# Yucca Mountain Unsaturated Zone Flow and Transport

Presented to:
**Nuclear Waste Technical Review Board**

Presented by:
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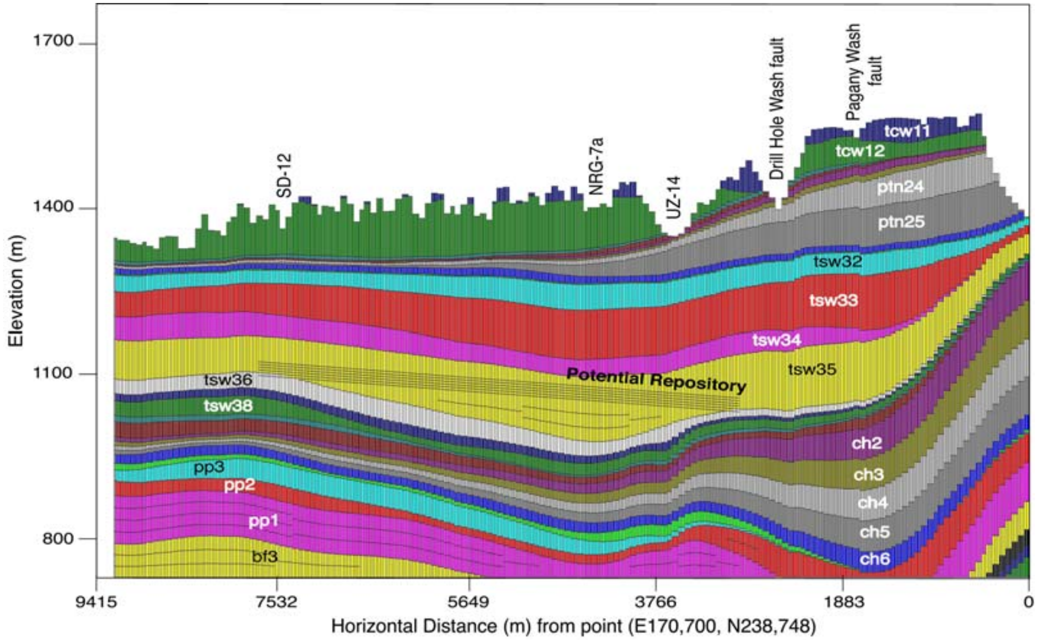
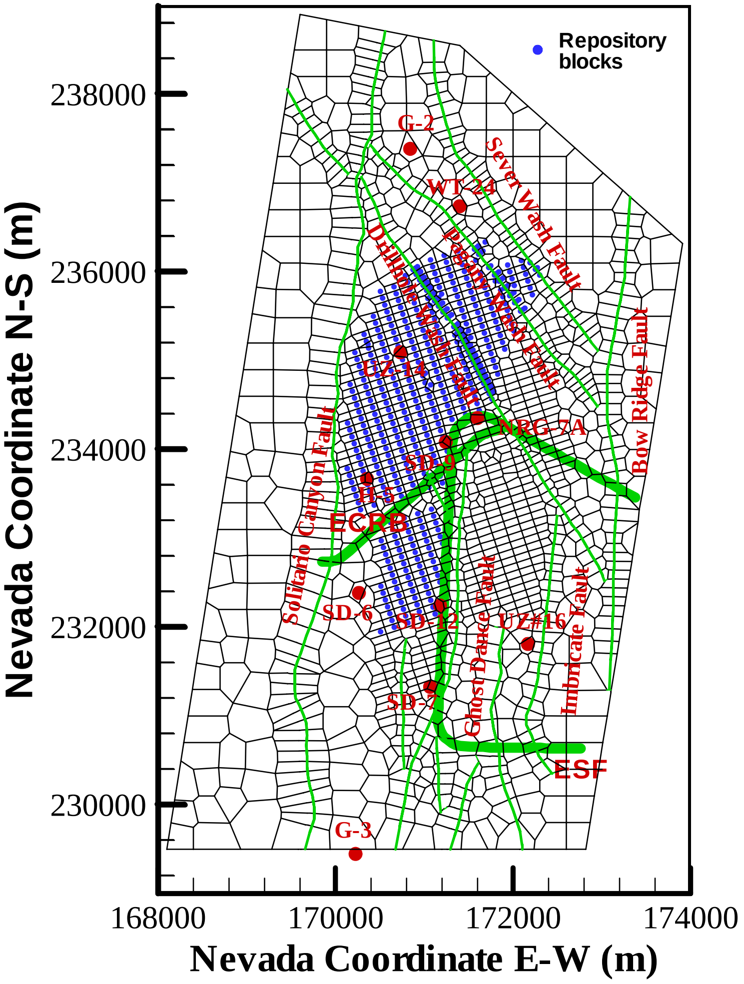
# Outline

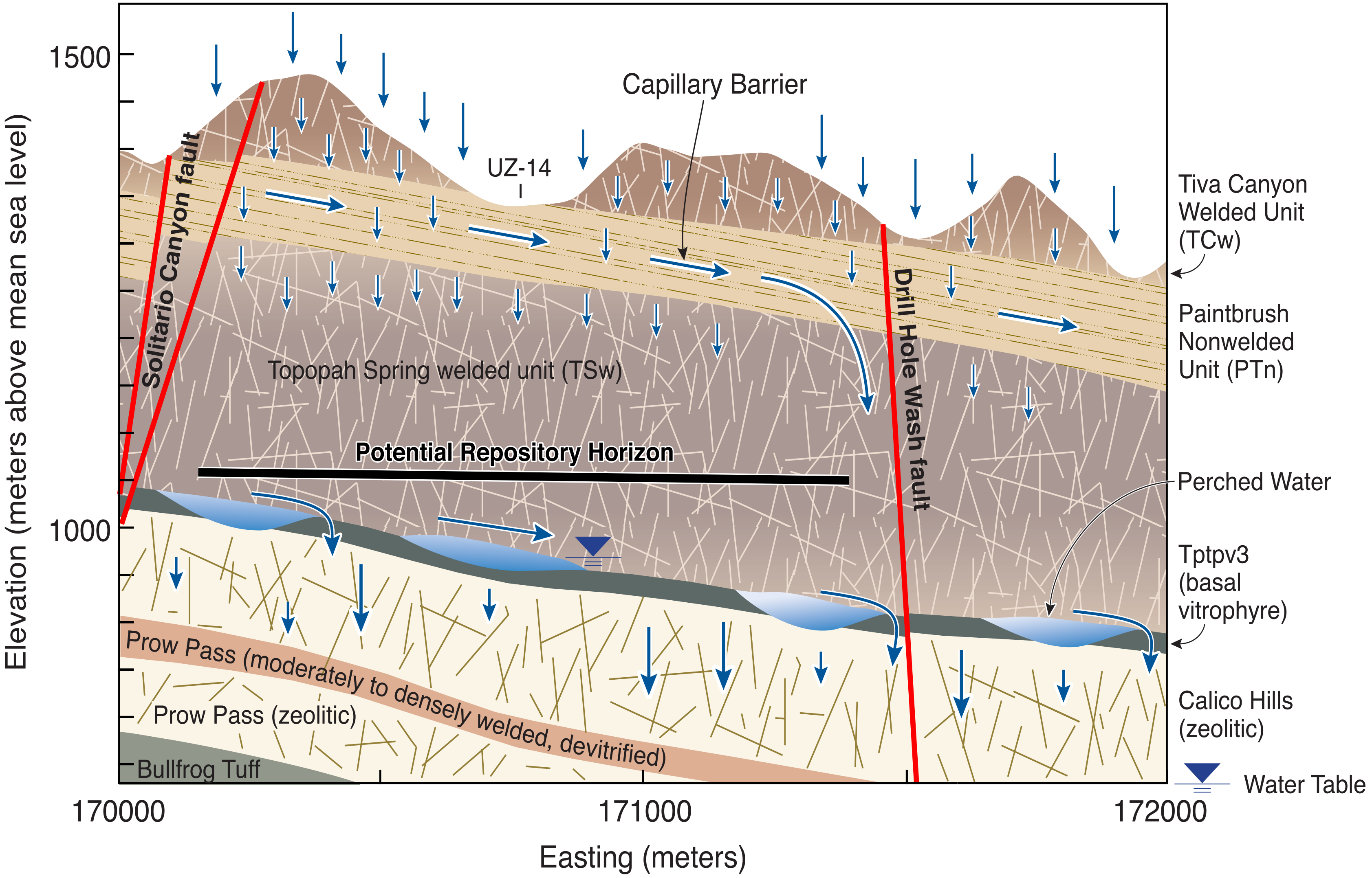
- Yucca Mountain geology
- Processes for flow
- Processes for transport
- Lessons Learned from site characterization
- Testing update
- UZ Flow: data feeding models, results, validation
- Tests specific to UZ transport, test predictions for confidence building
- Transport model development: source term, processes and geologic features, modeling tool
- Transport model results
- Summary

# Yucca Mountain Unsaturated Zone Cross Section and Repository Layout





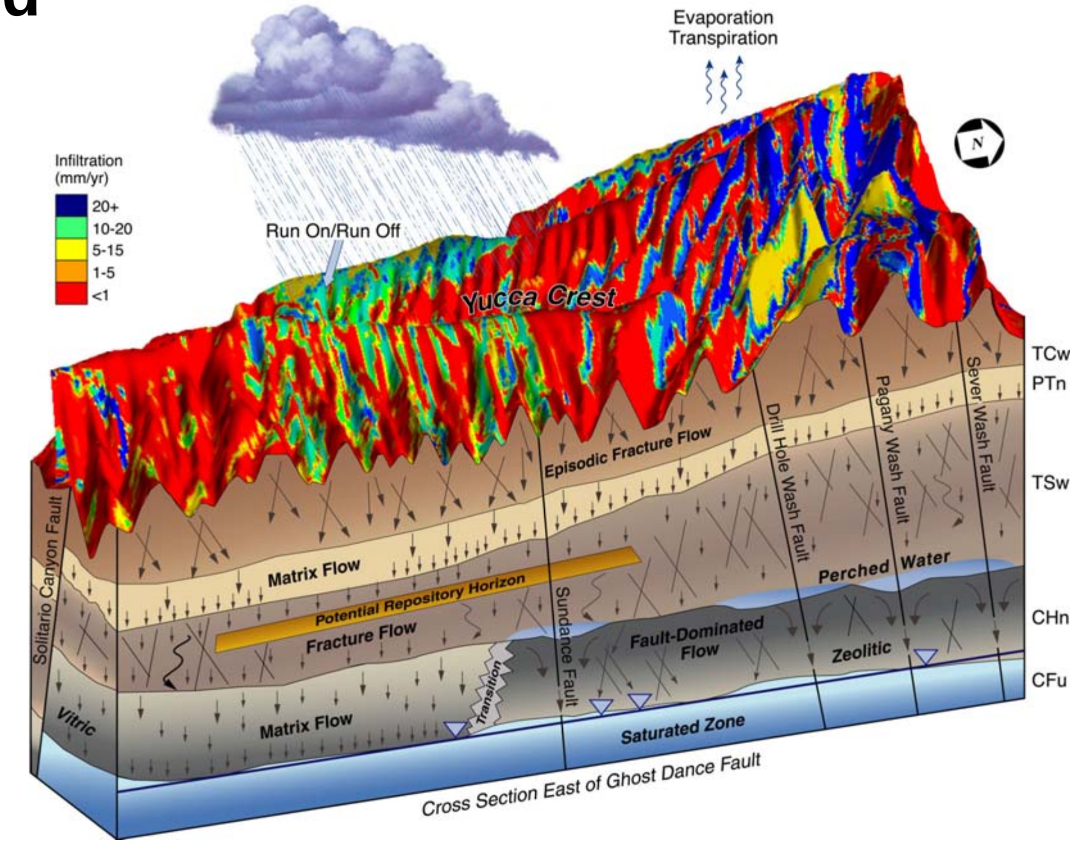
# Mountain Scale Flow Patterns



UZ03-002

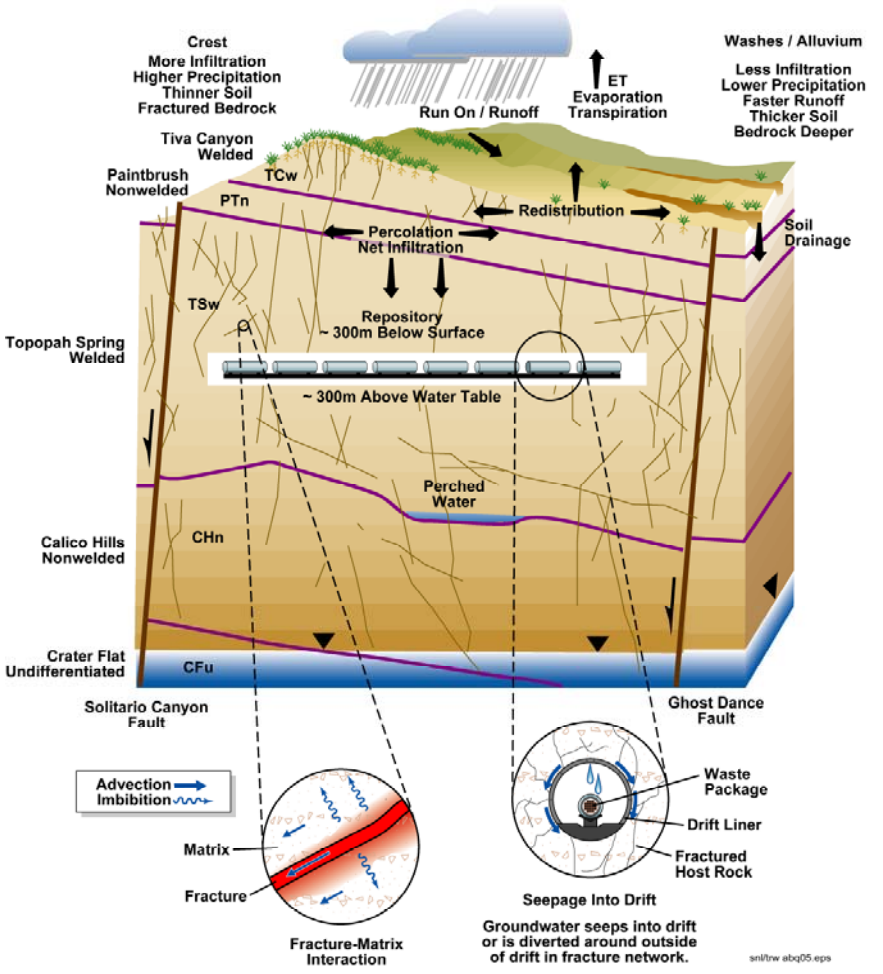
# Processes for UZ Flow

- Present and future climate
- Ambient Infiltration and percolation
- Lateral flow diversion
- Fracture/matrix interactions
  - van Genuchten model
  - Active fracture model
- Fault Flow
- Perched water
- Coupled processes (TH, THC, THM)



# Process for UZ Transport

- All processes pertaining to flow are important to transport
- Drift shadow effect
- Sorption
- Matrix diffusion
  - Active fracture model
- Daughter products of radioactive decay
- Colloidal transport



# Site Evaluation and Scientific Investigations

- What has been done?
  - Surface-based Testing and Investigations
  - Underground Testing
  - Laboratory Studies
  - Modeling Activities for Evaluating Repository Performance
- What lessons have we Learned?

