Status of Ongoing Testing

Presented to:
Nuclear Waste Technical Review Board

Presented by:
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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**
- **Coupled Processes / In-Drift Environment / Corrosion**
  - **Drift Scale Test**
  - **Pore Water Geochemistry**
  - **Thermal Properties Investigations**
  - **Thermal-Mechanical Rock Properties Investigations**
  - **Dust Investigations**
  - **Metal Degradation Investigations**

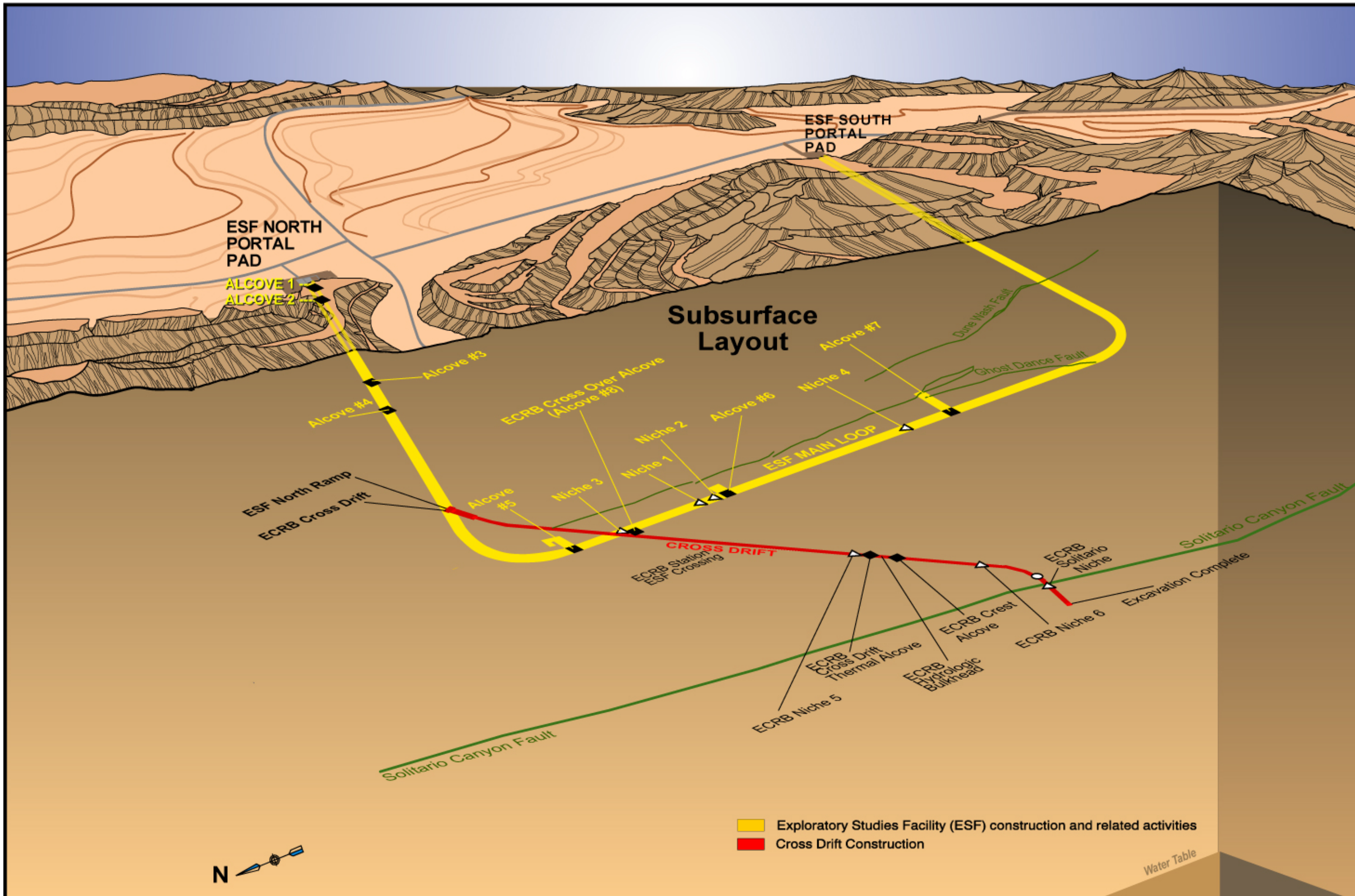
The data and conclusions presented are preliminary, in various stages of Project review, and not yet all in controlled databases/reports.

Overview
(Continued)

- Saturated Zone
  - Site-Scale Model Update
  - Lithostratigraphy / Hydrochemistry
- ^{36}Cl Validation
- Peña Blanca
- Igneous Consequences Studies
- 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



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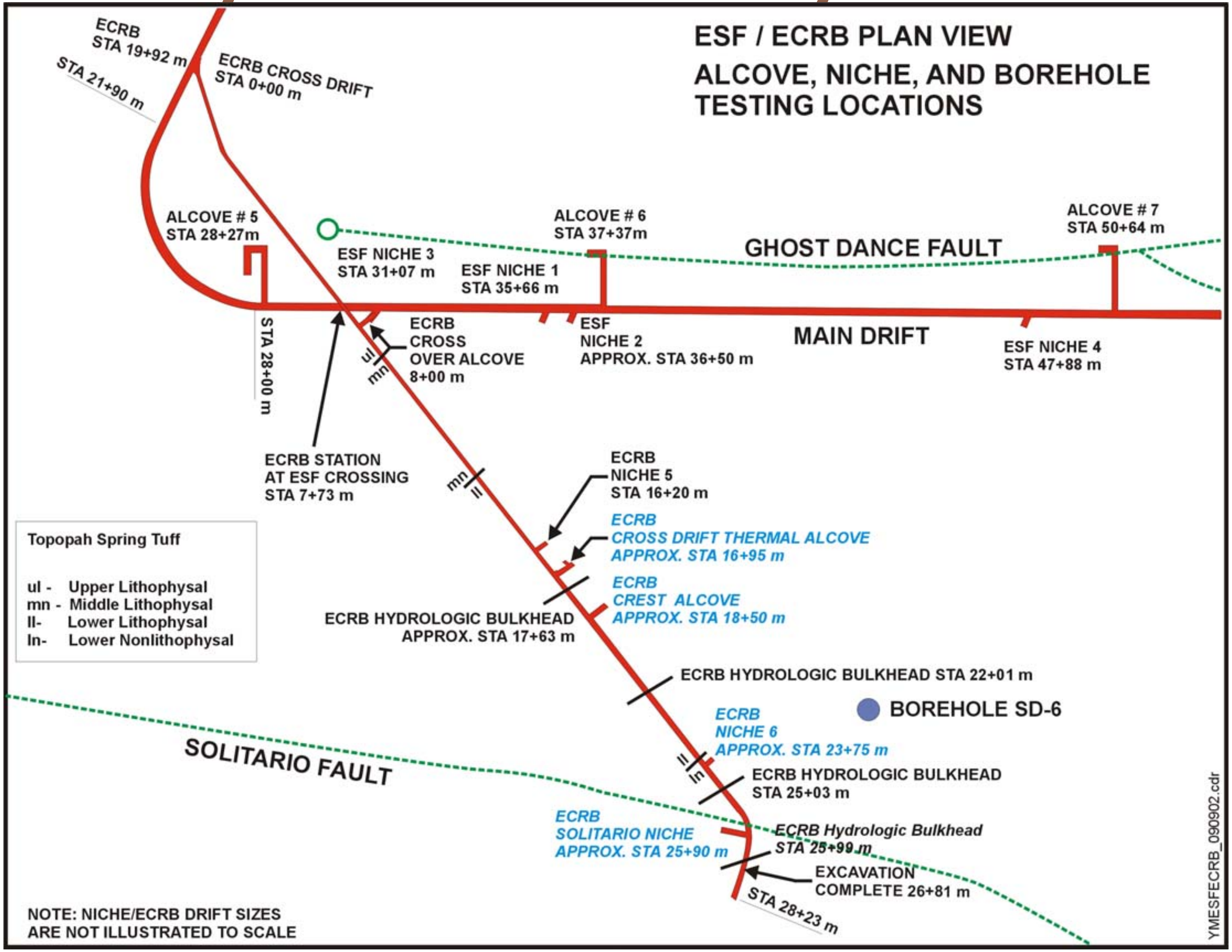
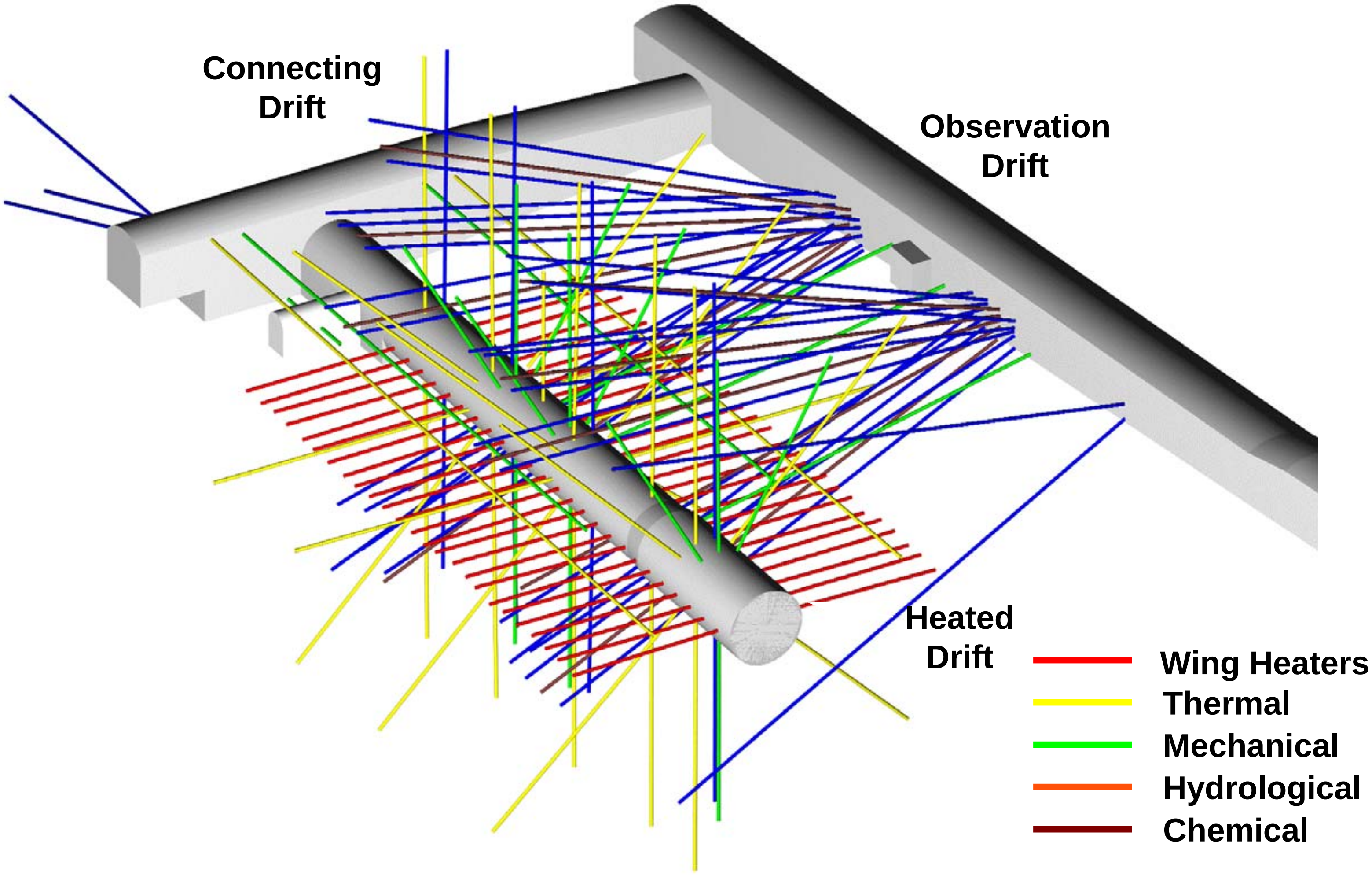
Exploratory Studies Facility and Cross Drift



