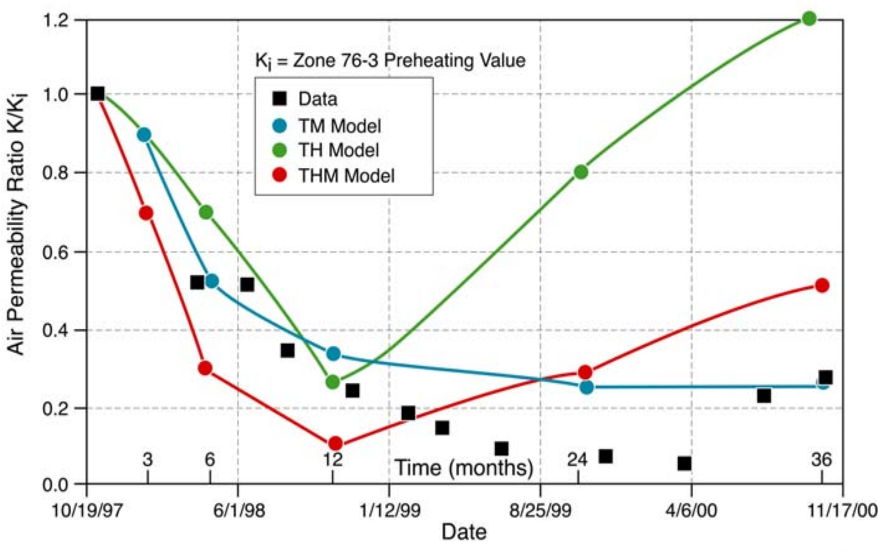
48 Months of Heating

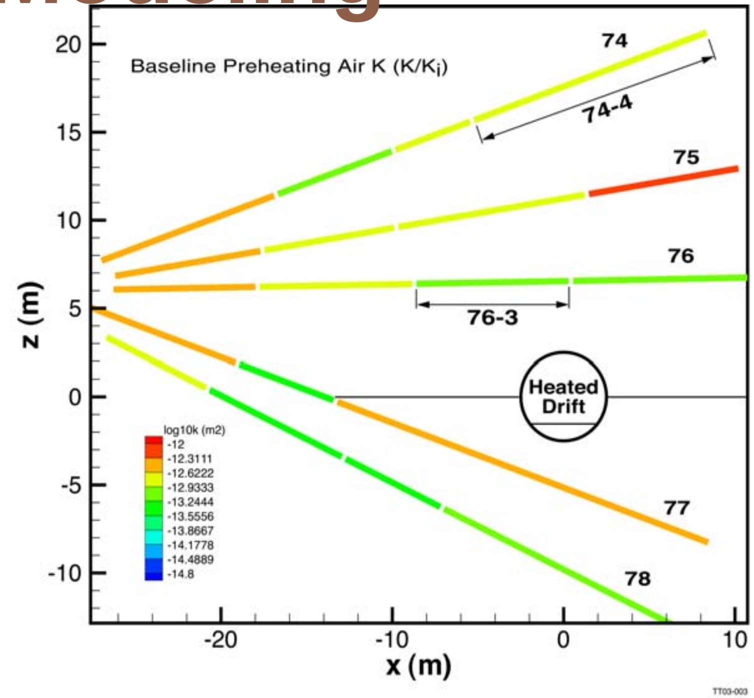


6 Months of Cooling

Drift Scale Test: Air-Permeability Data and TH and THM Modeling







- Due to its distance from anticipated drying and wetting regions, zone 77-4 air permeability data reflects mostly TM processes.
- Zone 76-4 air-k data reflects both TH and TM processes
- DTN: LB0208AIRKDSTH.001

Drift Scale Test: Water from Borehole 75 - Zone 2

- **Abnormal water chemistry occurred in six samples (February 19th to June 26th, 2002) from one of 46 collection zones**
- **Water Sample Characteristics:**
  - **Samples were distinguished by a dark yellow color**
  - **Conductivity measured 10 to 100 times stronger than other Drift Scale Test (DST) waters**
  - **Relative to ambient pore water, samples contained unusually high amounts of Cr, Mn, Ni, Zn, Na, Ca, SO4 , and Cl**
- **Investigation included the following:**
  - **Literature search on neoprene thermal degradation**
  - **Complete chemical analysis of waters collected**
  - **Laboratory tests to determine possible sources of chloride and other water contaminants using hydrothermal reactor vessels loaded with packer materials**
- **Tests indicate that neoprene packer materials become unstable at temperatures exceeding 60°C**

Drift Scale Test:
Red Spot on Floor Heater

- **Review of video from remote camera resulted in the following observations of the "red spot":**
  - **Located on the top of a floor heater approximately 32 meters from bulkhead**
  - **Also visible on floor and nearby power connection**
  - **Occurred between March 20th and September 18th of 2002**
- **Analyses of swipe sample indicate the "red spot" is mostly iron oxide with traces of alumina and silica**
- **Mostly likely source of the iron oxide, based on current investigations, is an overhead rock bolt**
- **Ongoing investigations include additional swipes, additional video from remote camera, and effect of rock bolt boreholes on thermal seepage**

^{36}Cl Validation

- Validate occurrence of "bomb-pulse" ^{36}Cl at two locations in the ESF (Sundance Fault Zone and Drillhole Wash Fault Zone) in support of UZ Flow Model
- Update
  - Final USGS/LANL/LLNL report currently in progress - due date – June 2003
    - Will include a path forward (further experiments for consideration)
  - Conceptual model for UZ flow and UZ process and Total System Performance Assessment (TSPA) models do not rely directly on this data and will not be modified based on results to date
  - DOE is also pursuing an independent study of ^{36}Cl/Cl systematics - to be conducted by completely independent expert(s)

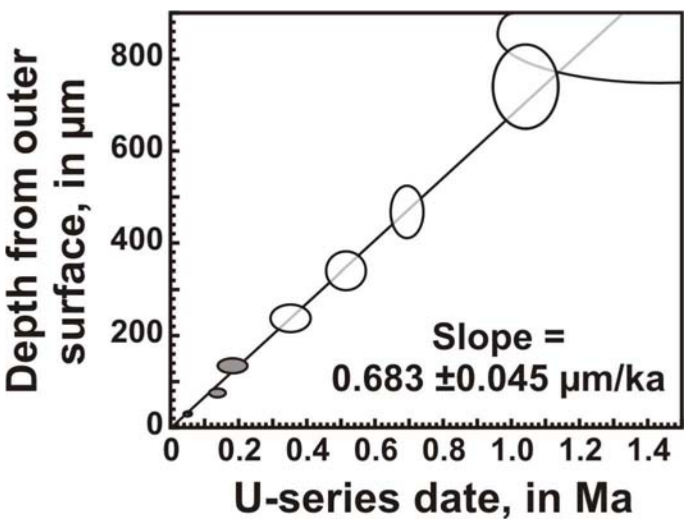
Secondary Fracture Minerals

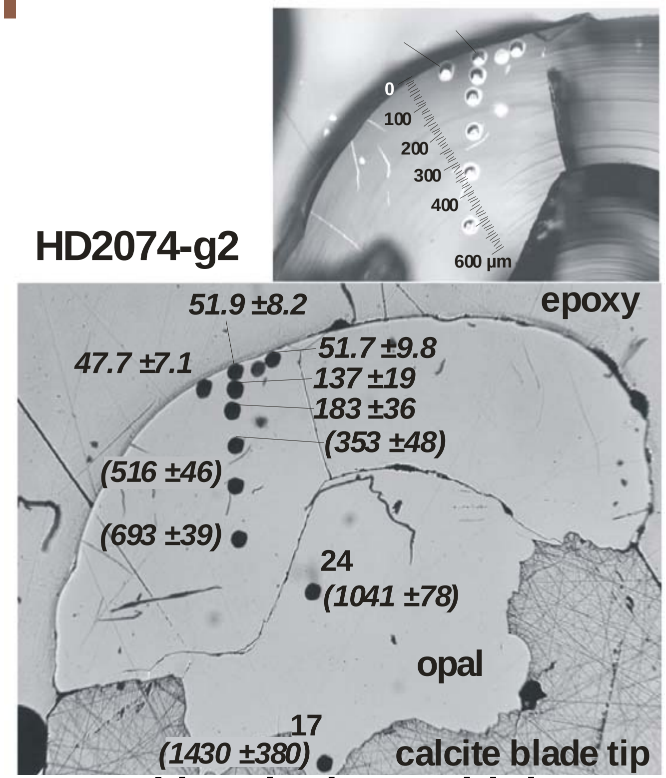
- Ongoing studies of fracture minerals
- Confirm slow mineral growth rates throughout the Quaternary
- Establish a linkage between climate variations and UZ percolation flux
- Add confidence to the UZ flow and transport models by integration of climate records

Secondary Fracture Minerals (Continued)

U-series Ion-Probe Dating of Unsaturated Zone Opal

- Ion-microprobe data using ~35 µm-diameter spots traversing several individual opal hemispheres
- U-series ages indicate uniform average growth rates of 0.5 and 0.7 µm/k.y. over the past ~1.5 million years - consistent with long-term average percolation fluxes





Opal hemisphere with ion-probe spots and resulting U-series ages (in ka)

- Slower Pleistocene growth rates (compared to 1-5 µm/k.y. Tertiary rates) may reflect decreasing moisture during the Quaternary

Thermal History of the Unsaturated Zone Fluid Inclusion Studies

- **During 1999-2002, the U.S. Geological Survey (USGS) studied the timing and distribution of secondary-mineral-hosted fluid inclusions**
  - **fluid inclusions in calcite indicate that depositional temperatures have ranged from present-day ambient to as high as 90°C**
  - **Depositional temperatures are highest in the older parts of deposits**
  - **Calcite delta ^{18}O values correlate with and corroborate the fluid inclusion temperatures**
  - **Both the fluid inclusion and delta ^{18}O data indicate that calcite/opal deposition has been at or near present-day ambient temperatures for the past 2 to 4 m.y.**

U-Series Delineation of Flow Paths

- Radioactive disequilibrium in the U-series decay chain is a consequence of water/rock interactions
- The degree of U-series disequilibrium in bulk-rocks
  - Is a function of hydrologic conditions
  - Is proportional to the amount of water flux
  - Integrates the effects of water/rock interactions throughout the Quaternary
- U-series disequilibrium in bulk rocks offers a geochemical test to build confidence in various aspects of the UZ flow and transport model

U-Series Delineation of Flow Paths

(Continued)

- **Recent Work**
  - **Focused on demonstrating analytical feasibility using two contrasting underground hydrogeologic settings:**
    - **Proposed repository-level samples not associated with faulting**
    - **Near-surface samples at the Bow Ridge fault zone**
  - **Samples of deeper, unfaulted rock are expected to have**
    - **Smaller amounts of water/rock interaction**
    - **$^{234}U/^{238}U$ and $^{230}Th/^{238}U$ close to equilibrium (activity ratios ~1.0) - consistent with preliminary results from proposed repository horizon samples**
  - **Samples of shallower faulted rock are expected to have**
    - **Focused flow and greater water/rock interaction**
    - **Greater ^{238}U-^{234}U-^{230}Th disequilibrium - consistent with preliminary results from Bow Ridge Fault samples**

Geochemistry of Pore Water

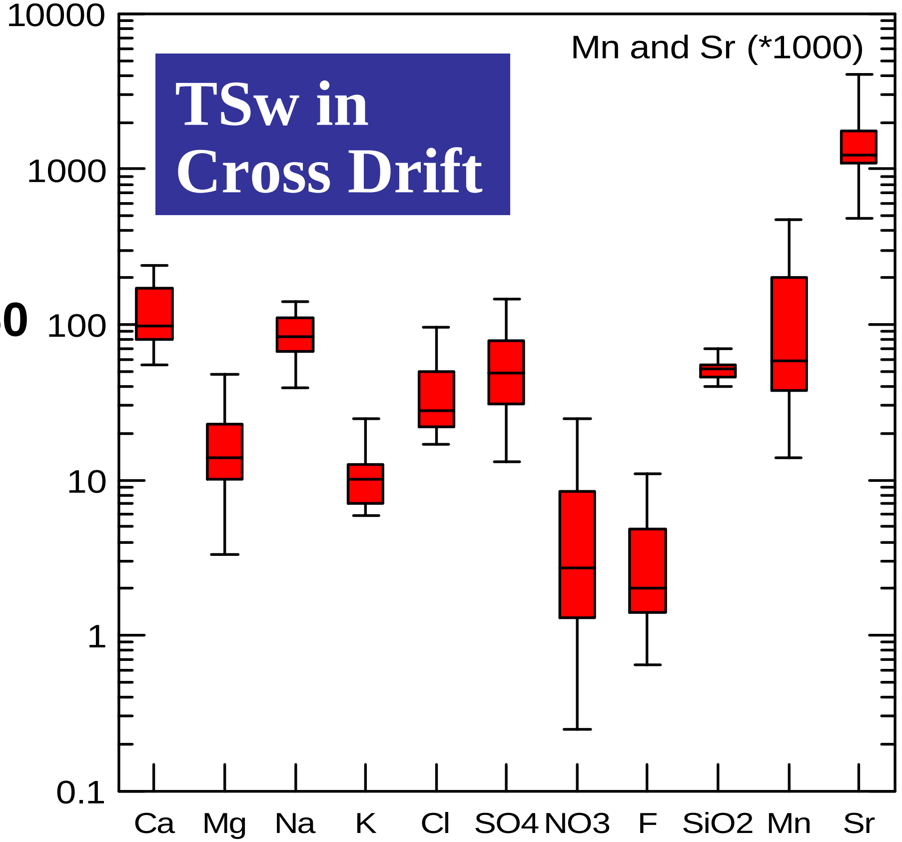
- **Relevance of pore water compositions to the UZ hydrologic system**
  - **Tuffs contain several liters of water per m^3 of rock**
  - **Pore water may seep into drifts and contact waste packages**
  - **Evaporation of pore water on drift walls supplies salts to dust load**
  - **Pore water composition must be known to understand total hydrologic system**

Geochemistry of Pore Water
(Continued)

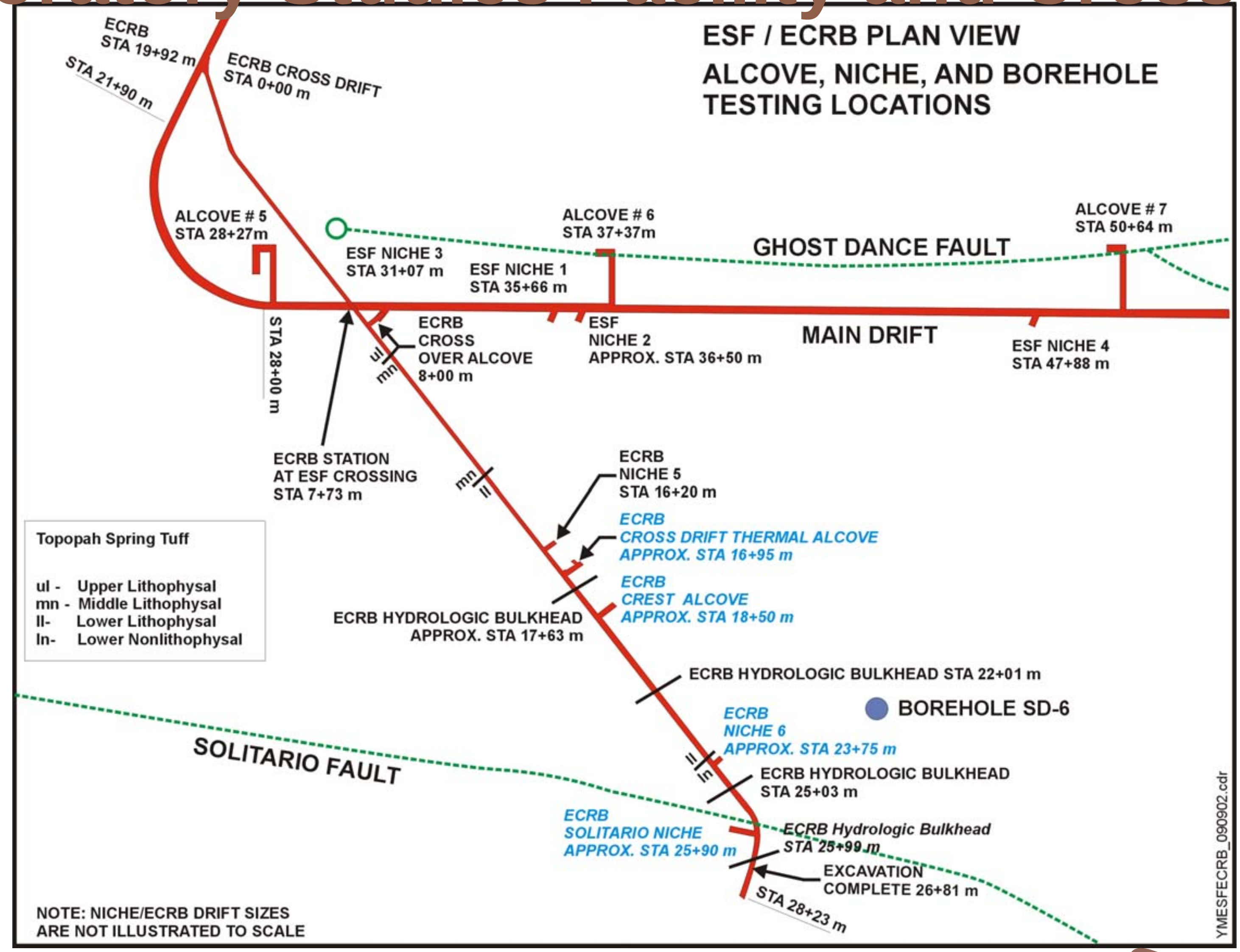
- **Pore water is extracted from dry drilled core by**
  - **Compression of nonwelded tuffs and**
  - **Ultracentrifugation of welded tuffs in 150 gram batches**
- **Chemical (major and trace anions and cations) and isotopic (O, H, C, Sr, and U) analyses are conducted on extracted samples**

Geochemistry of Pore Water
(Continued)

- **Compositional Variability (n=28)**
  - **Variability at meter scale**
  - **Nitrate shows greatest variability**
  - **Silica shows least variability**
  - **Variability of alkaline earths is ±60 percent**
  - **Variability of alkalies is ±35 percent**
  - **Integrated with waste package environment and corrosion studies**



Exploratory Studies Facility and Cross Drift



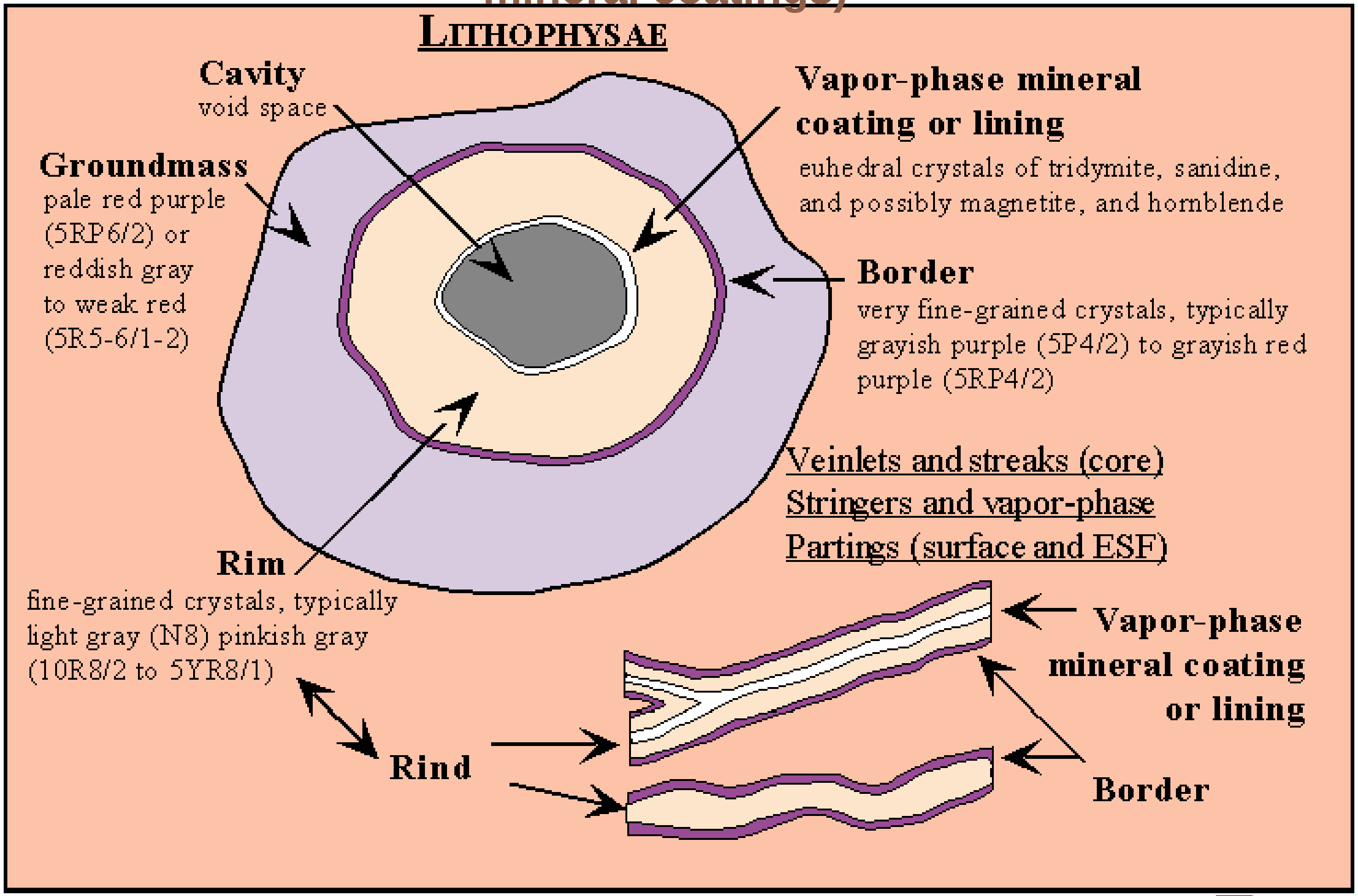
Lithophysal / Fracture Studies

- **Objective is enhanced understanding of fracture geometry and relations to lithophysae -- important link to thermal and mechanical properties investigations**
- **Methods of Lithophysal Data Collection**
  - **Visual estimates – entire Enhanced Characterization of the Repository Block (ECRB) Cross Drift (1998)**
  - **Panel Maps – 1 X 3 m photomosaics - Topopah Spring Lower Lithophysal (Tptpll)**
  - **Tape Traverses – Physically measured "line" traverses on 5m centers throughout the Tptpll**
  - **Angular Traverses – Laser traverses at selected locations in the Tptpll**
  - **Large Lithophysae Survey – Locating only lithophysae >50 cm in size in upper Tptpll**

Lithophysal / Fracture Studies (Continued)

Lithophysae, Spots, and Vapor Pathways

(spots are the same as lithophysae, but do not have cavities and vapor-phase mineral coatings)