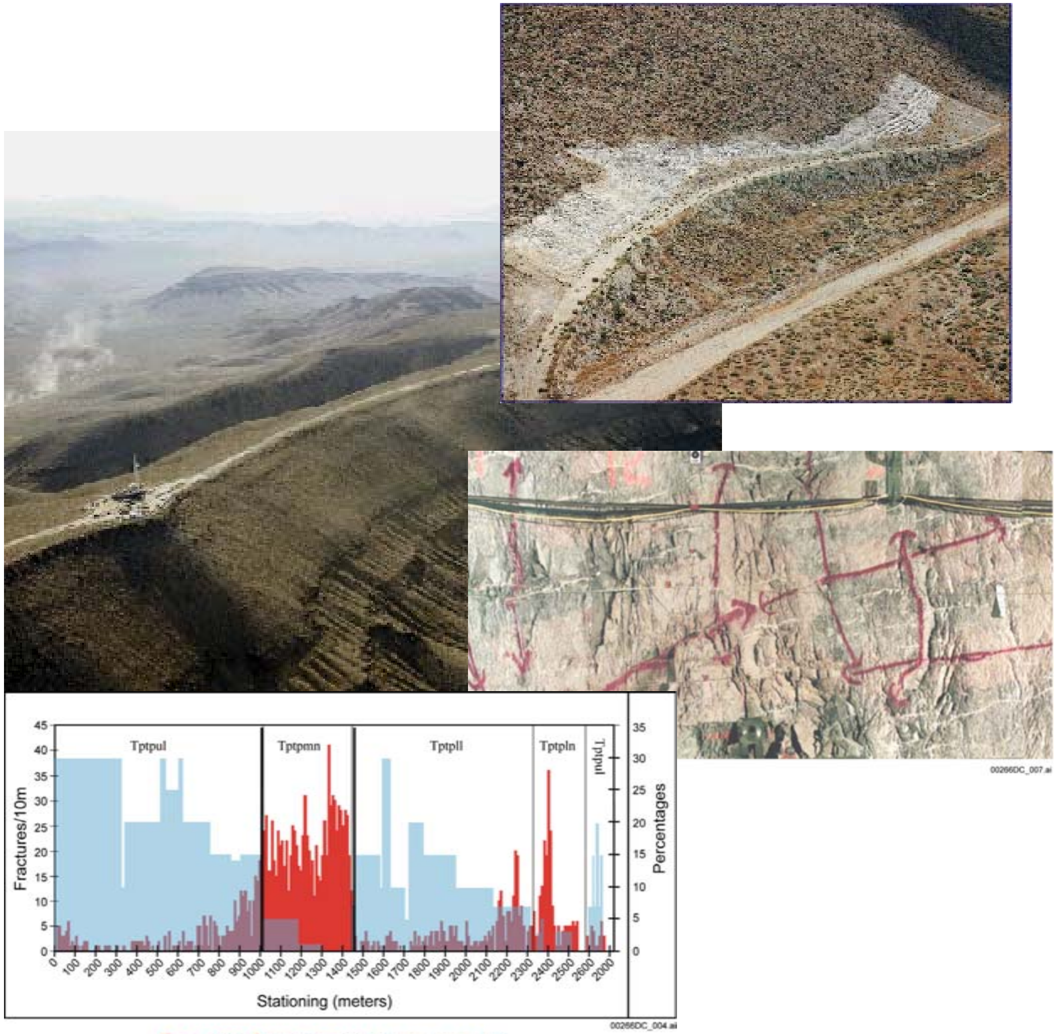
# Geological Studies

## Studies:

- Extensive surface mapping and trench studies
- Stratigraphy of tuff layers by over 60 deep boreholes
- Detailed line and full periphery maps of fractures on drift walls

## Lessons Learned:

- Water flow is associated with faults and a small fraction of fractures
- Detailed fracture mapping is useful mainly for fracture-matrix interaction evaluation



Fracture frequency/ Lithophysal %

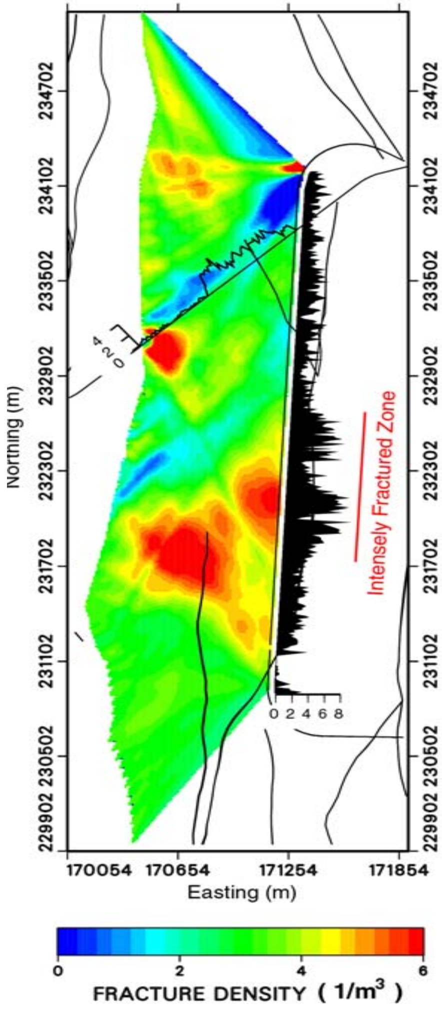
# Geophysics Studies

## Studies:

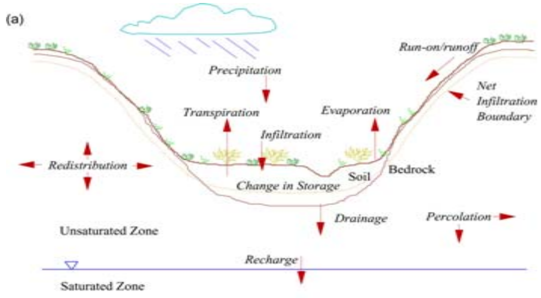
- Electromagnetic (EM) imaging
- Seismic imaging (large scale)
- Radar tomography (ten-meter scale) in ESF and Busted Butte

## Lessons Learned:

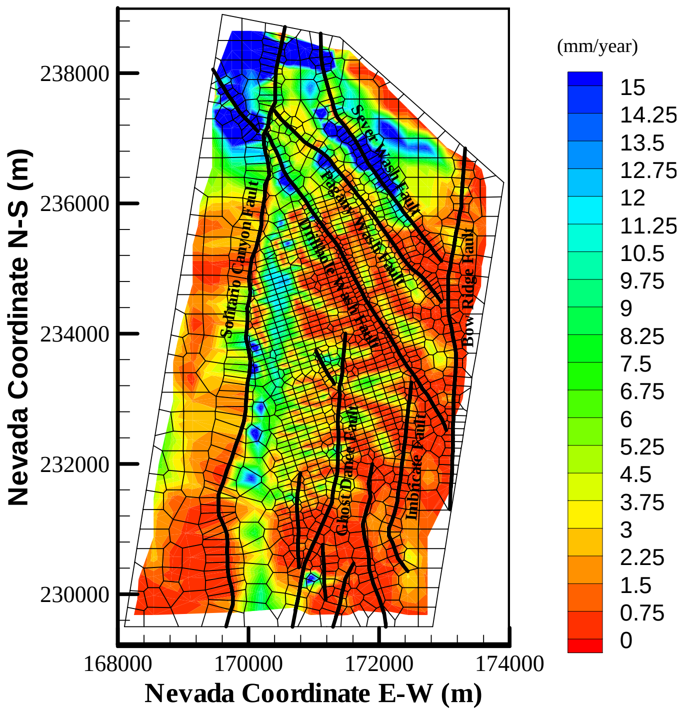
- EM of limited use due to difficulty to inject current into ground
- Radar tomography successful in detecting saturation changes
- Surface to underground seismic imaging identified intensively fracture zones
- Improvement in geophysical tools needed to detect large hydrological features: perched water bodies, hidden faults



# Water Flow Evaluation – *Infiltration*



Present Day Infiltration (Mean)



## Studies:

- Meteorological stations to measure precipitations and evaporation-transpiration potentials
- Neutron logging of hundreds of shallow boreholes
- Stream gauges to monitor channel runoff
- Water bucket models for wetting front migration

## Lessons Learned:

- Difficult to estimate infiltration with conventional approach (above)
- Essential to use geochemical and thermal data to support and constraint the model

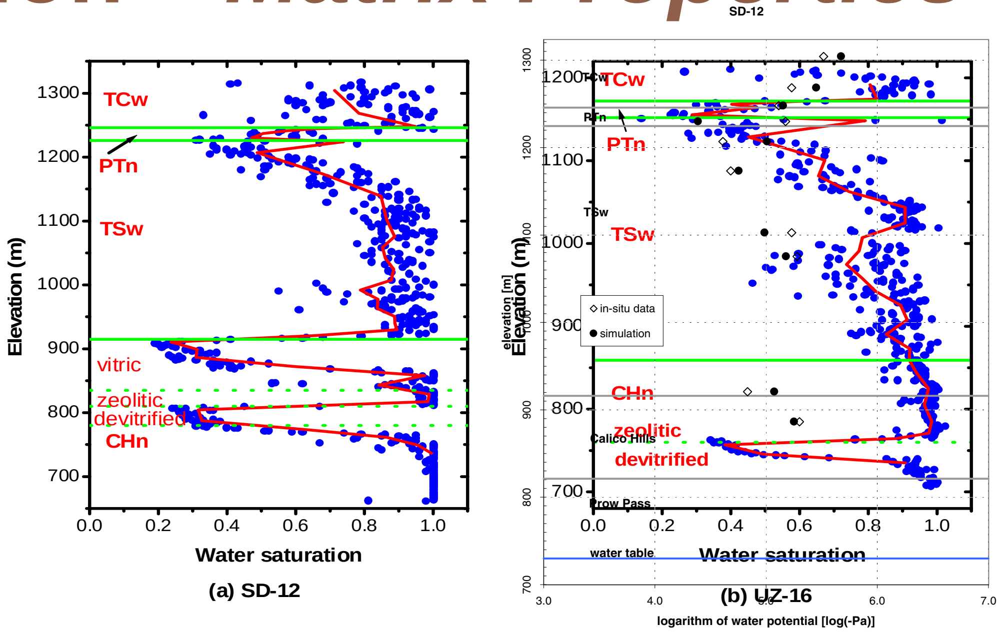
# Water Flow Evaluation – *Matrix Properties*

## Studies:

- Saturation and water potential measurements on cores and in boreholes
- Upscaling achieved by inverse modeling

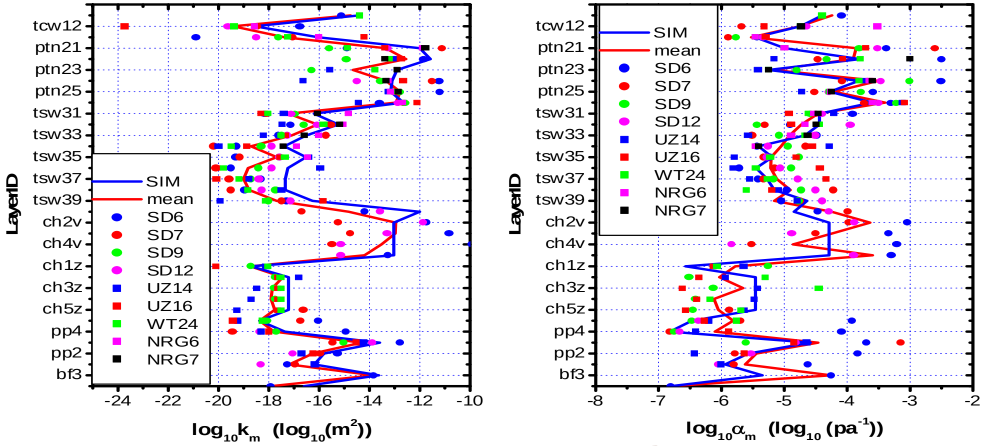
## Lessons Learned:

- Water potential is extremely difficult to measure in the range of 0 to –5 bar (may not be important)
- Practically impossible to separate effects of fractures in borehole measurements
- Core drying affects saturation data

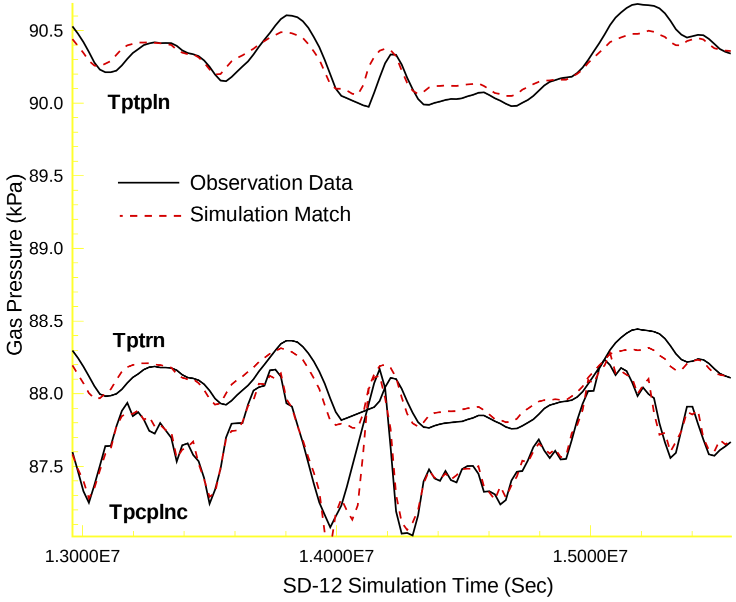


(a) SD-12

(b) UZ-16



# Water Flow Evaluation – *Fracture Properties*



## Studies:

- Air permeability (K) measured by packer tests (0.3 to 10 m)
- 100 m scale air-K inferred from pneumatic data (damping of atmospheric pressure signals)
- Fracture porosity determined by gas tracer tests and inferred from inverse modeling of seepage and thermal test data

## Lessons Learned:

- Pneumatic data extremely useful – confirming theoretical upscaling power law (and no air-K upscaling is needed in YM evaluation)
- Fracture porosity is on the order of 0.5% - similar to other rocks

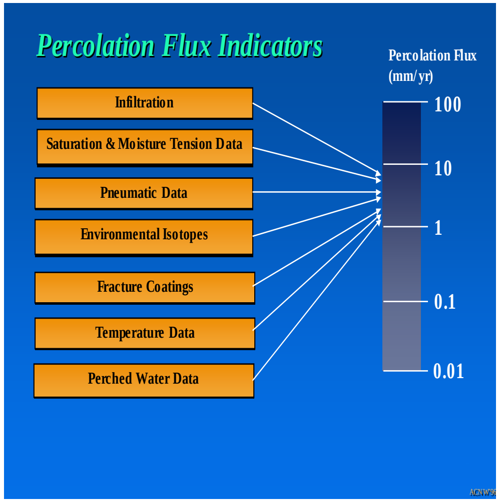
# Water Flow Evaluation – *Percolation*

## Studies:

- Site-Scale Model, matched with all available data, is used to determine percolation from redistribution of infiltration
- In addition to hydrological and pneumatic data, temperature and geochemical data (especially total chloride) are used to constraint both flux magnitude and spatial distribution

## Lessons Learned:

- Total chloride and temperature data provide most useful constraints for both magnitude and distribution



*Percolation Flux Indicators*

Infiltration

Saturation & Moisture Tension Data

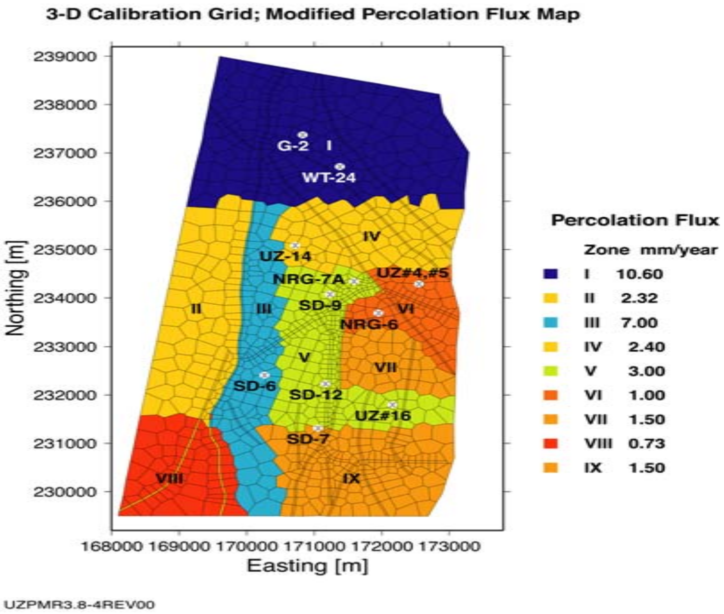
Pneumatic Data

Environmental Isotopes

Fracture Coatings

Temperature Data

Perched Water Data



3-D Calibration Grid; Modified Percolation Flux Map

UZPMR3.8-4REV00

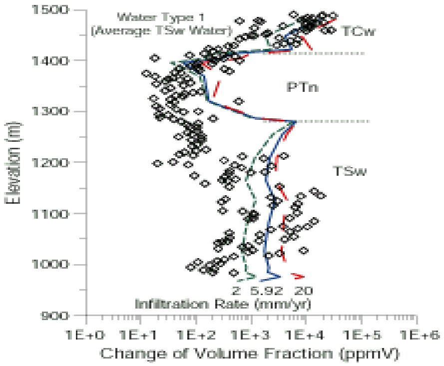
# Water Flow Evaluation – *Geochemistry*

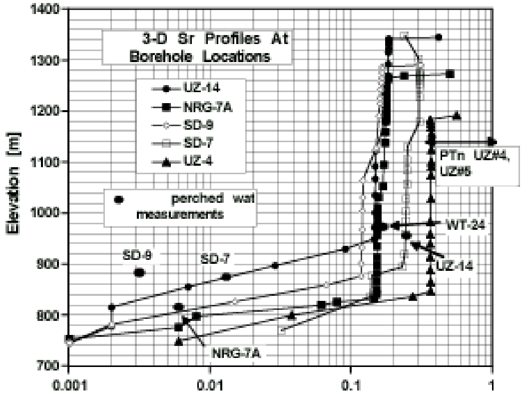
## Studies:

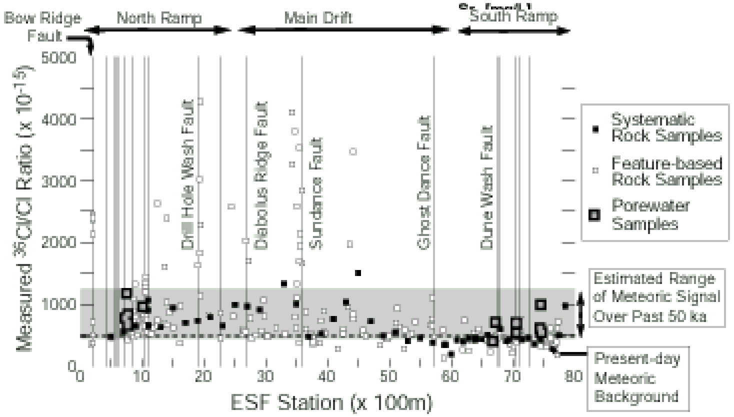
- Porewater samples are collected from squeeze and ultracentrifuge
- Gas and perched water samples are collected from pumping
- Systematic and feature-based samples are collected for bomb pulse analyses