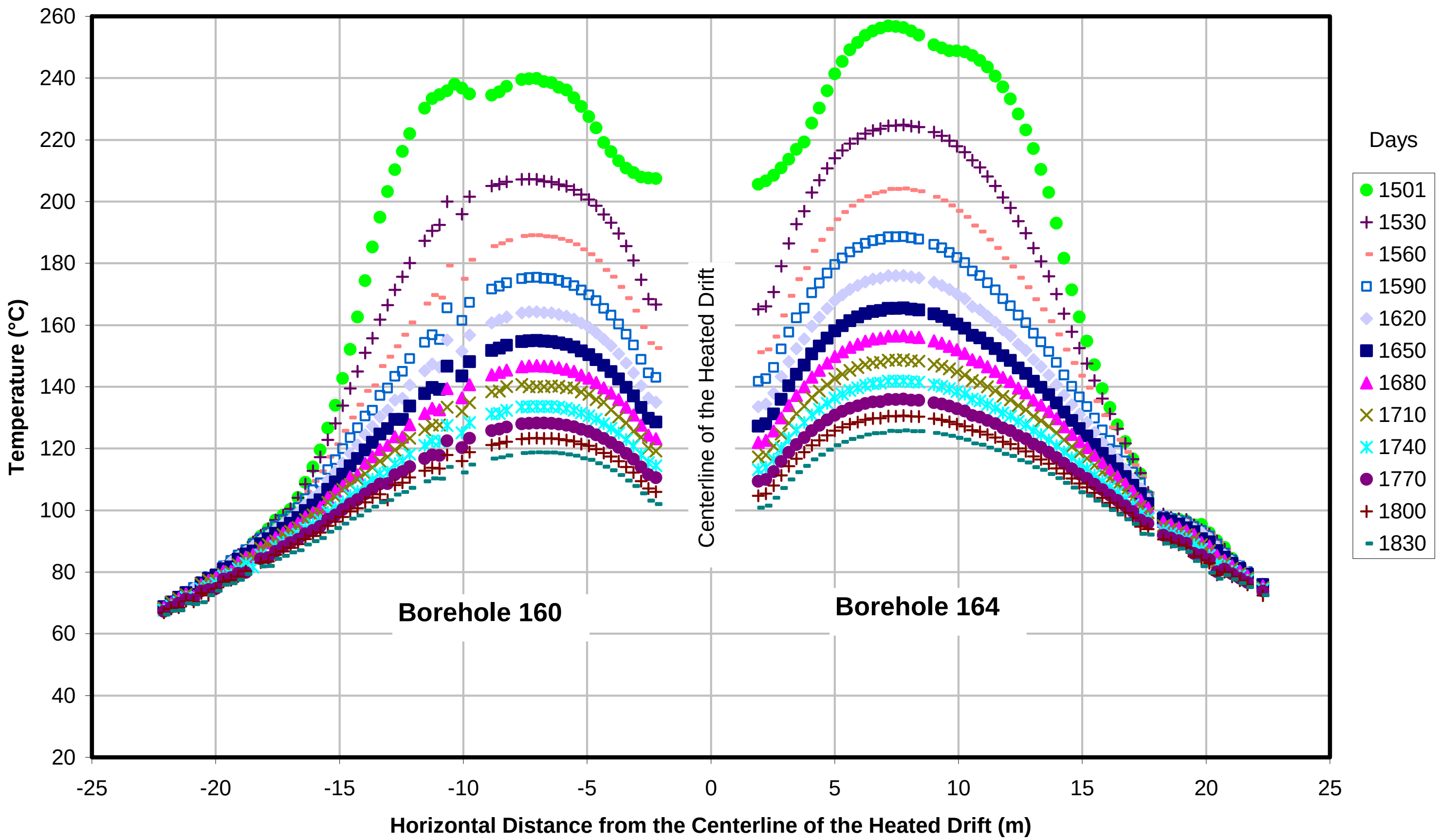
Drift Scale Test

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

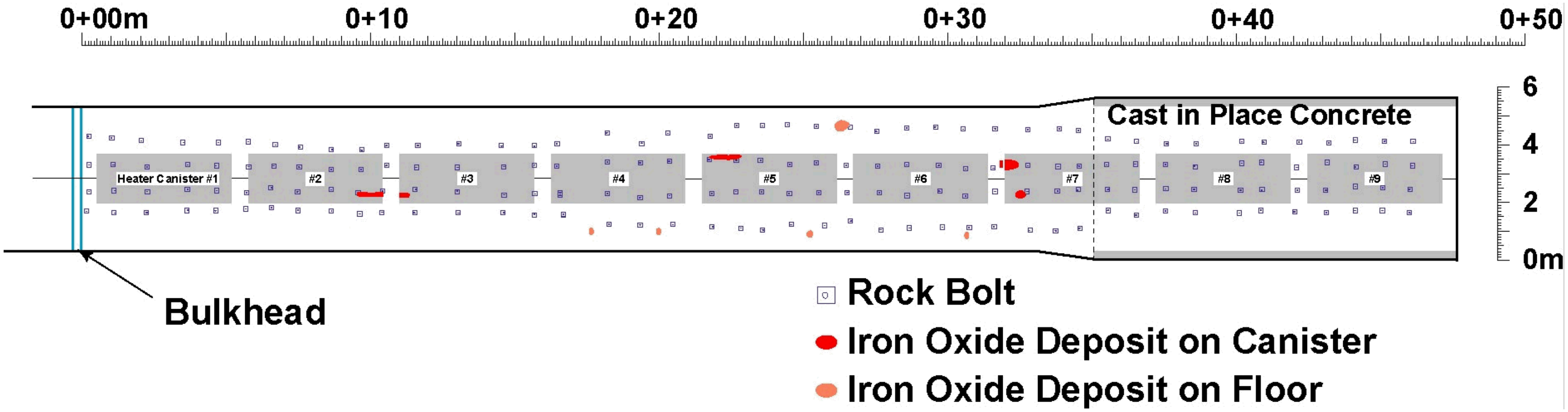


Drift Scale Test
Cooling Phase Results

Temperatures Parallel to the Wing Heaters Approximately at Mid-length of the Heated Drift (BH 160 and BH 164)



Iron Oxide Deposits in the Heated Drift



- Iron oxide material first noticed last August on Canister 7 at about 32 m from the bulkhead
- All spots were deposited sometime between April and August, 2002 (rapid cooling period after heater shut-off)
- Extremely fine-grained material believed to originate from Swellex® rock bolts

Thermal-Hydrologic-Mechanical-Chemical Coupled Processes Validated Against the Drift Scale Test

- The Drift Scale Test (DST) has provided a rich and complete data set for process identification and model testing
- Improved understanding obtained through iterative cross-check between process modeling and measurements
- Confidence in our knowledge of coupled processes because of the favorable comparison between measurements and model predictions
- Models validated against the DST data form the basis for thermal-hydrologic-mechanical-chemical coupled processes models to predict repository performance

Geochemistry of Pore Water

- **Relevance of pore water compositions to the unsaturated zone (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**

Chemistry of Pore Water from Repository Rock Units

- **Strontium isotope analyses of leached pore water salts validated by direct analyses of pore water**
  - **$^{87}Sr/^{86}Sr$ of pore water salts (0.7122-0.7127)**
  - **$^{87}Sr/^{86}Sr$ of pore water (0.7121-0.7127)**
- **Data are being used to apply advection-reaction model of UZ flow (Marshall and Futa, 2003, *IHLRW Symposium*)**
  - **Water-rock interaction in the PTn is responsible for narrow range of $^{87}Sr/^{86}Sr$ of pore water in the Topopah Spring Tuff**
  - **Reactions require low velocities of a few centimeters/year as suggested by Yang (2002, *Applied Geochemistry*)**

Engineered Barrier System Studies Thermal Properties Investigations

Supports coupled process models, engineered barrier system (EBS) process models, and design.

Review of Field Test Program in Tptpll

- **Test 1: Single heater and single instrumentation borehole, run below 100°C**

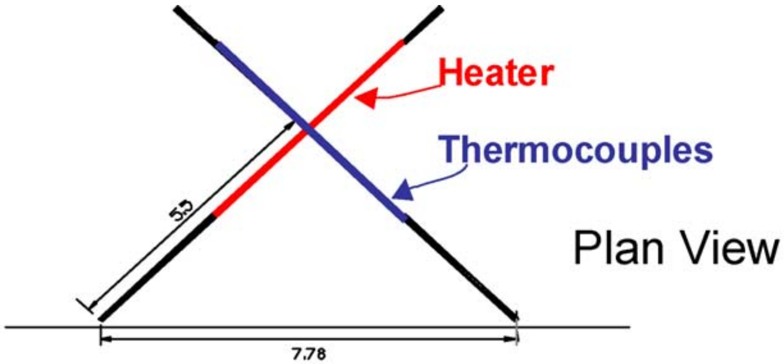
  Status: Completed

- **Test 2: Three heaters and three 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 dried out (phase 2)**

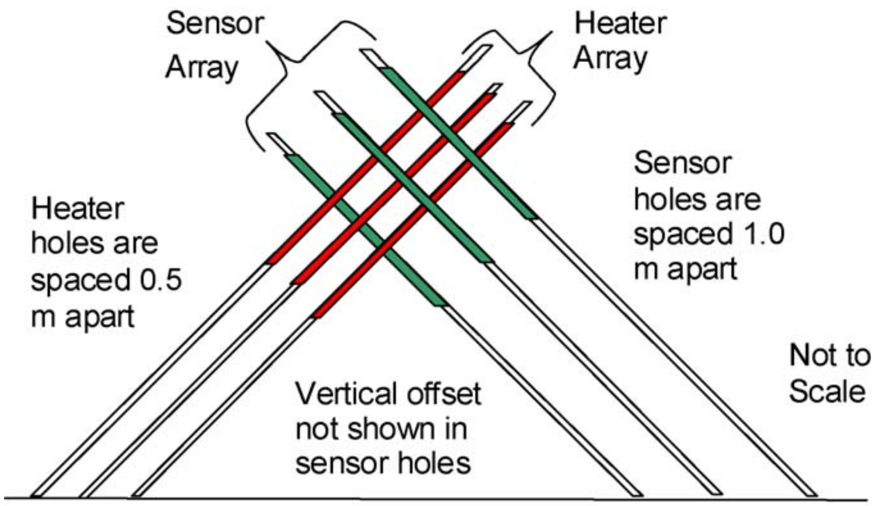
  Status: Completed

- **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 below 100°C (phase 1), and also after the test area dried out (phase 2)**

  Status: Completed

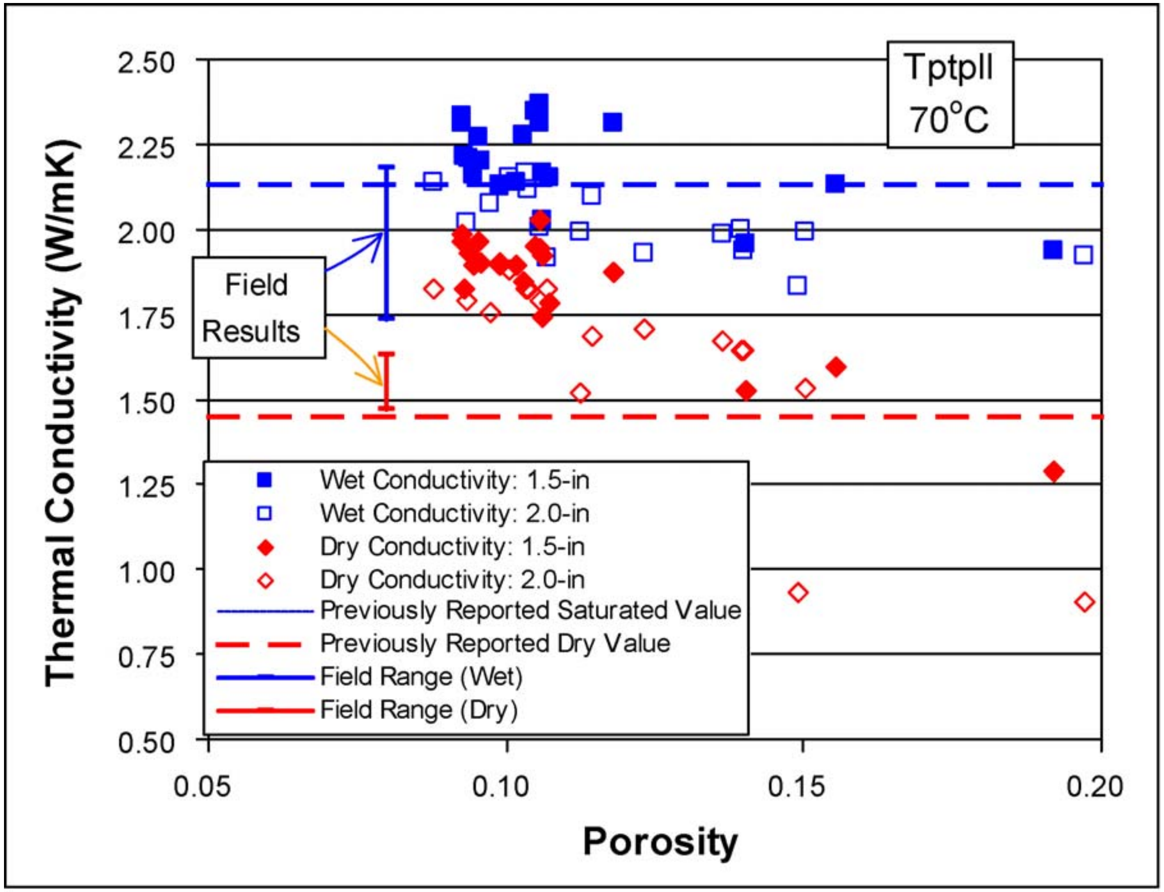


Geometry for Tests 1 and 3



Geometry for Test 2

Comparison of Field and Laboratory Tptpll 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.

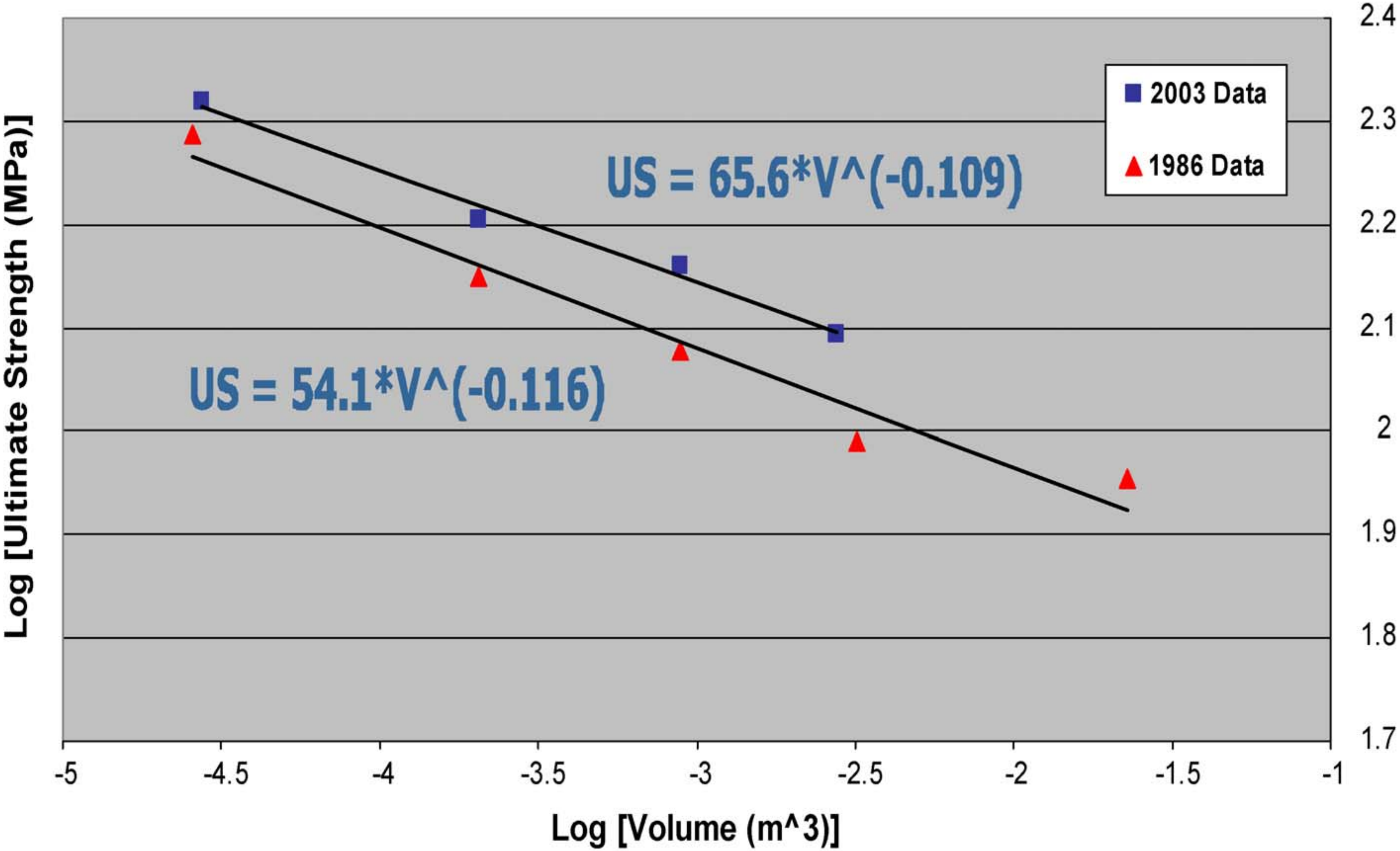
Field and laboratory data are consistent.