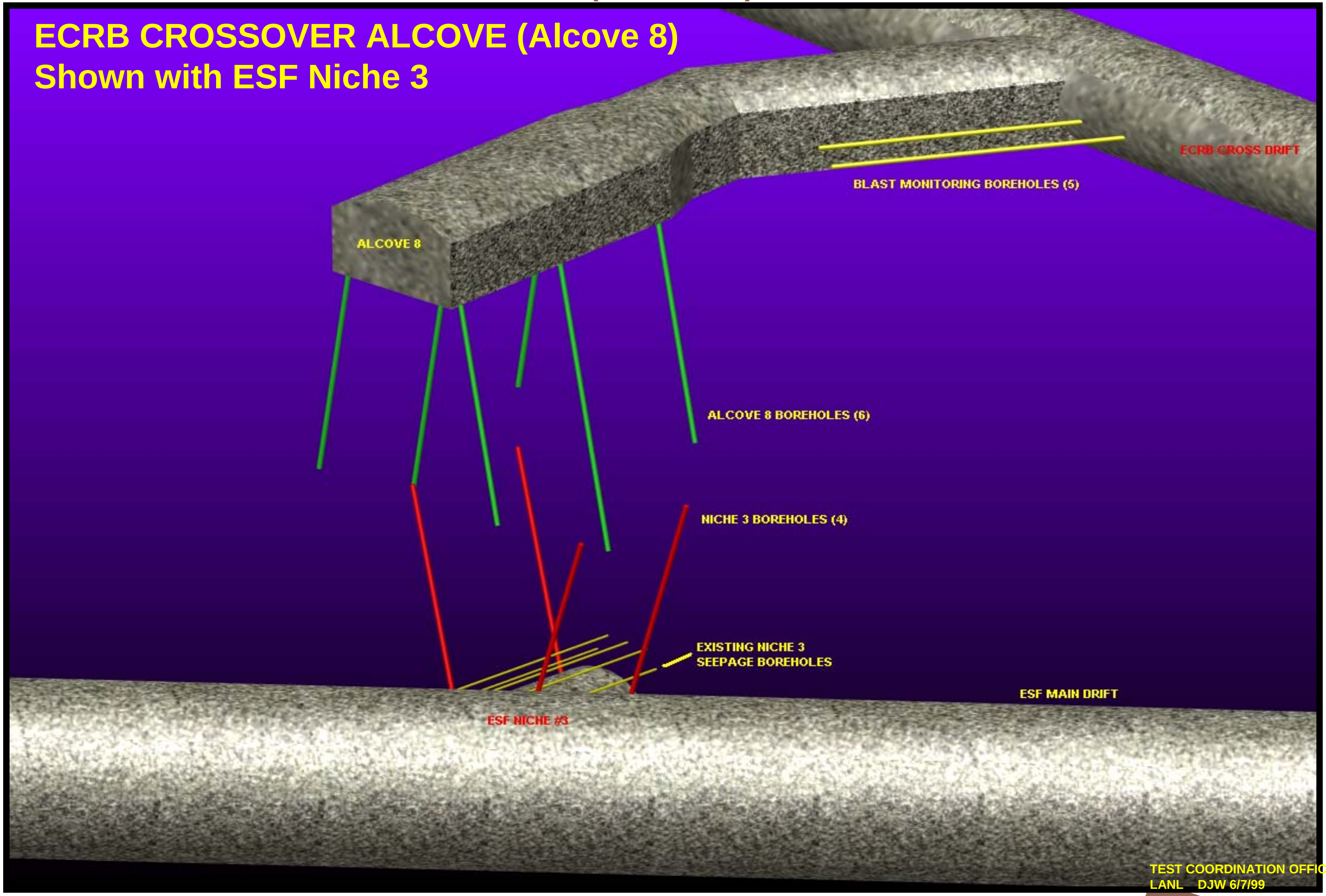


Cross Drift Studies

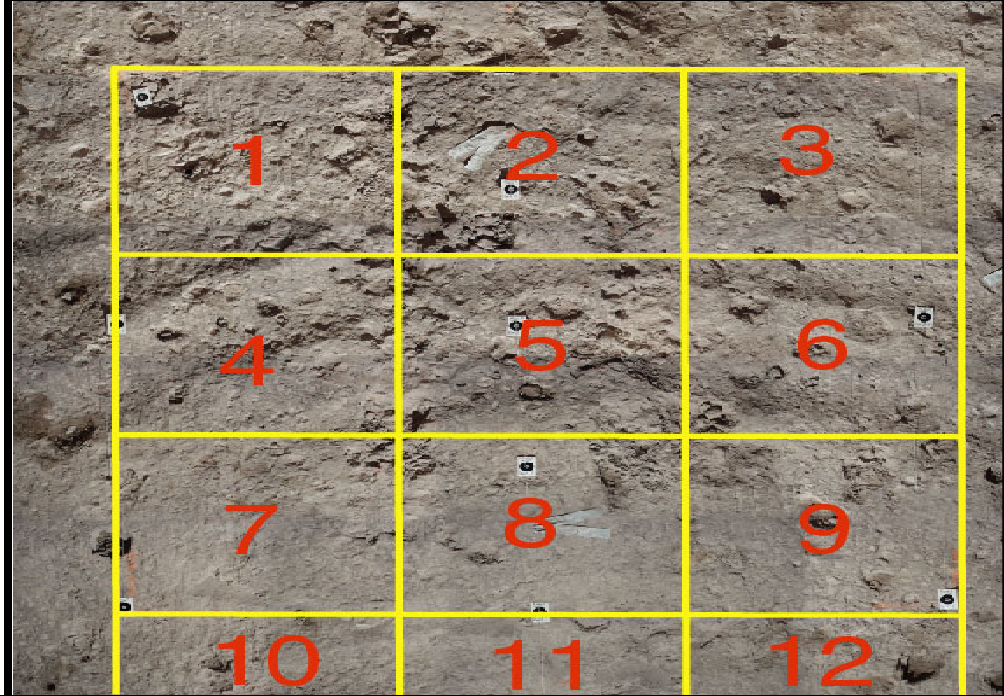
- **Alcove 8 / Niche 3 (Crossover Alcove) (Station 8+00 meters)**
  - **Evaluate flow and seepage processes in potential repository horizon rocks at scale of tens of meters**
  - **Supports UZ Seepage and Transport models**

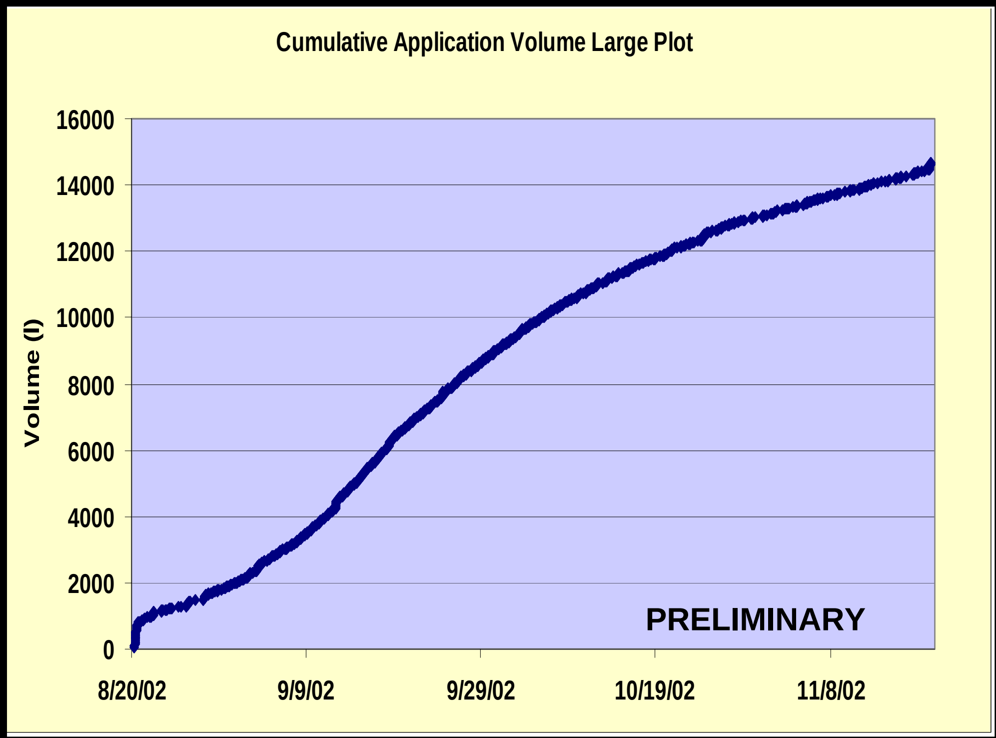
Cross Drift Studies

(Continued)

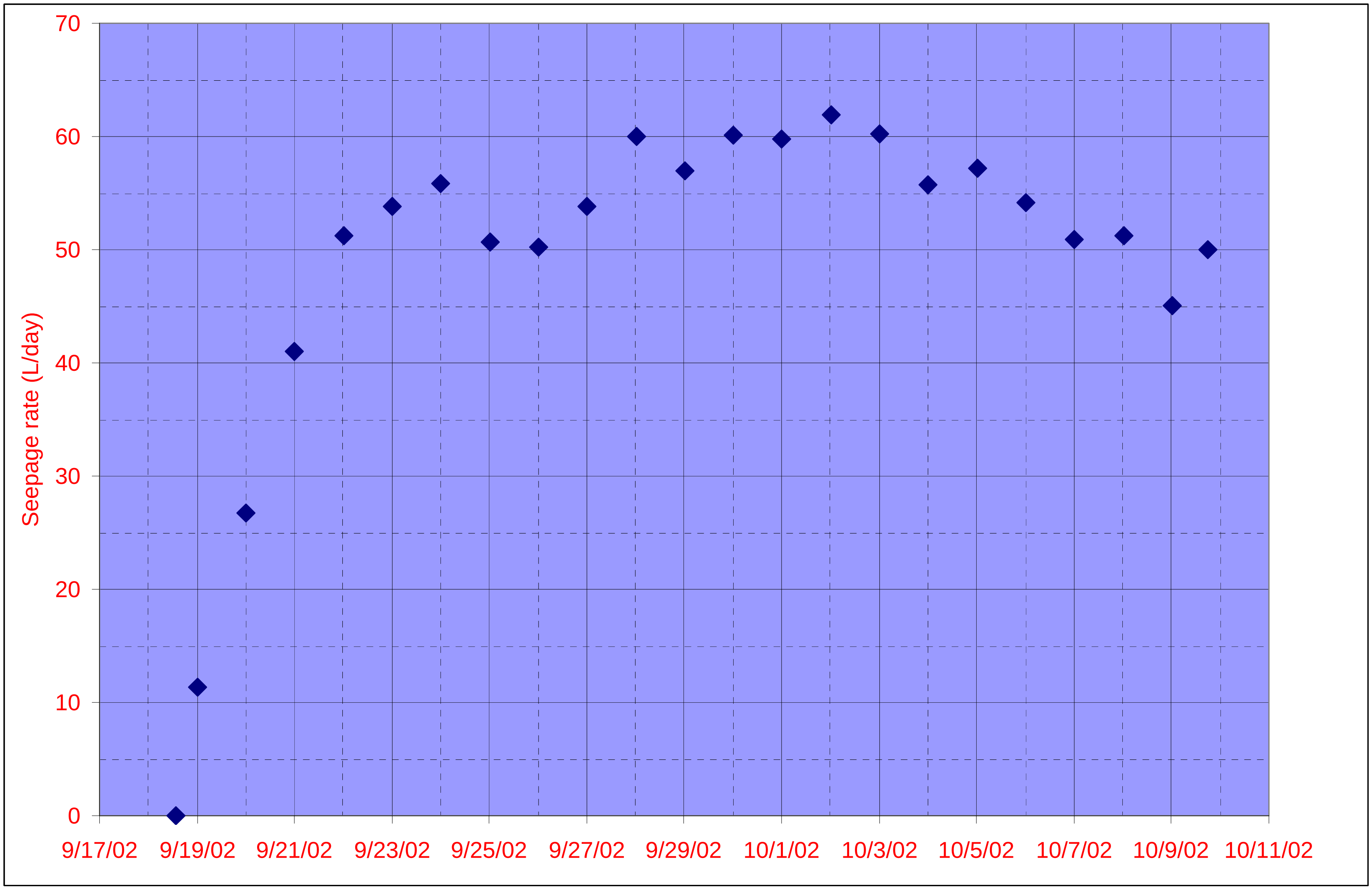


- **LARGE PLOT EXPERIMENT**
  - **Saturated application began on 8-20-02 and continues.**
  - **Three zones of water application, Z1 = 1,2 Z2 = 3,4,5,6,7,8,9 Z3 = 10,11,12**
  - **Infiltration rate of fast zone 3.20 cm/day**



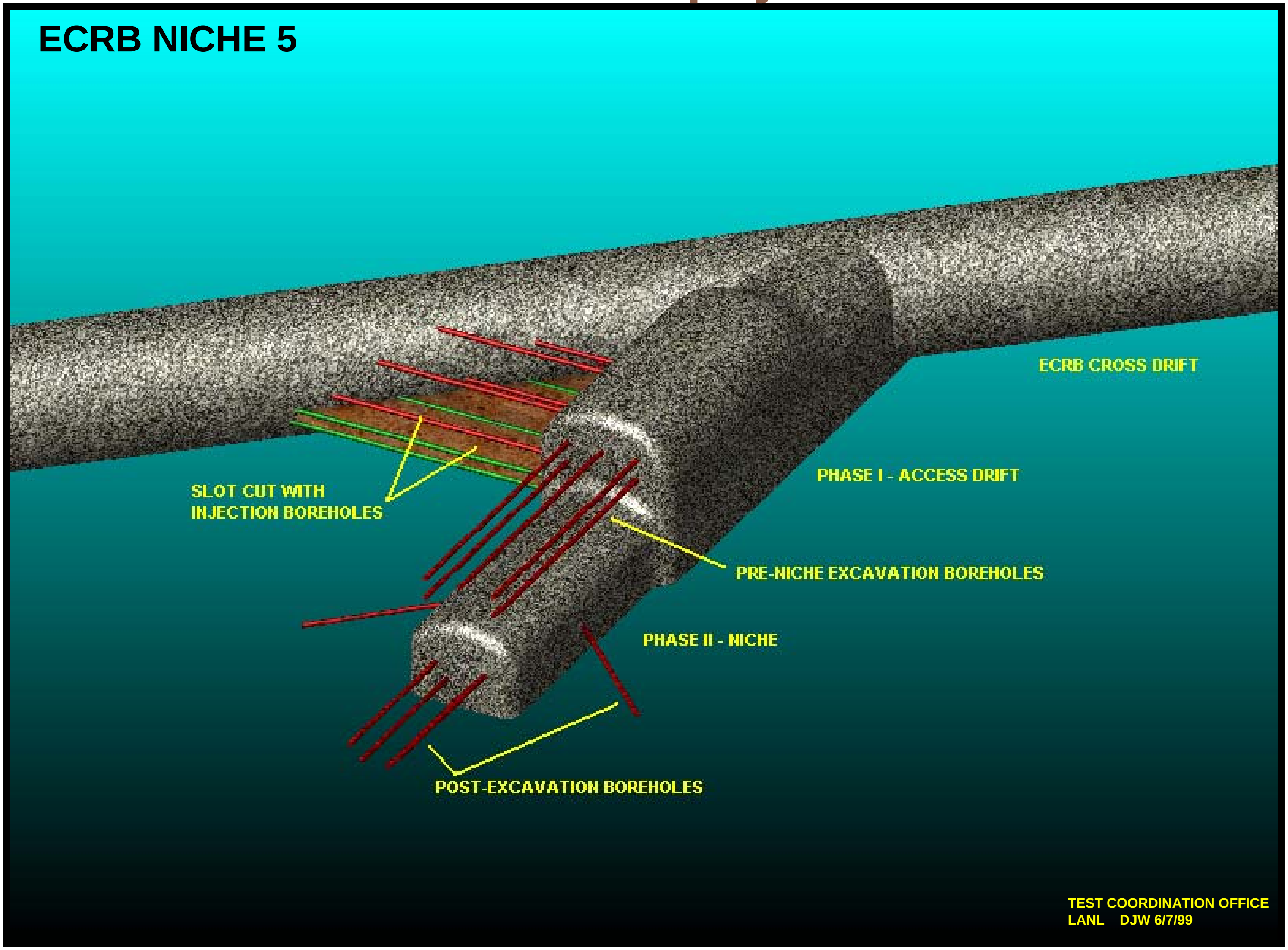


Seepage rates measured in Niche 3 following liquid release in large block in Alcove 8 on August 20, 2002

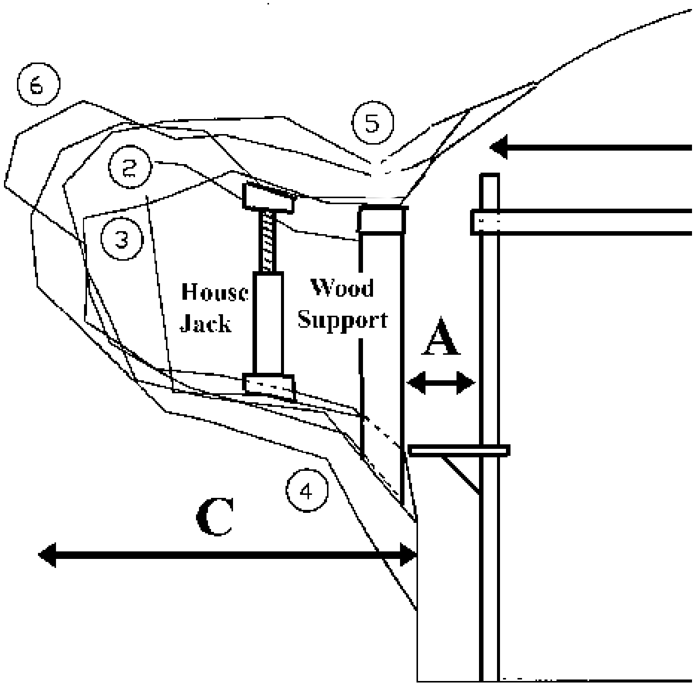


Cross Drift Studies

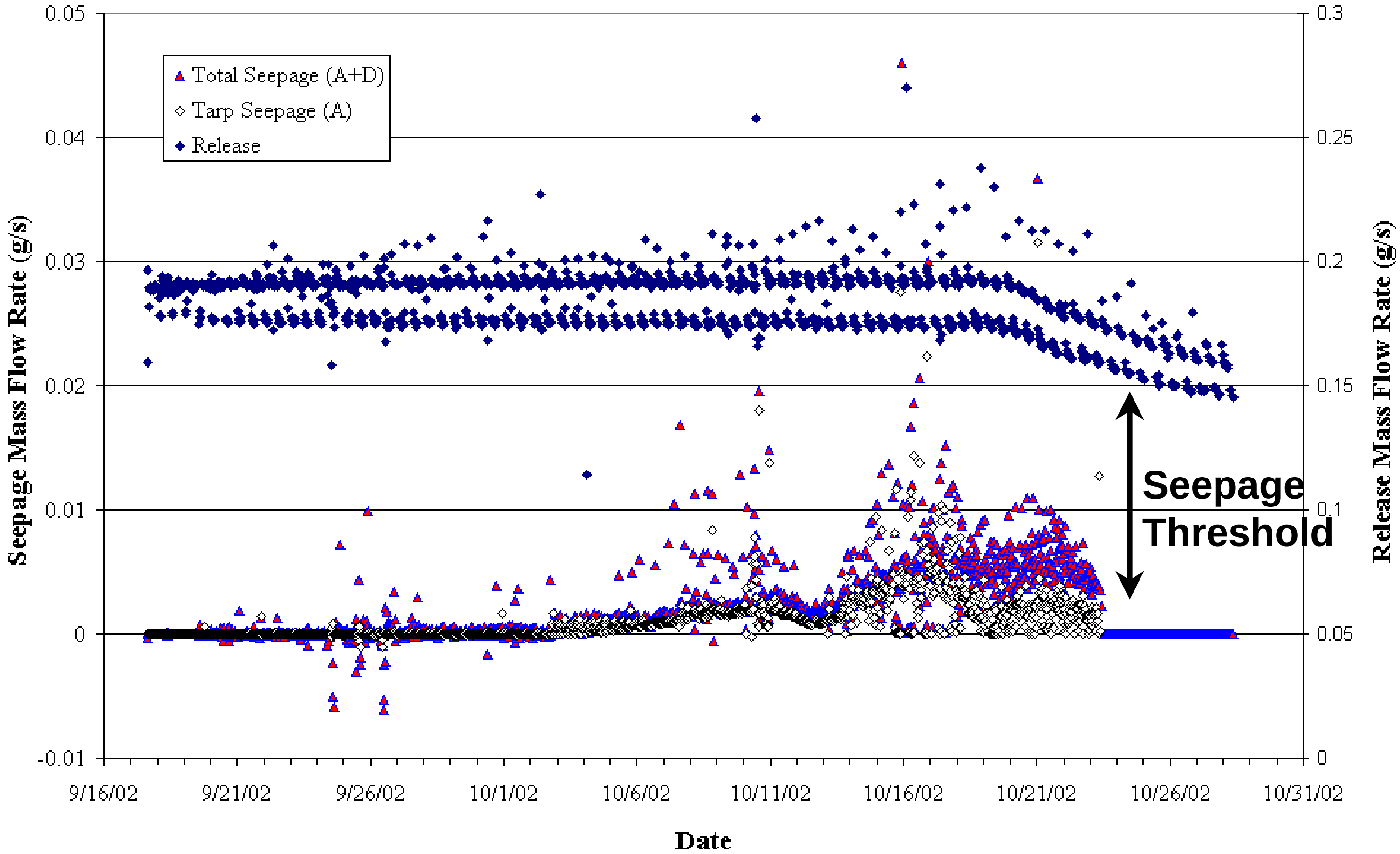
Niche 5 — Supports UZ Seepage Models — Evaluate Seepage in Lower Lithophysal Unit



Niche 5 (Continued)
Seepage Collection



Niche 5 (Continued)
Release and Seepage Mass Flow Rates Test #2 9-17-02

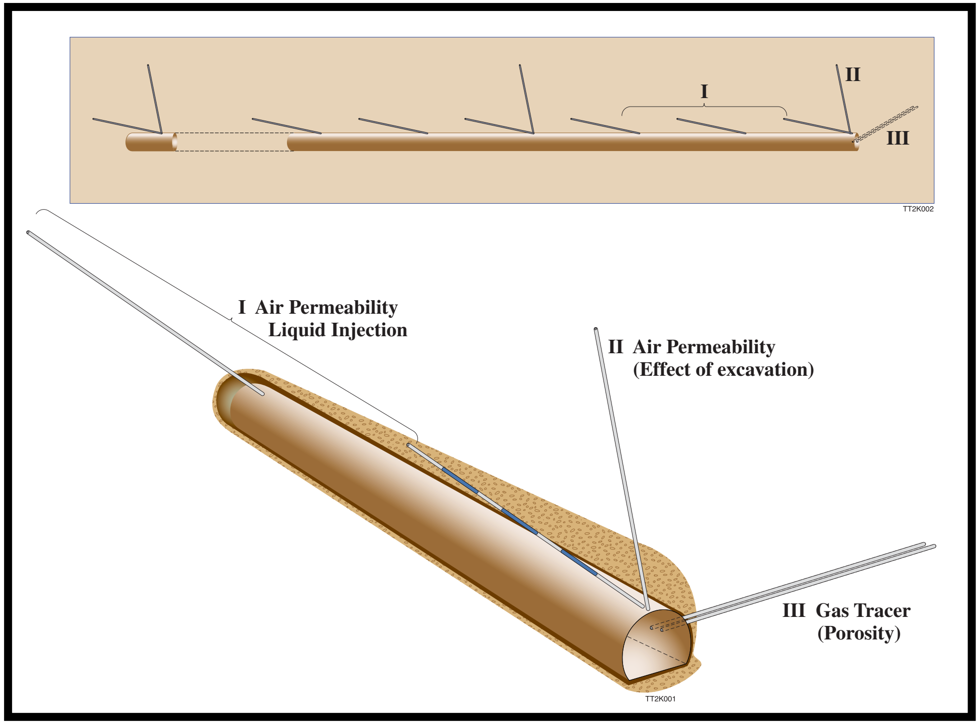


Niche 5 (Continued)
Objectives / Results

- Data being used to calibrate and validate the drift-scale seepage model
- Demonstrated that a capillary barrier and seepage threshold exist in the Tptpll
- Could not definitively show that lateral flow occurred into slot by visual inspection
  - However, photographic evidence indicates liquid released above the ceiling reaches the niche wall

Cross Drift Studies Systematic Hydrological Testing in the Topopah Spring Lower Lithophysal Unit