## Lessons Learned:

- Total chloride, calcite, Sr, $Cl^{36}$ are very useful to elucidate different flow phenomena
- Controversy persists on bomb pulse finding (may not be important)







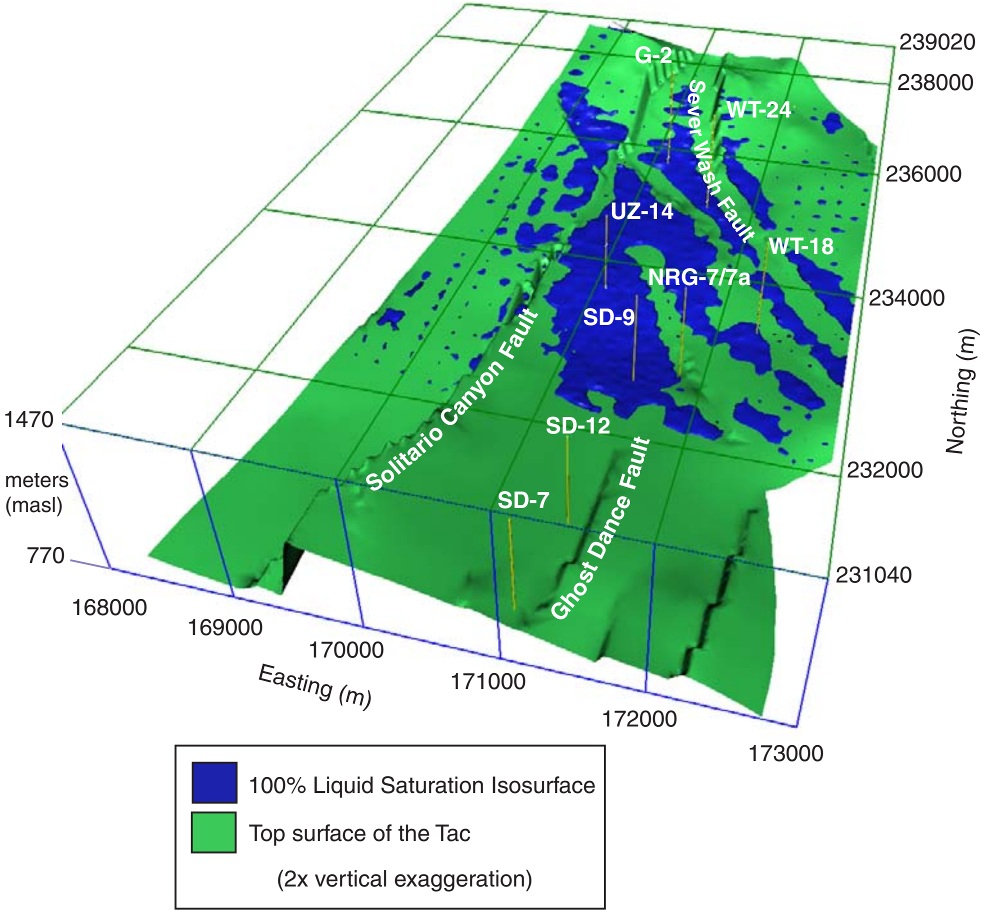
# Water Flow Evaluation – *Perched Water*

## Studies:

- Pump testing to determine the spatial extent
- Water sampling to determine ages and chemical mixing

## Lessons Learned:

- Existence of perched water bodies infers that fracture permeability below perched water is low
- Partial diversion minimizes contact with zeolitic tuff with strong sorbing capacities
- Model results suggest flow focusing and channeling to faults



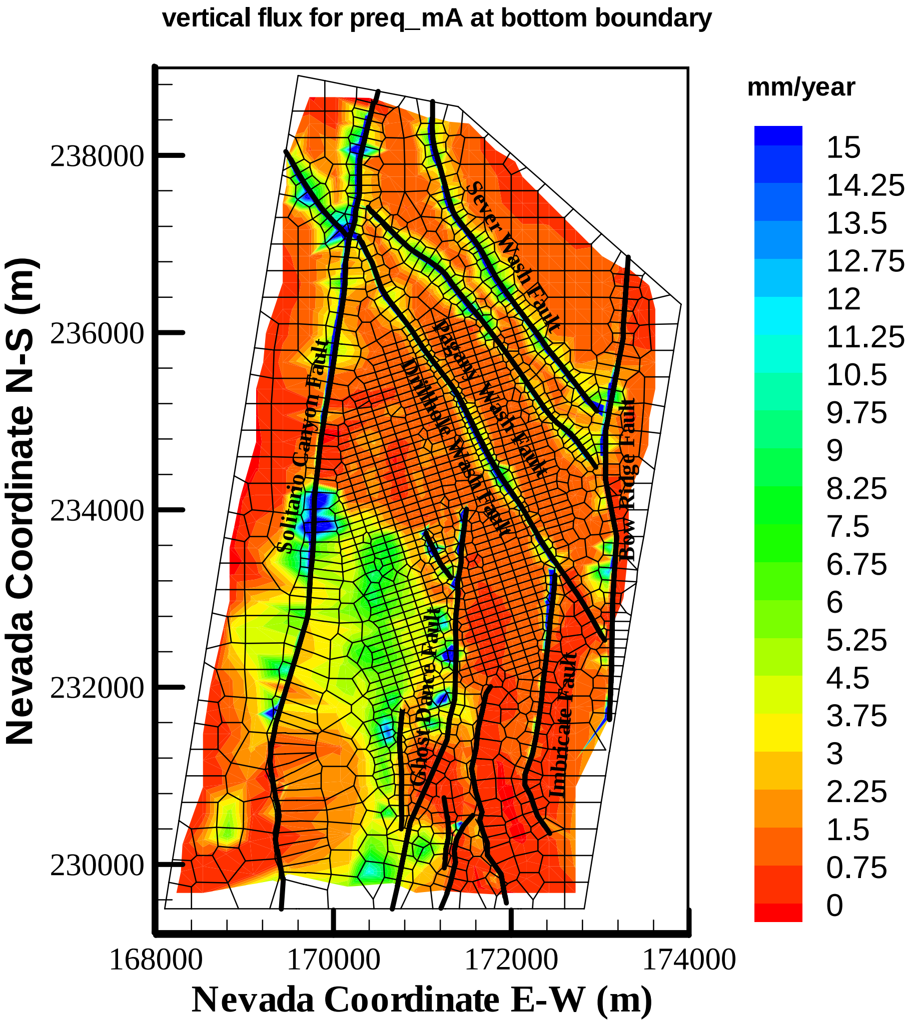
# Flow Pattern Below Repository

## Studies:

- Use information from limited number of deep boreholes
- Site-scale flow model is used to evaluate flow pattern

## Lessons Learned:

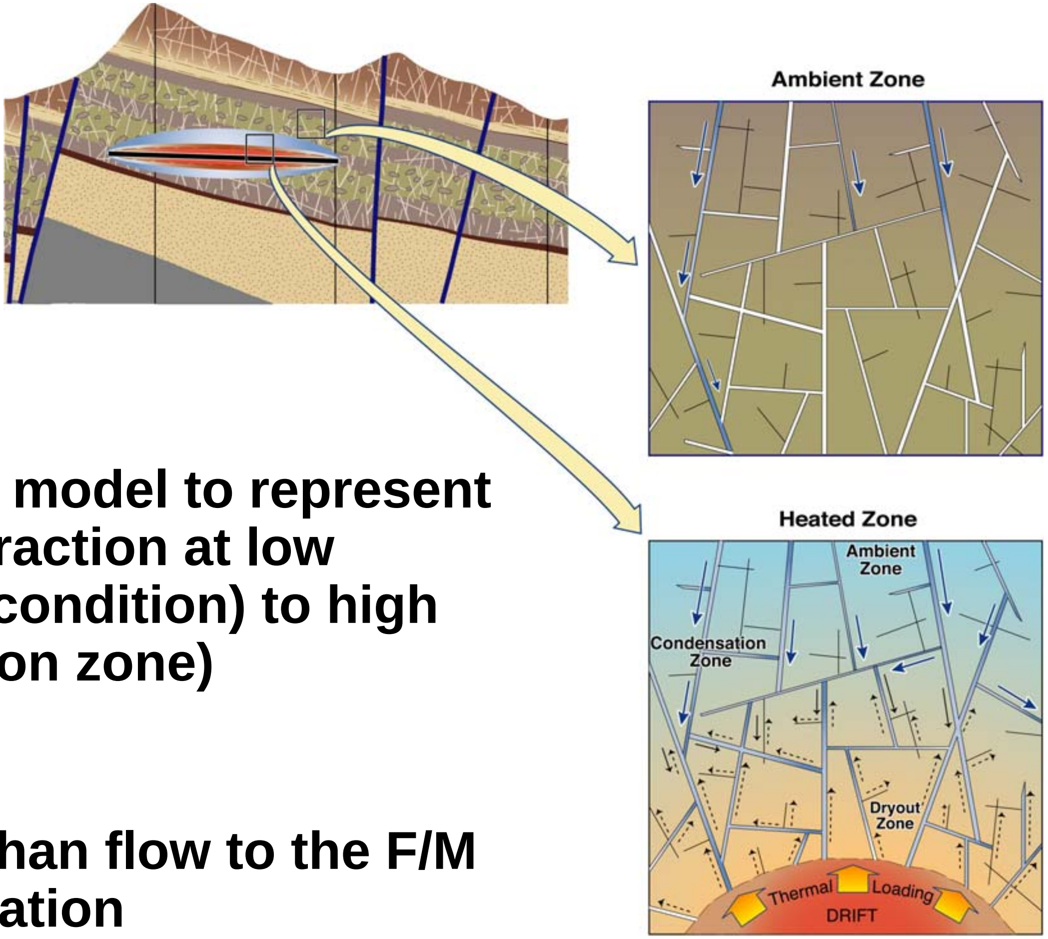
- Lack of data makes the large-scale geological layer structure and features very important
- Modeling results suggest significant diversion to the faults for percolation and radionuclide transport


vertical flux for preq_mA at bottom boundary

# Fracture-Matrix Interaction – *Conceptual Model*

## Studies:

- Use double-porosity, dual-permeability, multiple-interacting continuum, and discrete fracture models to evaluate the fracture-matrix interaction
- Formulate the active fracture model to represent the transition from weak interaction at low fracture saturation (ambient condition) to high saturation (in the condensation zone)



## Lessons Learned:

- Transport is more sensitive than flow to the F/M and active fracture representation
- Condensate imbibition into matrix block is better understood than drainage

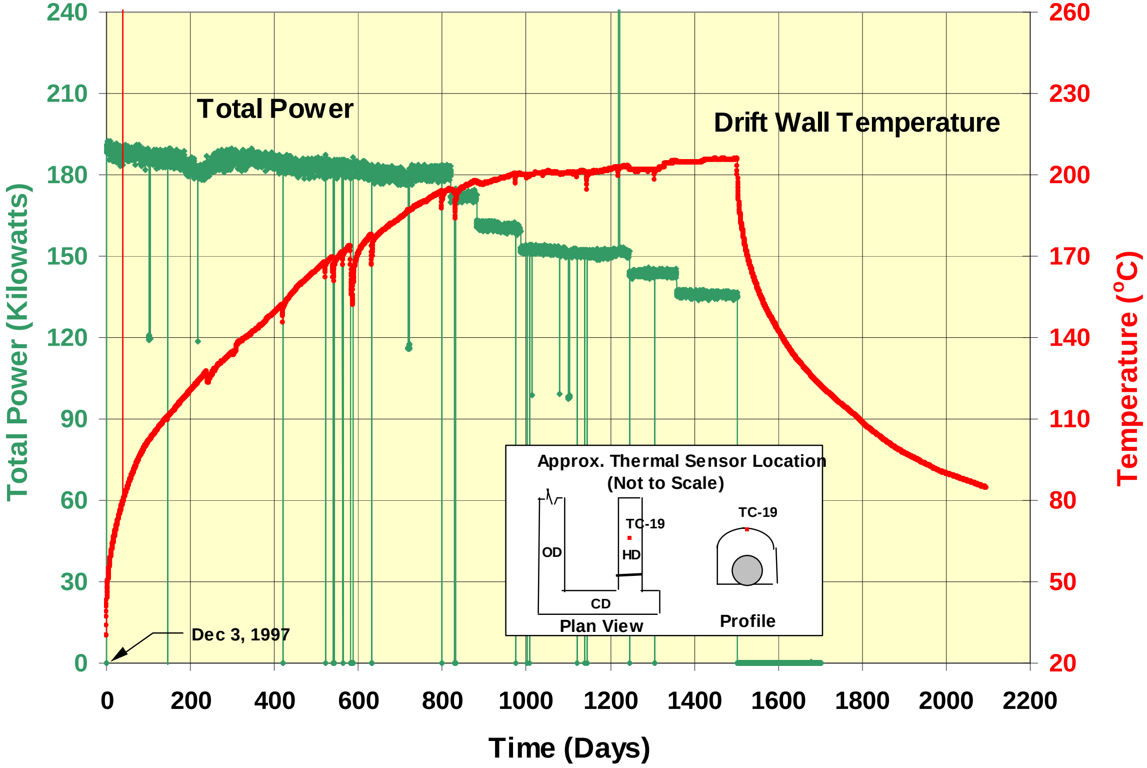
# UZ Testing Update

- Exploratory Studies Facility (ESF) studies
  - Drift Scale Test in the ESF - coupled processes
  - Secondary fracture minerals/fluid inclusions/hydrochemistry
- Cross Drift Studies
  - Alcove 8 - Niche 3
  - ECRB Moisture monitoring

# Drift Scale Test Update

*(preliminary)*

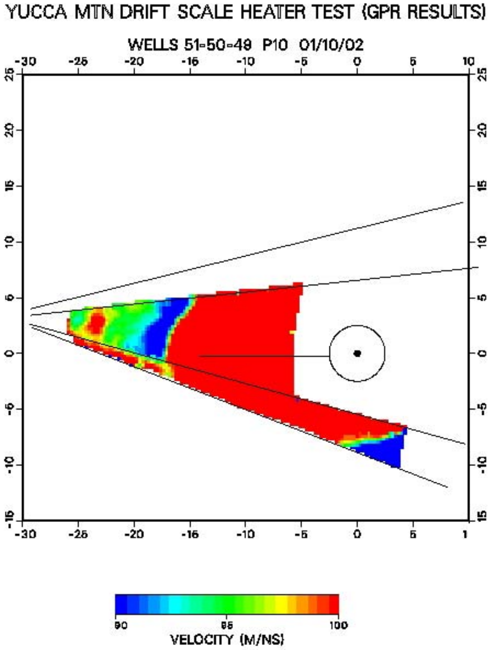
- Cooling continues (since termination of heating in January 2002)
- Air temperature in the Heated Drift is ~ 84°C at end of August 2003
- Highest temperature within rock formation is ~ 95°C



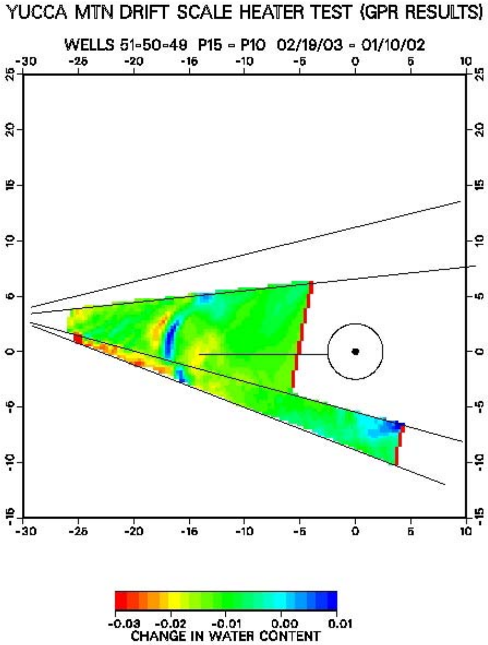
# Drift Scale Test Update (2)

*(preliminary)*

- **Rewetting of dryout zone is slow and is most prominent in regions where the moisture gradient is largest (at the outer boundary of the dryout zone), as predicted by modeling**
- **No water has been collected in quarterly sampling trips since August 2002, consistent with modeled results**