Field data are plotted at an arbitrary porosity

Engineered Barrier System Studies Thermal-Mechanical Rock Properties Investigations

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

Effect of Sample Size on Strength



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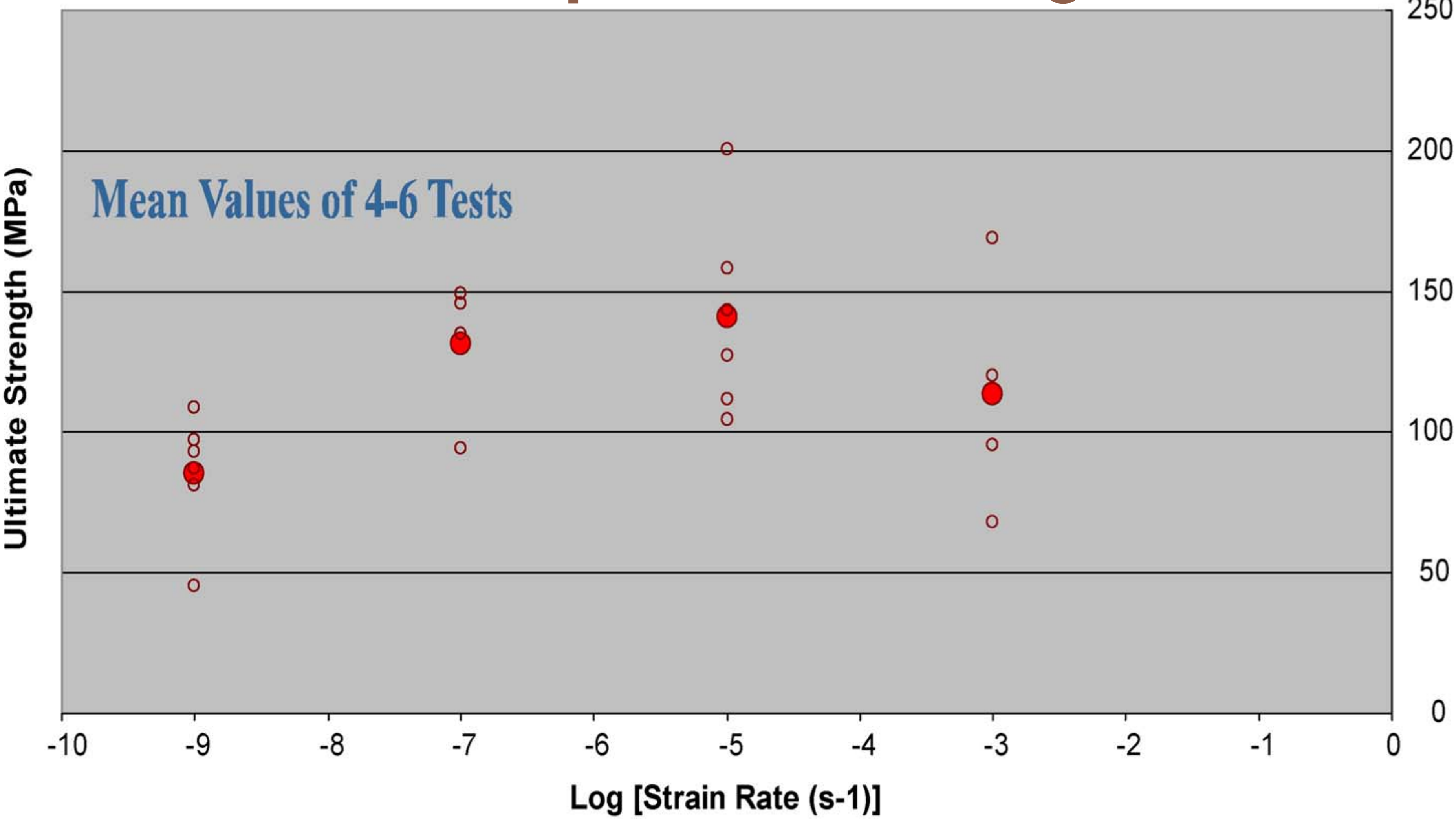
Time Dependent Mechanical Behavior

- Time dependency on strength noted in data from experiments at different strain rates on samples of middle non-lithophysal Topopah Spring tuff
- Some constant stress experiments in the early to mid-80's confirmed a static fatigue behavior for the welded tuffs
- Experiments are being planned to gather the appropriate data to define the best fit to the stress versus time-to-failure data

Rate Dependent Strength



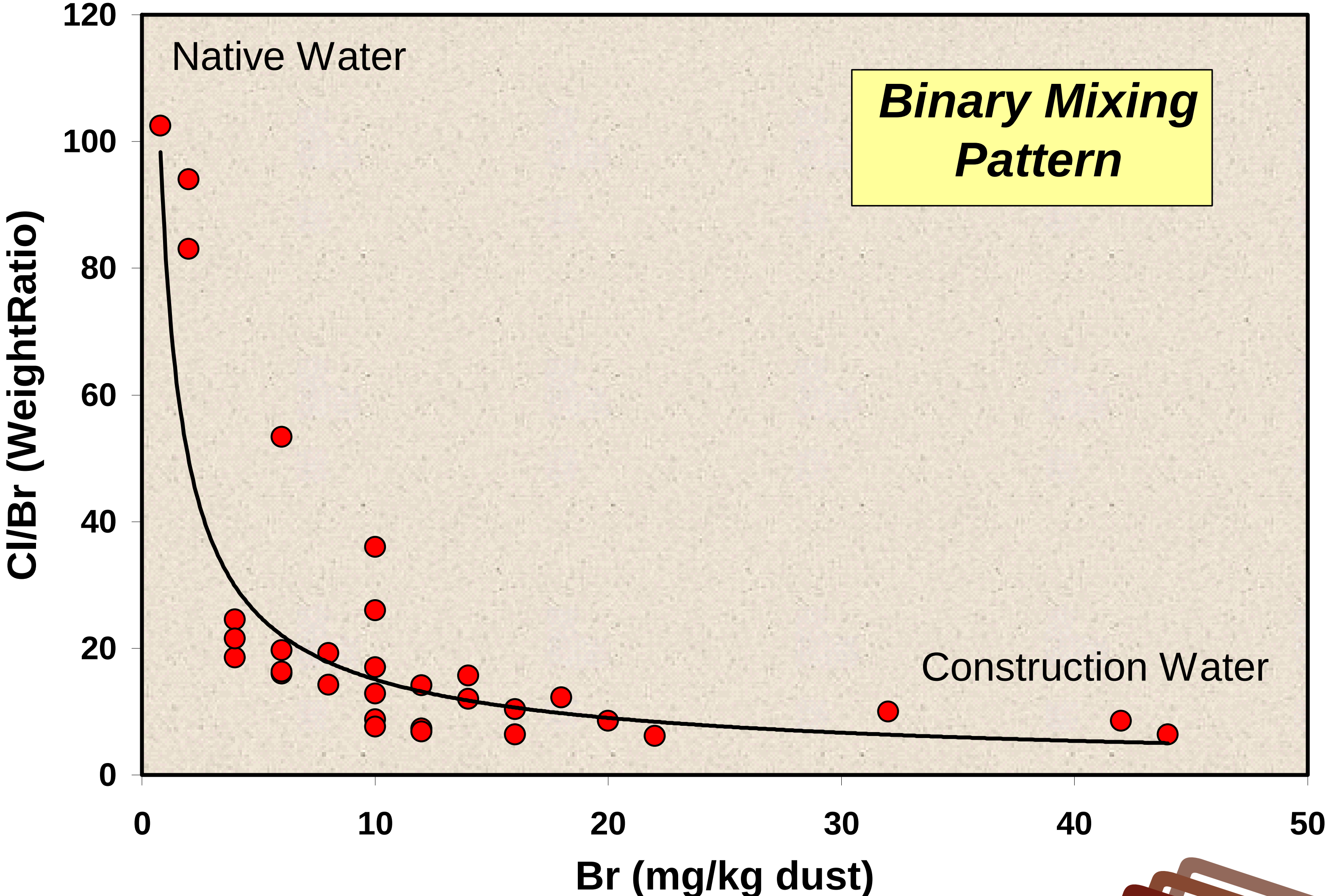
Dust Investigations
Chemistry of Dust in the Exploratory Studies Facility

- **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**

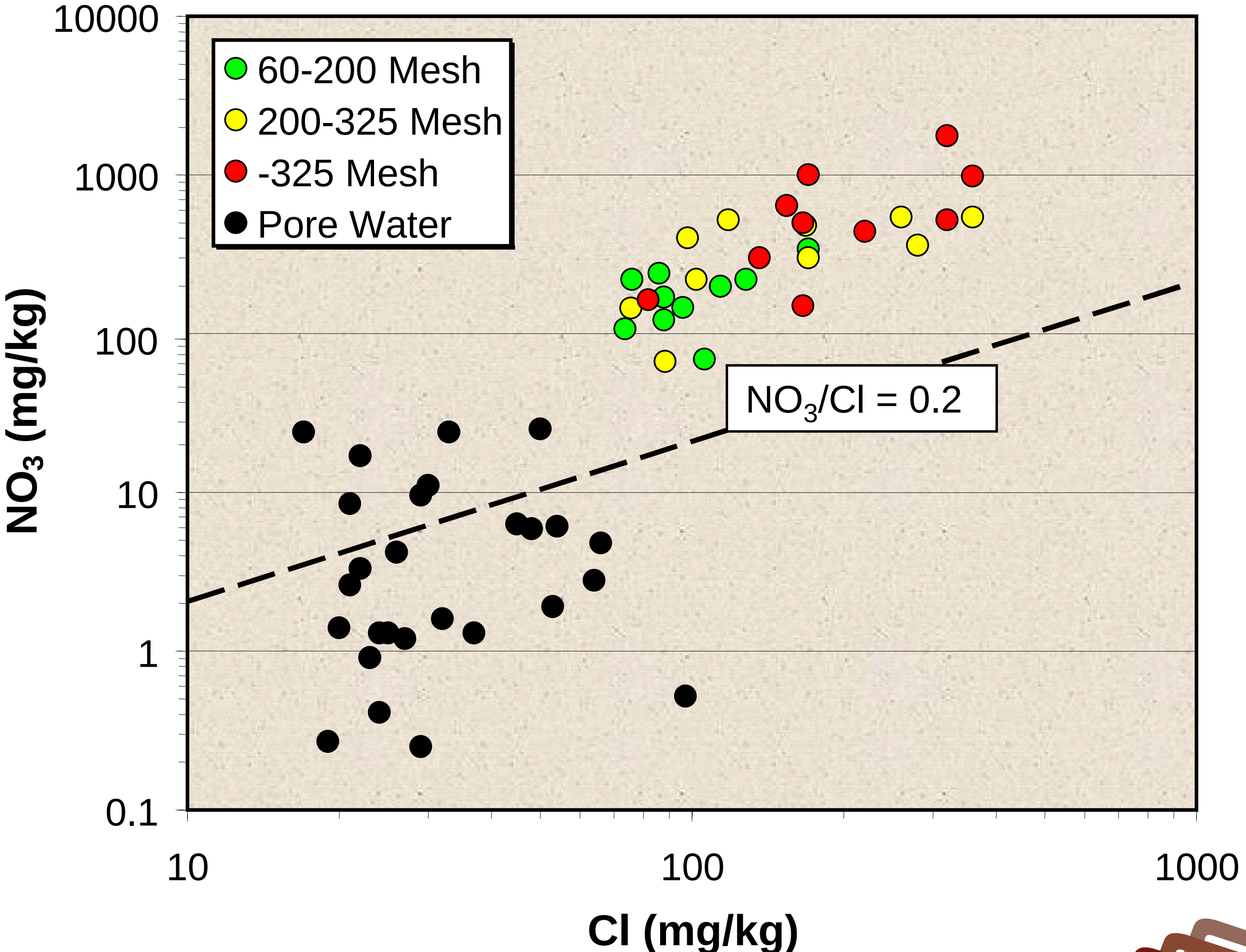
Geochemistry of Exploratory Studies Facility Dust

- **Non-rock components in <325 mesh dust fraction**
  - **Organic carbon 0.5 to 2.9 percent, m=1.4 percent**
  - **Water-soluble anions and cations (Ca^{+2}, Mg^{+2}, Na^{+1}, K^{+1}, SiO_2, Cl^{-1}, Br^{-1}, F^{-1}, SO_4^{-2}, NO_3^{-1}, PO_4^{-3}) 0.1 to 1.4% (m=0.4%)**
  - **Zero valence Fe (0.7 to 2.9%, m=1.9%)**
  - **Cl and Br indicate mix of salts from native and construction waters**

Mixing of Salts from Native Pore Water and Construction Water



Nitrate-to-Chloride Ratios in Soluble Dust Fractions

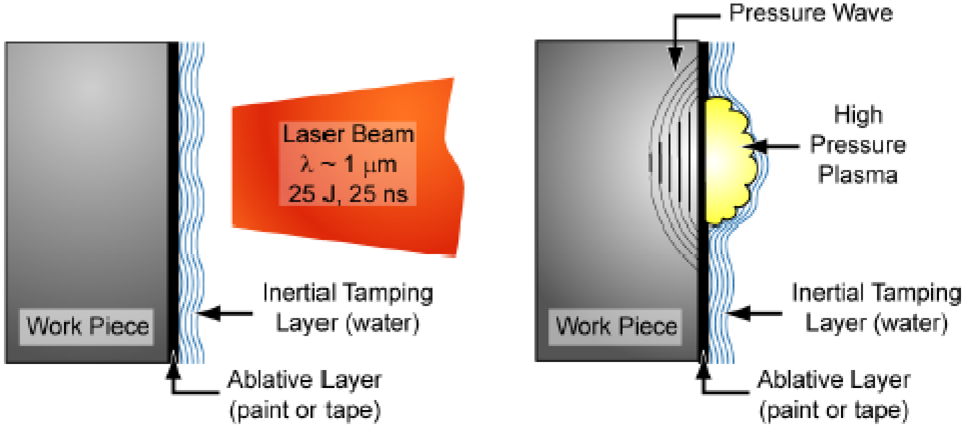


Nitrate-Chloride Ratios

- **Ratio of soluble nitrate-to-chloride is an important parameter for corrosion**
- **Excess nitrate suppresses formation of $CaCl_2$**
- **Soluble salts in dust typically have ratios greater than 1**
- **Pore waters typically have ratios less than 0.2**