- Supports UZ Seepage Model - Heterogeneity of fracture characteristics, permeability, and seepage
- Perform hydrological tests in 20-m long boreholes drilled at regular intervals (every 30 meters) along the Cross Drift regardless of specific features (fractures, lithophysal cavities etc.)
- Equipment systems (for air-k and liquid release tests) fitted on flatcar units are moved from one borehole station to another



Systematic Hydrologic Testing (Continued)

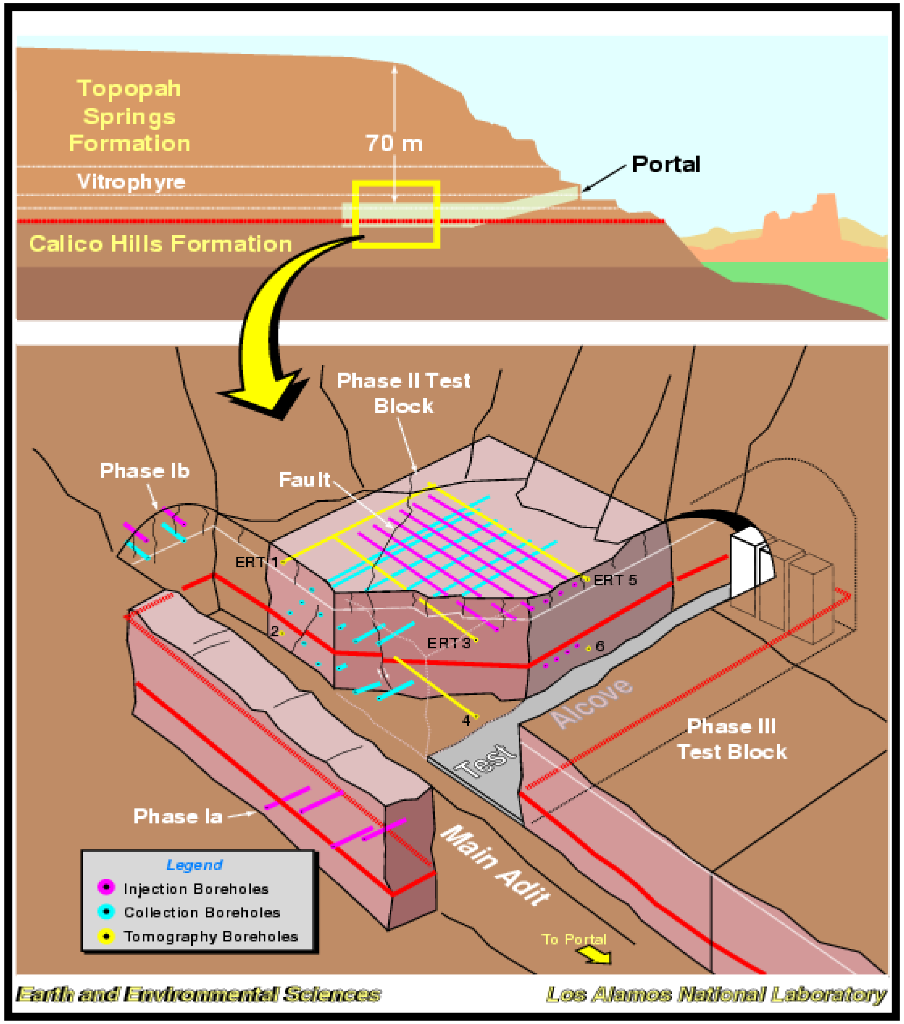
Systematic Approach Designed to Evaluate Spatial Heterogeneity

- Variability in formation response at different locations
  - Some of the test locations do not let any water enter the formation; all introduced water returned in overflow
  - Some locations show complete diversion of all water from entering the drift regardless of uptake rate
  - Most test zones show partial diversion of introduced water from entering the drift
- Flow characteristics common to all locations
  - Small fractures and lithophysal cavities connect to provide discrete, preferential flow paths
  - Participation of lithophysal porosity in liquid flow paths is small
- This variability is being addressed within the drift-scale seepage model

Cross Drift Studies (Continued)
Bulkhead Investigations

- Evaluate flow and seepage processes in potential repository horizon rocks and Solitario Canyon Fault Zone in support of UZ Flow and Seepage Models
- Terminal 918m of the Cross Drift isolated from ventilation to observe in situ drift conditions and re-wetting after closing bulkheads
- Monitor for free liquid water from either seepage or condensation
- Multiple lines of evidence (e.g., water chemistry, moisture distribution) suggest condensation is dominant
- Ongoing and planned testing and analysis program in place to address observations

Busted Butte Unsaturated Zone Transport Test



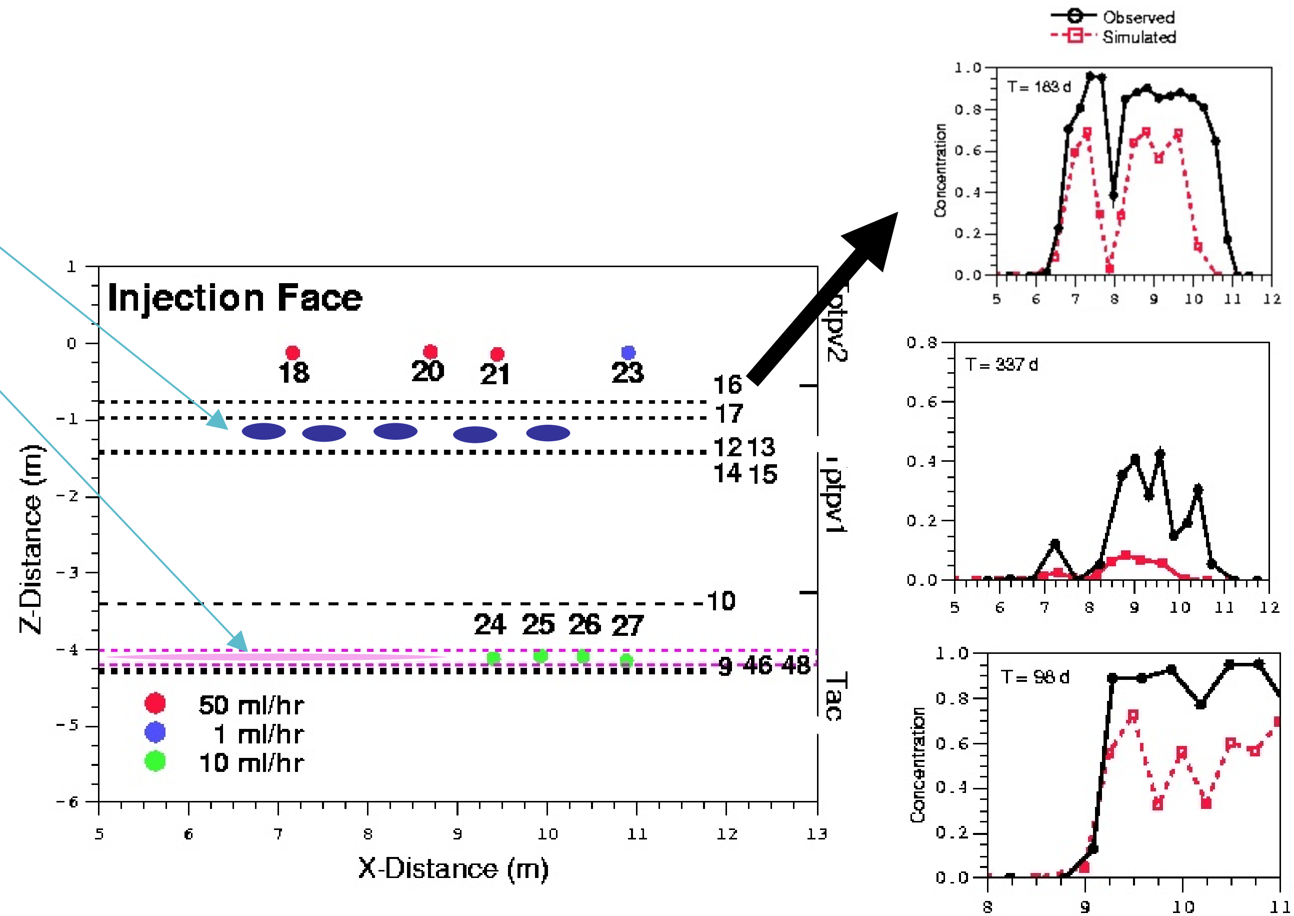
- Evaluate influence of heterogeneities on flow and transport
- Evaluate other aspects of site, including fracture/matrix interactions and permeability contrast boundaries
- Consider colloid migration in unsaturated zone
- Test use of laboratory sorption data at field scale
- Calibrate and validate site-scale UZ flow and transport model
- Address scaling issues

Busted Butte Unsaturated Zone Transport Test
(Continued)
Modeling Goals

- **Apply model used in site-scale predictions to small-scale test at Busted Butte**
- **If model accurately predicts small-scale field behavior, our confidence in site-scale predictions is increased**

Busted Butte Unsaturated Zone Transport Test
(Continued)
Permeability Contrast Results: Phase 2

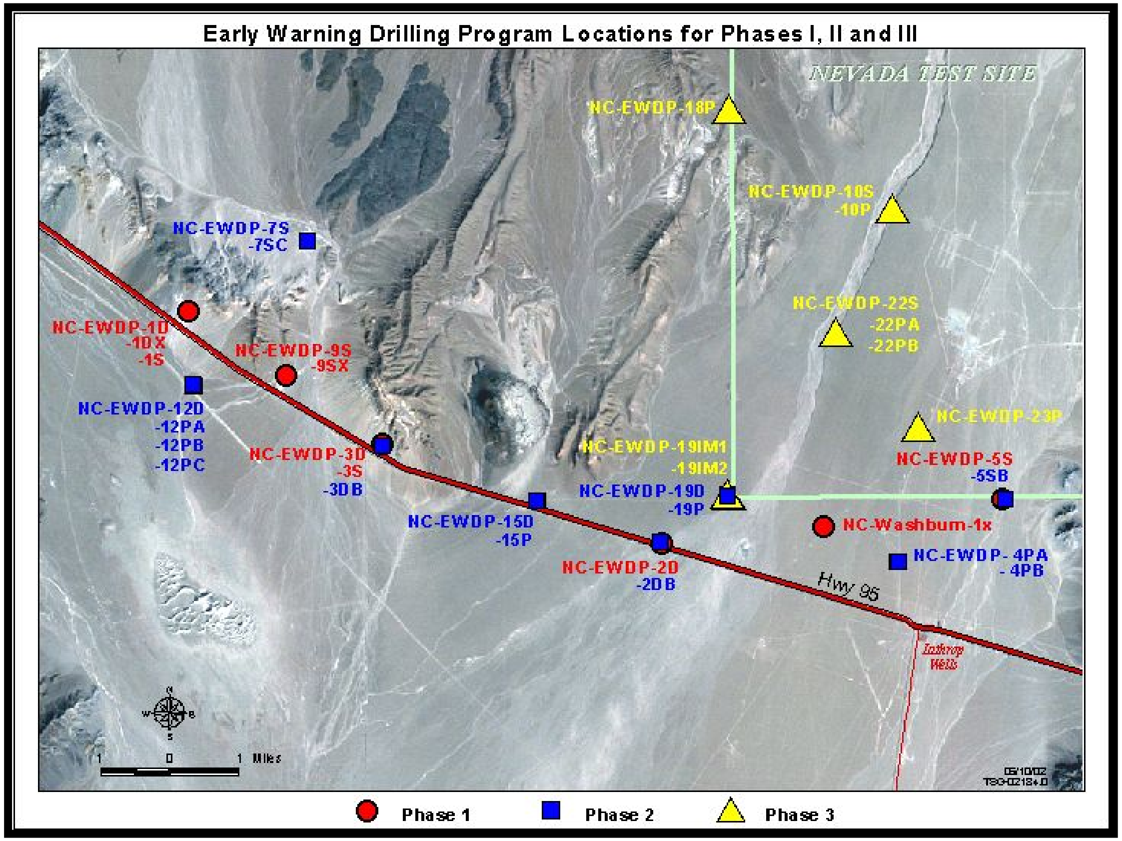
- **Thin interfaces found during mineback affected breakthrough**
  - Pumice
  - Ash layer



Busted Butte Unsaturated Zone Transport Test
(Continued)
Conclusions

- Busted Butte shows that rocks in the field behave in a manner similar to rocks in the laboratory with respect to capillary forces
- Permeability contrasts and unit boundaries appear to be more important for transport than fractures, at the flow rates used
- Busted Butte is consistent with the current conceptual model
- Busted Butte provides support for modeling parameters used in the site-scale flow model

Saturated Zone
Nye County Early Warning Drilling Program



Site-Scale Data Being Collected in support of the SZ Flow and Transport Model:

(1) Lithologic data into the hydrogeologic framework model
(2) Water-level data for flow field calibration
(3) Hydraulic testing data for flow and transport models
(4) Laboratory sorption measurements (^{237}Np, ^{129}I, and ^{99}Tc) on alluvium for process models and TSPA
(5) Hydrochemistry data for flow field calibrations
(6) Eh/pH data for use in flow and transport models
(7) Hydraulic and transport testing of alluvial aquifer for flow and transport models

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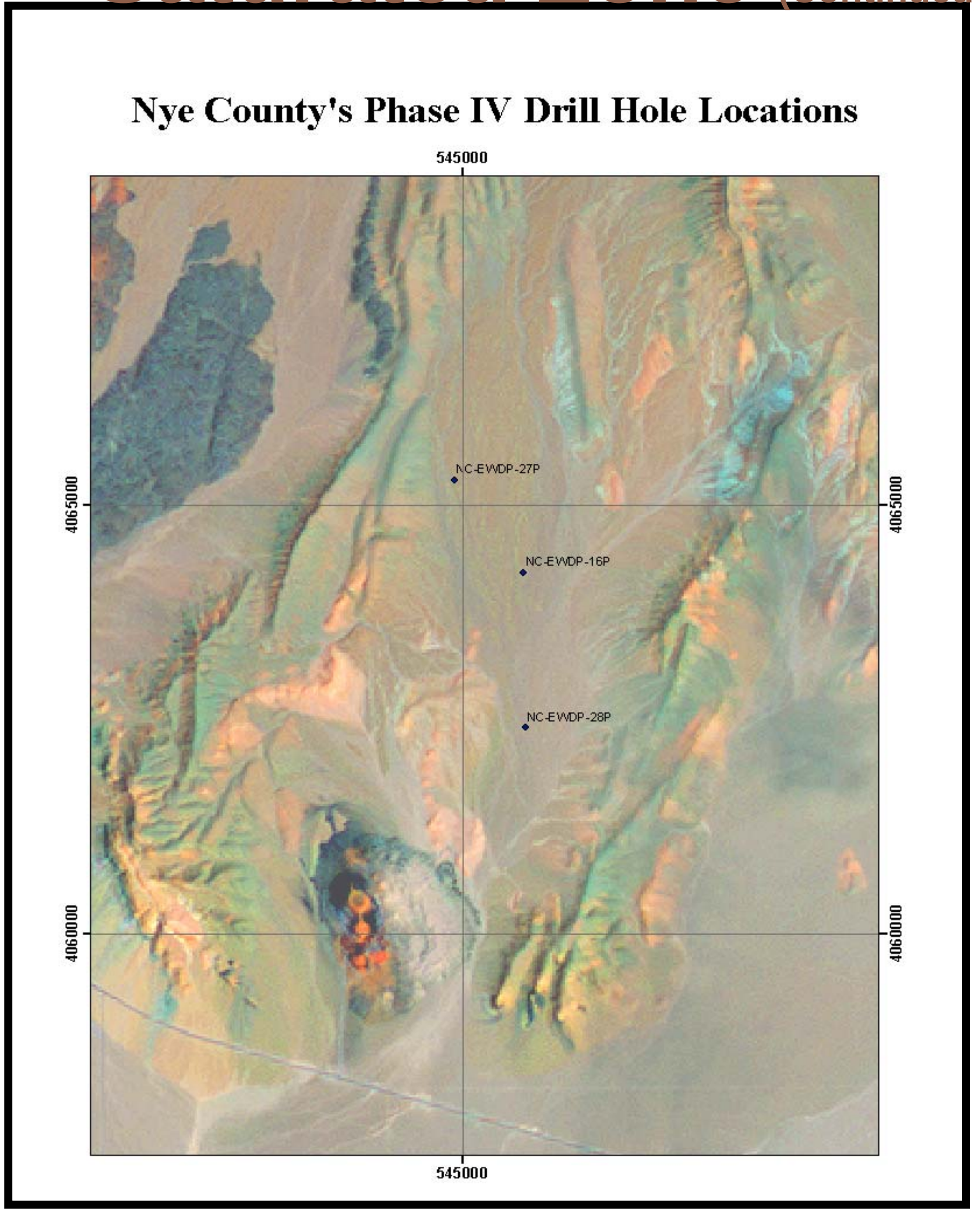
Saturated Zone (Continued)

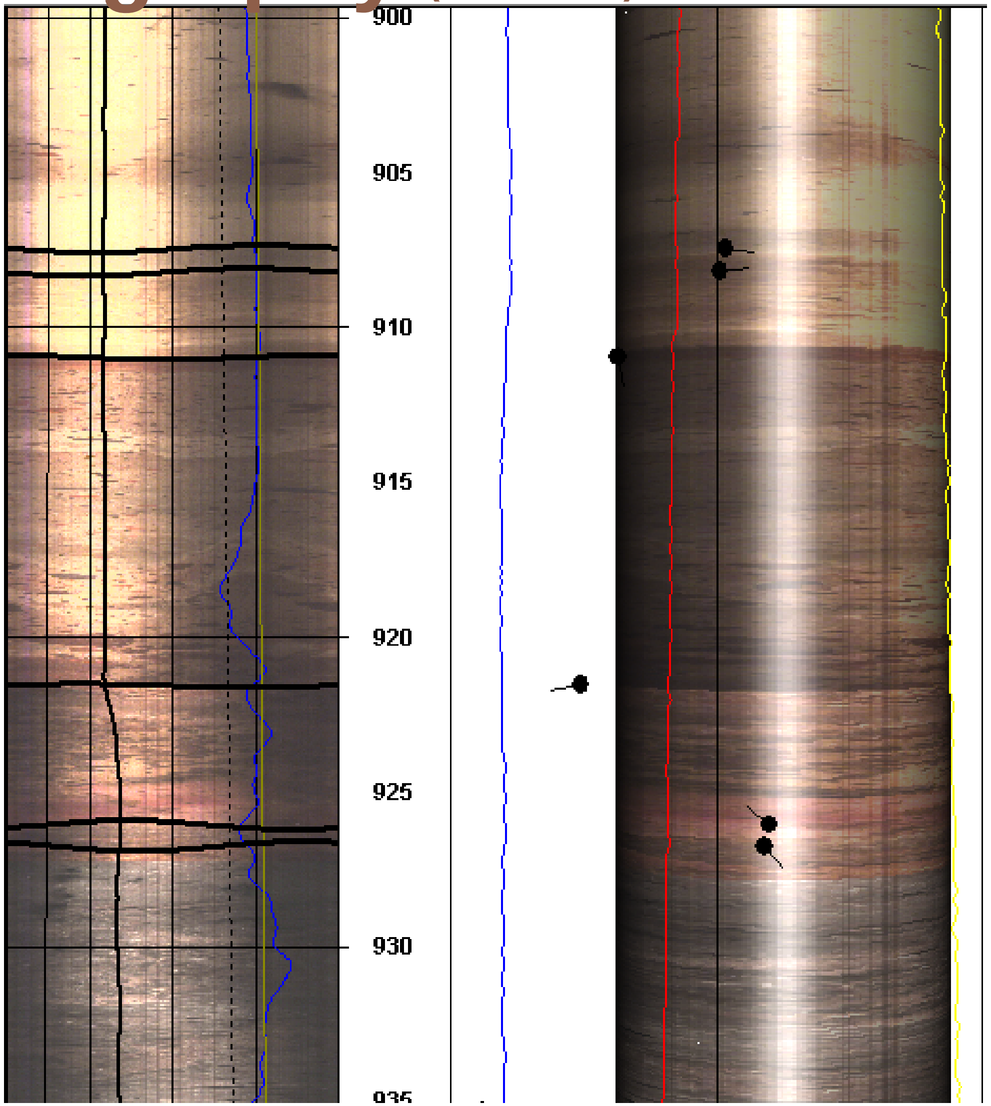


Cross Sections Nye-1, Nye-2, and Nye-3

- Cross sections Nye-1, Nye-2, and Nye-3 have been revised to include phase III drill hole data
- Three new deep boreholes have been drilled as part of Phase IV drilling
- Samples from Nye County Phase IV drilling are currently being processed

Lithostratigraphy (Continued)

Where possible, digital images of borehole walls of Nye County drill holes are being collected using state-of-the-art technology



Selected interval from NC-EWDP-27P

Saturated Zone (Continued)
Hydrochemistry Objectives

- **Identify and map hydrochemical facies in Yucca Mountain region**
- **Identify potential flow paths from Yucca Mountain to accessible environment**
- **Assess interaction and mixing among different facies, including transition from volcanic to alluvial aquifer downgradient from Yucca Mountain**
- **Improve understanding of compositional variability in the third dimension**

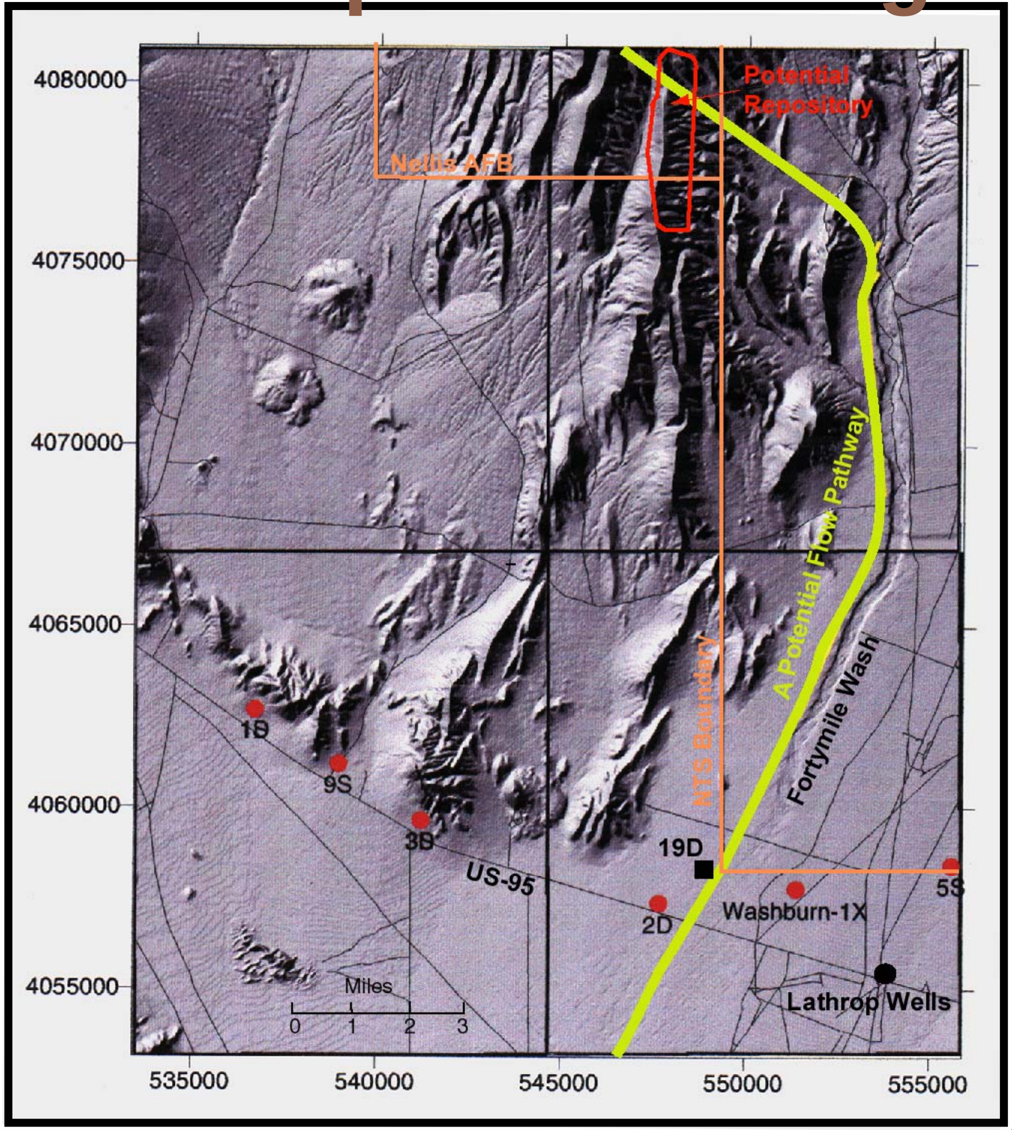
Saturated Zone Hydrochemistry (Continued)
Current Activities