**Reference GPR tomogram of radar velocity at end of heating phase**



**Difference GPR tomogram of saturation changes (March 2003) from end of heating phase**

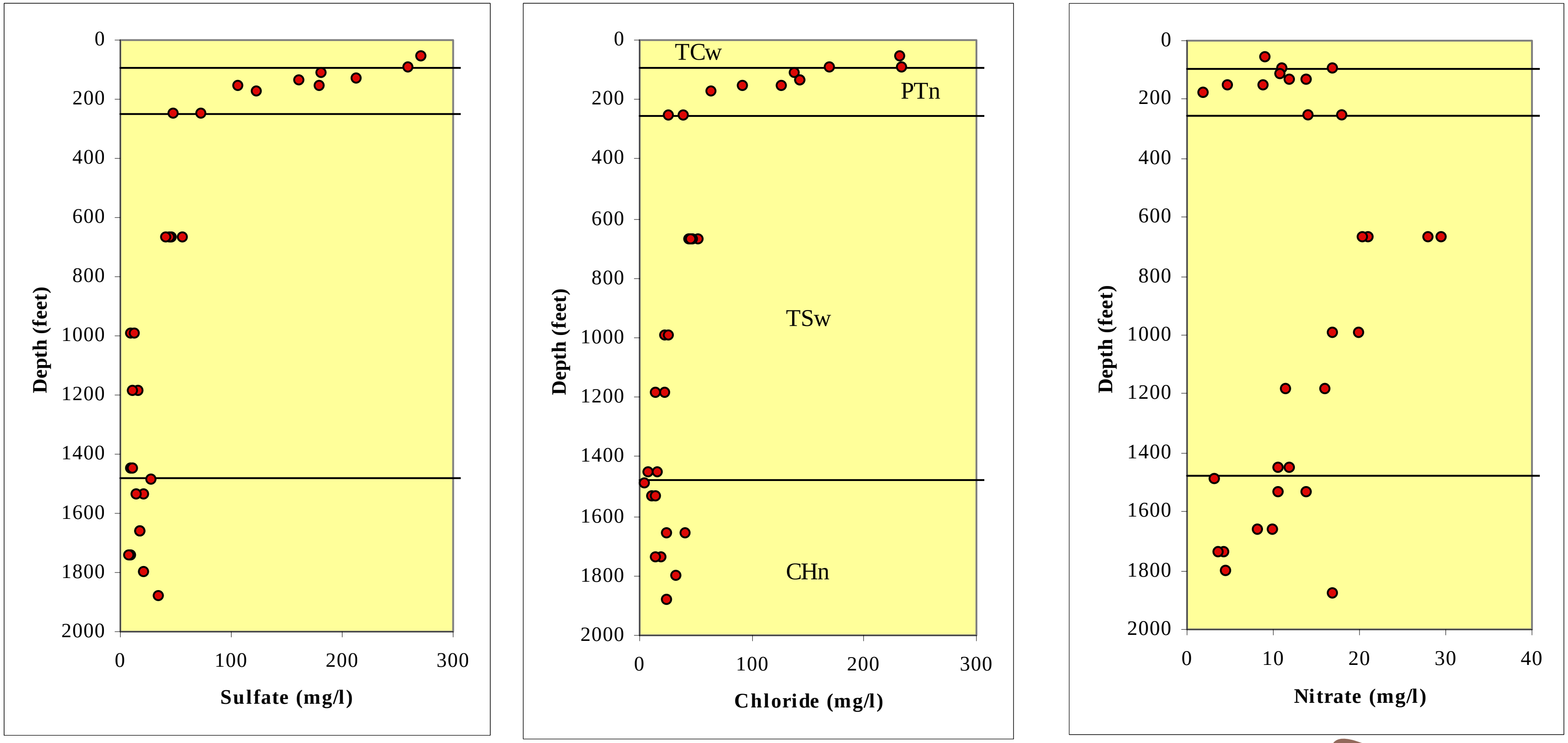
# Testing Update: *U-Series Isotope Studies (USGS)*

## *(preliminary)*

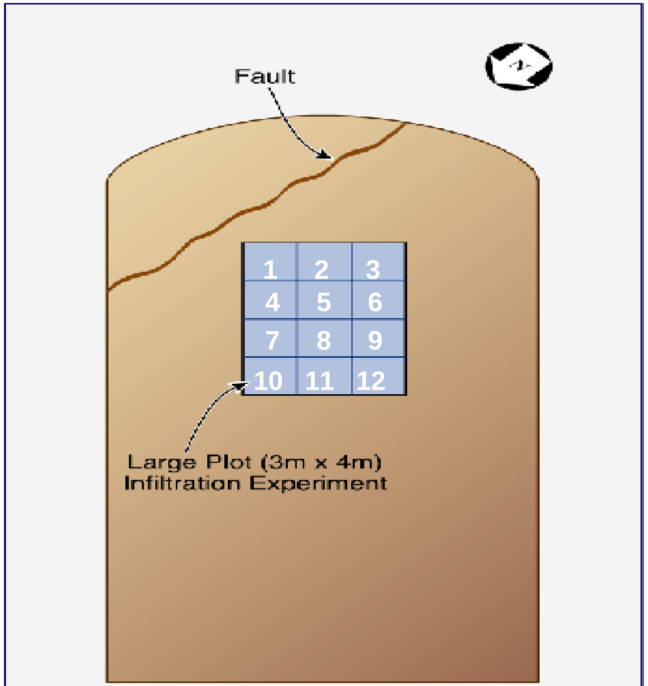
- Objective is to determine zones of greater and lesser flow (water-rock interaction)
- Establishing vertical profile of U-series variations in core from USW SD#9
  - Observing disequilibrium at bulk rock scale in $^{234}U/^{238}U$ and $^{230}Th/^{238}U$ ratios
  - Disequilibrium reflects water-rock interaction on $10^3$ to $10^5$ year scale
- Lateral variability in U-disequilibria being evaluated in samples from the ESF
- U-series ages range from 3,000 to 140,000 years in recently analyzed sample

# Testing Update: *Chemical/Isotopic Analyses of Pore Water (USGS) (preliminary)*

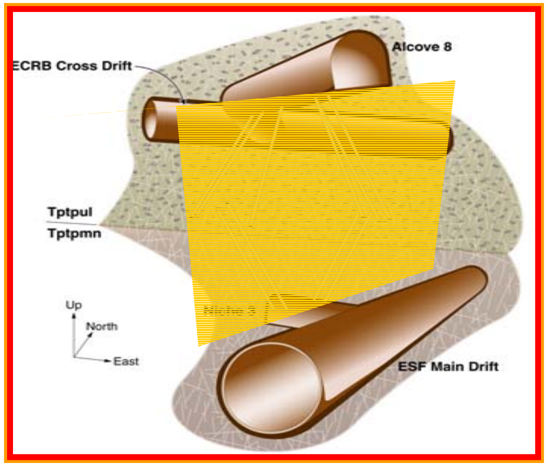
**Vertical variability of dissolved anions and cations in SD-9 pore water probably reflects: evaporation in the PTn, water-rock interactions, and probable microbial activity**



# Alcove 8-Niche 3 Updates
## *Large Plot Liquid Release*

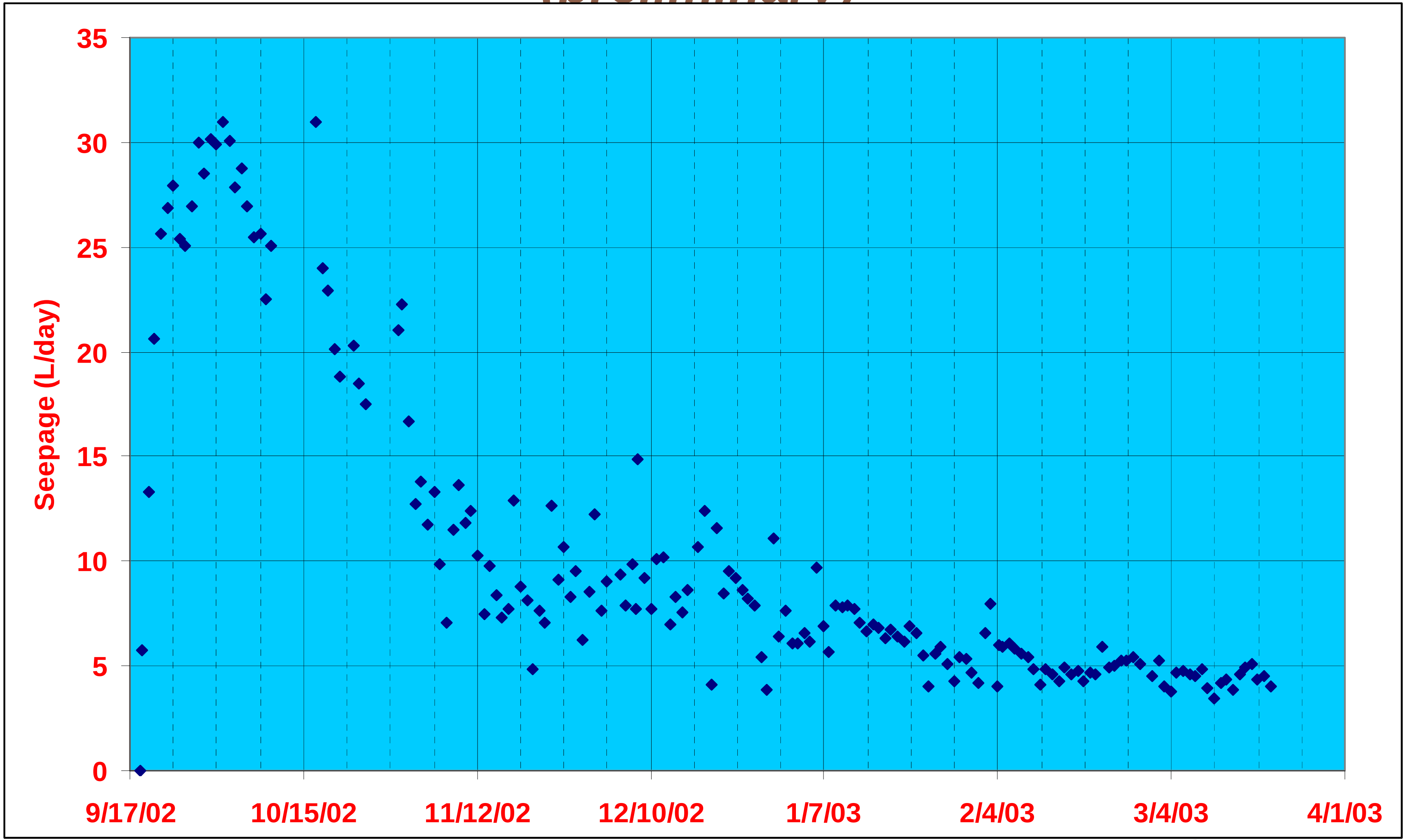


Location of Fault Along Alcove 8 Floor
with Large Plot Injection Experiment



# Seepage rates in Niche 3 from ponded liquid release in Alcove 8 on 8/20/02

*(preliminary)*



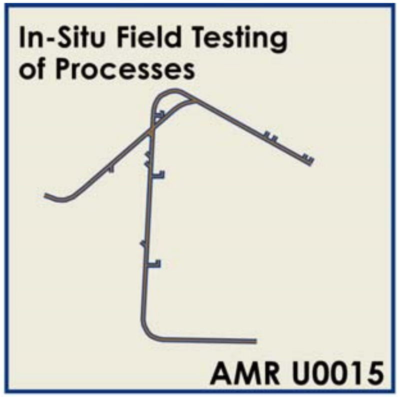
YUCCA MOUNTAIN PROJECT

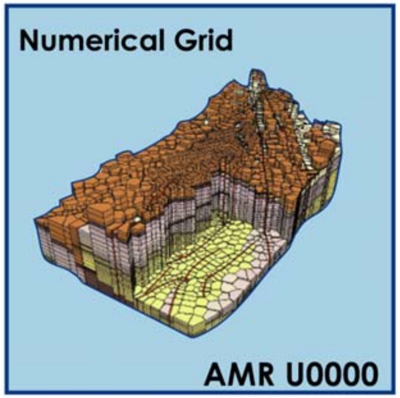
# UZ Testing Update:
# *Moisture Monitoring behind Bulkhead*
## *(preliminary)*

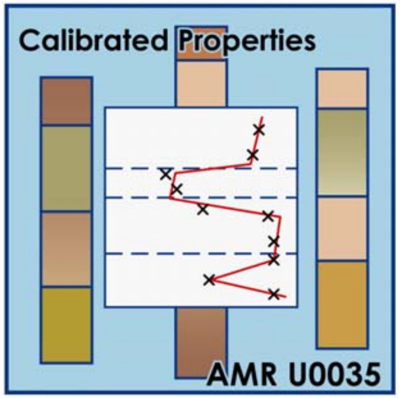
- **Terminal section of ECRB from station 22+00 onwards maintained under non-ventilated conditions from 11/15/01-2/3/03 and then from 2/5/03-7/7/03**
- **Observations made on 2/3/03 and 7/7/03 (under non-ventilated conditions) show:**
  - **Water droplets along ventilation tube and cables at various locations.**
  - **Mold along railway ties and walkway in some locations**
  - **Wettest area between Stations 25+02 and 25+40**

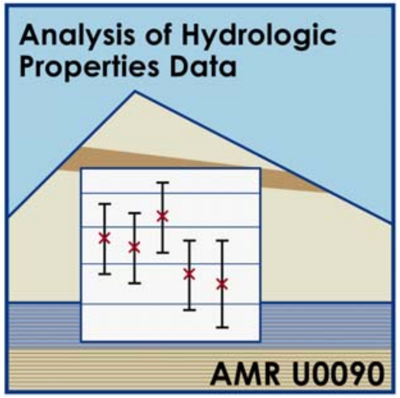
**Bulkhead installation in the ECRB July 2002**

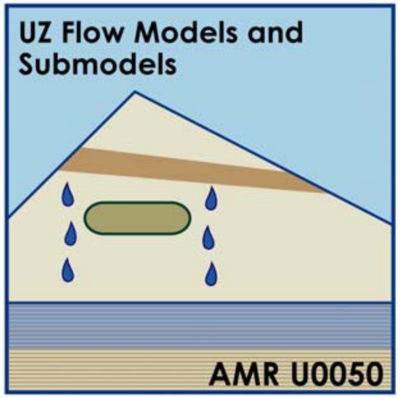
# UZ Analysis and Model Reports Relevant for Flow and Transport

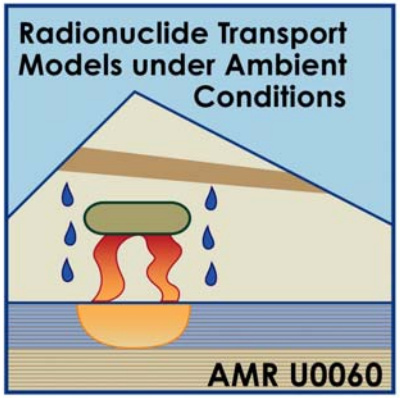


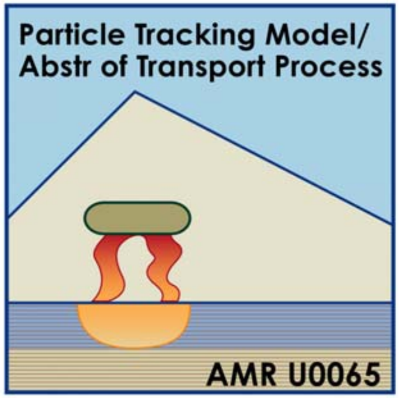






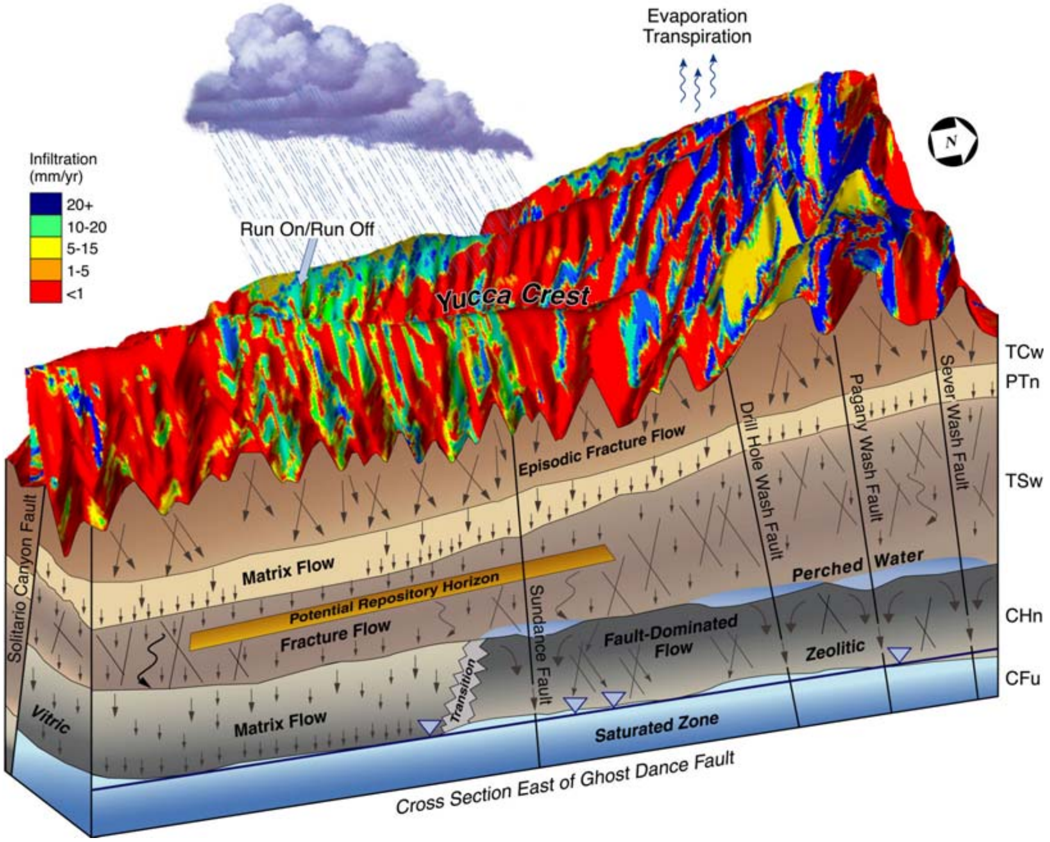






# Unsaturated Zone Flow

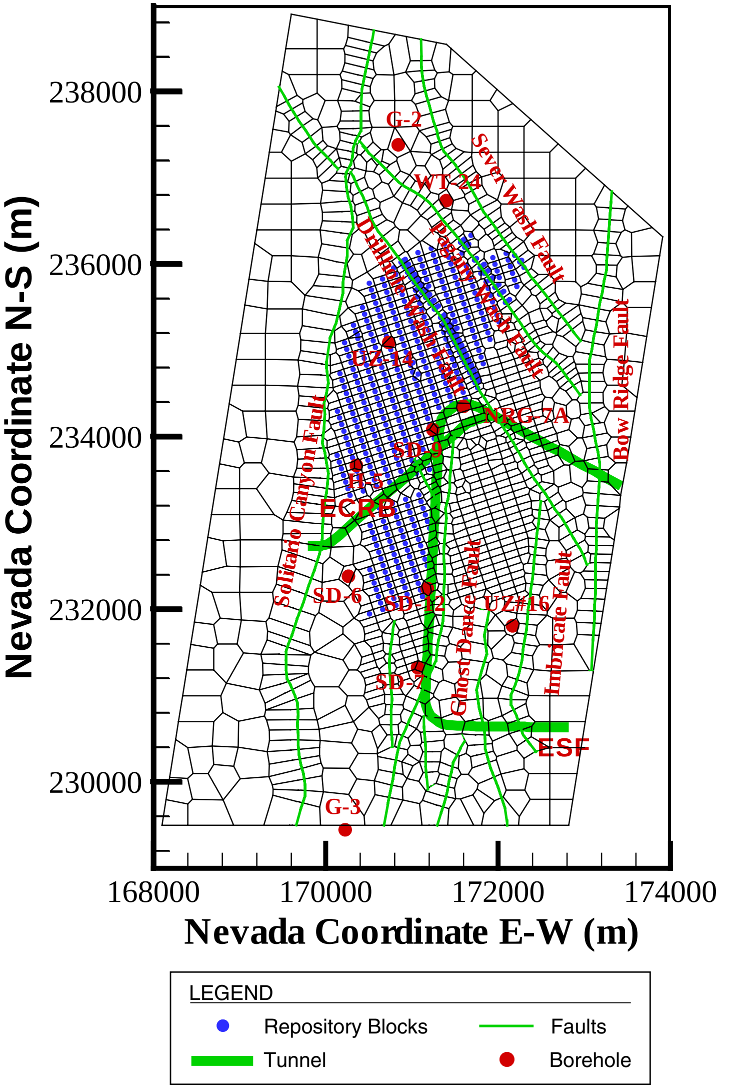
- Present and future climate
- Ambient Infiltration and percolation
- Lateral flow diversion
- Fracture/matrix interactions
  - van Genuchten model
  - Active fracture model
- Fault Flow
- Perched water
- Coupled processes (TH, THC, THM)