Materials Degradation Investigations

Laser Peening Theory



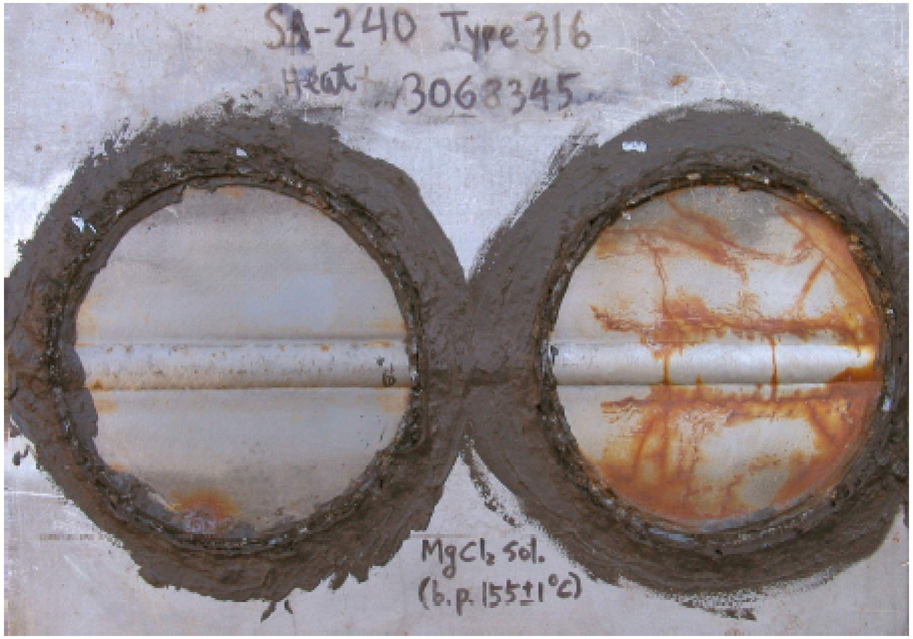
- Laser peening provides
  - Highly compressive surface residual stress
  - Deep layer of compressive residual stress
  - Smooth surface
- Good process control

Materials Degradation Investigations

(Continued)

Laser Peening Mitigates Weld Stress

- 316 Stainless Steel exposed to 40% $MgCl_2$ at 160°C

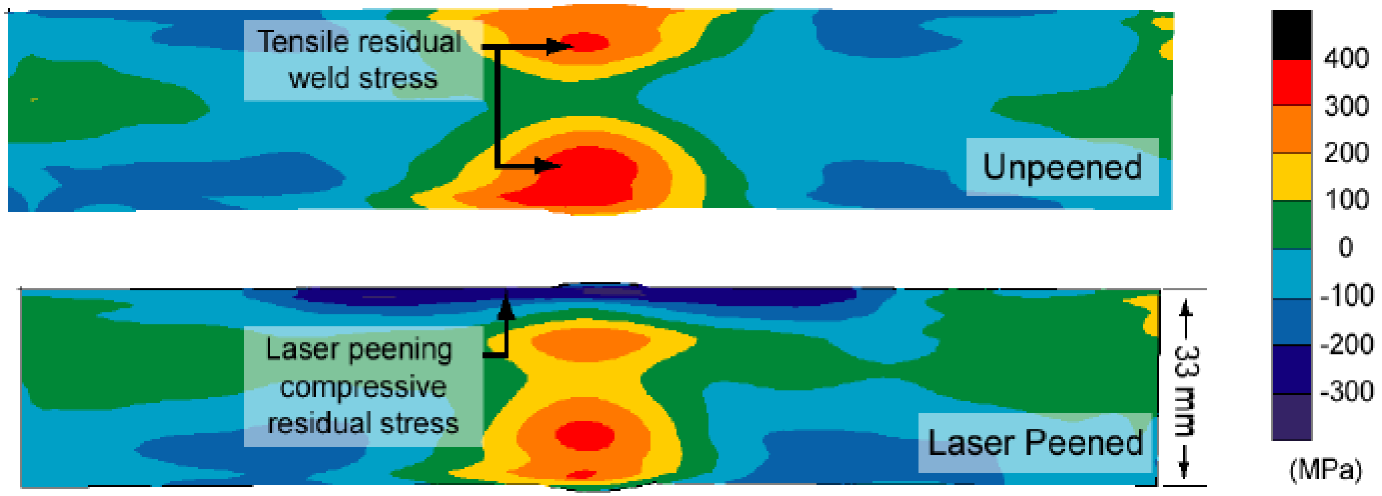


The unpeened side (right) is corroded and cracked, while the peened side (left) is essentially untouched

Materials Degradation Investigations
(Continued)

Contour Method to Measure Residual Stress

- Laser Peening has been used to generate extremely deep compressive residual stress in Alloy 22 weldments

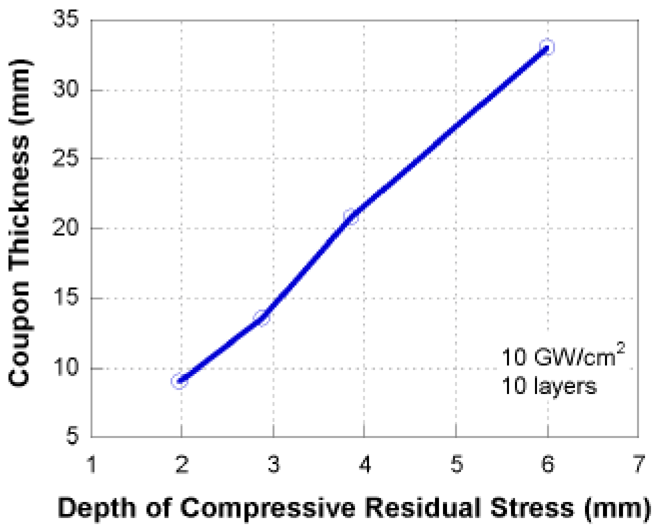


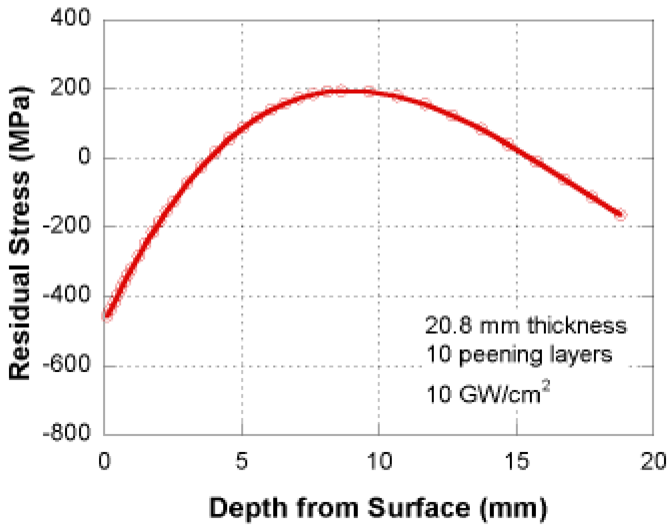
Stress measured with the contour method parallel to the welding direction in a 2-sided V-prep GTAW weld.

Materials Degradation Investigations
(Continued)

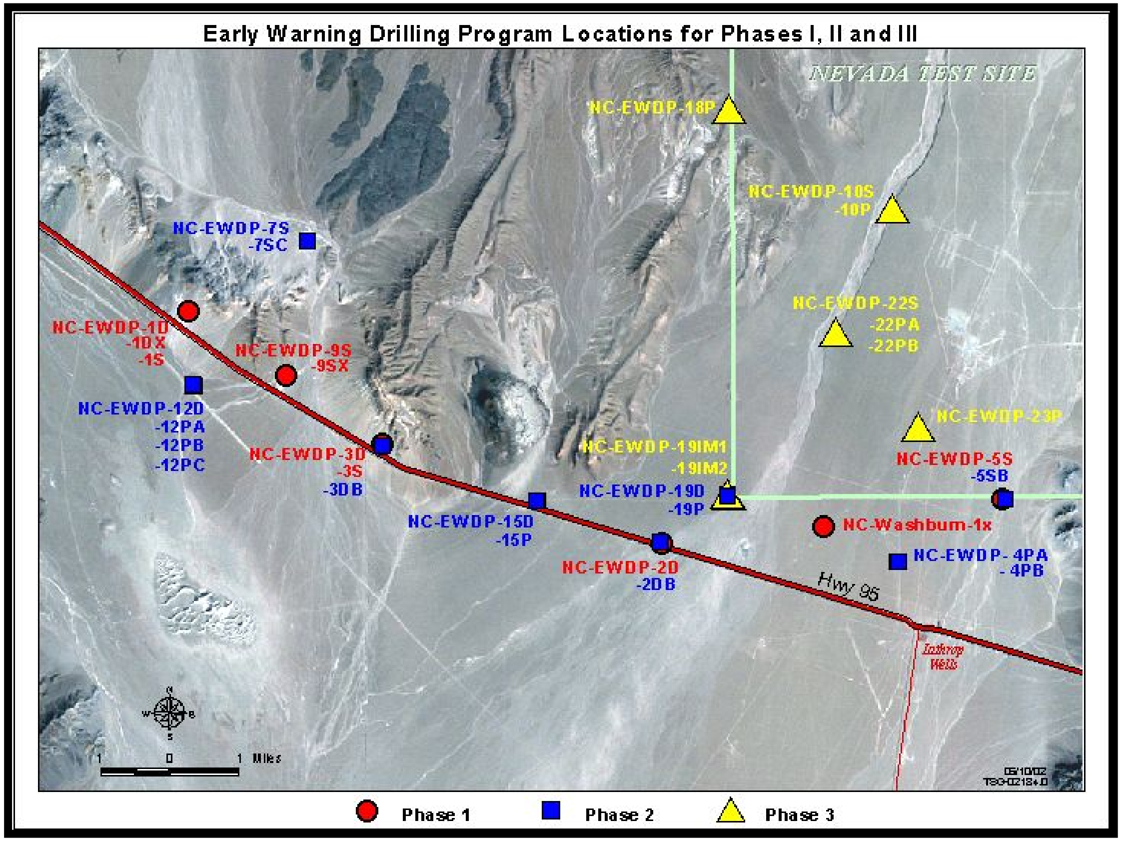
Depth of Laser Peening Residual Stress

- Depths of residual compressive stress reaching 20% of the part thickness have been achieved in Alloy 22 coupons





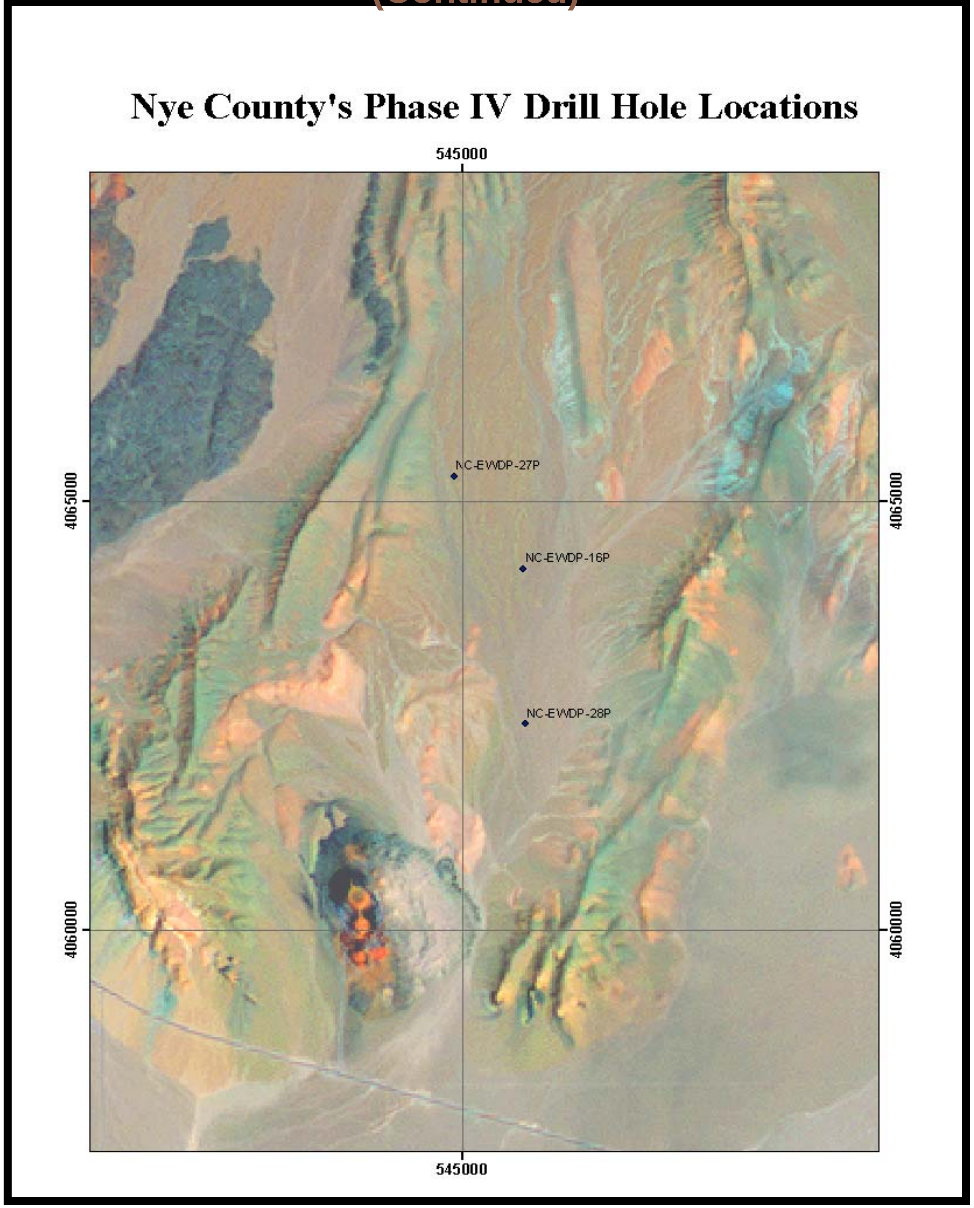
Saturated Zone
Nye County Early Warning Drilling Program



Site-scale data being collected in support of the saturated zone (SZ) flow and transport model:

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

Saturated Zone
(Continued)



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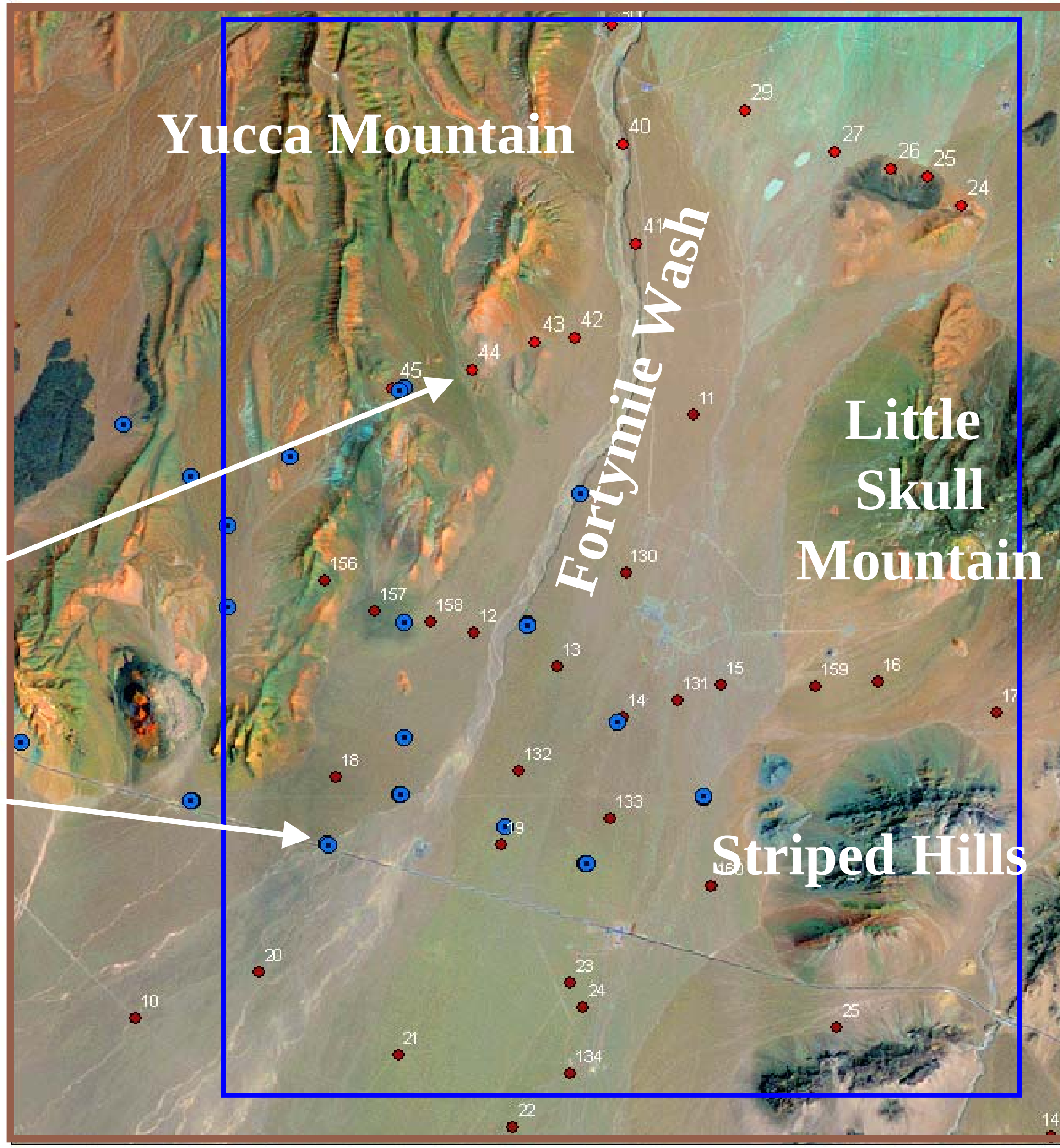
Site-Scale Saturated Zone Model Update

- **Model being updated to support License Application**
- **Key aspects:**
  - **Calibration includes parameter optimization, use of water-level and head measurements, and permeability parameterization**
    - **Results in predicted flow paths from proposed repository in the south-southeastern direction and then trend to south-southwest and follow Fortymile Wash**
  - **Confidence-building includes:**
    - **Prediction and comparison of Nye County water-level data**
    - **Comparison of permeability data to calibrated values**
    - **Comparison of hydrochemical data**
    - **Comparison with temperature data**
    - **Alternate model development (updated framework and effect of faults)**

Lithostratigraphy
Purpose of Demonstration Modeling

- **Is there sufficient variability in resistivity to model resistivity contrasts**
- **Does resistivity variability suggest any correlation with lithologic variability or hydrologic property**
  - **Particularly in the alluvial fill of the Fortymile Wash basin**
- **Are there resistivity trends or anomalies that can be investigated with future Nye County Early Warning Drilling Programs (EWDP) drill holes**

Area of Demonstration Modeling Centered Within Fortymile Wash



Locations of existing Shlumberger sounding

Locations of planned or existing Nye County EWDP drill holes

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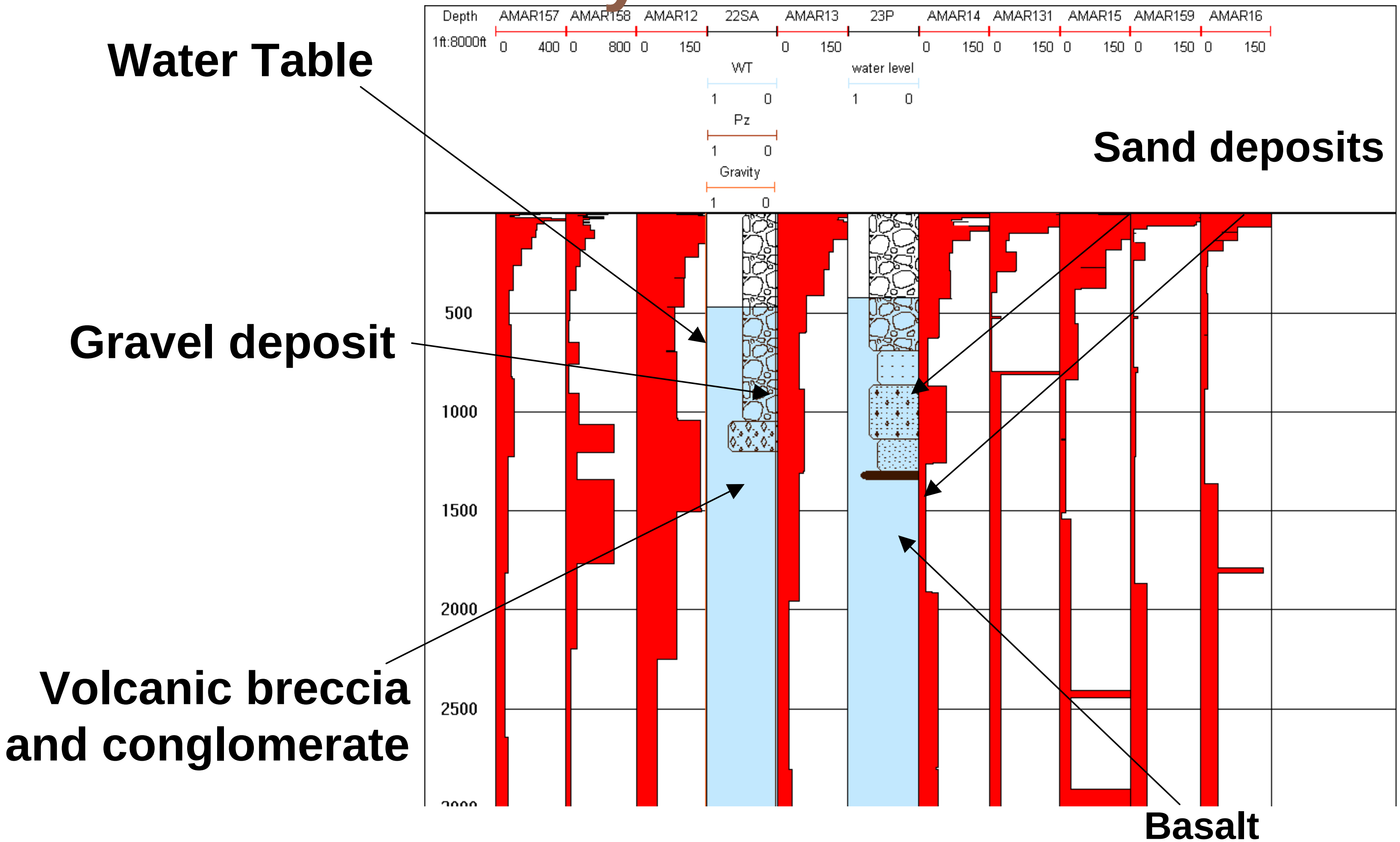
Apparent Resistivity Profiling Across Fortymile Wash

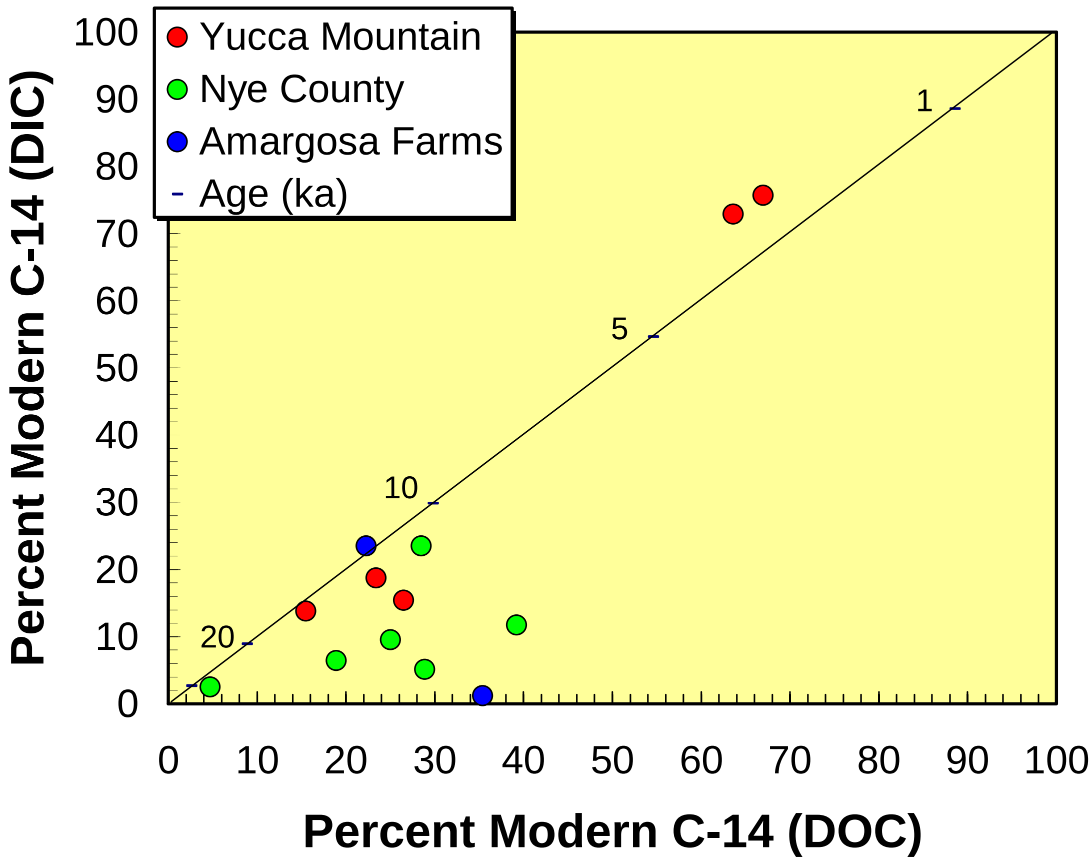


Saturated Zone Hydrochemistry Objectives

- **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**

Radiocarbon Dating of Dissolved Organic Carbon

- Dissolved organic carbon (DOC) analyses of 13 samples completed
- DOC ages expected to be younger than Dissolved inorganic carbon (DIC) ages
- Most DOC ages are between 8 and 16 ka
- Most DIC ages greater than 12 ka
- Youngest ages from upper Forty Mile Canyon (reverse discordance being evaluated)



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Radiocarbon Dating of Dissolved Organic Carbon

(Continued)

- **Uncertainties in significance of DOC ages**
  - Very light $\delta^{13}C$ values may suggest organic contamination of some sampled waters
  - DOC analyses of blind standards are slightly outside of tolerances
  - Local recharge along flow paths may compromise significance of groundwater ages downgradient from Yucca Mountain

^{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
- Status
  - Final report summarizing the ^{36}Cl Validation Study is due in August, 2003
  - DOE is evaluating a proposed study by an independent third party to resolve the ^{36}Cl issue
  - New study would involve
    - Background investigation
    - Experimental design
    - Analytical effort
    - Final conclusion