- **Continue sampling of Nye County wells**
- **Sample Inyo County wells when drilled**
- **Other sampling—Nevada Test Site, Bond Gold monitor wells, domestic wells in Amargosa**

Saturated Zone Hydrochemistry (Continued)
Hydrochemical Facies

- Yucca Mountain—Eastern Crater Flat
  - Volcanic aquifer, zeolitized tuffs influence water chemistry
- Fortymile Wash
  - Alluvial/volcanic aquifer
- Bare Mountain
  - Similar to regional carbonate waters
- Amargosa River
  - Isotopically influenced by Precambrian rocks
- Eastern Amargosa Valley
  - Transitional from volcanic to alluvial aquifers

Saturated Zone (Continued)
Alluvium Sorption Investigations



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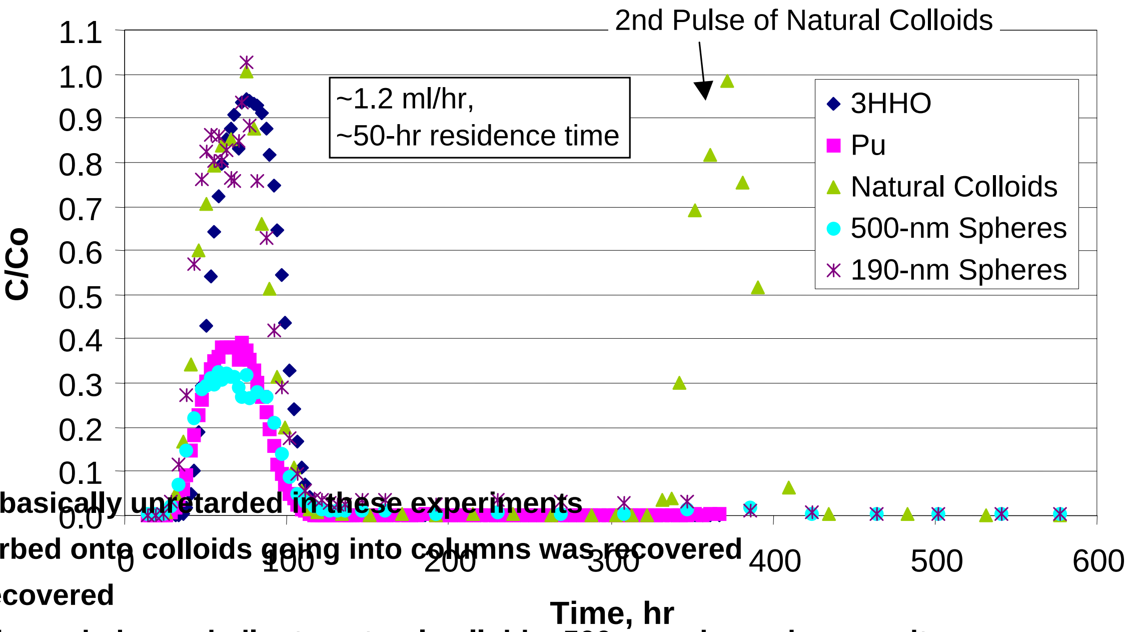
Alluvium Colloid and Colloid-Facilitated Transport Experiments

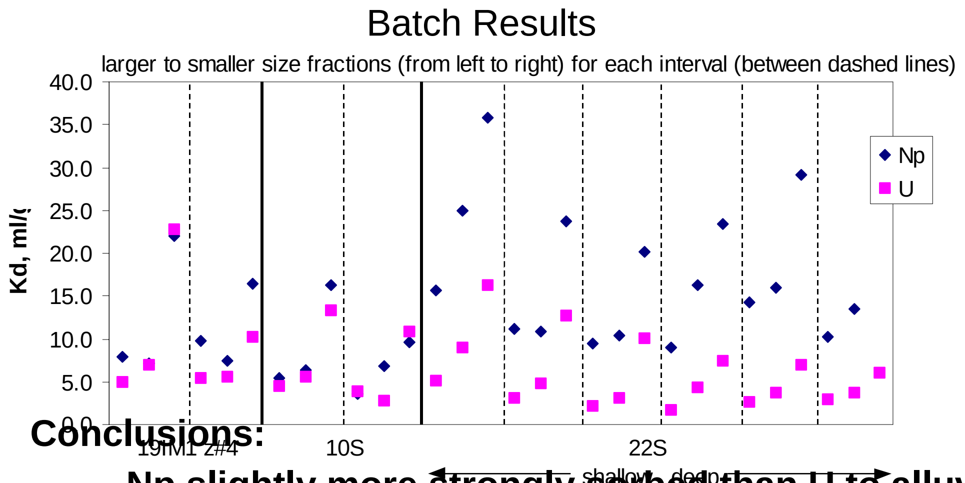
- **4 experiments; 2 different flow rates in 2 columns packed with EWDP-19D alluvium**
- **Pu(V) sorbed onto natural colloids collected from 19D**
- **2 different sizes of carboxylate-modified latex microspheres**
- **Breakthrough curves for tritium, Pu, natural colloids, and microspheres**

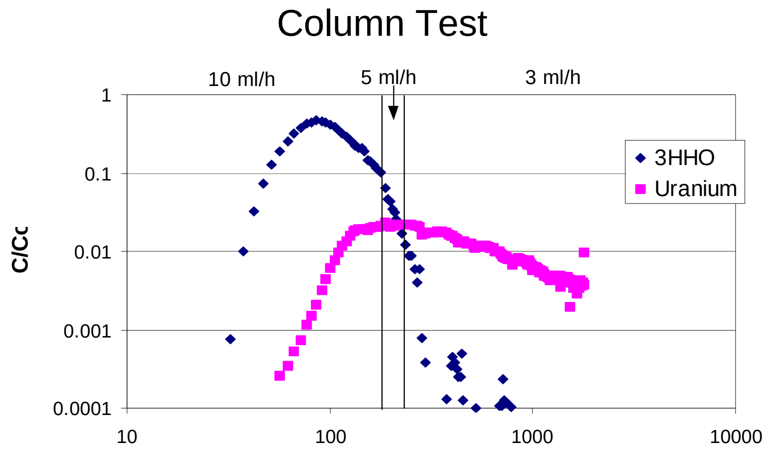


- **Conclusions:**
  - **Natural colloids basically unretarded in these experiments**
  - **Almost all Pu sorbed onto colloids going into columns was recovered**
  - **No soluble Pu recovered**
  - **190-nm microspheres behave similar to natural colloids; 500-nm microspheres quite attenuated**

Uranium and Neptunium Sorption and Transport Experiments in Alluvium

- Numerous batch sorption experiments onto Alluvium from 19IM1, 10S, and 22S
- Np and U column experiments using 19IM1 alluvium





- **Conclusions:**
  - Np slightly more strongly sorbed than U to alluvium in most batch experiments
  - Column experiments suggest a wide distribution of Kd values.
  - Small fraction of radionuclide mass has smaller Kd values than in batch experiments, but a significant fraction have larger values. Kinetics may play a role as well

PRELIMINARY

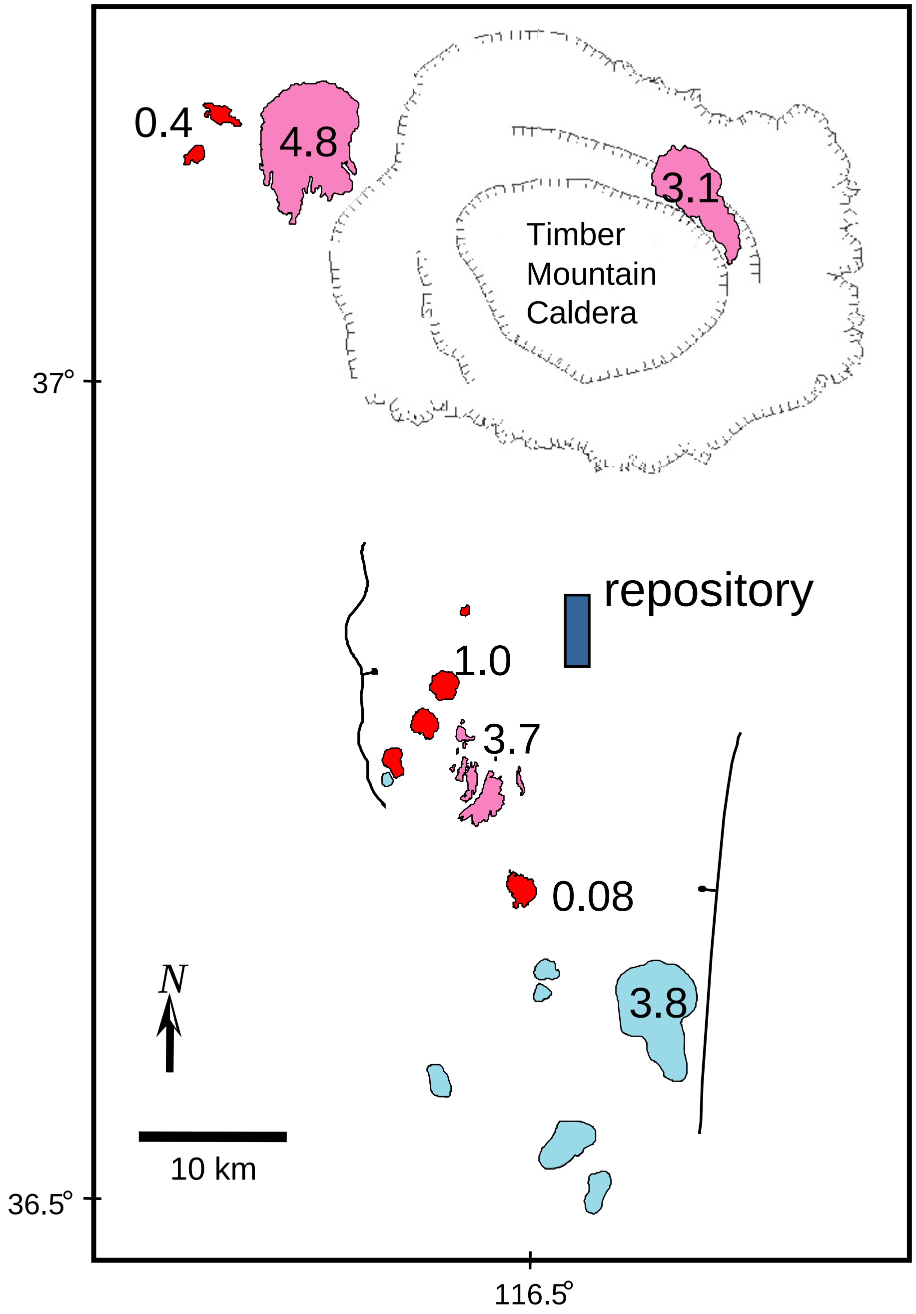
Igneous Events Studies Support Igneous Disruptive Events Analyses and Models

- Evaluating igneous consequence scenarios including
  - Modeling dike propagation through proposed repository
  - Modeling extrusive event through proposed repository
  - Completing Igneous Consequences Peer Review
    - Evaluate current technical basis to analyze consequences
    - Assess adequacy of the analysis and modeling program and recommend any augmentation of planned work
- Evaluating aeromagnetic data for identification of potential buried volcanic centers
- Evaluating probability of intersection based on aeromagnetic data

Igneous Events Studies

(Continued)

Buried Volcanoes are Part of the Geologic Record



- Buried volcanoes are potentially a factor contributing to the uncertainty in the recurrence rate
- At time of Probabilistic Volcanic Hazard Assessment (PVHA), known geologic record included presence of seven inferred (from geophysics) or known (from drilling) buried basalt centers

aeromagnatic anomaly

Residual Magnetic Anomalies near Yucca Mountain

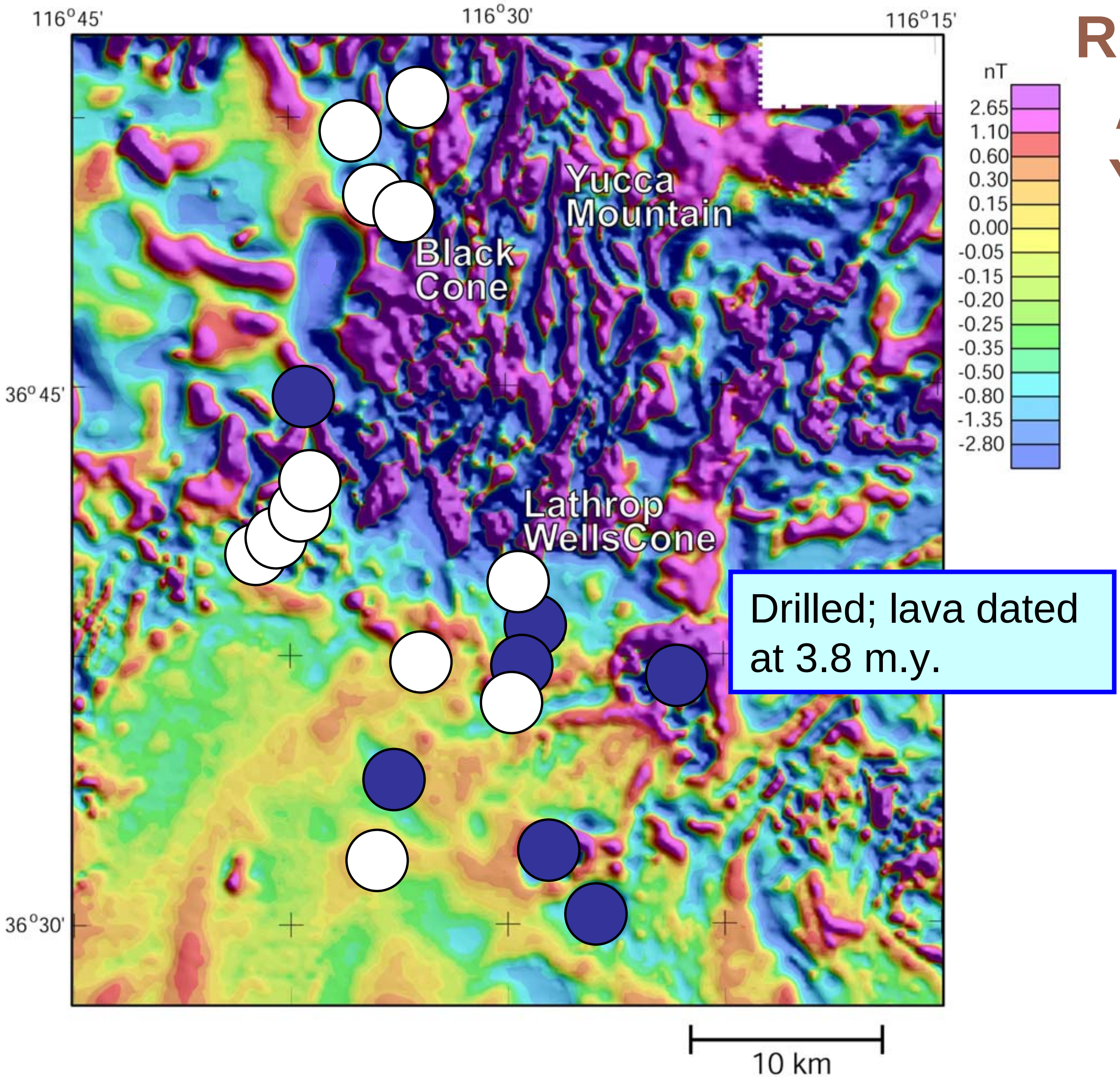


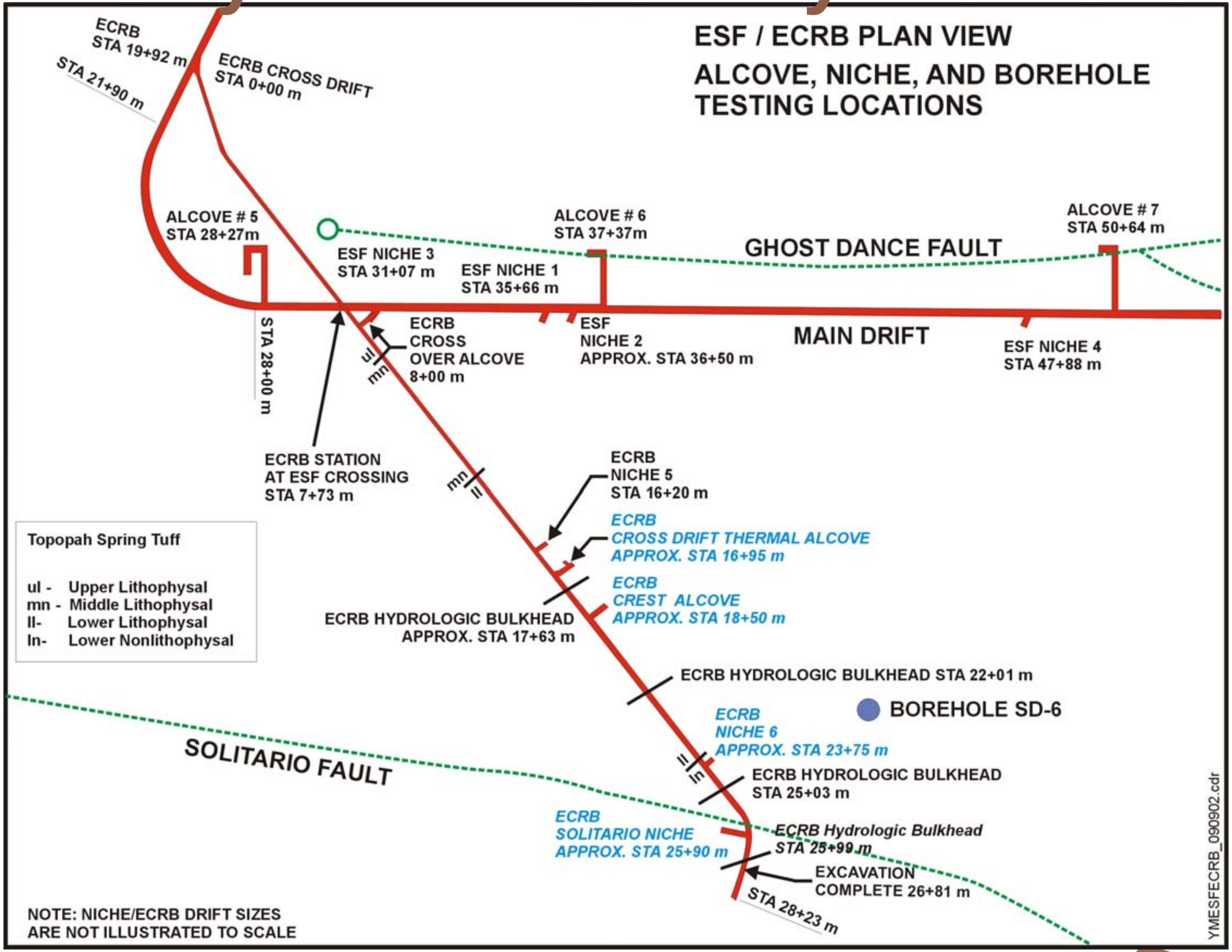
Figure 4 of O'Leary et al. (2002), USGS Open-File Report

Builds on earlier work from Langenheim (1995) and Blakely et al. (2000)

Engineered Barrier System Studies Thermal Properties Investigations

- Supports coupled process models, engineered barrier system (EBS) process models, and design
- Laboratory Testing Program on Tptpll. Status: 144 new tests completed; results presented September 2002
  - Oven-Dried Specimens
  - Saturated and Oven-Dried Specimens – Including matched pairs
  - Specimens containing both natural and artificial porosity
- Field Tests
  - One test completed, two nearly completed.
  - Two additional tests are planned for FY03: Tptpll and Tptpul

Exploratory Studies Facility and Cross Drift



Thermal Properties Investigations (Continued)
Field Data: Implications for Model

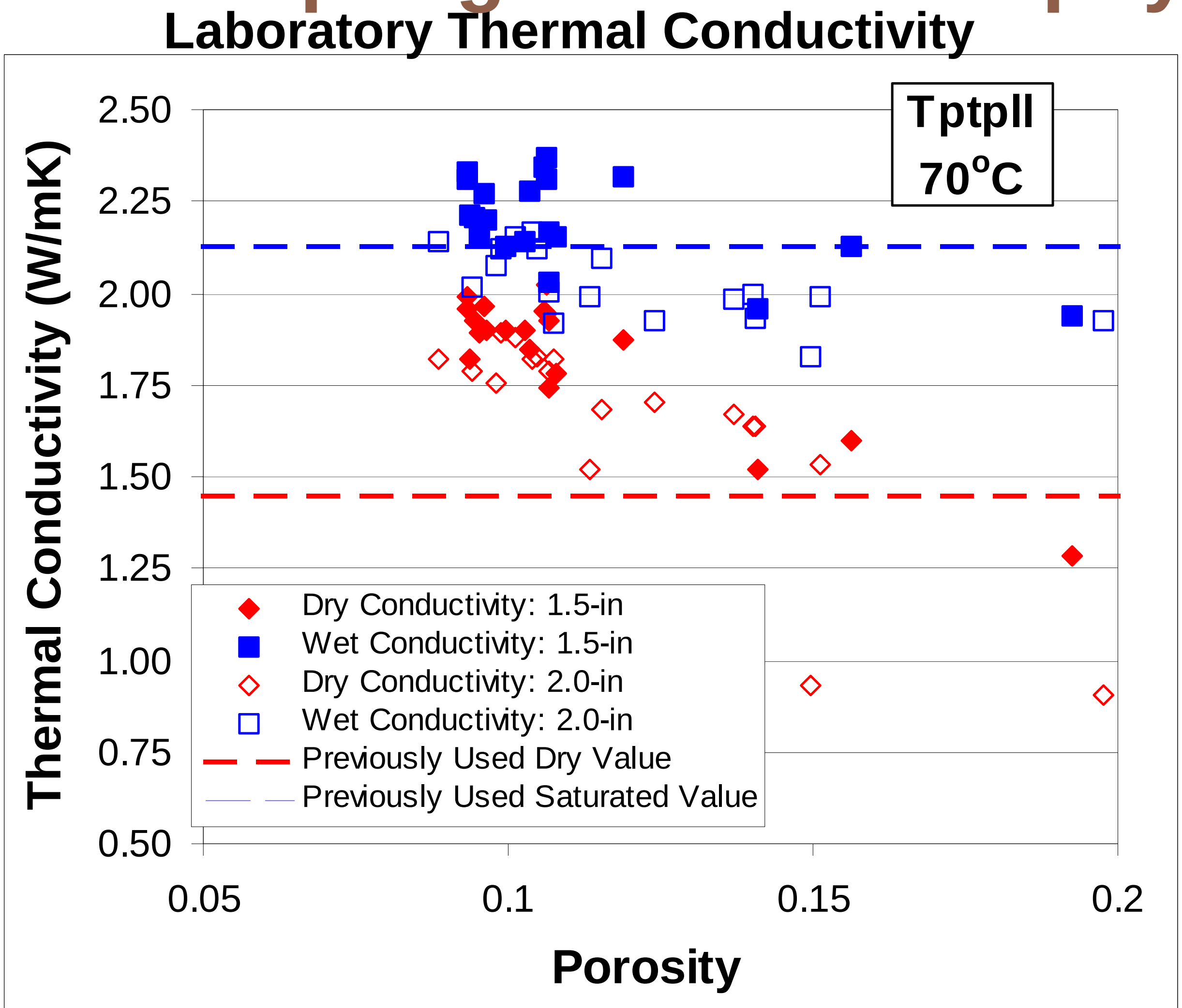
Model predictions given in: Thermal Conductivity of the Potential Repository Horizon Model Report, MDL-NBS-GS-000005. Model values account for moisture and lithophysal porosity

	Field Thermal Conductivity		Model Report (W/mK)
	Wet (Stg1) (W/mK)	Dry (Stg2) (W/mK)	
Test 1 (2-Hole Test)	1.74	---	1.66 ± 0.25
Test 2 (6-Hole Test)	2.03 – 2.18	1.59 –1.63	---
Test 3 (3-Hole Test)	1.73 – 1.76	1.47	1.62 ± 0.25

Wet field values of thermal conductivity are above model values but well within one standard deviation

Thermal Properties Investigations (Continued)

Comparison of Field and Laboratory Topopah Springs Lower Lithophysal Data



Field Thermal Conductivity

Wet: 1.7 – 2.2 W/mK

Dry: 1.5 – 1.6 W/mK

Laboratory data obtained on matrix specimens without lithophysae.