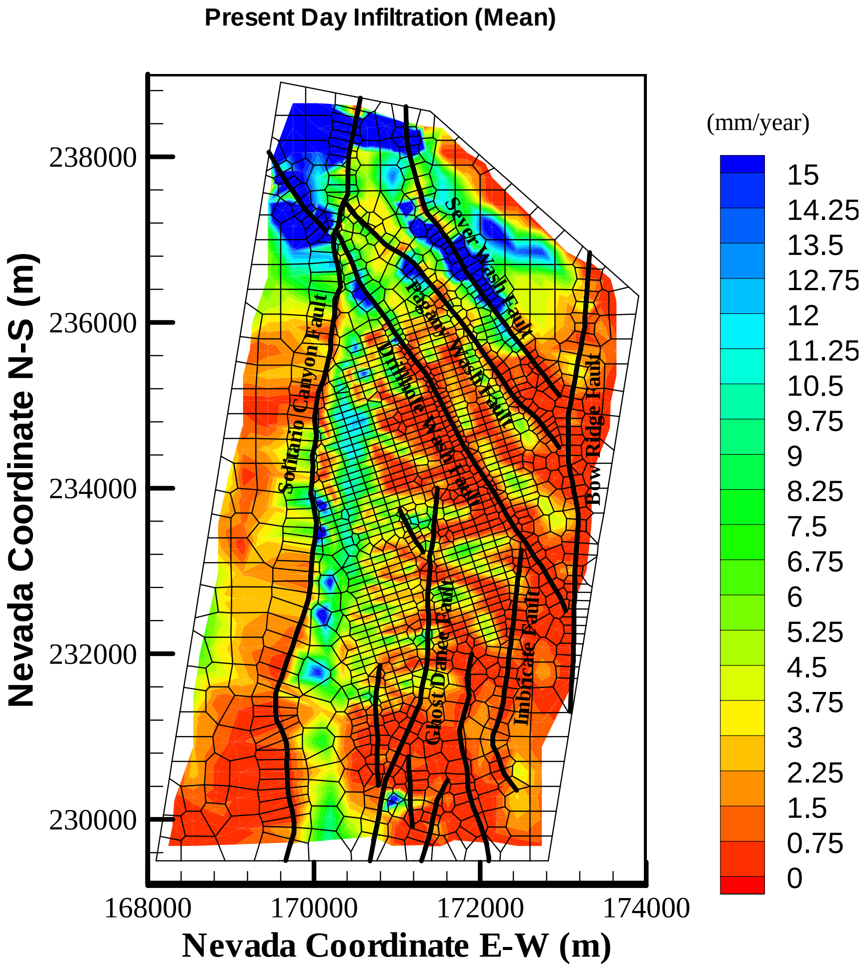


# Data That Feed Unsaturated Zone Flow Model(s)

- Geological layering
- Surface infiltration
- Water saturation and water potential on cores and in boreholes
- Pneumatic data
- Temperature profiles from boreholes
- Geochemical data: total chloride, calcite, strontium, $Cl_{36}$

# UZ Flow Model: *Plan View of 3D Numerical Grid and Infiltration Map*





# Numerical Tools for Flow Predictions: *TOUGH2 Family of Simulators*

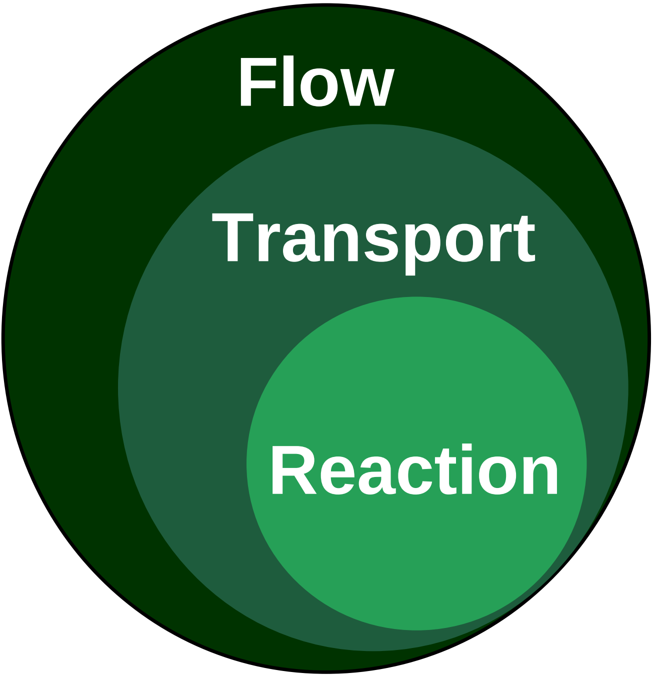
**TOUGH**: **T**ransport **O**f **U**nsaturated **G**roundwater and **H**eat

| | |
|---|---|
| • multidimensional | • 1D, 2D, 3D |
| • multiphase | • liquid, gas, NAPL |
| • multicomponent | • water, air, VOC, radionuclides |
| • nonisothermal | • heat |
| • flow and transport | • multiphase Darcy law |
| • fractured-porous media | • dual-f, dual-k, MINC, ECM |

**EOS**: Accurate description of thermophysical properties

# Numerical Tools for Geochemical Transport Predictions: *TOUGH/REACT*

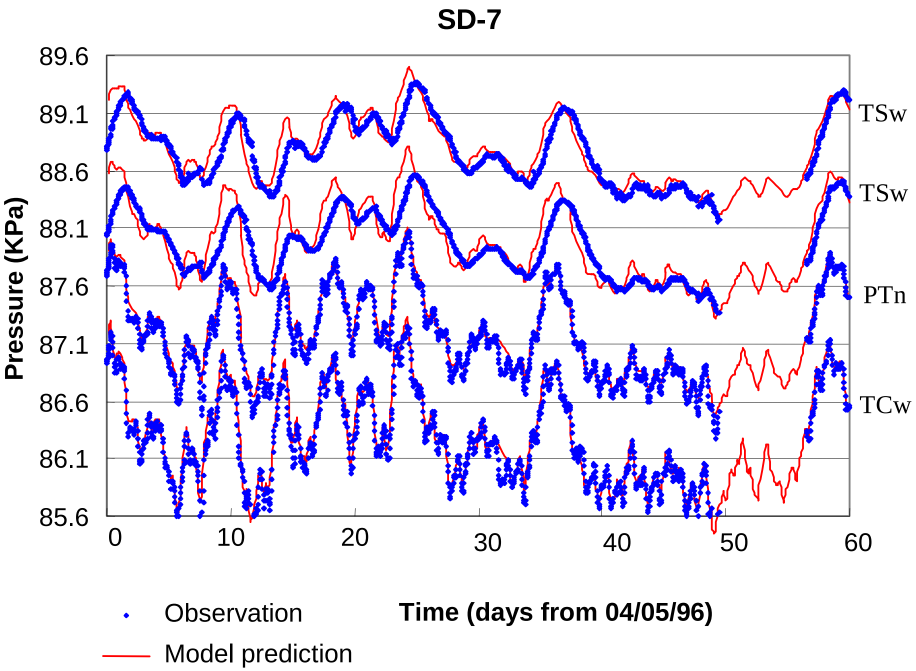
- **Multiphase fluid flow:**
  - **TOUGH2**
- **Transport of aqueous and gaseous species:**
  - **Advection**
  - **Diffusion**
- **Reactions:**
  - **Any number of chemical species present in liquid, gas and solid phases**
  - **Chemical equilibrium and kinetics**
  - **Aqueous complexation**
  - **Mineral dissolution/precipitation**
  - **Gas dissolution/exsolution**
  - **Cation exchange**
  - **Surface complexation**
  - **Chemical heterogeneity**

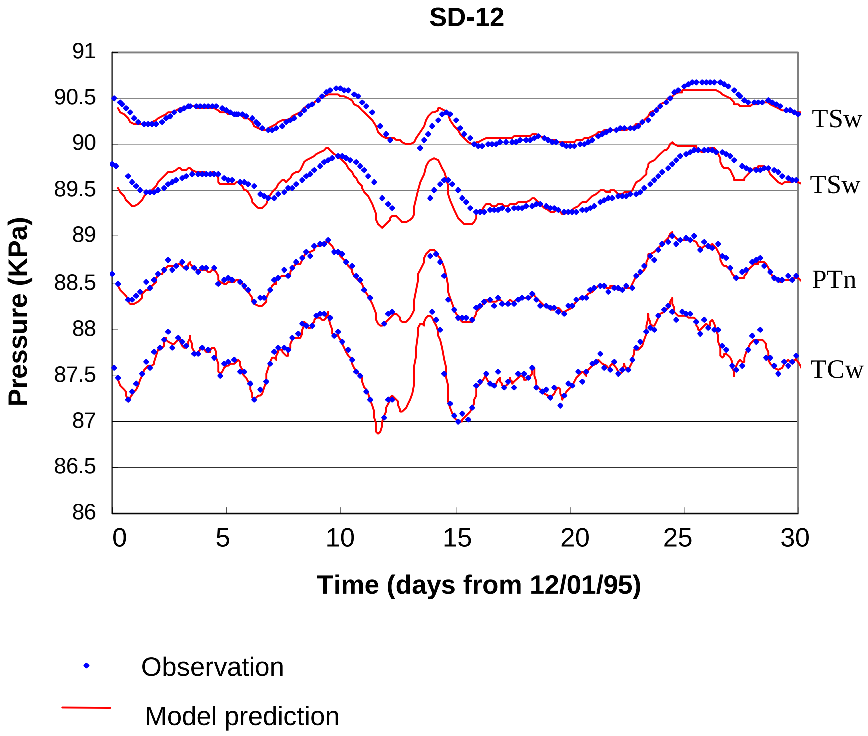


# Selected Calibration Examples

- **Pneumatic Pressure**
- **Liquid Saturation and Water Potential**
- **Temperature**
- **Chloride along ESF**
- **Calcite in WT-24**

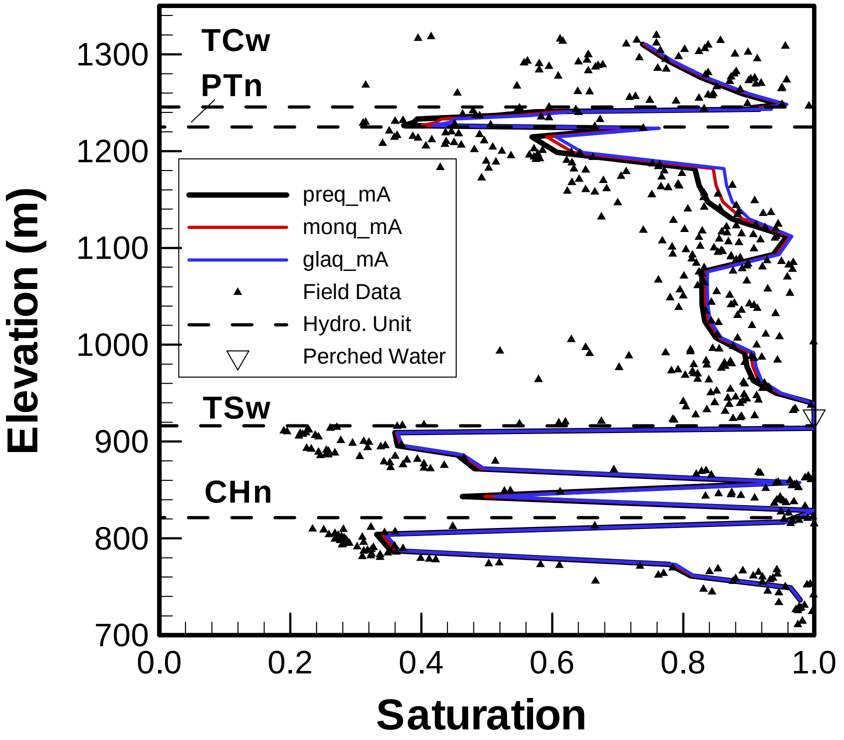
# Calibration to Pneumatic Data in Borehole SD-7 and SD-12 (3D Numerical Simulation)