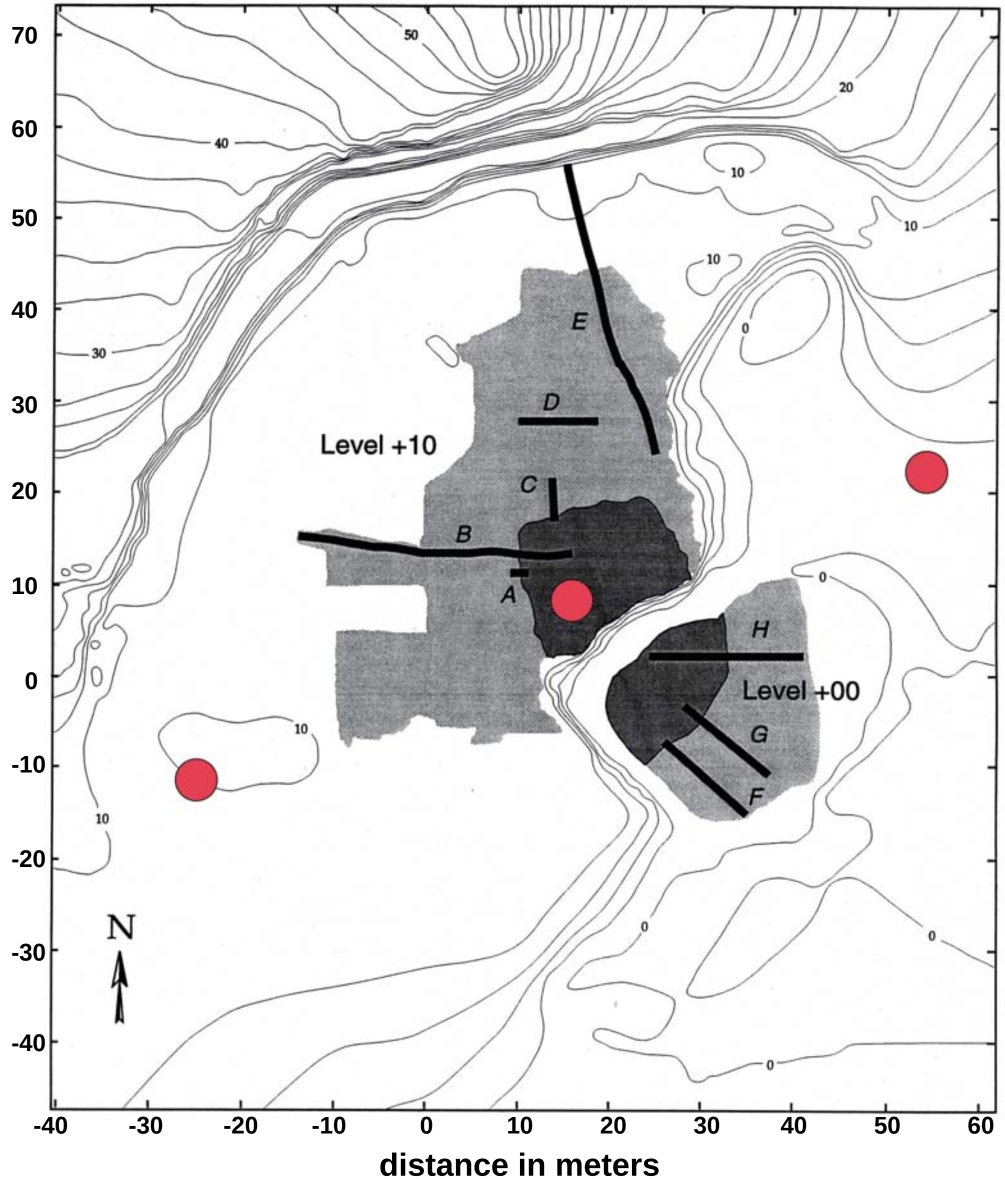
Why Study Peña Blanca

- Similar geologic setting to Yucca Mountain
  - U deposit hosted by welded ash-flow tuffs
- Similar hydrological setting to Yucca Mountain
  - U deposit in UZ ~100 m above water table
- Similar climate to Yucca Mountain region
- U deposit similar to waste form materials

Previous Studies at Peña Blanca

- Geologic studies
  - Mapping of Nopal I ore deposit
  - Mineralogical characterization of ore body
- Radionuclide studies
  - U-series isotopic measurements of minerals and waters
  - Radionuclide migration modeling

Peña Blanca Workscope



- Drill one continuously cored well and two additional boreholes to water table
- Collect and analyze rock and water samples
- Construct conceptual model for Peña Blanca

Update on Activities

- **New driller contracted for work**
- **Continuous coring of well drilled through Nopal I U ore body**
- **Satellite wells drilled upgradient and downgradient from ore body**

Rig at PB-2 at 30 m

Update on Activities
(Continued)

- Collection of core and cuttings samples for analysis

Core from PB-1 at 8.95-16.6 m

- Collection of water samples for analysis

Well 1.3 km from PB-1 sampled at 97.3 m

Path Forward

- **Complete drilling of boreholes**
- **Conduct sampling and characterization of core and cuttings**
  - **Lithologic description of samples at rig site**
  - **X-ray diffraction and petrographic studies of mineralogy**
  - **Radionuclide composition of rock samples**
  - **Analysis of leachate from rocks to determine characterize sorbed radionuclides**

Path Forward
(Continued)

- **Sample and analyze water from wells**
  - **Determine abundance and composition of U series isotopes and other radionuclides in waters**
- **Use drilling observations to construct stratigraphic and hydrological framework for Peña Blanca**
- **Develop conceptual flow and transport model for Peña Blanca**
- **Develop models to simulate U migration in the UZ**

Igneous Consequences Studies
Igneous Consequence Peer Review

- A DOE-sponsored peer review was conducted to address specific issues related to potential consequences of a hypothetical igneous event intersecting the proposed repository
- Igneous Consequence Peer Review (ICPR) was asked eight questions related to
  - adequacy of the models being used to represent the initiating events and associated processes
  - ability of the models to quantify uncertainties
  - level of analysis necessary given to adequately address the issues given the limitations of science

Igneous Consequences Studies
Igneous Consequence Peer Review
(Continued)

- ICPR Panel issued a final report February 26, 2003
- ICPR was a thorough and complete review that has triggered actions on the part of the Project
- Many of the comments are being addressed in ongoing work or planned work to support the technical basis for license application
- Some of the planned work will be confirmatory
- A complete response to the ICPR report is scheduled to be completed the end of June 2003
- The planned work and response will also take into consideration the reports of the Nuclear Waste Technical Review Board (NWTRB) consultants

Igneous Consequence Peer Review Ongoing and Planned Work

- Estimates of magma discharge rate into the repository drifts and magma pressure within the drifts
- Estimates of the length of the gas vapor cavity behind the propagating dike tip
- Mathematical modeling of magma flow into a drift following dike/drift intersection
- Additional field studies are also under consideration

Summary

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

Backup

Probing Thermal-Hydrologic-Mechanical-Chemical Processes-Drift Scale Test

Pre-Test Characterization

Laboratory

T-Properties
H-Properties
M-Properties
MIN/PET
Pore Water

Field

Rock Classification
Fracture Mapping
Borehole Videos
Air Permeability

Passive Monitoring During Heating and Cooling

- Temperature
- Displacement
- Strain
- Humidity
- Pressure
- Acoustic Emission (microfracturing)

Periodic Active Testing during Heating and Cooling

GPR
Neutron log
ERT

} Matrix Liquid Saturation

Air Permeability : Fracture saturation and fracture aperture changes
Gas Sampling
Water sampling

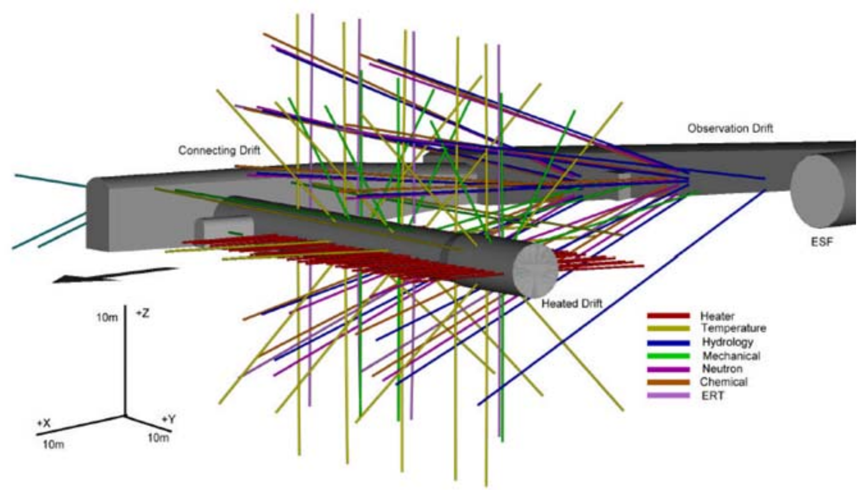
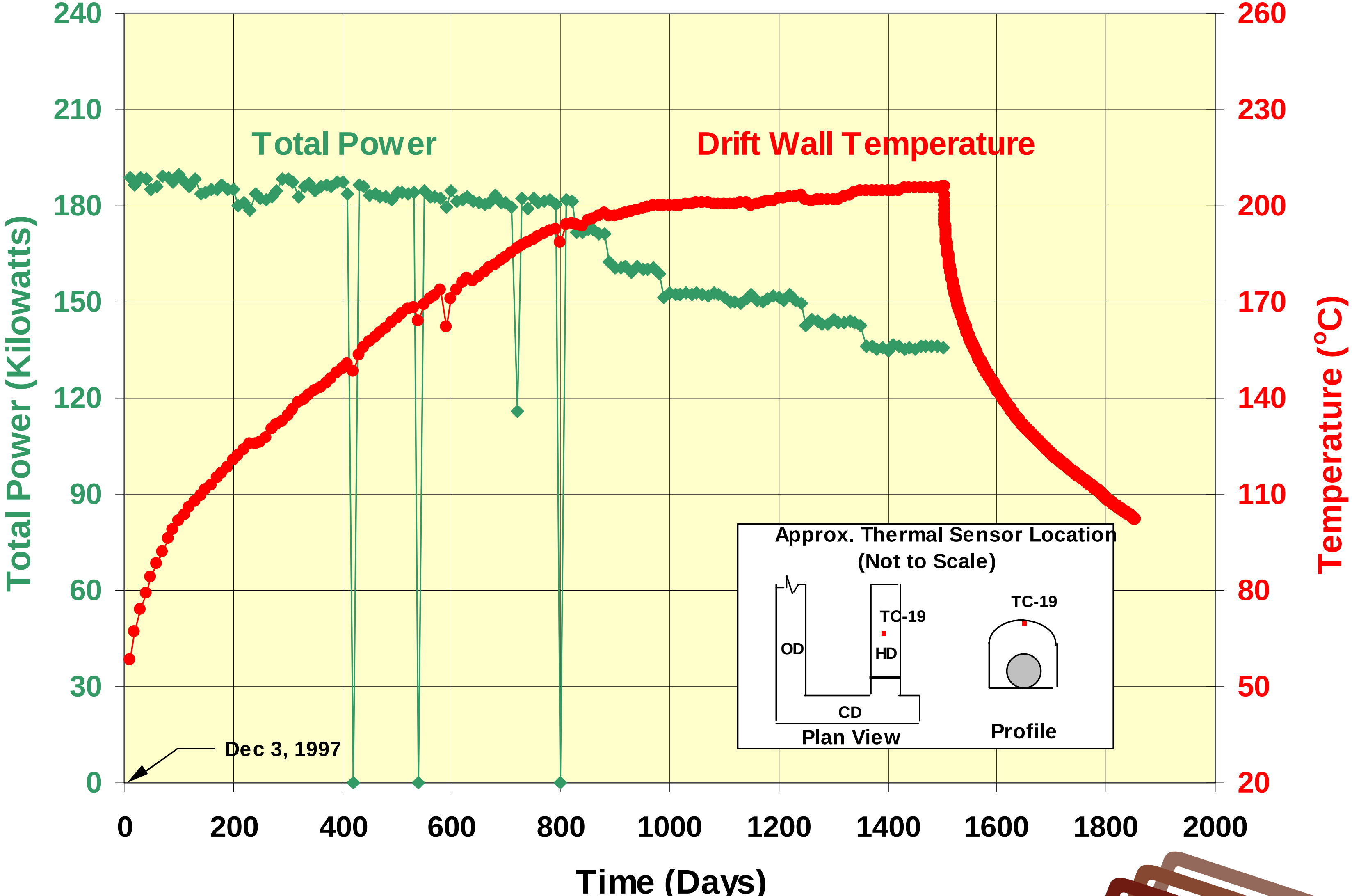


Figure A-1. Perspective View Showing Drifts and Boreholes of the Drift Scale Test.

Drift Scale Test: Power and Temperature History



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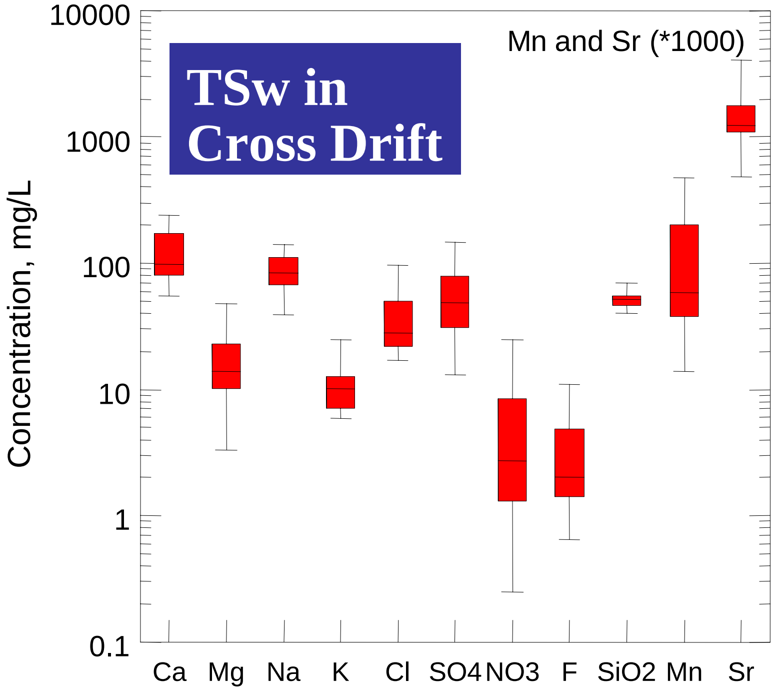
Geochemistry of Pore Water

- **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**



Status: Thermal Conductivity Testing

- Laboratory testing program on Tptpll. Status: 144 new tests completed; results presented September, 2002
  - Saturated and oven-dried specimens
  - Specimens containing both natural and artificial porosity
- Field tests
  - Two additional tests completed (three completed in total)
  - Preliminary data for Stage 2, high temperature (dried-out) phase, of two tests have been used to calculate thermal properties. Data presented at last NWTRB meeting
  - Two additional tests are planned for FY03: Tptpll and Tptpul
    - Boreholes have been drilled, surveyed
    - Equipment prepared, ready for installation for one test