Field and laboratory data are consistent.

Engineered Barrier System Studies (Continued)

Thermal-Mechanical Rock Properties Investigations



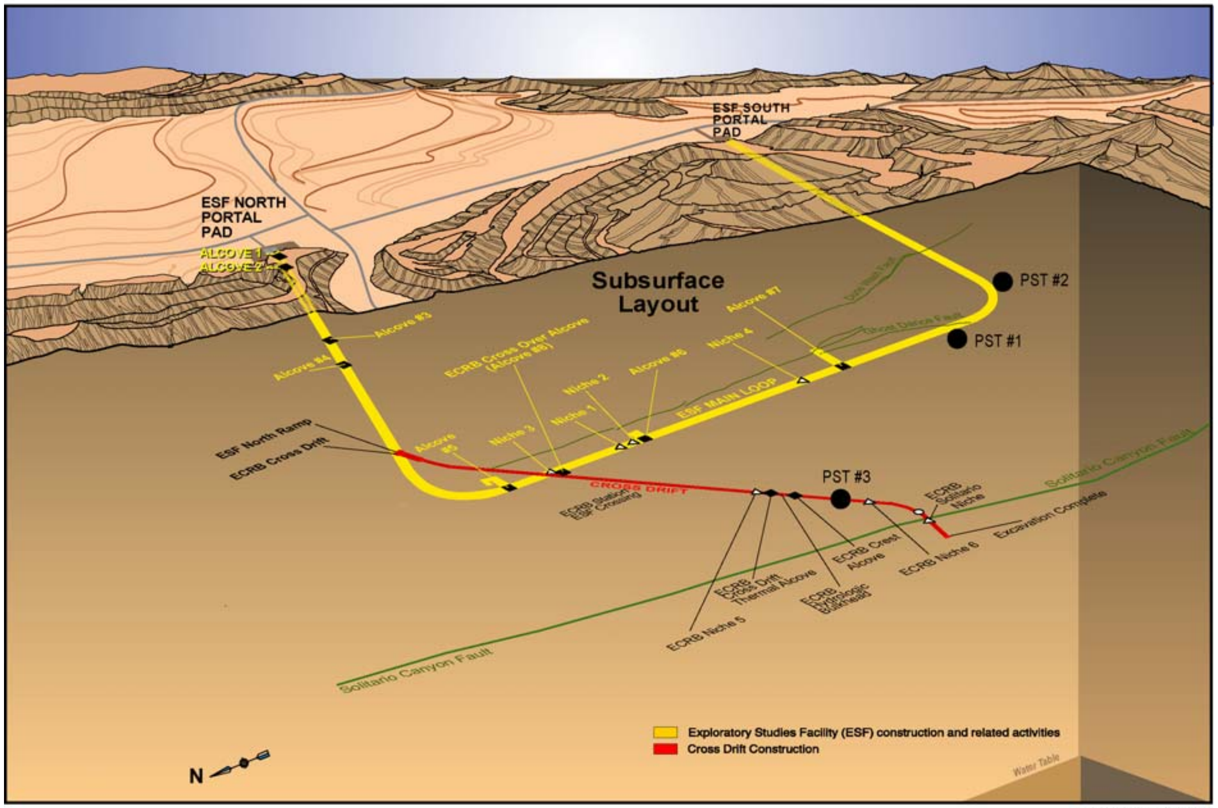

- **Objectives**
  - **Provide data in support of ground support design, rockfall models, and thermal models**
- **Status**
  - **Large diameter coring and sampling ongoing**
  - **In situ field tests complete**
  - **Laboratory measurements ongoing**

Thermal-Mechanical Rock Properties Investigations

(Continued)

Pressurized Slot Test Locations

Exploratory Studies Facility and Alcoves



ESF_subsurface_01_03.ai

PST #1 – Station 57+77 of ESF, Tptpll (Completed)
PST #2 – Station 63+83 of ESF, Tptpul (Completed)
PST #3 – Station 21+25 of Cross Drift, Tptpll (Completed)

Thermal-Mechanical Rock Properties Investigations

(Continued)

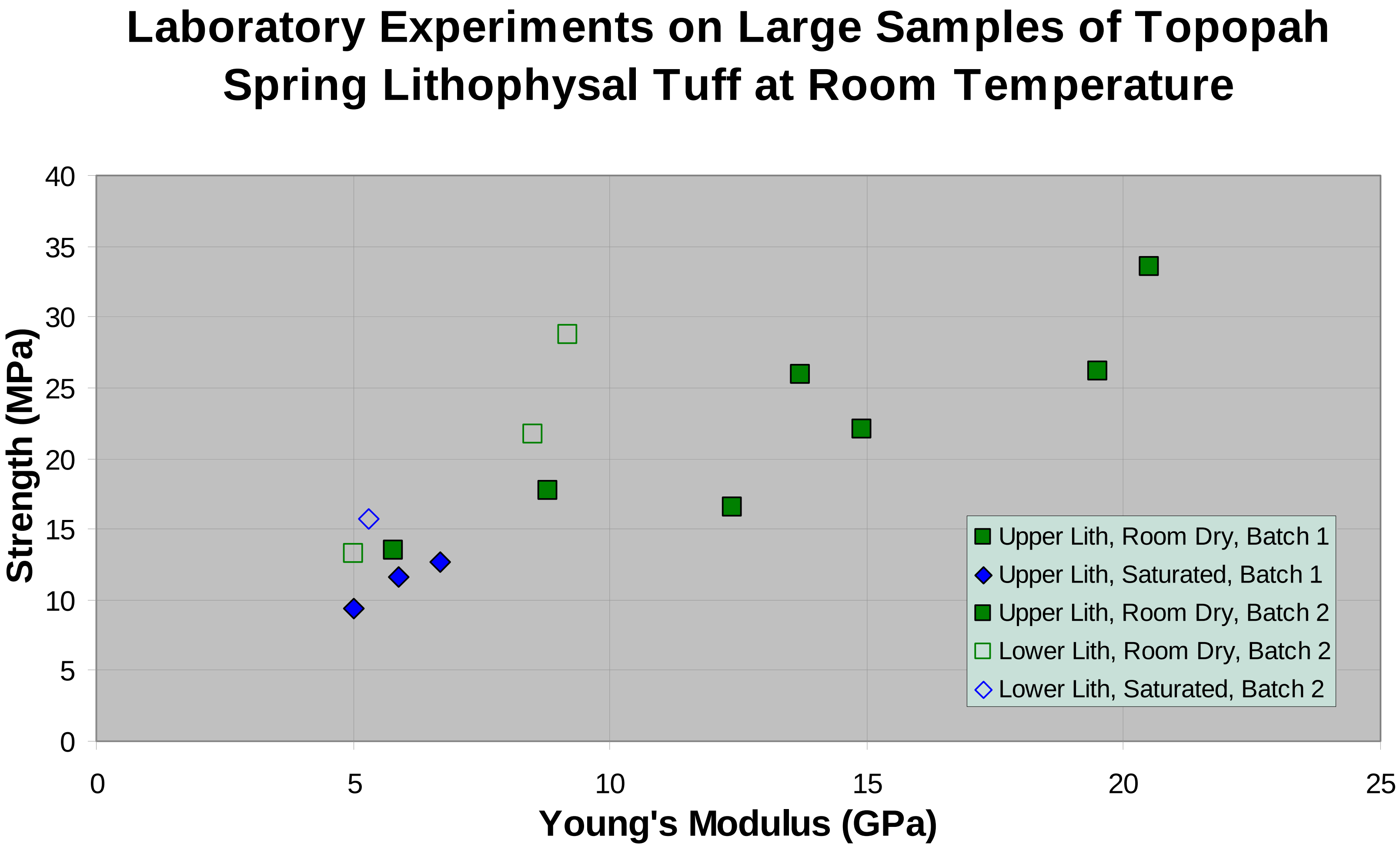
Pressurized Slot Test Results

Test	T-M unit	Location	Temperature	E (GPa)	ν
PST #1	Tptpll	ESF 57+77	ambient	0.5	0.2
PST#2	Tptpul	ESF 63+83	ambient	3.0	0.2
PST#2	Tptpul	ESF 63+83	T>80^{o}C	1.5	0.2
PST#3	Tptpll	ECRB 21+25	ambient	0.7	0.3

- **The estimated Young's modulus of Tptpll and Tptpul is only a fraction of the value of Tptpmn modulus measured in the Thermal Test Facility (0.5~3.0 GPa vs. 20 GPa)**
- **It appears that the effects of lithophysae on mechanical properties of Tptpll are more significant than anticipated**
- **Results are being incorporated into drift degradation models**

Thermal-Mechanical Rock Properties Investigations

(Continued)

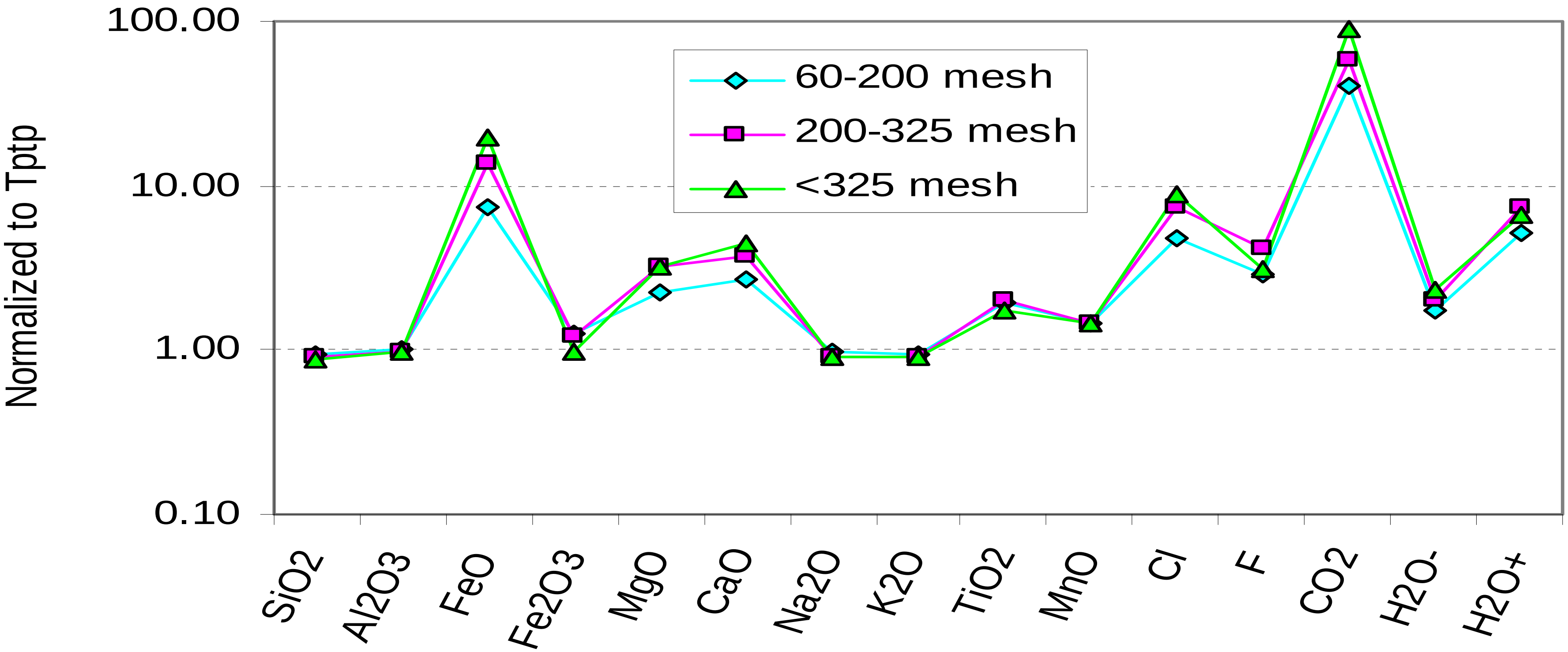


Dust Investigations
Chemistry of Dust in the Exploratory Studies Facility

- **Why is dust chemistry important?**
  - **Dust will accumulate on waste packages**
  - **Soluble fractions will dissolve in water dripping on canisters or deliquesce in variable relative humidity environments to form brine droplets or films**
  - **Potential effects on environment on waste package surface**
- **What is the source of dust?**
  - **Construction activities**
    - **Rock dust**
    - **Anthropogenic dust**
  - **Ambient atmospheric dust**

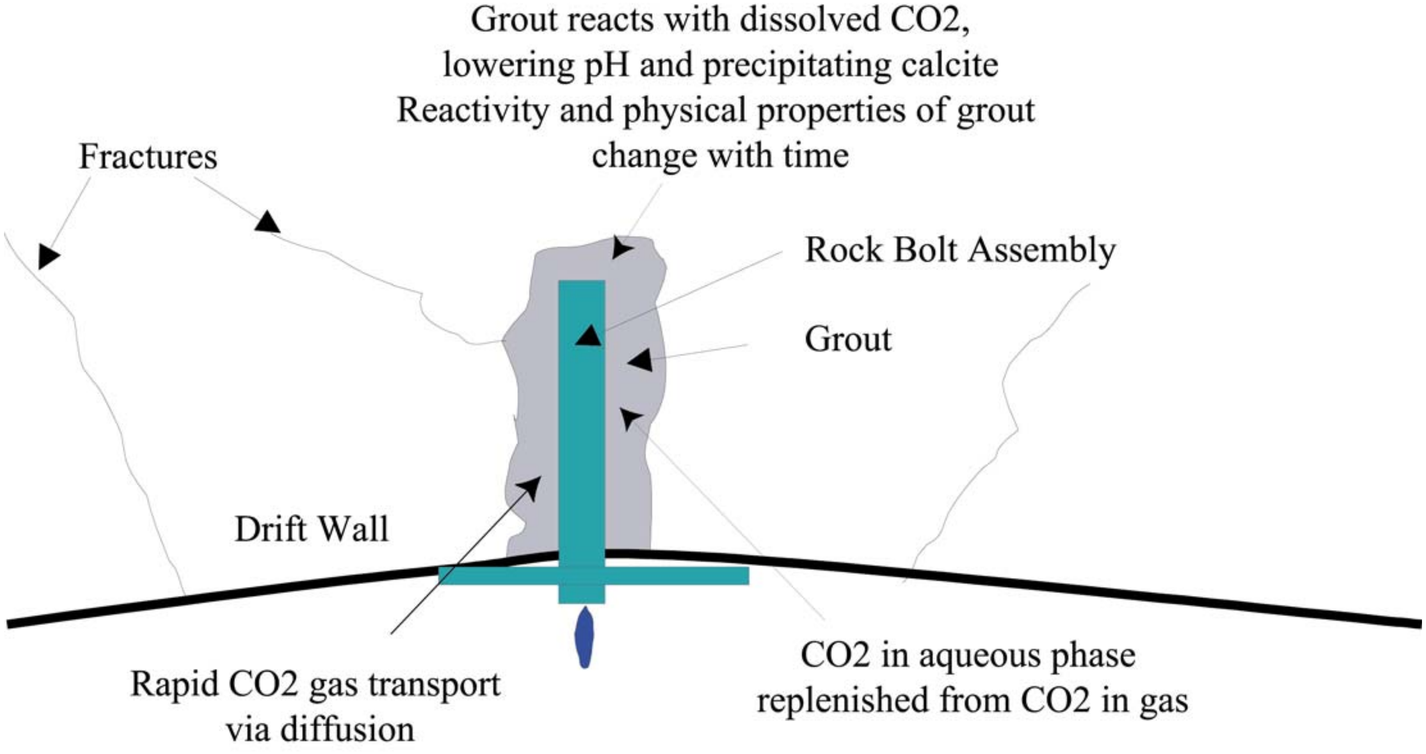
Dust Investigations (Continued)

Chemistry of Dust in the Exploratory Studies Facility Comparison with Mean Rock Composition Shows Major Element and Oxide Enrichment in Dust



YUCCA MOUNTAIN PROJECT

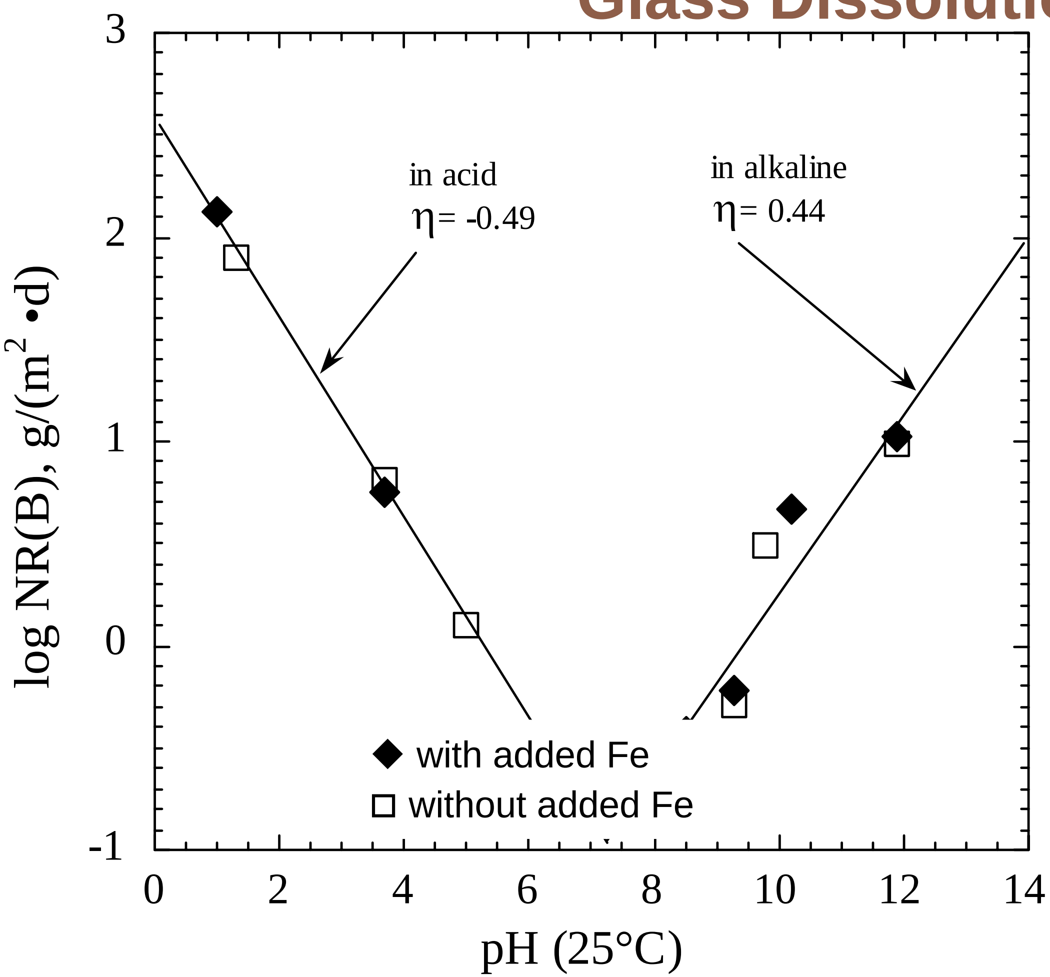
Reactive Transport Experiments Grout-Seepage Water Interaction



Reactive Transport Experiments (Continued) Conclusions to Date

- **Neutralization of hyperalkaline drip takes place on time scale of hours to days at atmospheric CO_2 concentrations**
  - **Time scale of 1 to 2 hours for a 1 mm drip**
  - **Presence of gas phase with CO_2 important in attenuating hyperalkaline plume**
- **Portlandite dissolves faster than Ca-silicate phases, thus controlling solution chemistry**
- **Steam-autoclaved grout with 5% silica fume still shows high pH (portlandite not all consumed)—high silica cement needed to reduce pH**
- **Carbonation via calcite precipitation reduces reactivity of grout**
- **These data are being used in the in-drift chemistry model**

Engineered Barrier System Studies
Waste Form Investigations — Support Waste Form Degradation Models and Design
Tests Show No Effect of Iron Corrosion Products on Glass Dissolution Rate



Tests at 90°C show no effect of iron (added as $FeCl_3$, $FeOOH$, Fe_3O_4, or Fe_2O_3) on glass dissolution rate. (addresses KTI issue)

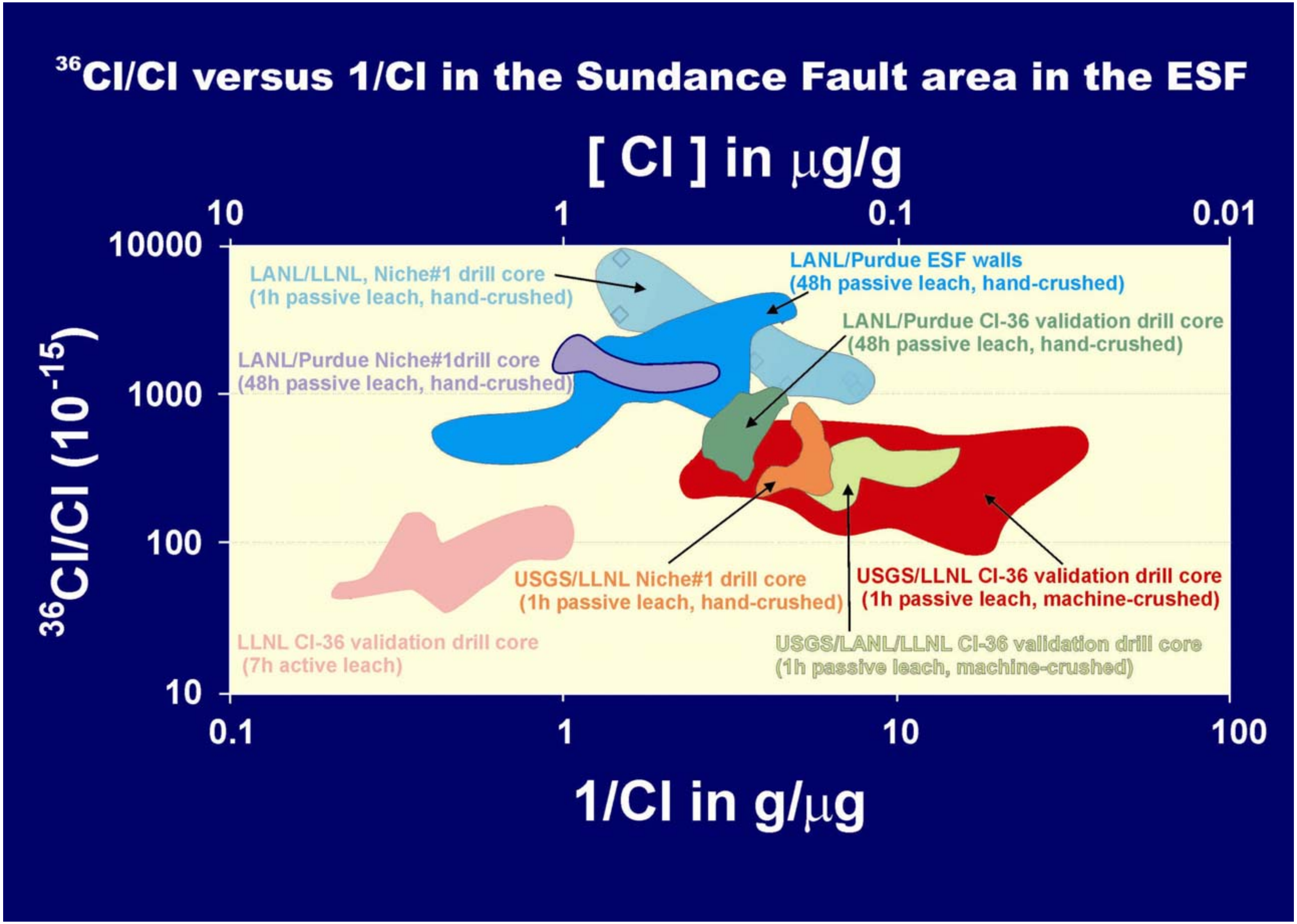
Tests provide measure of pH-dependence (η) for glass degradation model at 90°C.