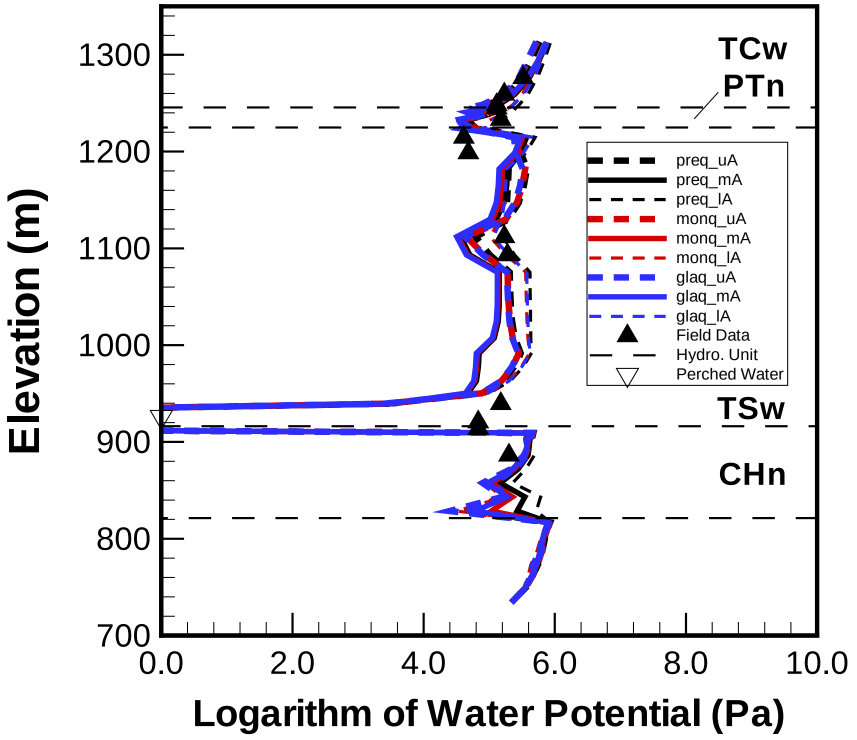


# Calibration to Liquid Saturation and Water Potential (3D Model)

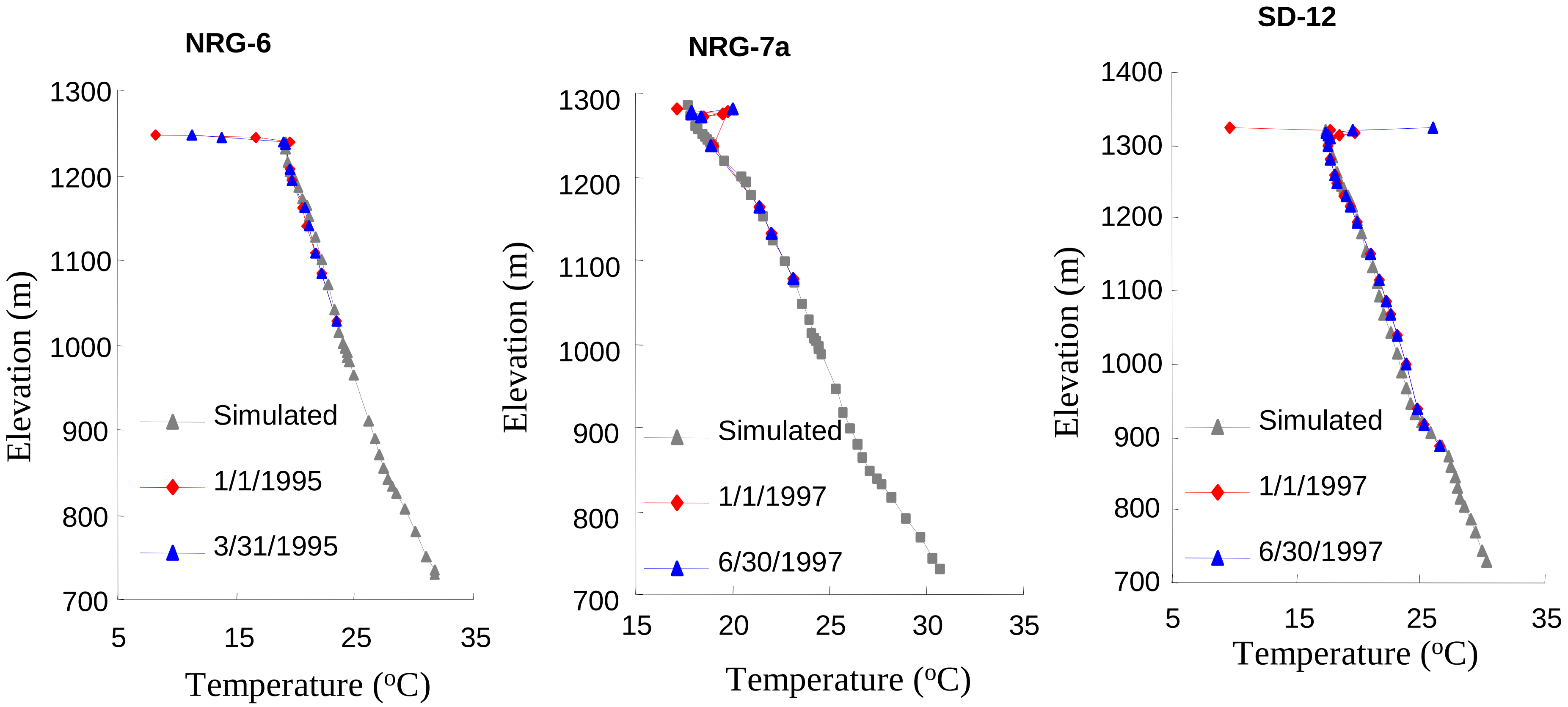
SD-12



SD-12

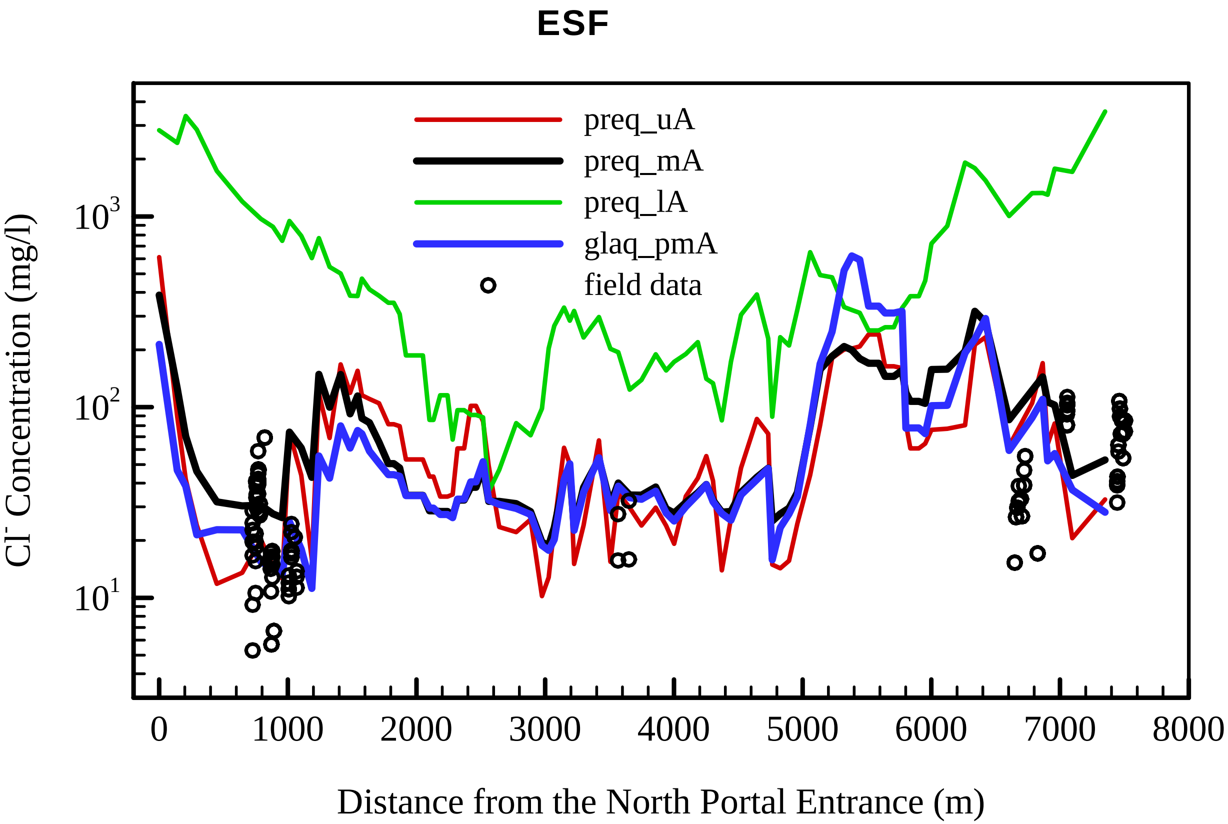


# Calibration to Temperature Data in Boreholes (3D Numerical Simulation)



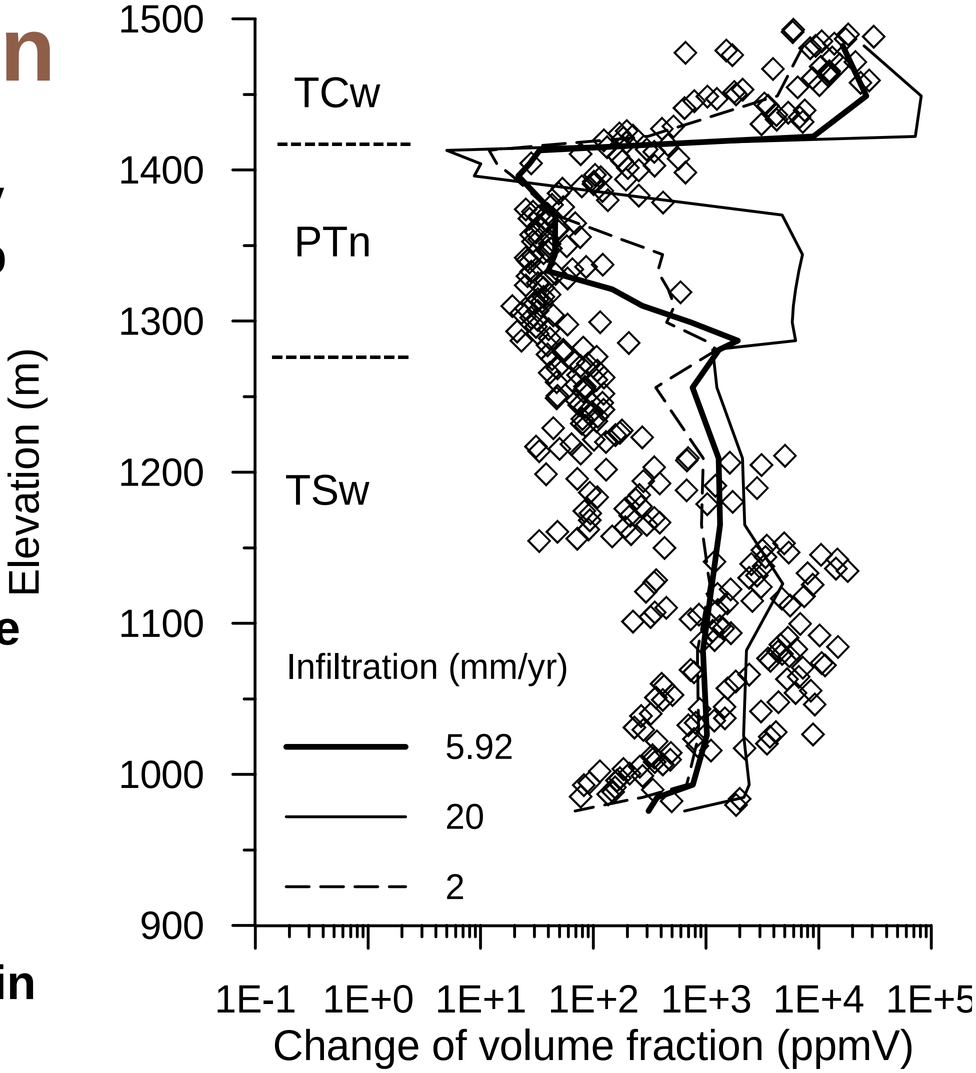
# Use of Chloride Profile along ESF to Calibrate Percolation

- **Observation**
  - **Pore water chloride from samples along ESF**
- **Modeling**
  - **3D UZ flow fields**
  - **Present day and glacial transition infiltration scenarios**

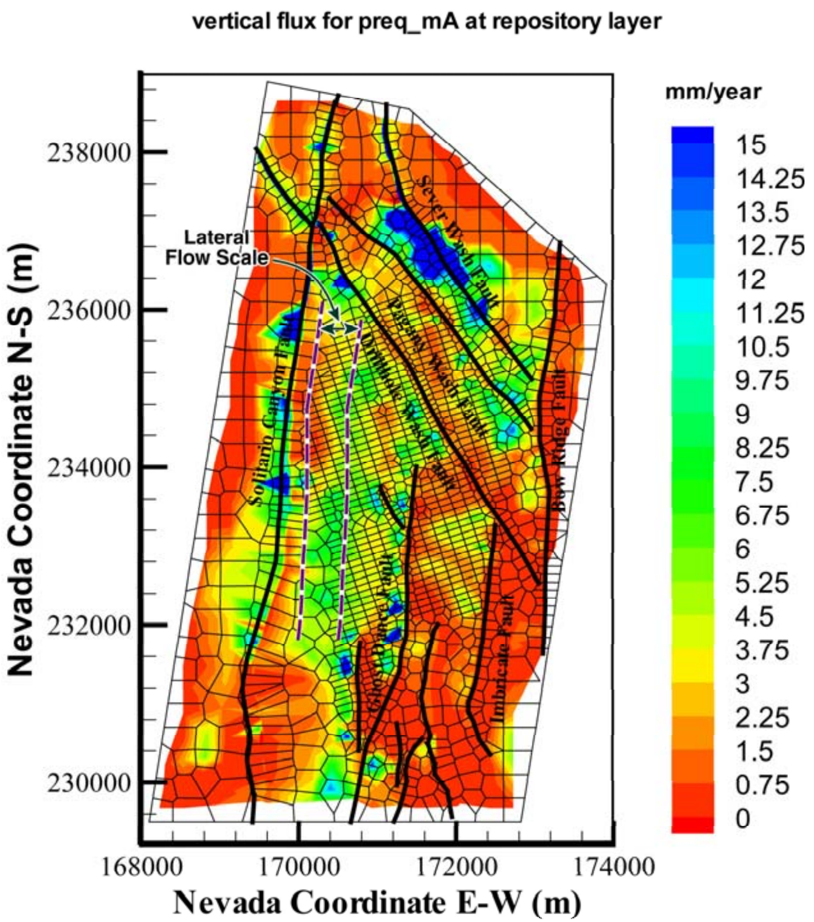


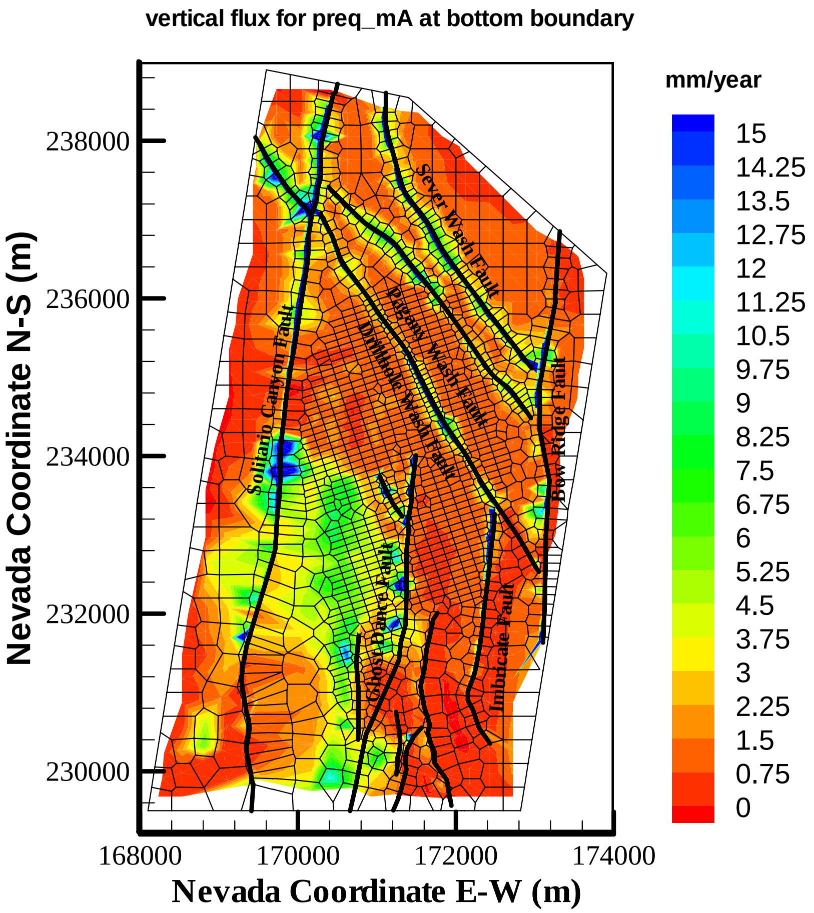
# Use of Calcite Data to Constrain Percolation

- **Observation**
  - **Total calcite abundance (ppmV or 10-6 volume fraction in deep boreholes WT-24**
- **Modeling Approach**
  - **1D geochemical transport simulation under different infiltration rates**
  - **Compare simulated total calcite abundance (matrix plus fracture) with data**
- **Results**
  - **Over a range of 2–20 mm/yr infiltration rates, the simulated abundances generally fall within the range of calcite observed**



# Model Results: Percolation Fluxes at the Repository Horizon and Water Table


vertical flux for preq_mA at repository layer


vertical flux for preq_mA at bottom boundary

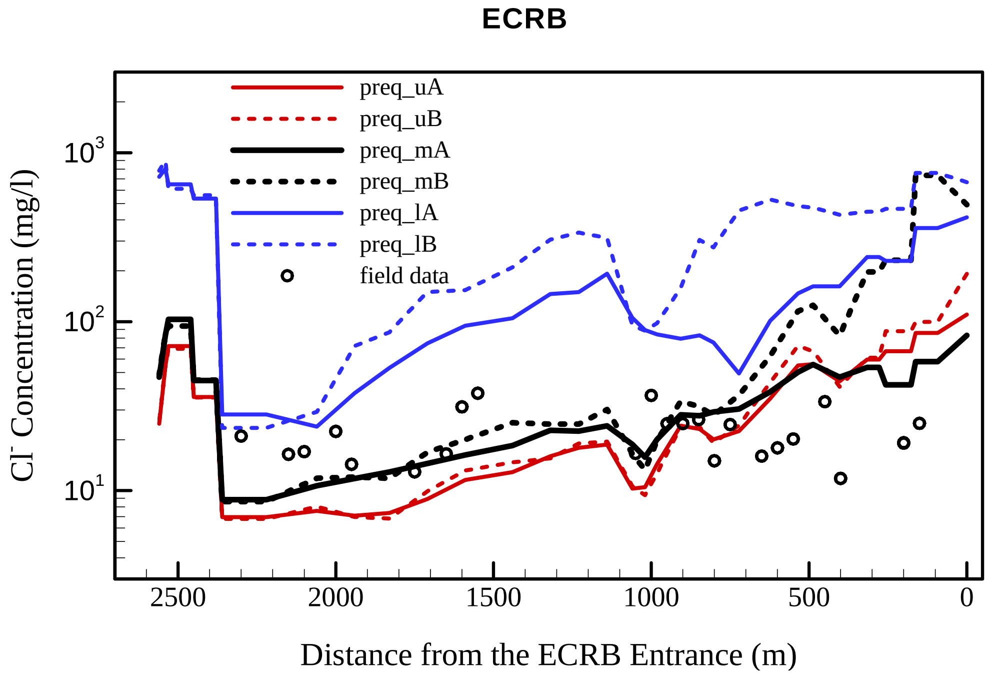
# Validation of UZ Flow Models

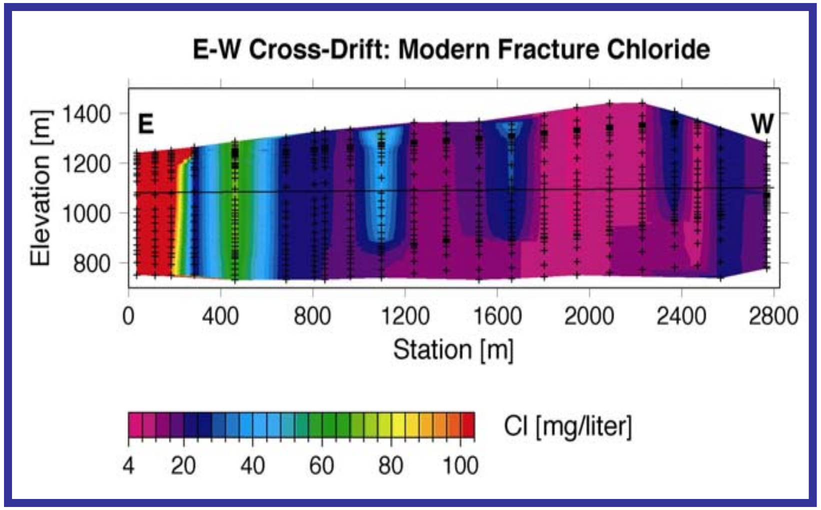
- Observed ECRB geology consistent with predictions
- Construction water migration
- Predictions of Chloride concentration in ECRB
- Carbon 14 on pore water age