Field Data: Implications for Model

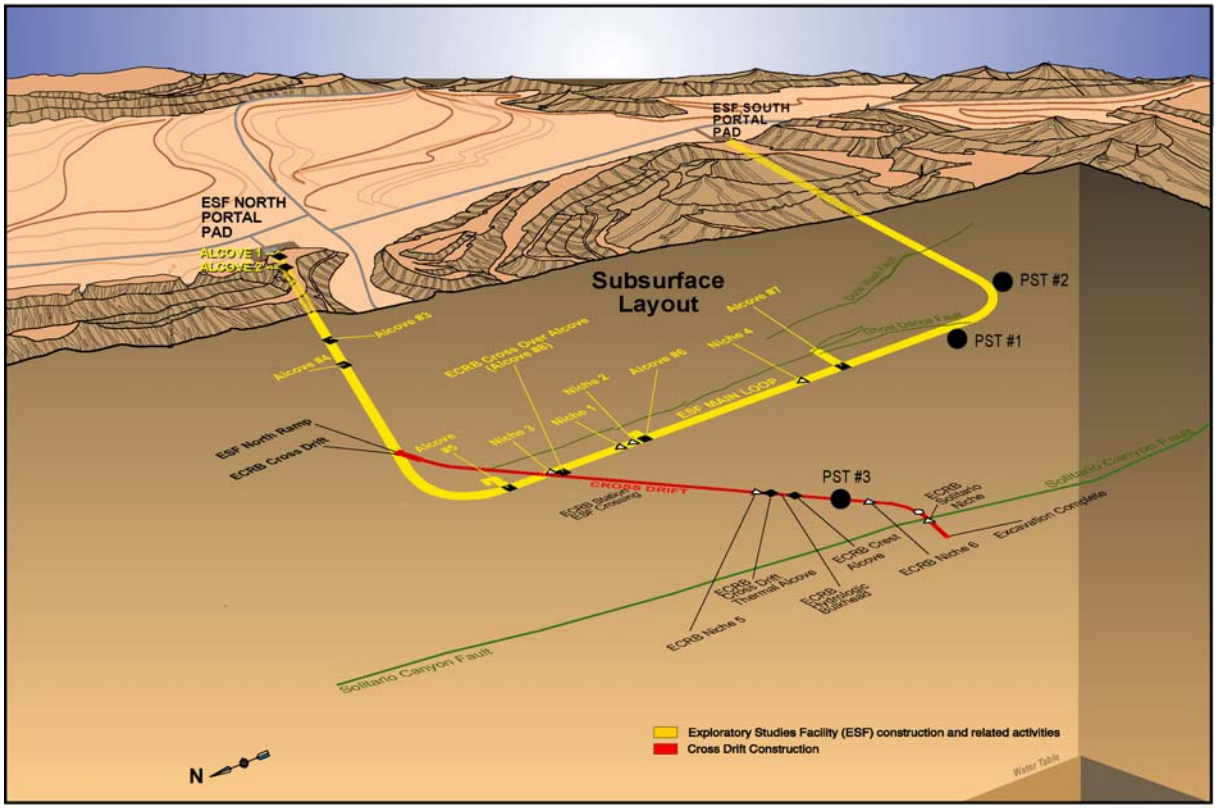
Model predictions given in: *Thermal Conductivity of the Potential Repository Horizon Model Report*, MDL-NBS-GS-000005. Model values account for moisture and lithophysal porosity.

	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 prediction but well within one standard deviation.

Thermal-Mechanical Rock Properties Investigations
Pressurized Slot Test Locations

Exploratory Studies Facility and Alcoves

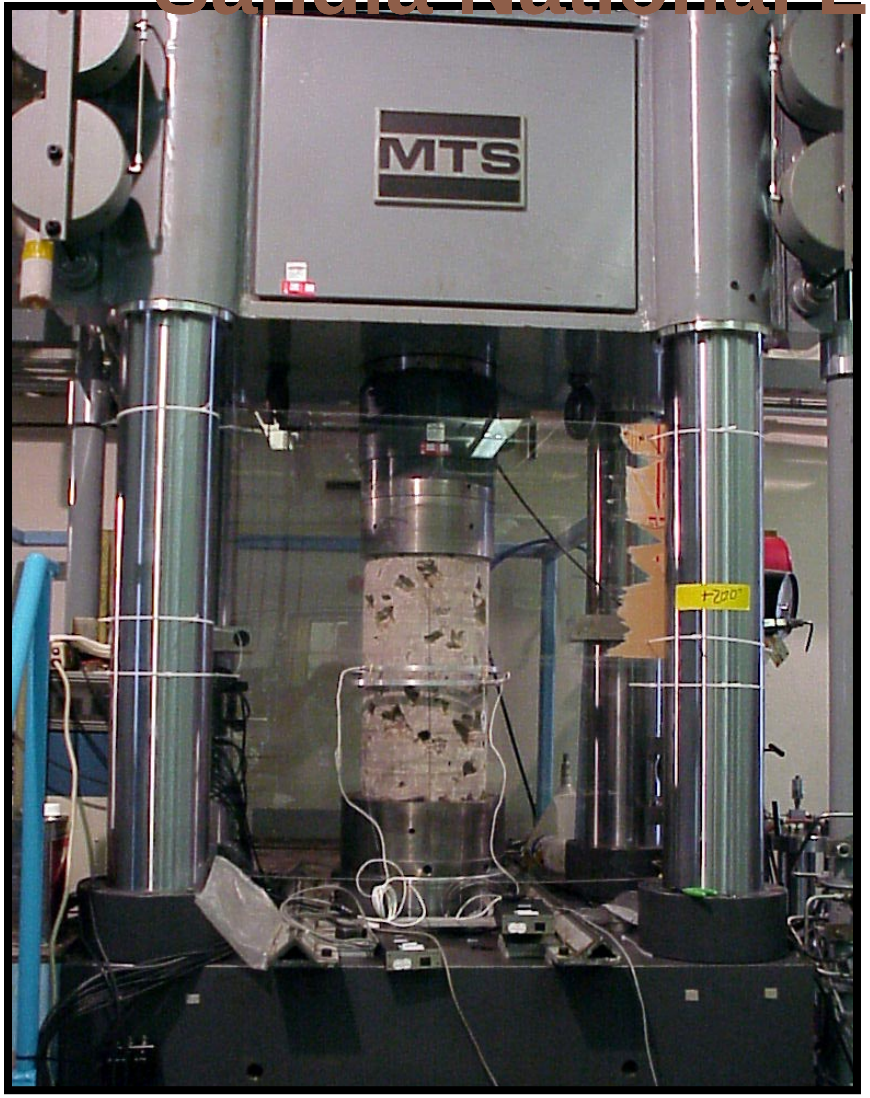


PST #1 – Station 57+77 of ESF, Tptpll (Completed)
PST #2 – Station 63+83 of ESF, Tptpul (Completed)
PST #3 – Station 21+25 of Cross Drift, Tptpll (Completed)

YUCCA MOUNTAIN PROJECT

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)

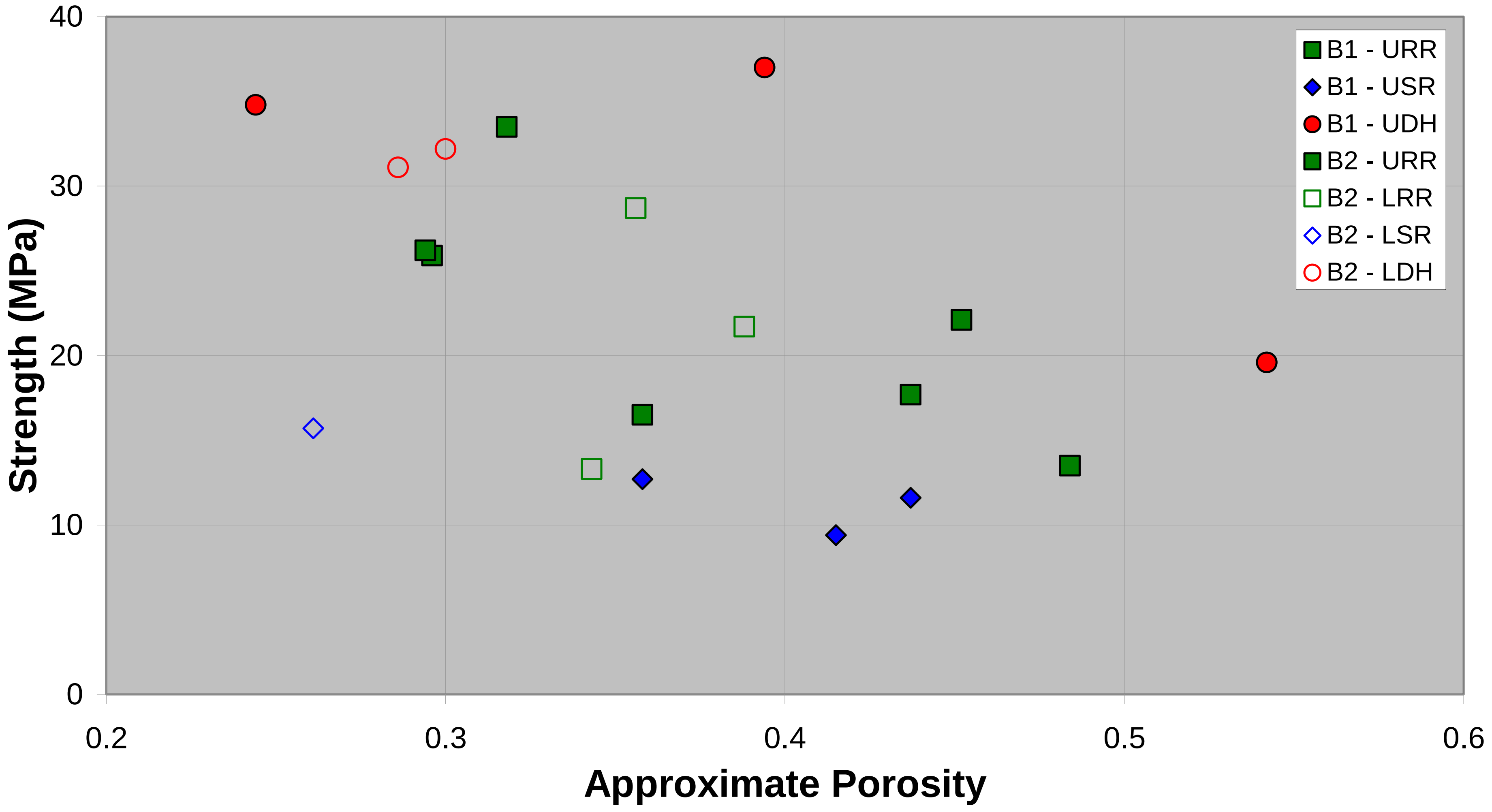
Thermal-Mechanical Rock Properties Investigations
Rock Properties Testing at Sandia National Laboratories

(Continued)

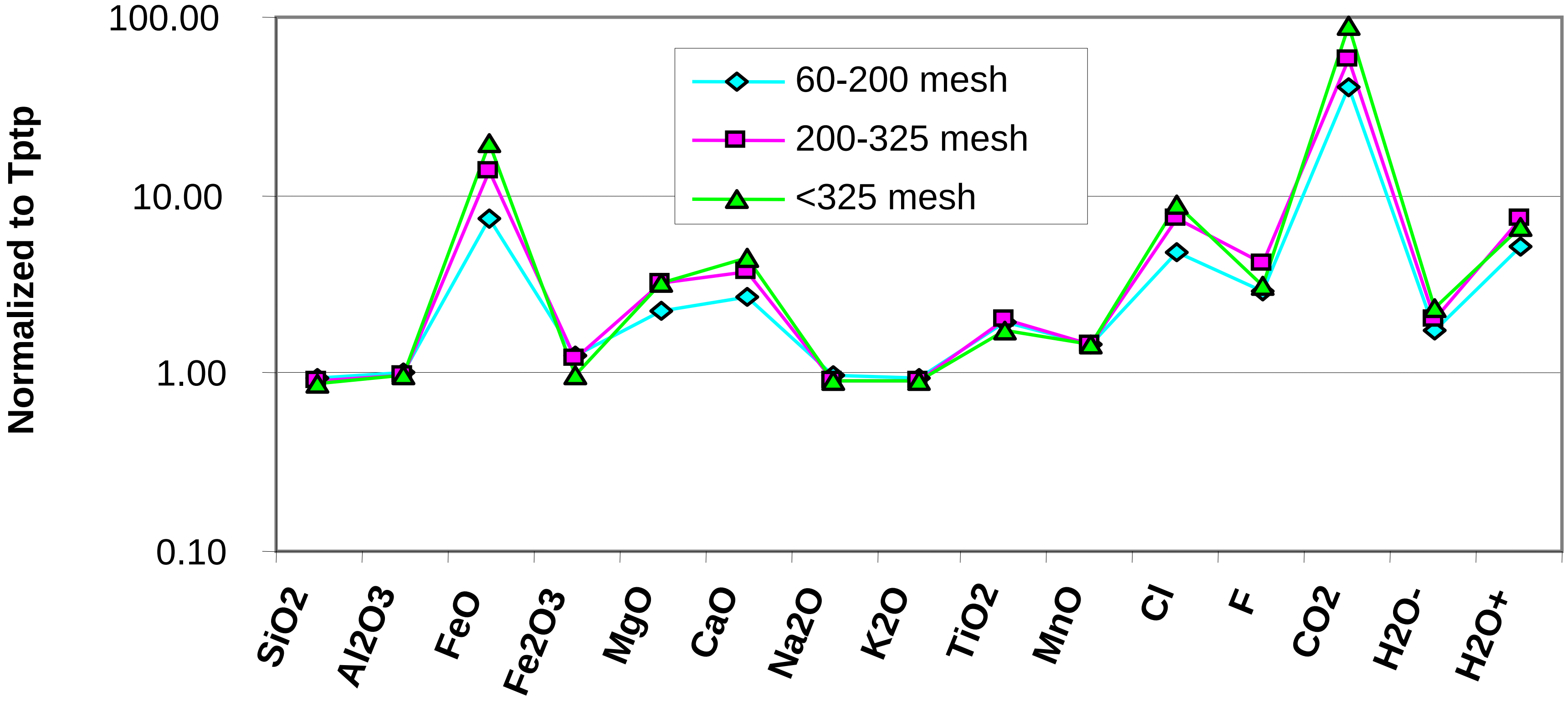
Uniaxial Compression Test on a Sample at 200 deg C (8/02)

Thermal Expansion Test Sample (8/02)