Summary

- **Ongoing data collection and testing in ESF, Cross Drift, and laboratories continue to address uncertainties and provide additional confidence in natural and engineered systems analyses and models and design in support of License Application**

Backup

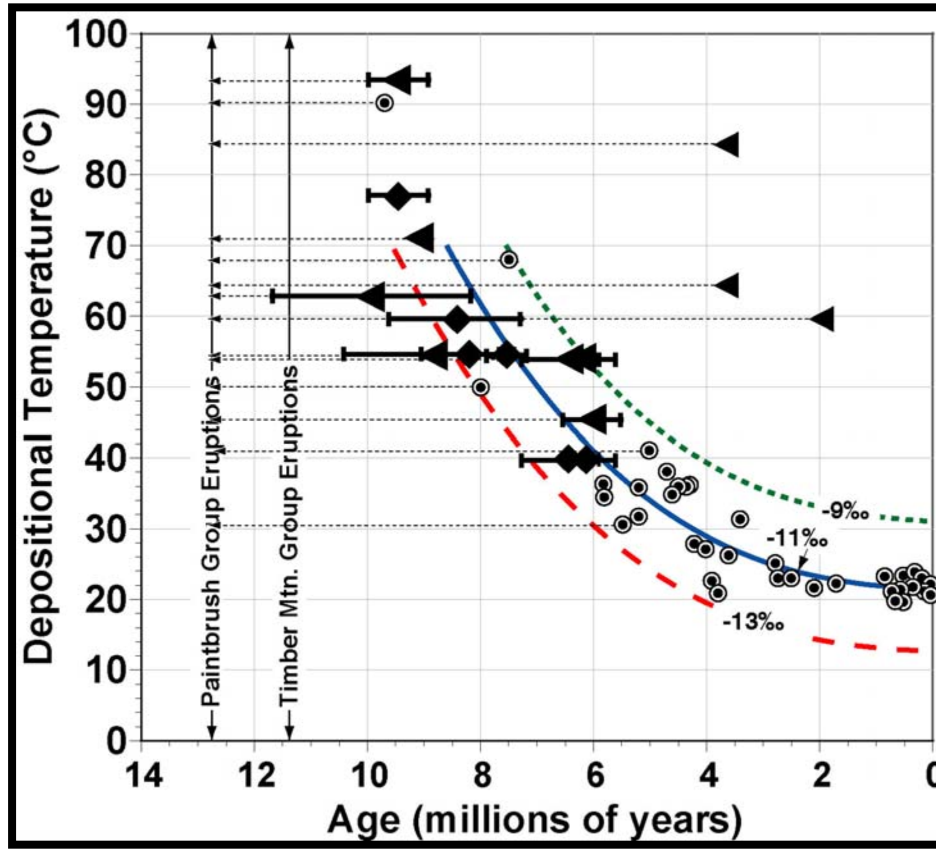
Comparison of Previous Los Alamos National Laboratory and Cl-36 Validation Project Data



PRELIMINARY

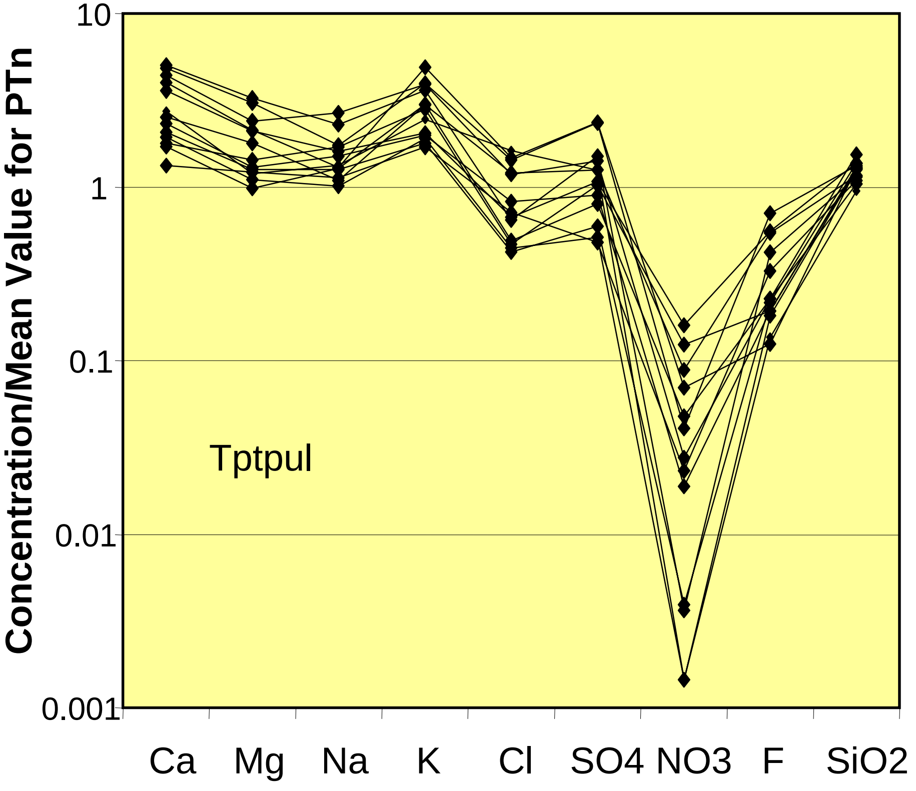
Temperature vs. Time in the Unsaturated Zone

- Age of calcite deposition can be constrained by associated opal or chalcedony U-Pb or U-series ages
- Dated silica overlying calcite provides a minimum age; true calcite age falls along the dashed lines and may be substantially older
- Temperatures can also be calculated from calcite delta ^{18}O values, assuming a delta ^{18}O for the depositing water of –11‰ (shown as circled dots)
- Curves shown are best-fit regressions to the calcite delta ^{18}O temperatures for waters having a delta ^{18}O value of -13, -11, and -9‰, similar to present-day meteoric water, and demonstrating
- The gradual cooling is consistent with heat provided by the formation and cooling of the batholith-scale upper crustal magma body that produced the 15 to 10 m.y.-old volcanic tuffs and alteration of the tuffs below the water table 11 to 9 Ma



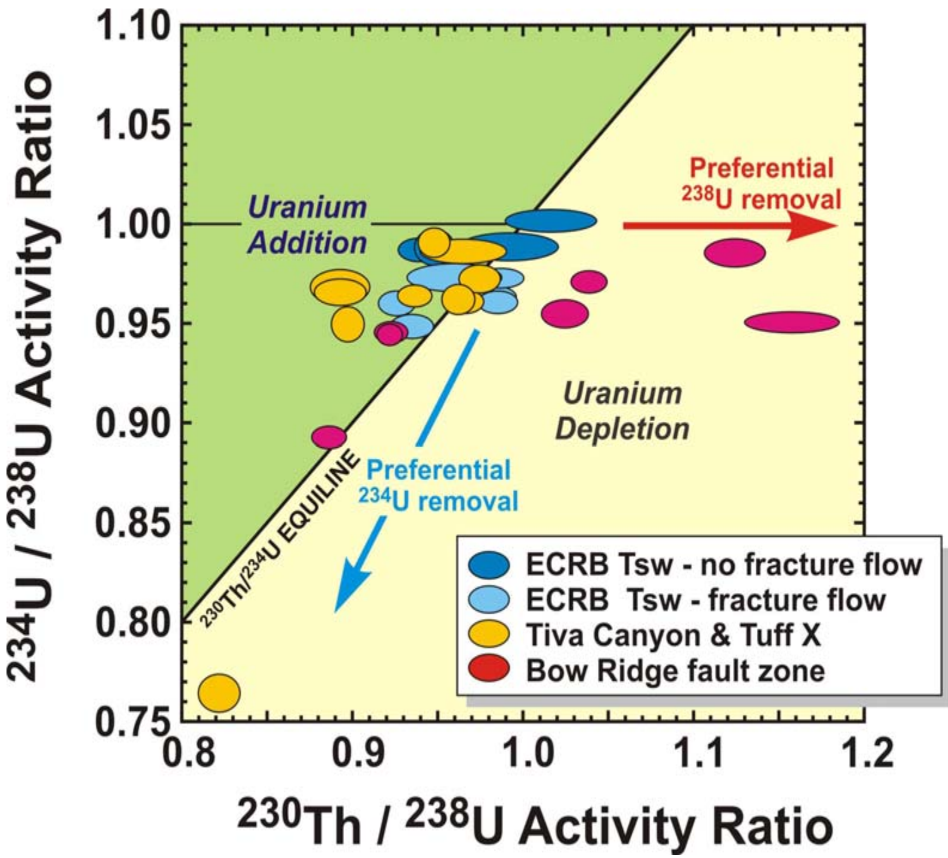
Geochemistry of Pore Water

- Dissolved-ion concentrations in pore water change systematically from PTn into TSw
- Decrease in NO_3^{-1} suggests microbial denitrification
- Microbial activity also suggested by presence of organic acids in pore water
- SiO_2 at saturation—no change

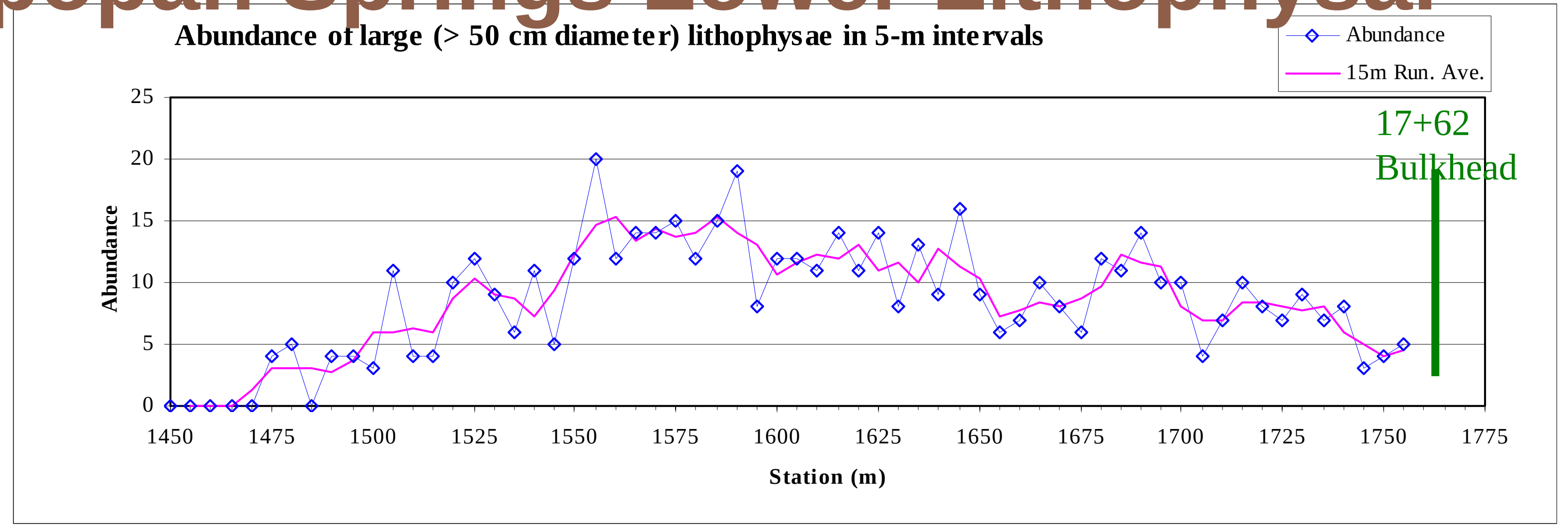


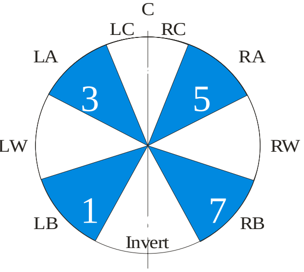
U-Series Delineation of Flow Paths

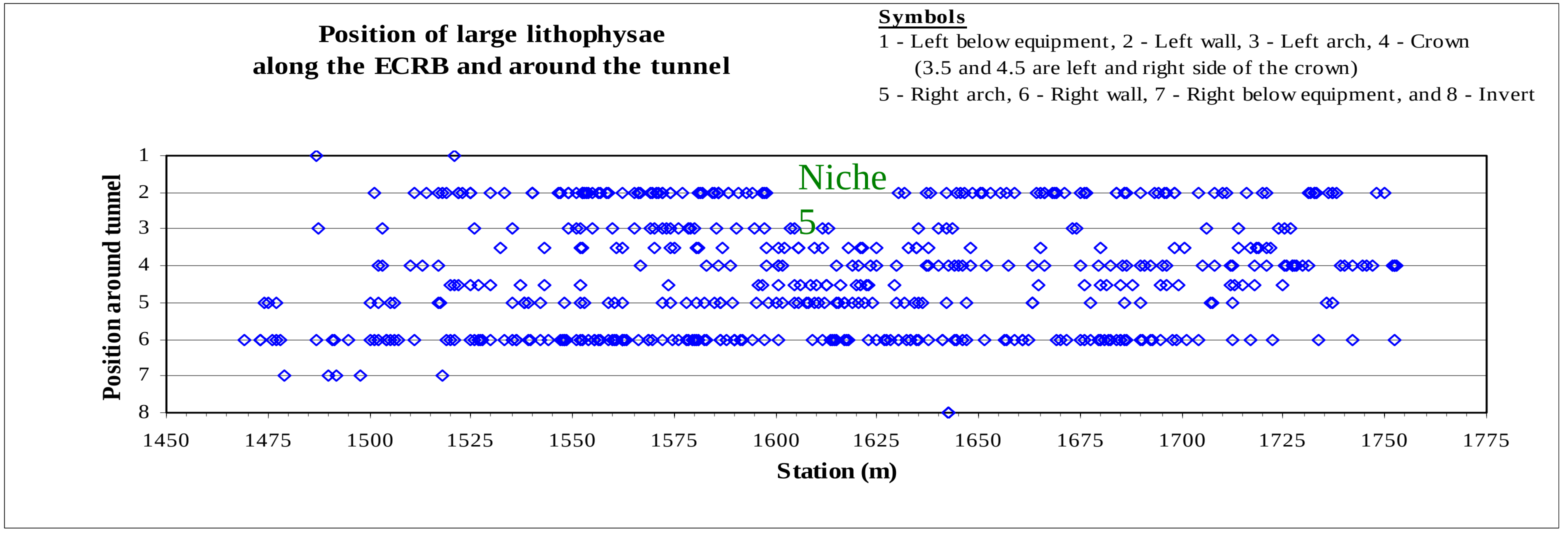
- **Recent results showed method applicability:**
  - Greatest disequilibrium observed within Bow Ridge fault zone (zone of focused flow)
  - Least disequilibrium observed in TSw samples from repository horizon
  - Intermediate values reflect variable, but low, amounts of water/rock interaction



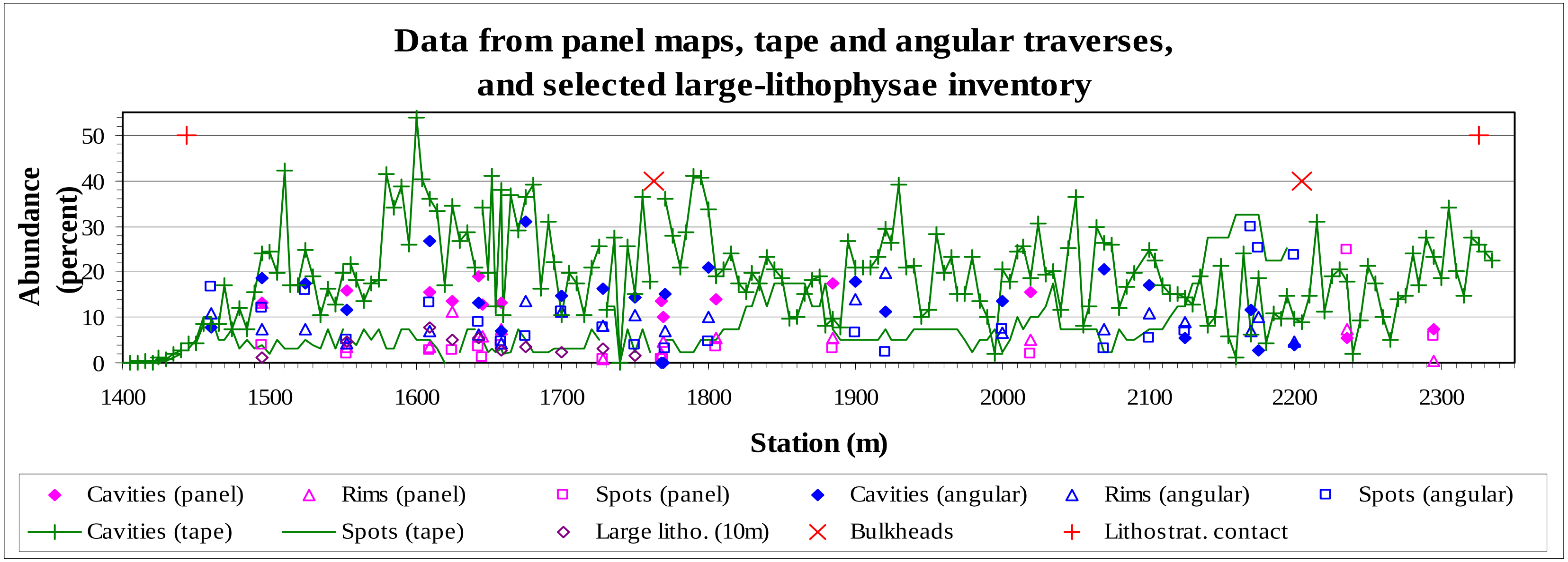
Large Lithophysal Inventory in the Topopah Springs Lower Lithophysal