# Observed ECRB Geology Well Represented by Predictive Report

- **Faults encountered were of the type, size, and offset anticipated by the Predictive Report.**
  - **A small number of minor faults were encountered (as expected)**
- **Characteristics of predicted faults were nearly identical to what was presented in the Predictive Report**
  - **The Solitario Canyon Fault (SCF) was encountered within a few meters of the predicted location. Orientation of the structure and offset along the fault were essentially identical to predictions**

# Use of Measured Chloride Concentration along ECRB to Validate 3D Geochemical Model

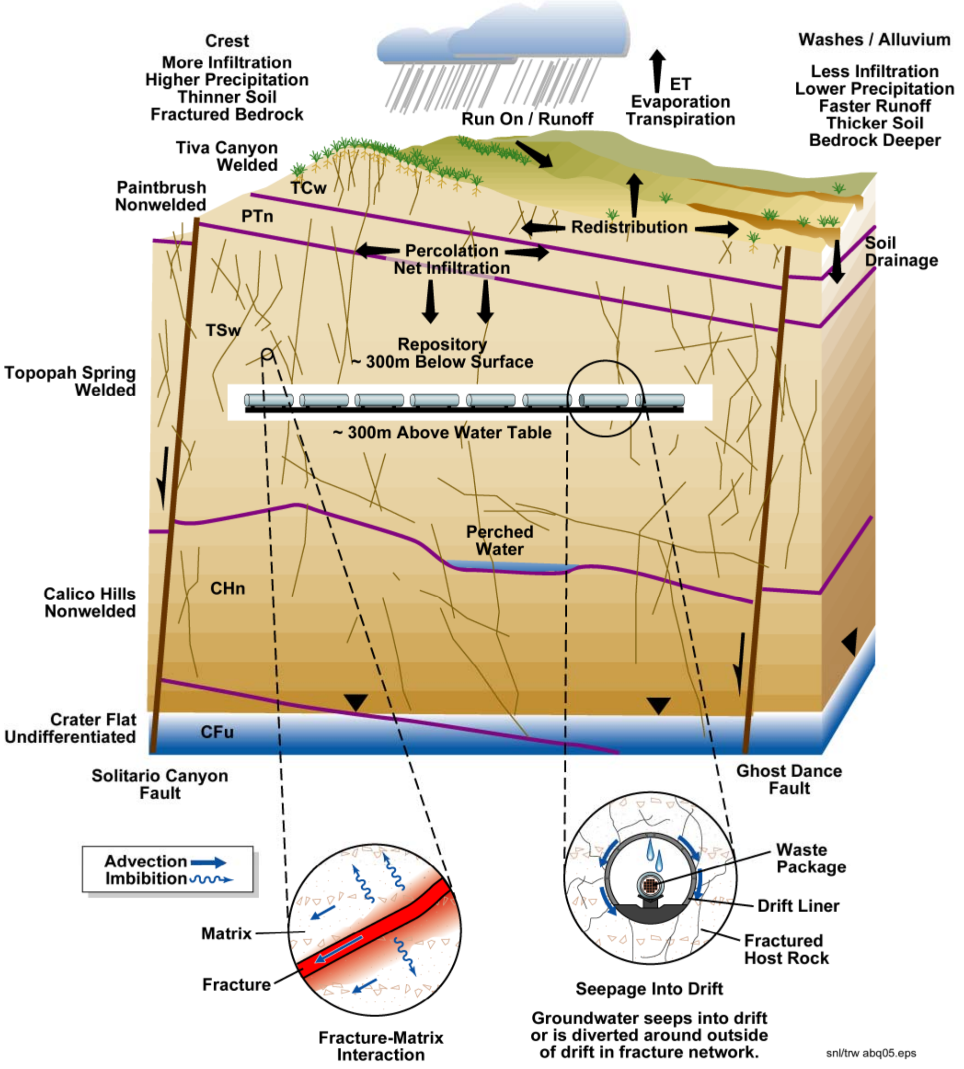




Adapted from J. Contaminant Hydrology 38 (1999) 107-156

# UZ Transport

- All process pertaining to flow are important to transport
- Drift shadow effect
- Suite of radionuclides
  - Sorbing and non-sorbing, different $k_d$'s
- Sorption
  - Vitric and zeolitic
- Matrix diffusion
  - Active fracture model
- Daughter products of radioactive decay
- Colloidal transport



# Testing Specific to UZ Transport *Model Predictions Provide Confidence for Validity of UZ Transport Model*

- **Alcove 1 in ESF**
  - **From surface through fractured Tiva Canyon welded tuff**
- **Alcove 8 ECRB-Niche 3 ESF**
  - **Crossing Topopah Spring welded upper lithophysal and middle nonlithophysal unit interface**
- **Busted Butte**
  - **Calico Hill outcrop**

# Solute Transport – Alcove 1 Infiltration Study on the Bedrock

## Test Studies:

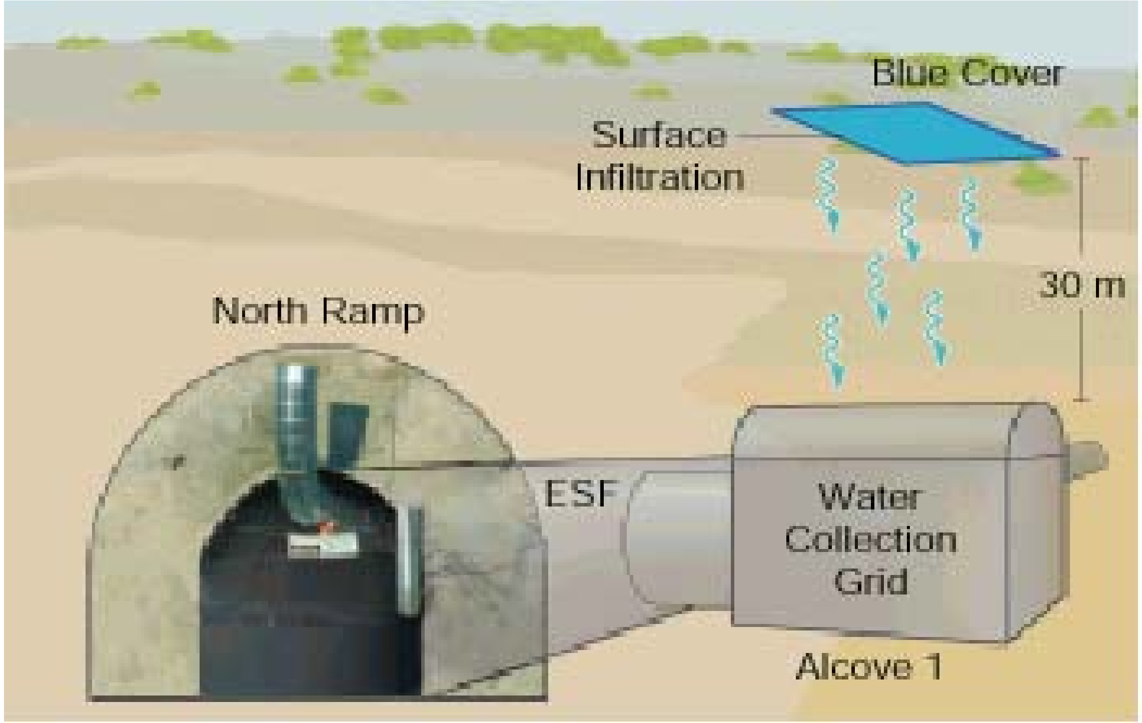
- Apply infiltration rates below run-off threshold on the ground surface
- Collect seepage at Alcove 1, 30m below, for water and tracer collection

## Modeling:

- Predict seepage
- Predict tracer breakthrough

## Results:

- Matrix diffusion is important in order to interpret delay in tracer breakthrough

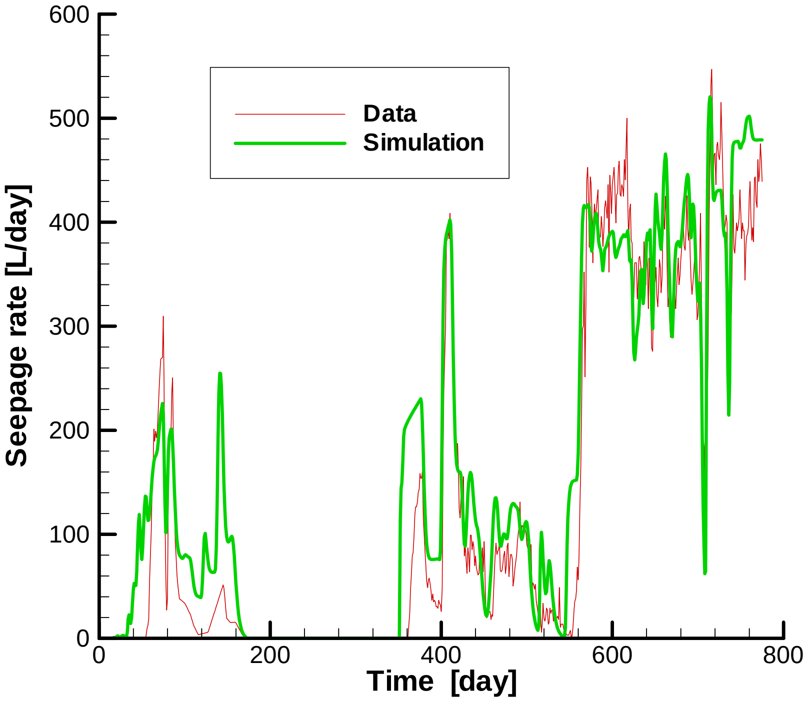


# Alcove 1 Test Predictions

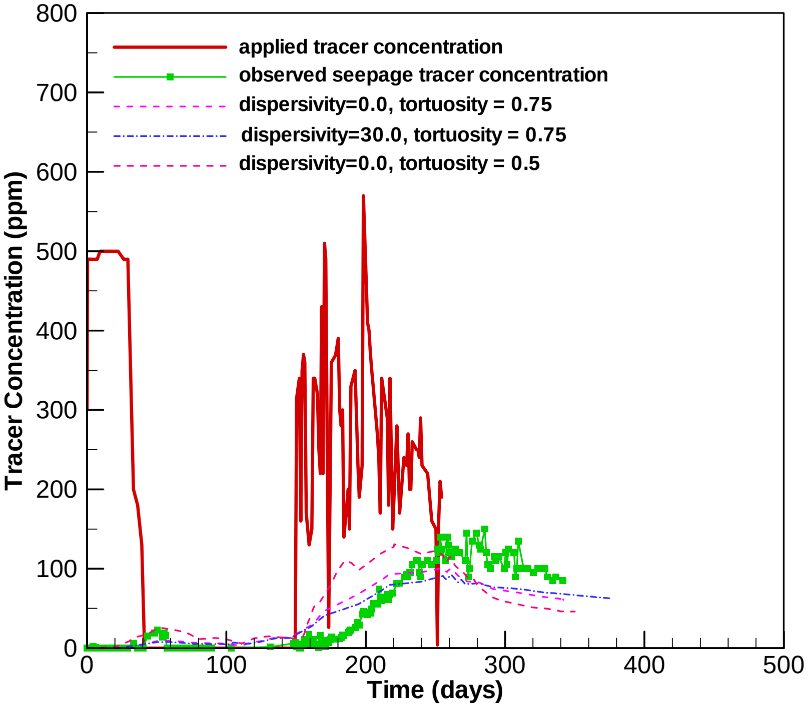
## *(preliminary)*

## Phase 1 calibration, phase 2 predictions

### Seepage

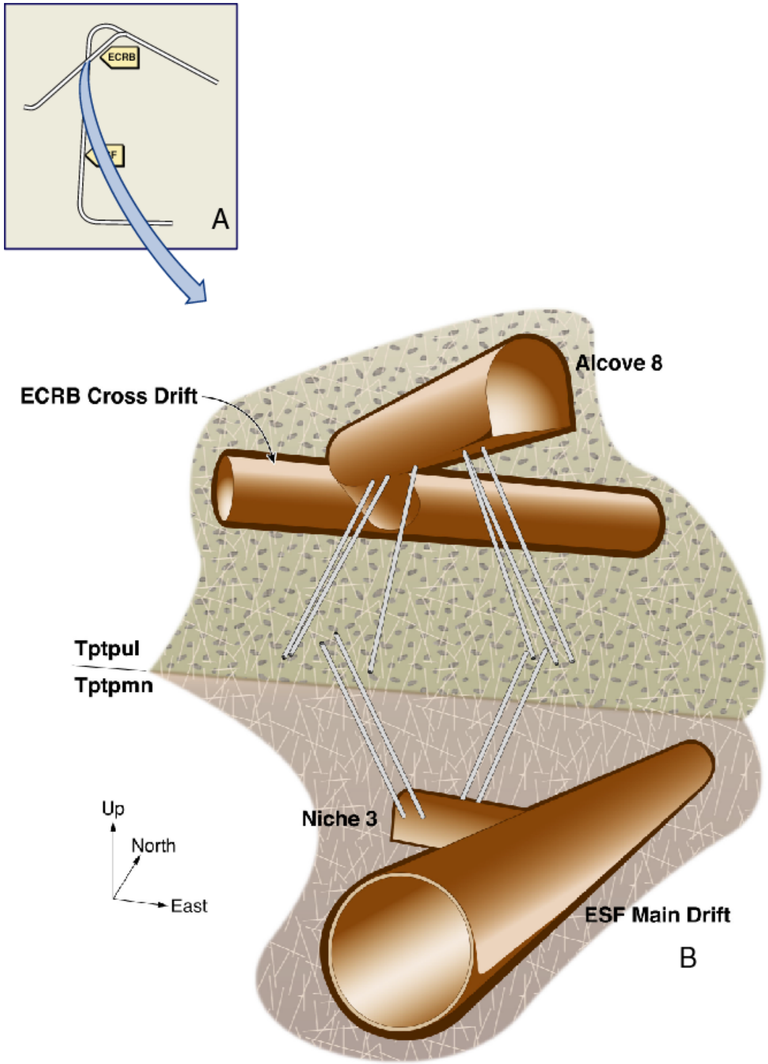


### Tracer breakthrough



# Alcove 8/Niche 3 Fault Test

# THE TESTBED



# Alcove 8-Niche 3

## *First Arrival along Fault and Evidence of Matrix Diffusion*

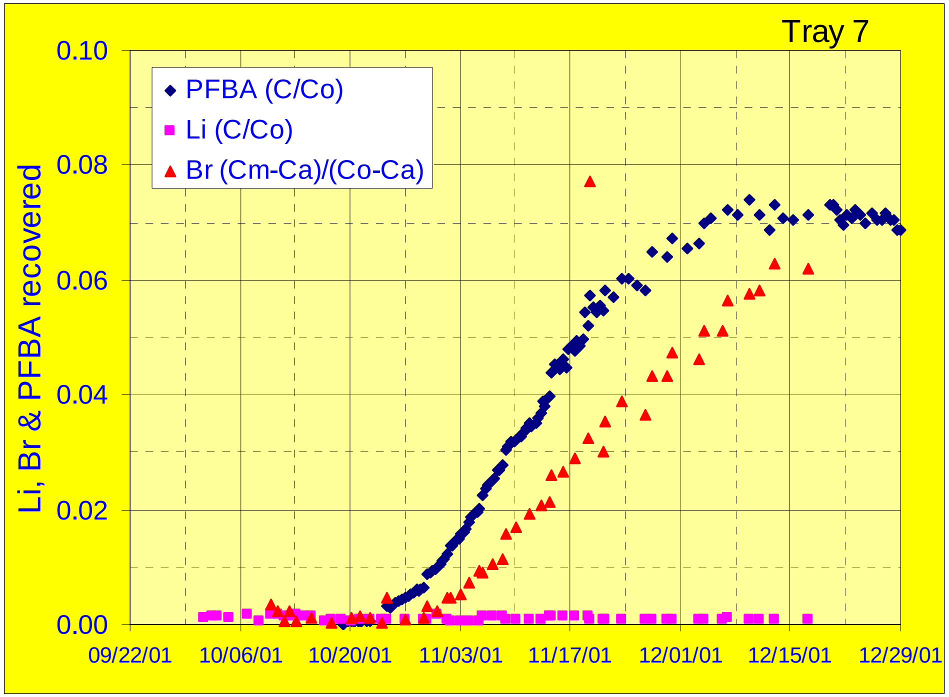
### *(preliminary)*

**Studies:**

- **Infiltrate water along a fault at Alcove 8 in the ECRB Cross Drift, and collect seepage in Niche 3 in the ESF Main Drift, ~20 m below**
- **Inject two tracers with different sizes to evaluate matrix diffusion effects**