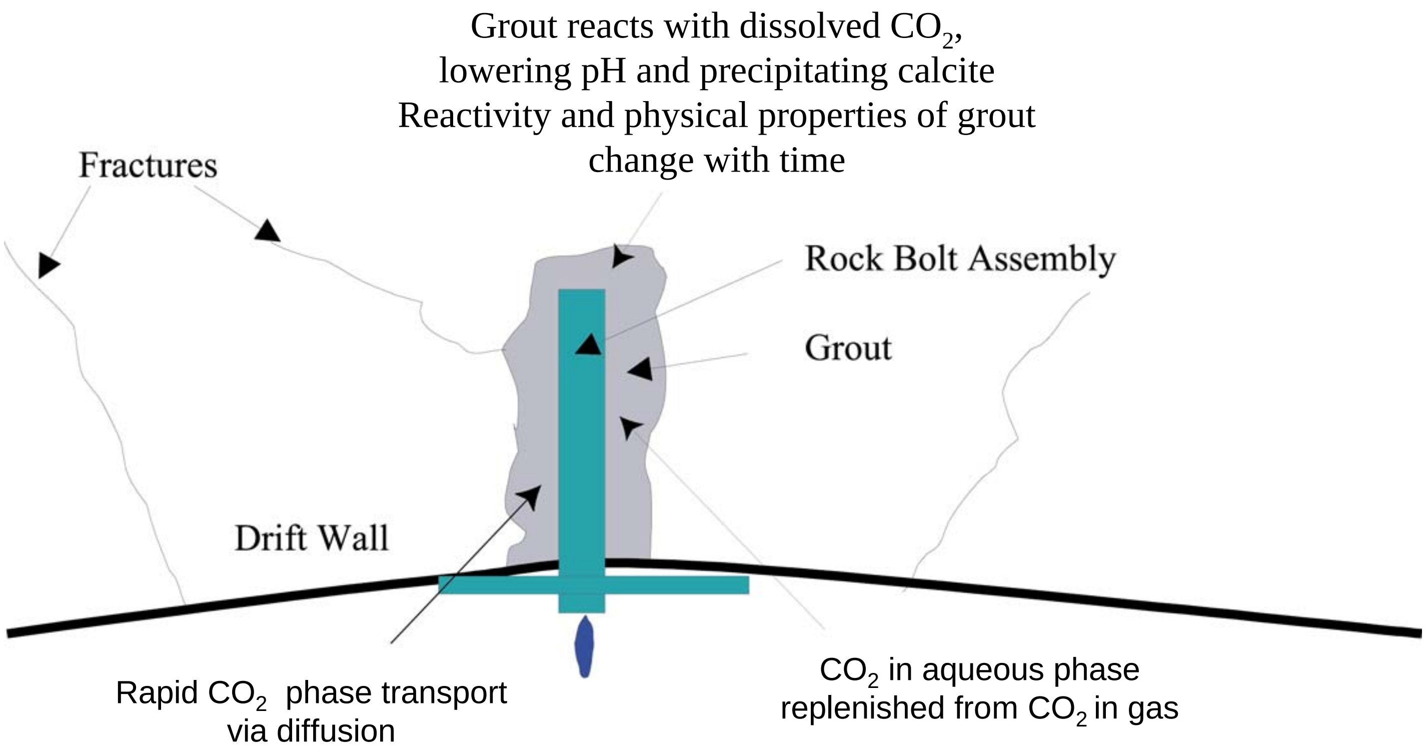
Strength vs Approximate Porosity Large Diameter Cores



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



Reactive Transport Experiments
Grout-Seepage Water Interaction

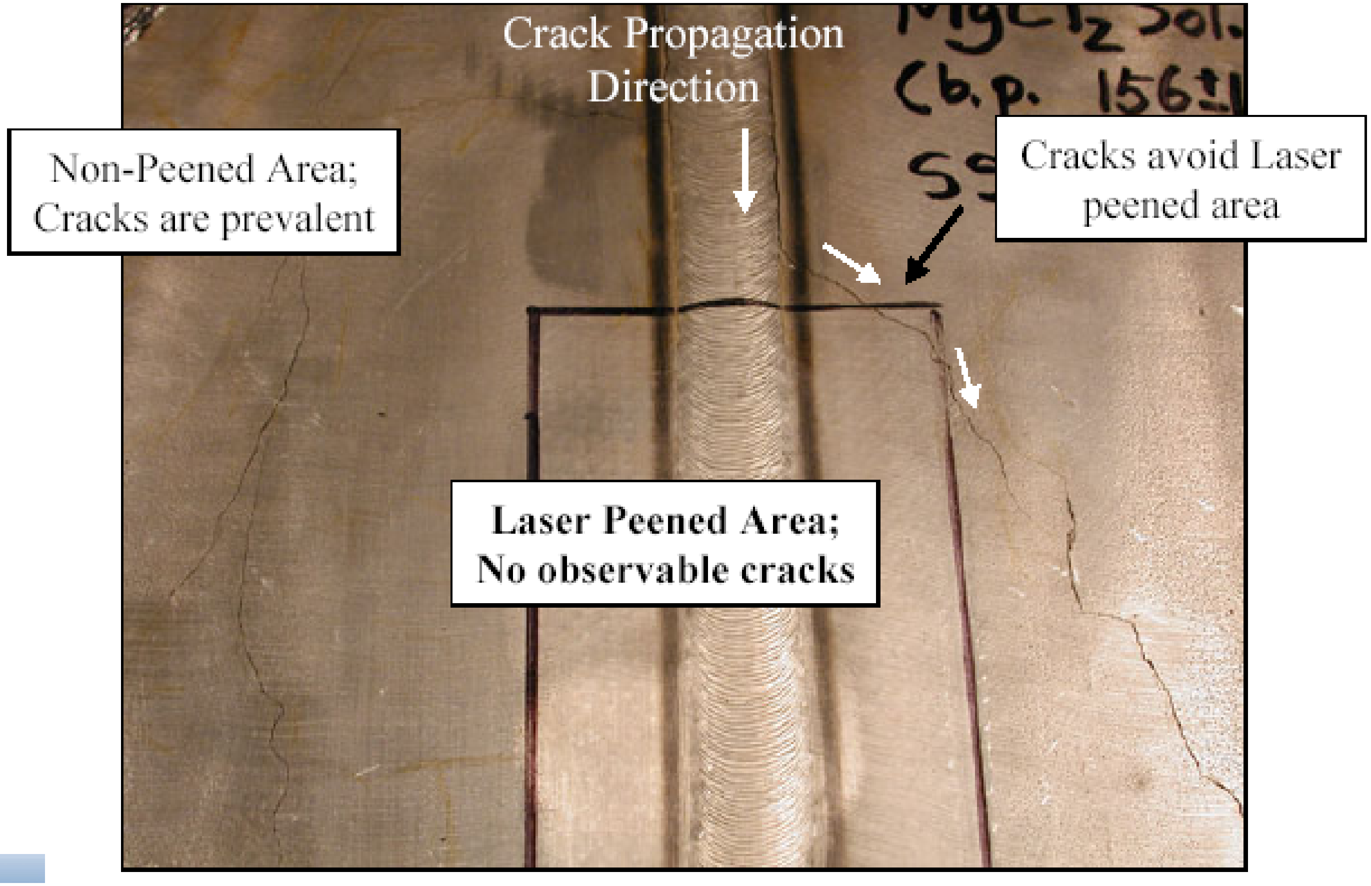


Reactive Transport Experiments Conclusions to Date

- **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 percent 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**

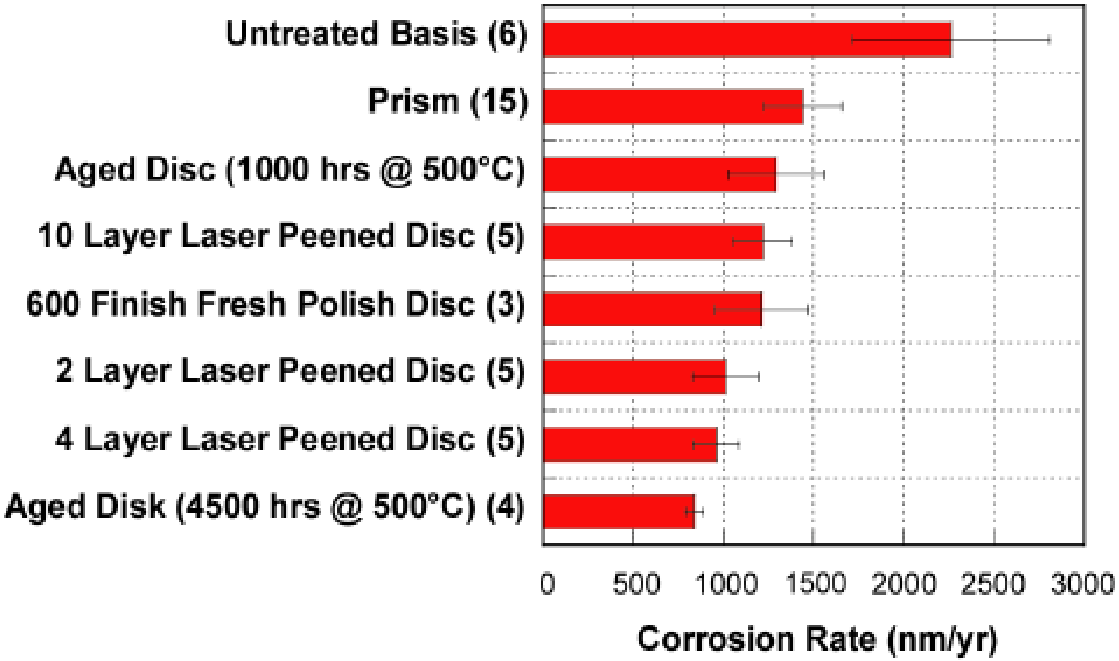
Laser Peening Mitigates Weld Stress

- 316 Stainless Steel exposed to 40% $MgCl_2$ at 160°C



Corrosion Resistance of Laser Peened Material

- Tests to date indicate good corrosion resistance for Laser Peened samples

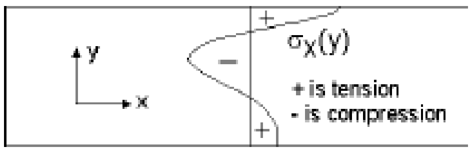


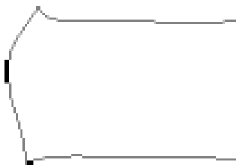
Electrochemical Polarization measurements on Alloy 22 samples with different surface conditions. Rates should not be construed as absolute.

Saturated Zone

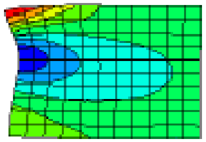
Contour Method to Measure Residual Stress

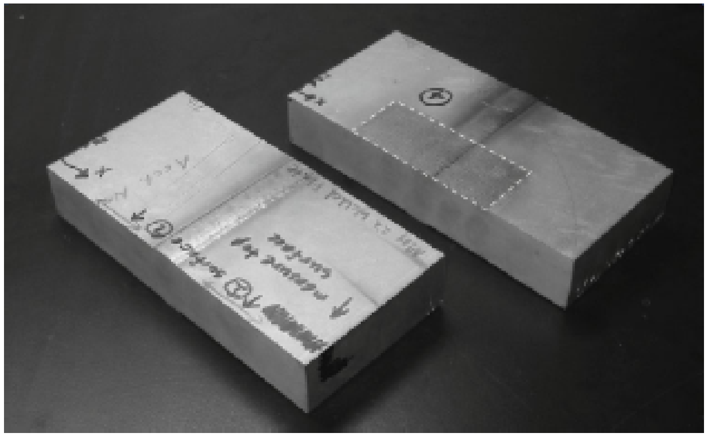
- The Contour method can determine a map of the longitudinal weld stress
  - New method
  - Cut part containing unknown residual stress in two (using wire EDM)
  - Measure deformed cut surfaces
  - Apply reverse deformation to finite element model of body
  - Stress determined





Figures from Mike Prime (LANL ESA/EA)





Alloy 22 plates. The one on the right is peened (indicated by dashed box) and on the left is the unpeened. RS was measured in these plates with the Contour method.

Saturated Zone Flow Model Validation Using Water Level Data

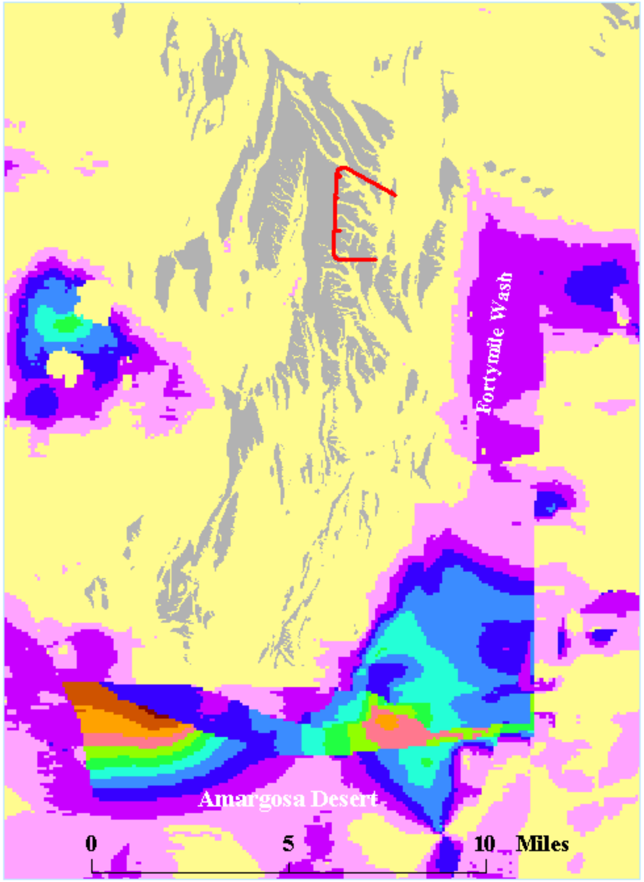
Validation of predicted water level to observed (data not used in calibration)

Nye County EWDP Wells Used as Calibration Targets in the Base-Case Model Calibration with Observed and Predicted Water Levels

Well ID	*x* (UTM) (m)	*y* (UTM) (m)	*z* (elevation) (m)	Observed Head (m)	Modeled Head (m)	Residual Error (m)
NC-EWDP-1D	536768	4062500	413.5	785.8	763.9	-21.1
NC-EWDP-1S	536771	4062500	747.8	786.7	773.3	-13.4
NC-EWDP-2D	547744	4057160	507.2	706.3	709.3	-3.3
NC-EWDP-3D	541273	4059440	376.7	717.1	703.9	-13.2
NC-EWDP-3S	541269	4059440	719.1	718.7	702.5	-16.2
NC-EWDP-5S	555676	4058230	603.9	724.1	718.0	-6.1
NC-EWDP-9S	539039	4061000	721.2	766.0	732.5	-33.5
NC-Washburn-1X	551465	4057560	668.8	714.6	714.6	0.0

Saturated Zone Lithostratigraphy

Thickness of Alluvial Deposits in the Vicinity of Yucca Mountain



Explanation

- Outcrops of the Tiva Canyon Tuff
- ESF

Thickness of Alluvium

FEET

- 0 - 200
- 201 - 400
- 401 - 600
- 601 - 800
- 801 - 1000
- 1001 - 1200
- 1201 - 1400
- 1401 - 1600
- 1601 - 1800
- 1801 - 2000
- 2001 - 2200
- 2201 - 2400

Thickness represents a composite of the major alluvial units of the HFM; they include the YAA, the YACU, the OAA, OACU, and the VSU_upper.

Radiocarbon Dating of Dissolved Organic Carbon