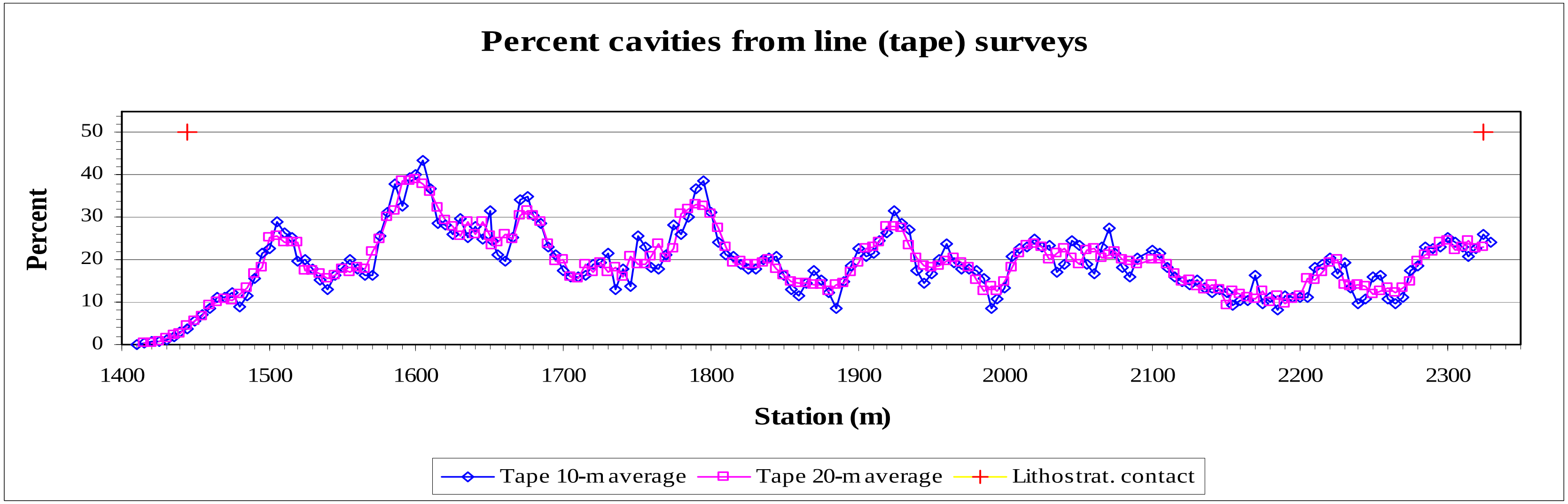






Lithophysal / Fracture Studies

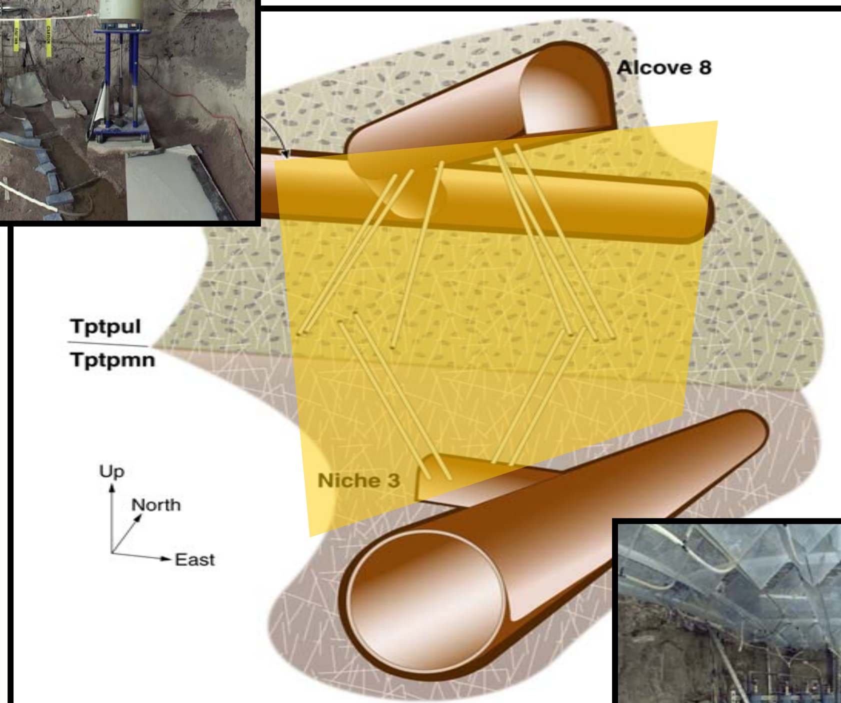




PRELIMINARY

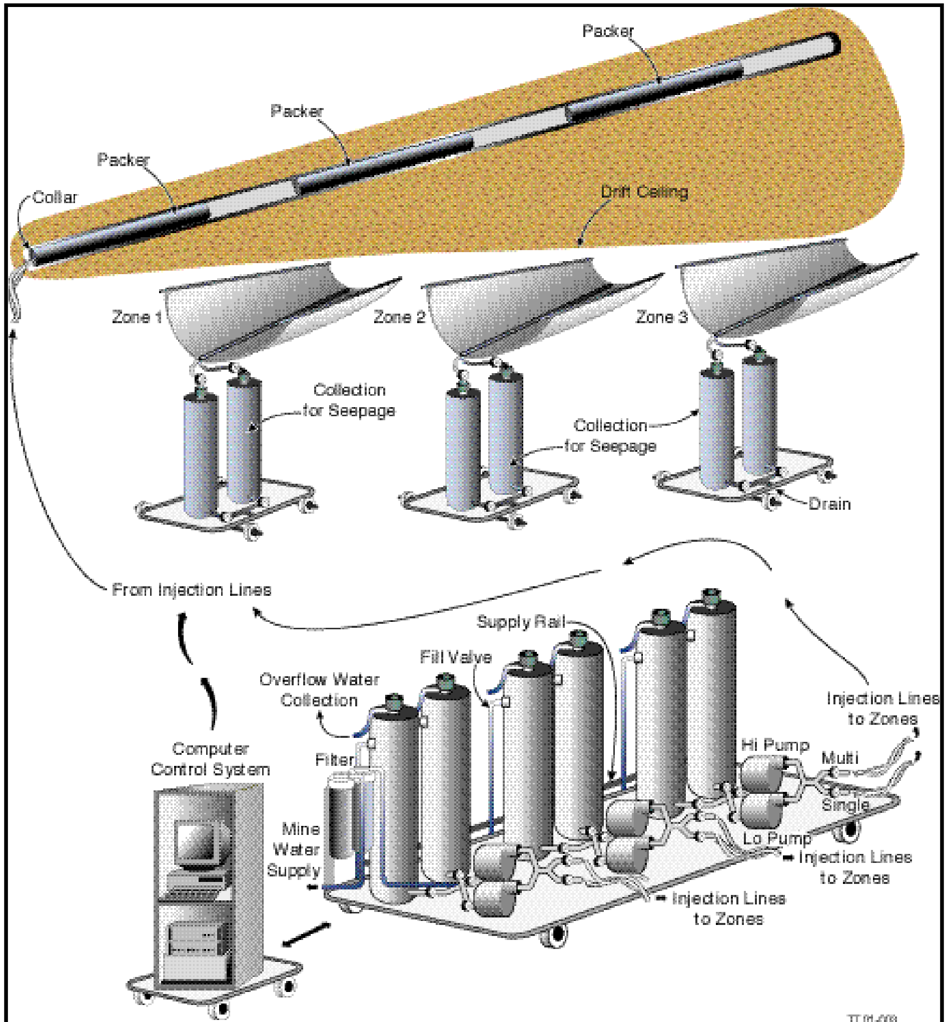
Alcove 8 / Niche 3 Fault Test

The Testbed



Systematic Hydrologic Testing

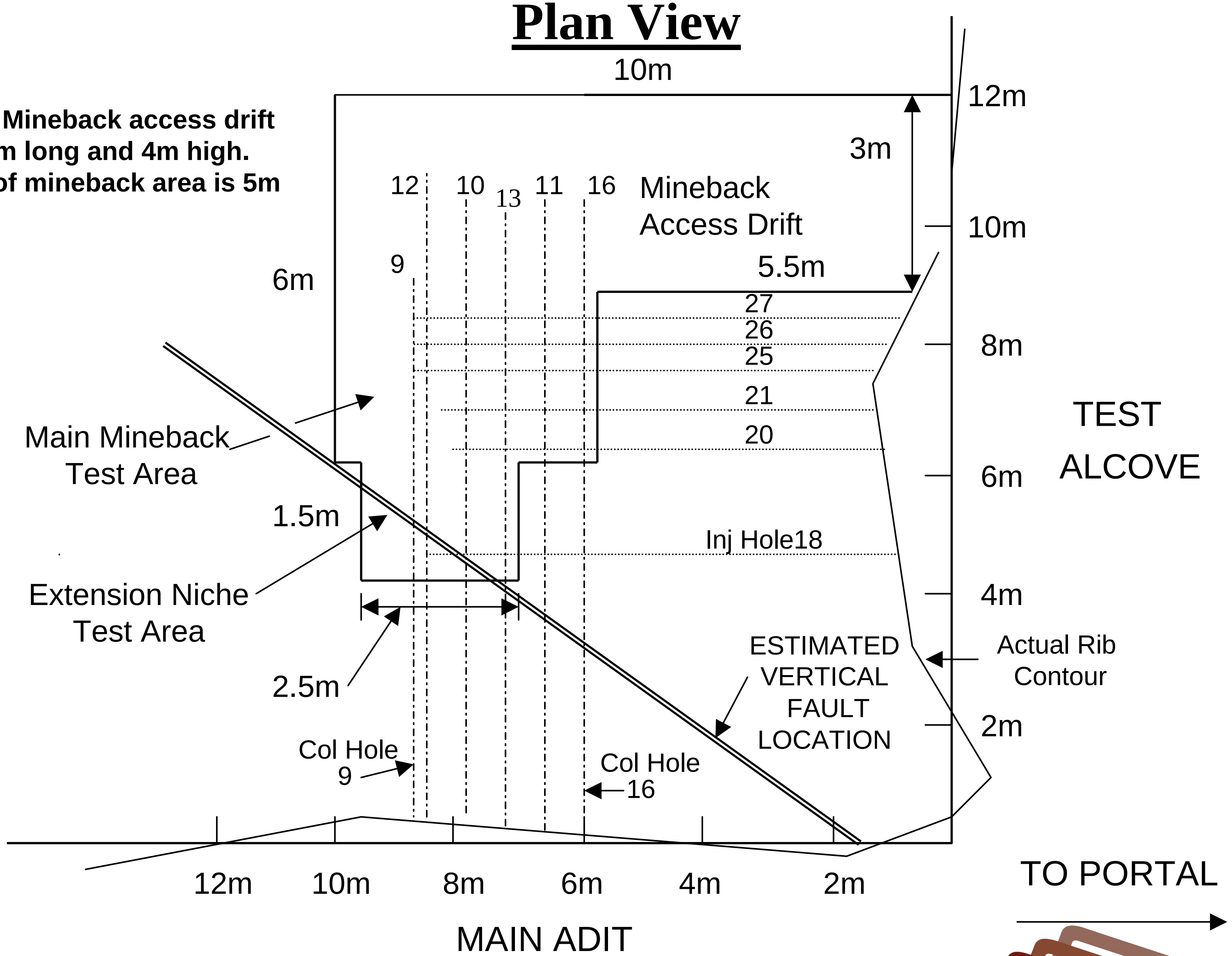
Equipment System: Schematics and Actual Field Deployment



Busted Butte Phase 2 Post-test Mineback Program

Plan View

Note: Mineback access drift is 5.5m long and 4m high. Rest of mineback area is 5m high.

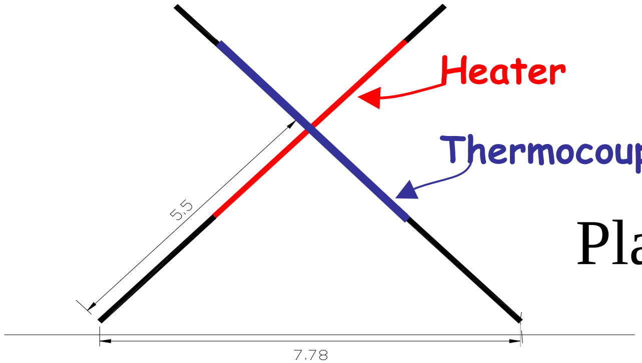


Thermal Properties Investigations Overview of Field Test Program in Tptpll

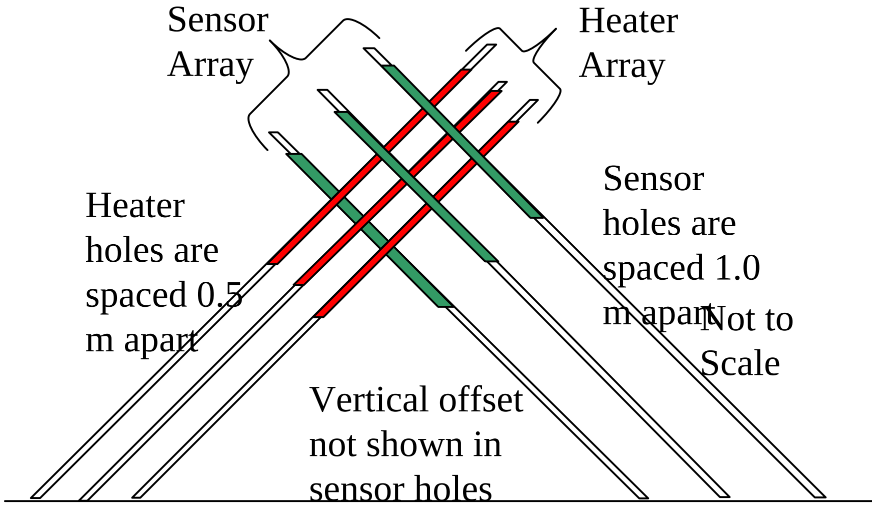
- **Test 1**: Single heater and single instrumentation borehole, run at temperatures below 100°C. ***Status: Completed***.

- **Test 2**: Three heaters and 3 instrumentation boreholes sample larger test volume, provide control of temperature distribution. Measure thermal properties at temperatures below 100°C (phase 1), and also after the test area has been dried out (phase 2). ***Status: At end of Stage 2.***

- **Test 3**: Sample 3rd location. Single heater with instrumentation holes both above and below it to measure effects of convection on temperature distribution. Measure thermal properties at temperatures below 100°C (phase 1), and also after the test area has been dried out (phase 2). ***Status: In cooling phase.***

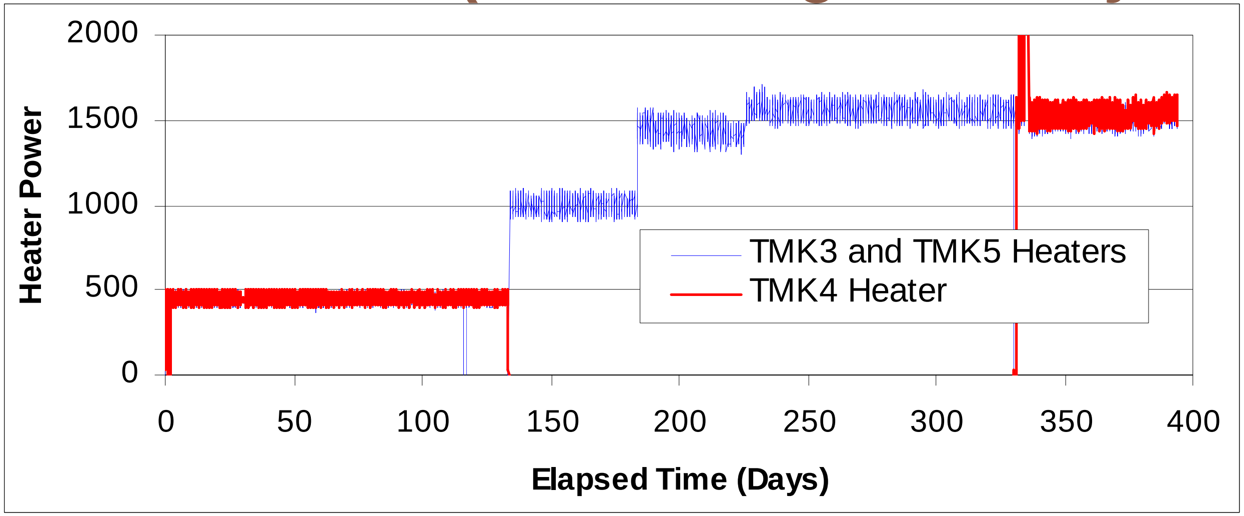


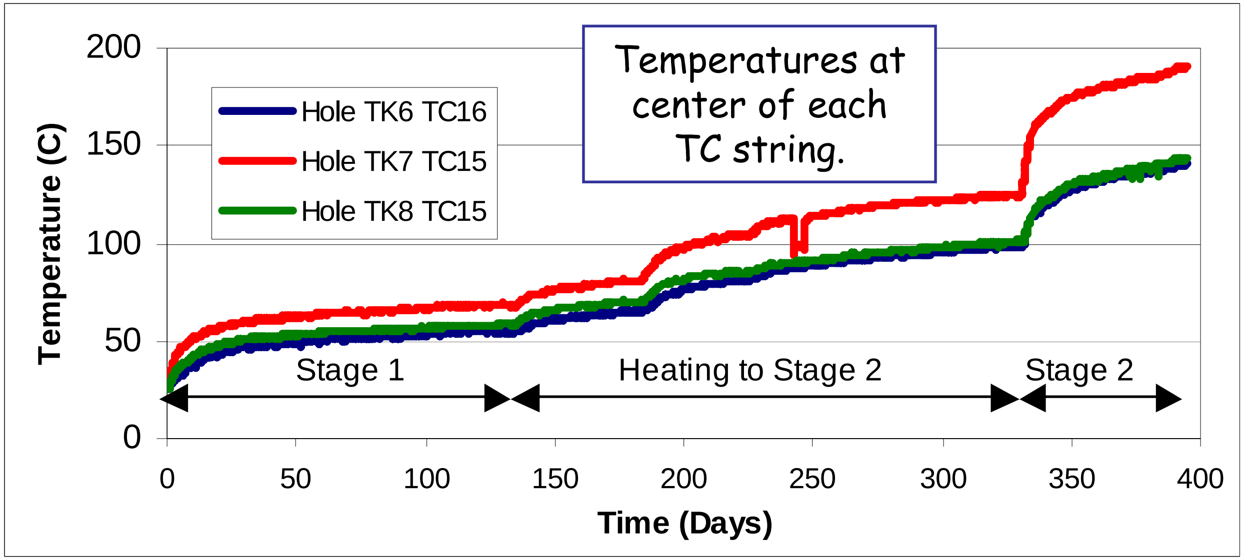
Geometry for Tests 1 and 3



Geometry for Test 2

Test 2: 6-Hole Test History
(Data through January 1, 2003)





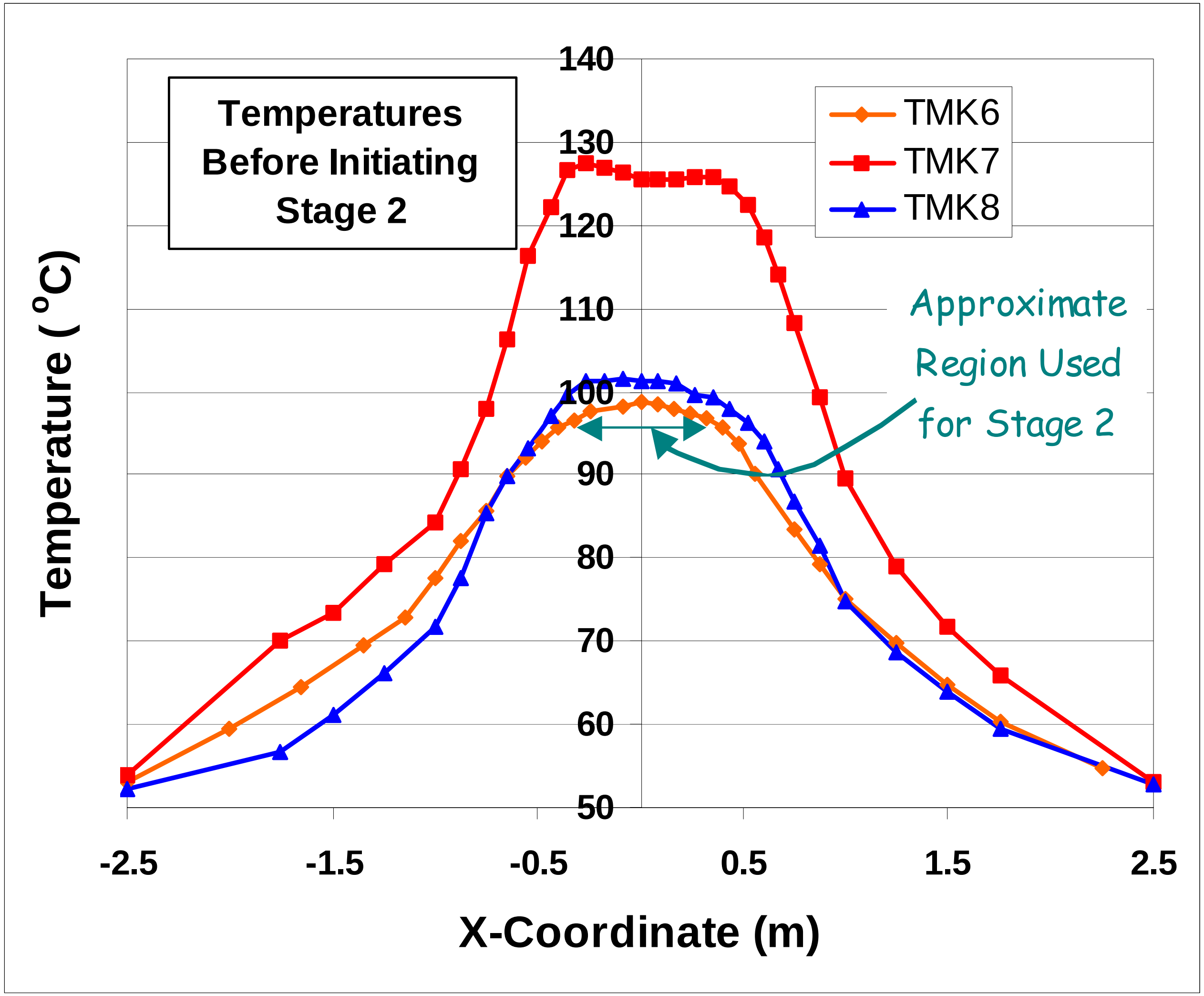
<u>Stage 1:</u> Plots show all heaters at 500W for Stage 1. Maximum temperatures (at center of each TC string) smoothly increase.

<u>Heating to Stage 2:</u> Center heater (TMK4) was shut down on Day 133. Outer heater powers were then stepped up, bringing central region to above boiling.

<u>Stage 2:</u> Central heater was reconnected on Day 330, initiating Stage 2.

YUCCA MOUNTAIN PROJECT

Test 2
Temperature Profiles Before Initiation of Stage 2



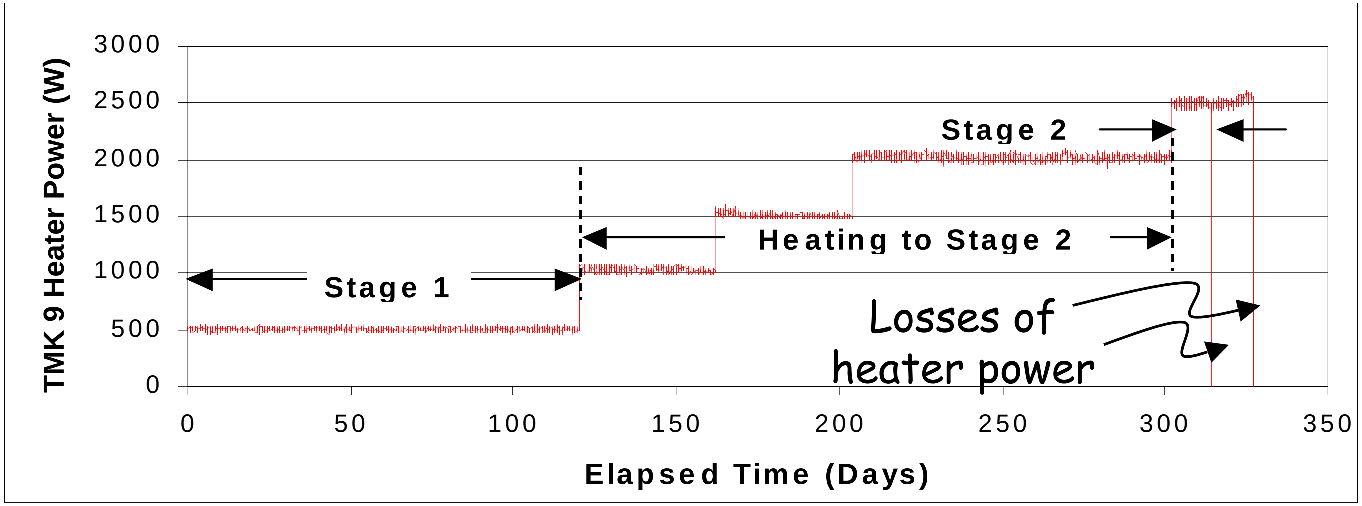
Relatively flat temperature profiles in central region.

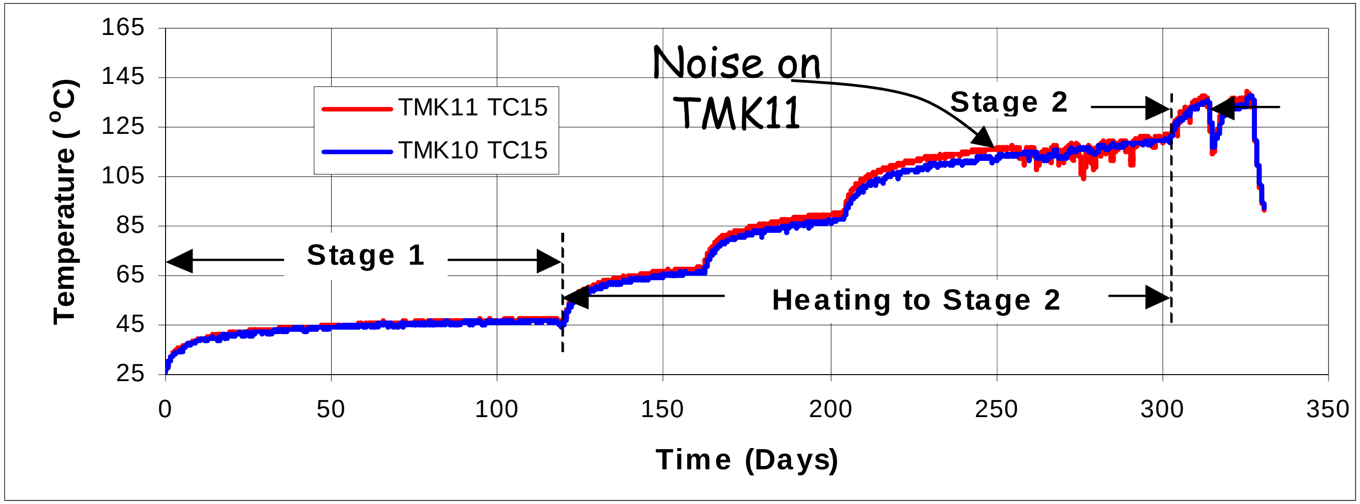
Heating rates below ~0.1C/day. (Not shown on this plot)

Thermal Properties for Test 2

Borehole Thermocouple String	Thermal Conductivity (W/mK)	Thermal Diffusivity m^2/s	Volumetric Heat Capacity (J/m^3K)
Stage 1: All Thermocouples			
TMK006	2.18	1.10×10^{-6}	1.97×10^{6}
TMK007	2.09	1.07×10^{-6}	1.95×10^{6}
TMK008	2.03	8.83×10^{-7}	2.30×10^{6}
Stage 1: Central Thermocouples (In Dried-Out Region), NQ			
TMK006	2.09	8.28×10^{-7}	2.53×10^{6}
TMK007	2.10	1.18×10^{-6}	1.77×10^{6}
TMK008	2.10	1.19×10^{-6}	1.78×10^{6}
Stage 2: Central Thermocouples (In Dried-Out Region), NQ			
TMK006	1.59	7.37×10^{-7}	2.16×10^{6}
TMK007	1.66	7.86×10^{-7}	2.11×10^{6}
TMK008	1.63	6.71×10^{-7}	2.43×10^{6}

Test 3:
3-Hole Test (Data through January 1, 2003)





<u>Stage 1:</u> Heater at 500W. Maximum temperatures (at center of each TC string) smoothly increase.

<u>Heating to Stage 2:</u> Heater power stepped up, bringing central region to above boiling.

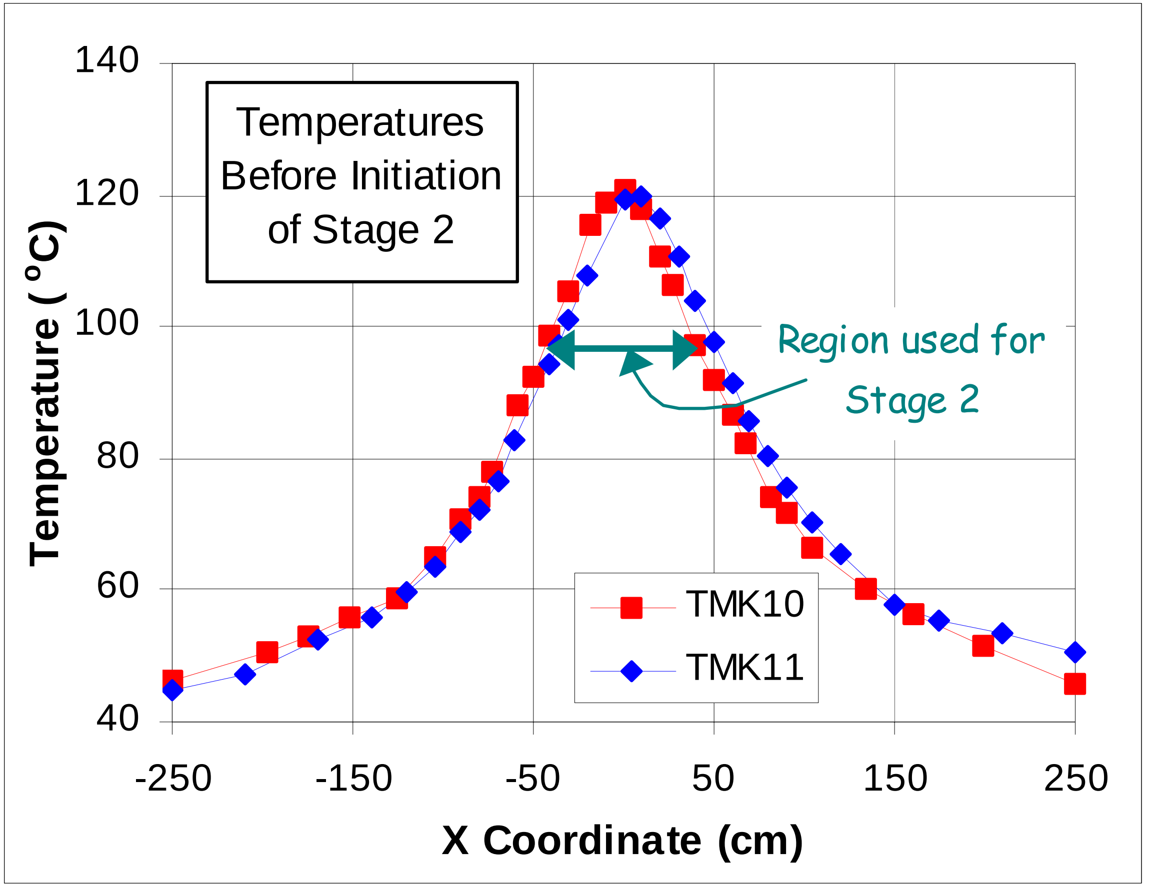
<u>Stage 2:</u> Heater power increased.

Test 3 (3-Hole Test) Temperature Data

Temperature profiles are the same above (TMK11) and below (TMK10) the heater. Implies impact of moisture convection on heat transport is not evident.

Central region of TC strings reached above boiling temperatures.

Heating rates of less than 0.5 ^{o}C/day before initiation of Stage 2 (Not shown on plot.)

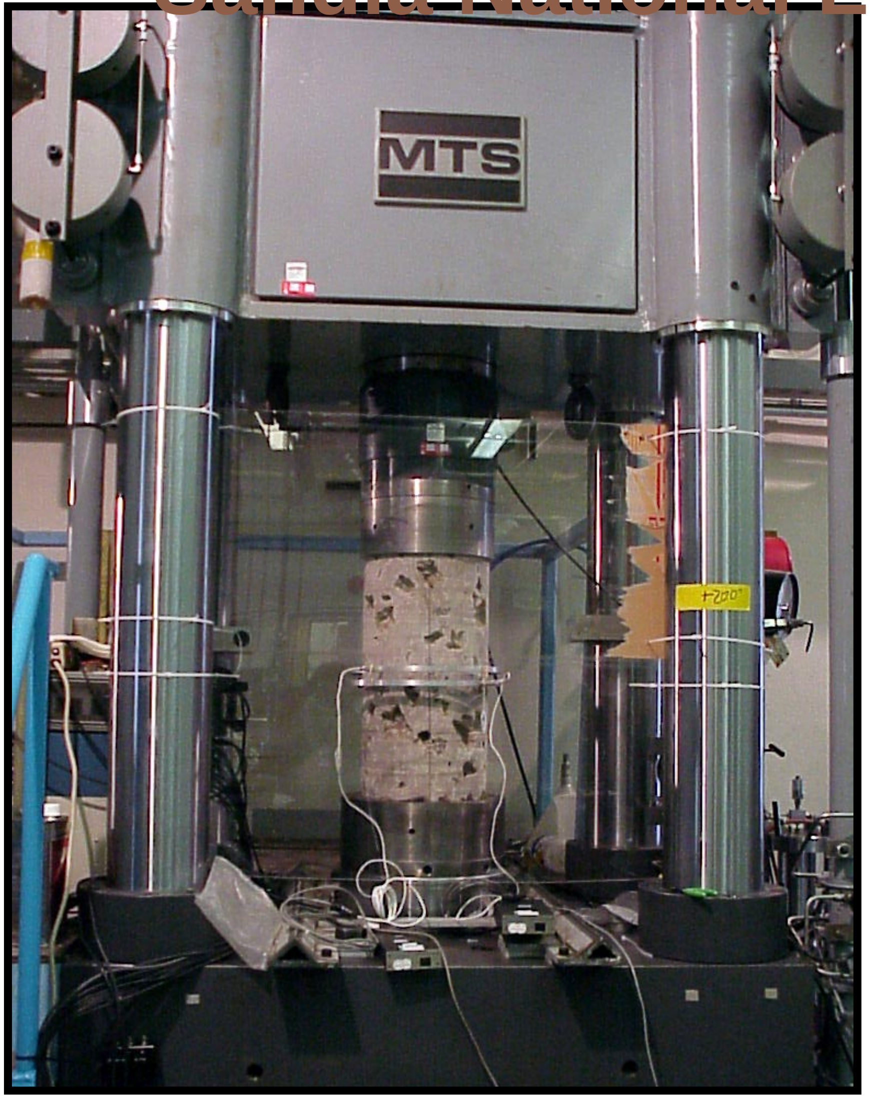


Thermal Properties for Test 3

Borehole Thermocouple String	Thermal Conductivity (W/mK)	Thermal Diffusivity m^2/s	Volumetric Heat Capacity (J/m^3K)
Stage 1			
TMK10	1.73	8.92×10^{-7}	1.94×10^{6}
TMK11	1.76	8.75×10^{-7}	2.01×10^{6}
Stage 1: Central Thermocouples, NQ			
TMK10	1.78	1.13×10^{-6}	1.57×10^{6}
TMK11: Packer Failure?			
Stage 2: Central Thermocouples, NQ			
TMK10	1.47	1.14×10^{-6}	1.30×10^{6}
TMK11: Packer Failure?			

Thermal-Mechanical Rock Properties Investigations

Rock Properties Testing at Sandia National Laboratories



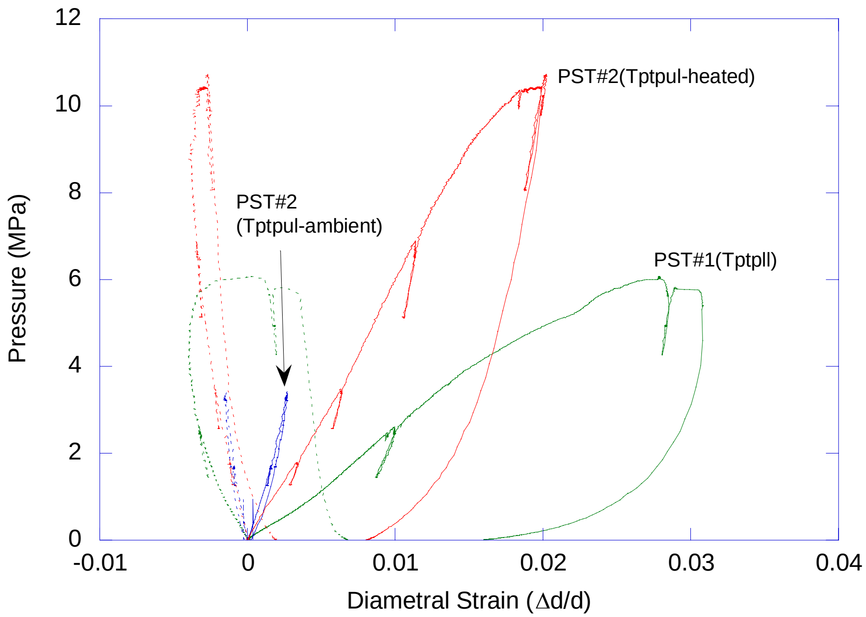
Uniaxial Compression Tests of the 11.5” diameter upper lithophysae samples (7-8/02)

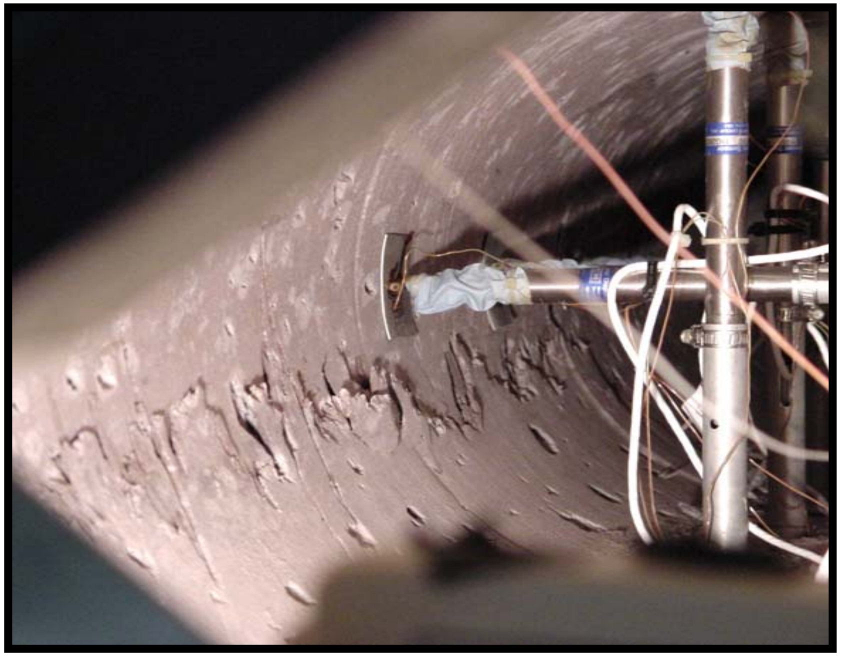
Thermal-Mechanical Rock Properties Investigations
Rock Properties Testing at Sandia National Laboratories

Uniaxial Compression Test on a Sample at 200 deg C (8/02)

Thermal Expansion Test Sample (8/02)

Pressurized Slot Tests





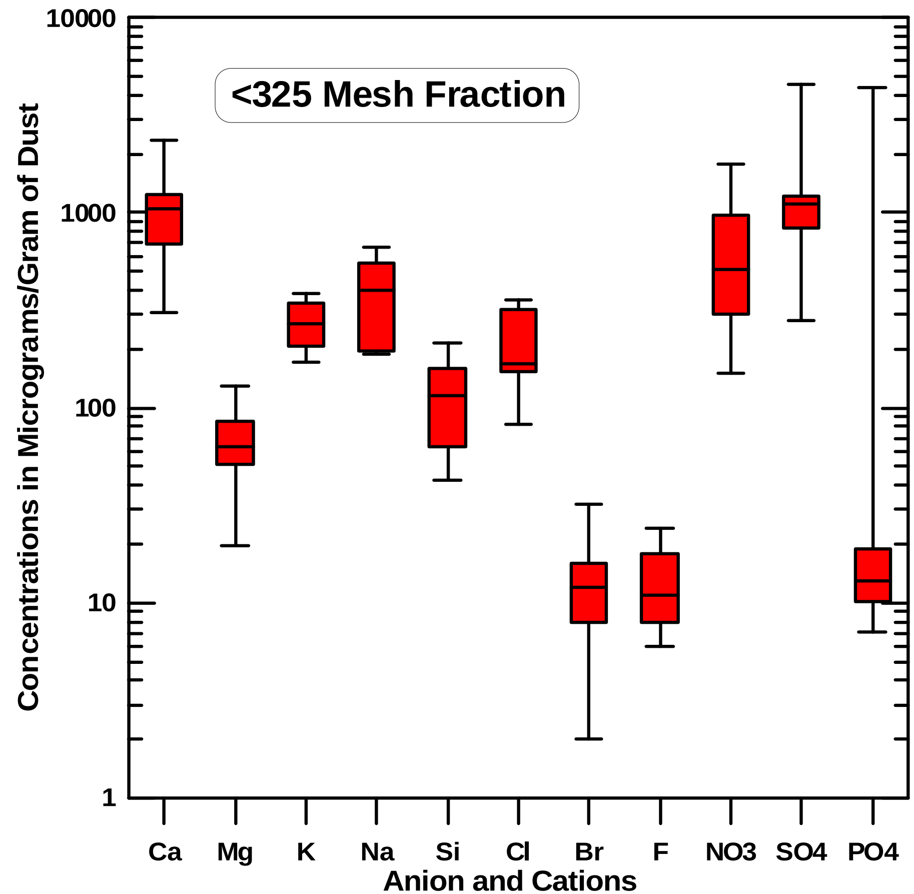
PRELIMINARY

Chemistry of Dust in the Exploratory Studies Facility

- **Analytical Approach**
  - Collect 200 to 400-gram samples from tunnel walls by vacuuming (mean accumulation of 0.017 grams/cm2)
  - Classify by size (~50% <325 mesh)
  - Chemical analyses (both total dissolution and water soluble components) of three size fractions (60-200 mesh, 200-325 mesh, <325 mesh)

Chemistry of Dust in the Exploratory Studies Facility
Water-Soluble Cations and Anions in Dust

- Plot shows medians, 2nd and 3rd quartiles (red boxes), and ranges (whiskers) of water-soluble anions and cations in dust
- Salts will form when the soluble fraction of dust dissolves and evaporates on canisters
- Cl/Br ratios indicate significant but variable amounts of salts derived from construction water



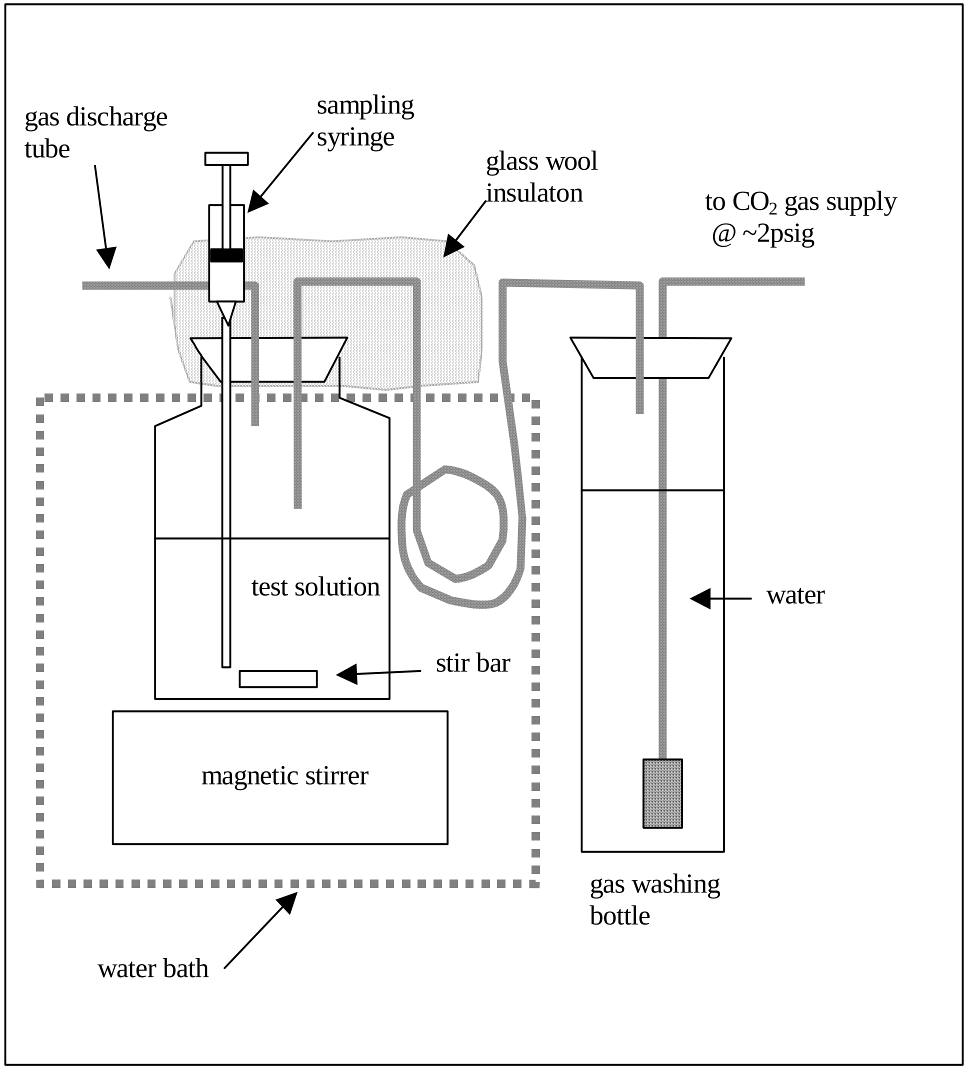
Chemistry of Dust in the Exploratory Studies Facility
Water-Soluble Anions and Cations
(in micrograms of ions or elements per gram of dust)

	60-200 mesh		200-325 mesh		-325 mesh	
	Mean	***SDOM***	**Mean**	***SDOM***	**Mean**	***SDOM***
Ca^{+2}	**380**	*87*	**686**	*123*	**1079**	*171*
Mg^{+2}	**37**	*6*	**45**	*5*	**68**	*10*
K^{+1}	**231**	*21*	**237**	*30*	**273**	*24*
Na^{+1}	**215**	*24*	**311**	*52*	**402**	*54*
Si^{+4}	**114**	*22*	**105**	*26*	**117**	*18*
Cl^{-1}	**102**	*9*	**171**	*31*	**209**	*29*
Br^{-1}	**8**	*2*	**16**	*5*	**13**	*3*
F^{-1}	**13**	*2*	**10**	*3*	**13**	*2*
NO_3^{-1}	**184**	*24*	**358**	*53*	**645**	*155*
SO_4^{-2}	**402**	*68*	**732**	*121*	**984**	*111*
PO_4^{-3}	**28**	*17*	**12.1**	*2.0*	**13.0**	*1.6*
Pb	**0.0027**	*0.0004*	**0.0031**	*0.0004*	**0.0019**	*0.0002*
As	**0.051**	*0.008*	**0.056**	*0.012*	**0.073**	*0.013*

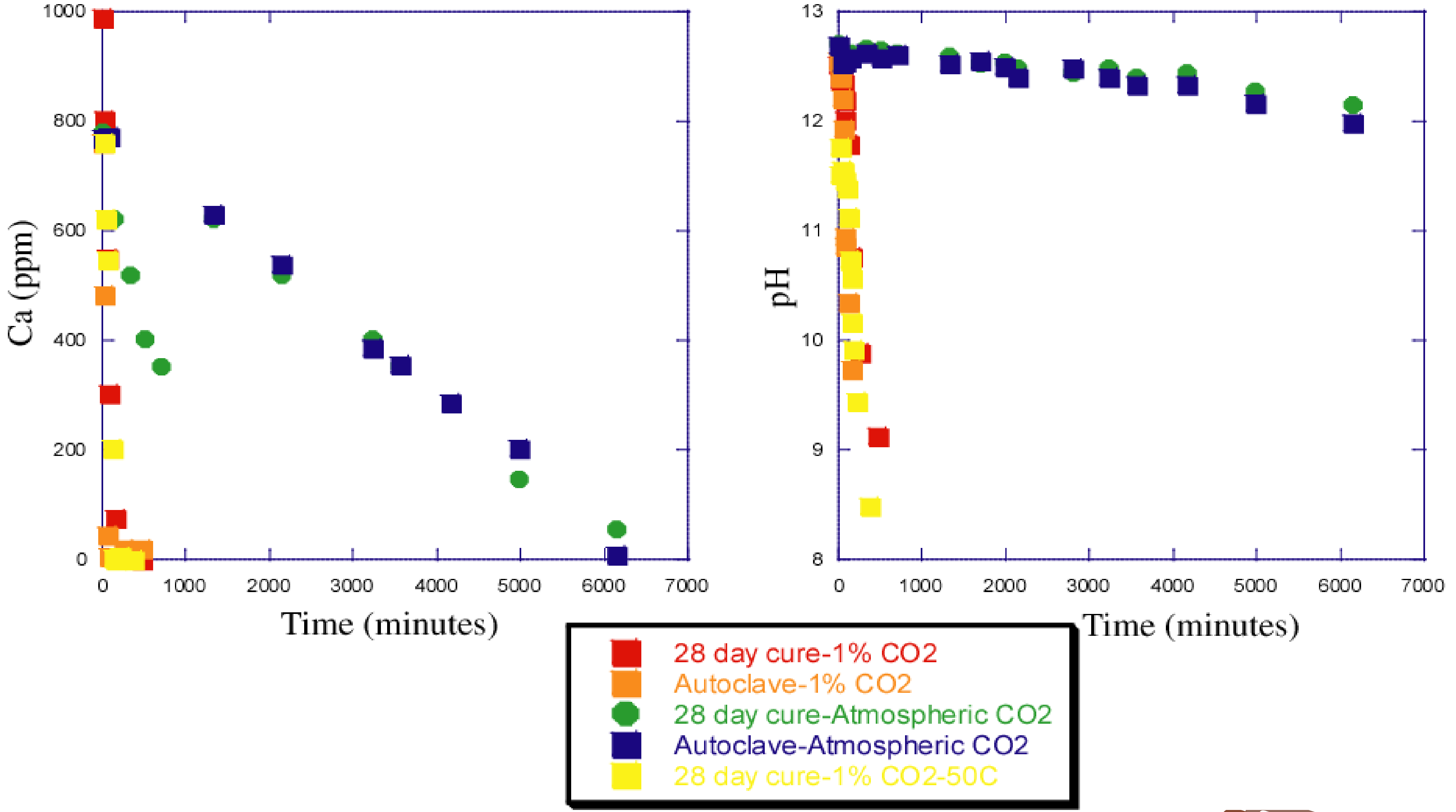
Reactive Transport Studies
Relevant Processes

- **Interaction of water with cement to produce high pH values**
  - **Highest pH values due to interaction with portlandite**
  - **Lower but still high pH values due to interaction with various CSH phases (amorphous CSH, crystalline CSH, tobermorite, ettringite, etc)**
- **Carbonation (calcite precipitation) may lead to passivation of cement**
  - **Carbonation may take place either in the liquid phase (fully saturated conditions), or under unsaturated conditions**

Reactive Transport Studies (Continued)
Carbonation of Hyperalkaline Fluid



Reactive Transport Studies (Continued)
Carbonation of Hyperalkaline Fluid



Reactive Transport Studies (Continued)
Flowthrough Stirred Cell Kinetic Results

Synthetic J-13 **NaCl**