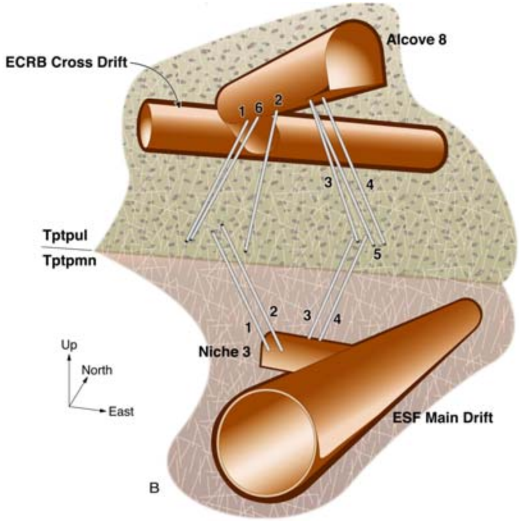
**Observations:**

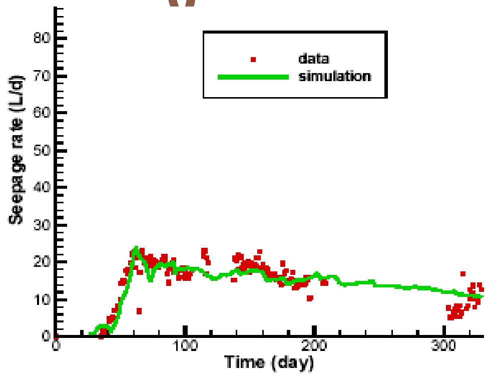
- **First arrival was along the fault, with subsequent seepage also through fracture network**
- **Clear observation of matrix diffusion dependence on tracer size, with large molecules staying more in the fractures**



# Alcove 8/Niche 3 Test Predictions

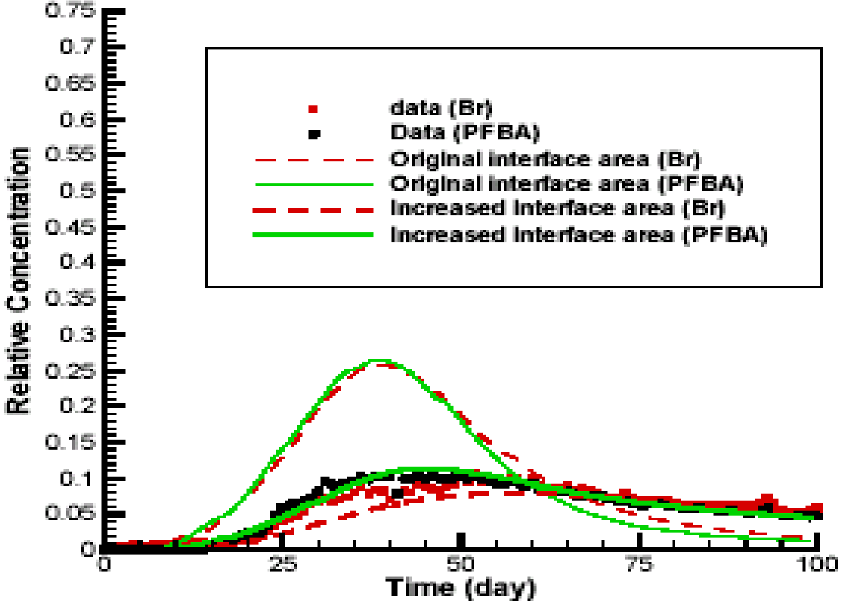
## *(preliminary)*



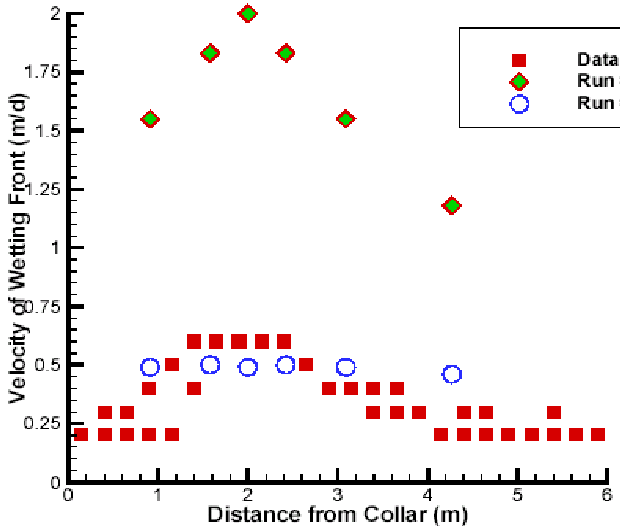


**Seepage**

## Tracer tests (Br and PFBA)



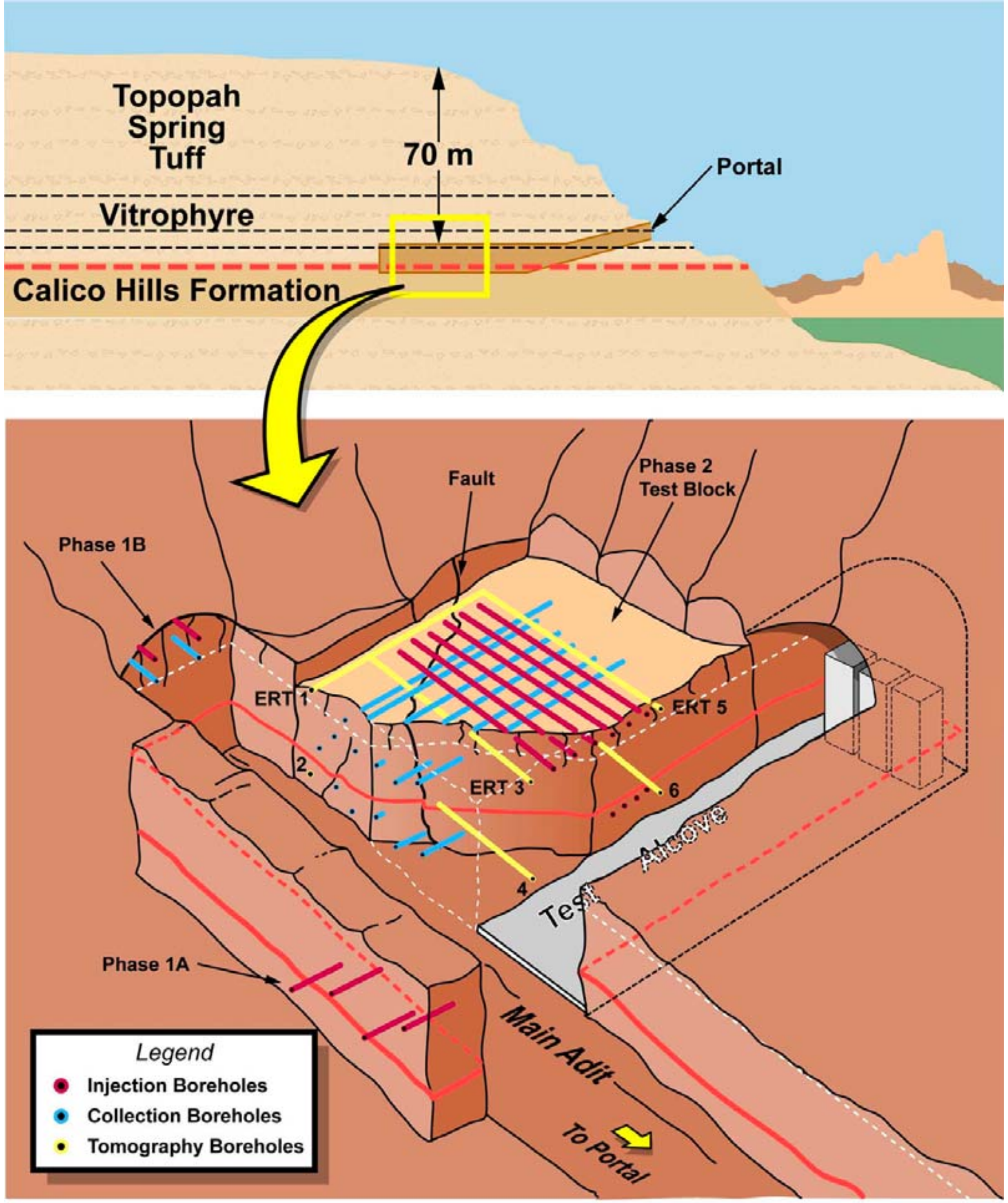
## Water travel velocity from fault testing



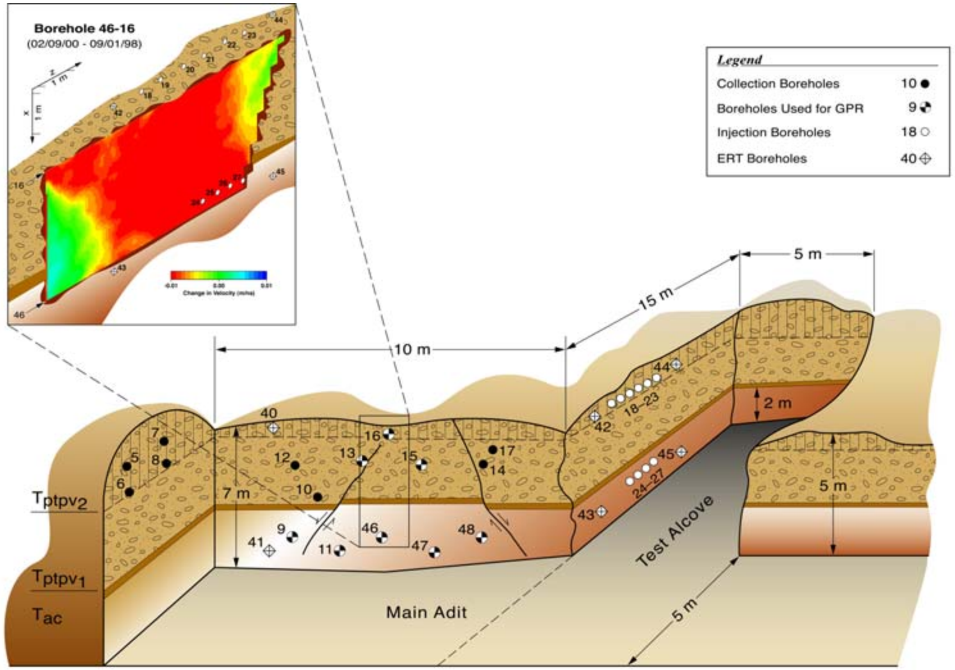
# Busted Butte Transport Test

**Studies:**

- Inject multi-tracer solutions into borehole arrays in and above Calico Hills vitric tuff
- Track plume migrations with periodic Ground Penetrating Radar imaging between borehole pairs



# Solute Transport
# – Busted Butte Transport Test



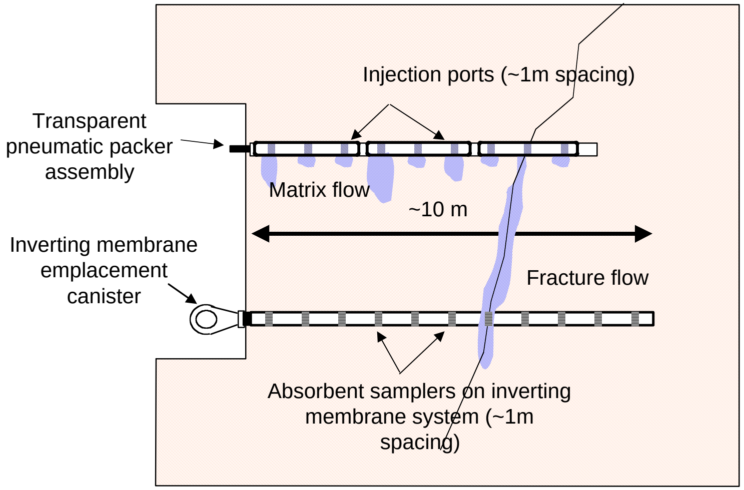
Earth Sciences Division

Layout of Boreholes in the Busted Butte Test Area

GEO2K001C

**Tracers:**

**Lithium Bromide**
**Sodium Fluorecein**
**Microspheres etc.**



Injection ports (~1m spacing)

Transparent pneumatic packer assembly

Matrix flow

~10 m

Inverting membrane emplacement canister

Fracture flow

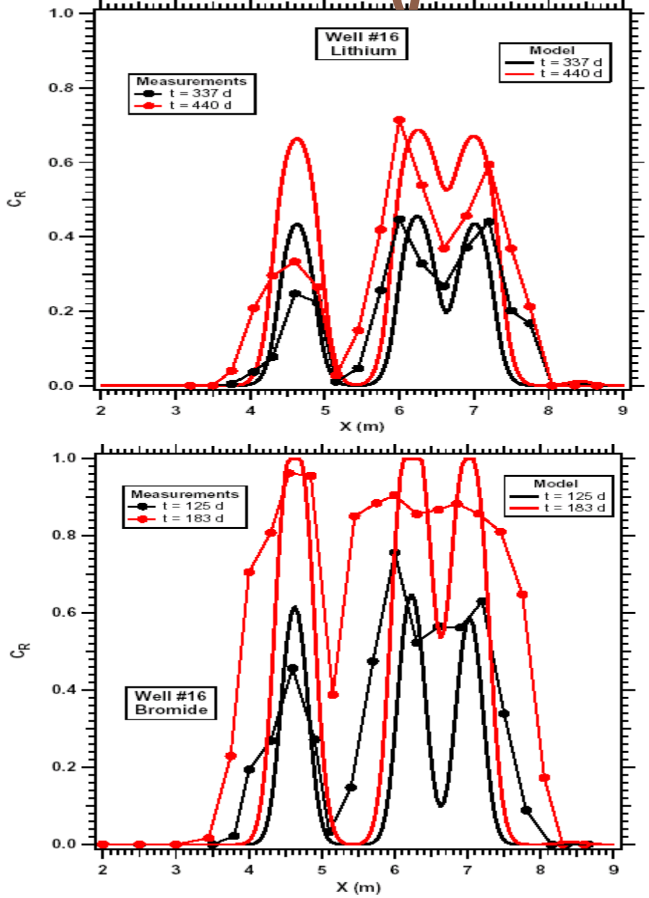
Absorbent samplers on inverting membrane system (~1m spacing)

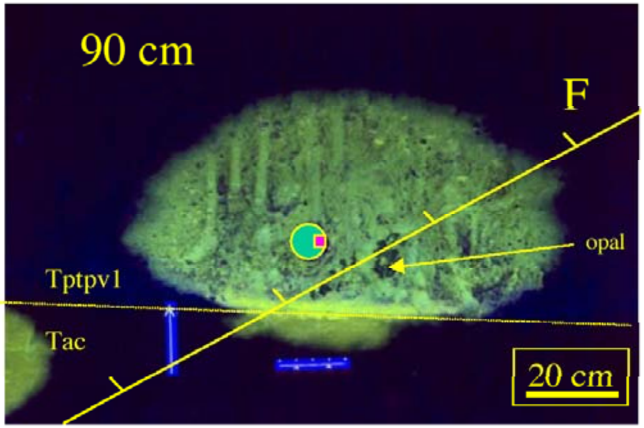
## Observation:

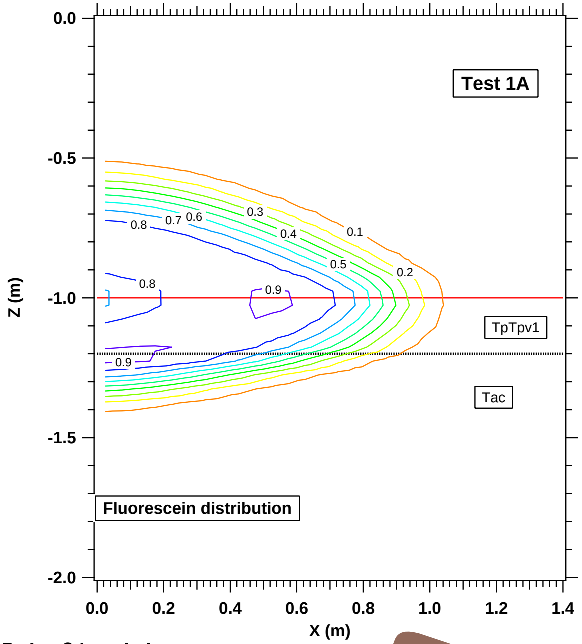
- **Calico Hills vitric tuff has simple porous medium characteristics with well-defined plume pattern**
- **Different tomographic techniques are useful to monitor plume migration**

# Busted Butte: *Model Calibration (preliminary)*

## Fluorecein plume and predictions using calibrated properties







**Measured and Predicted (calibrated) breakthrough curves for Li and Br**

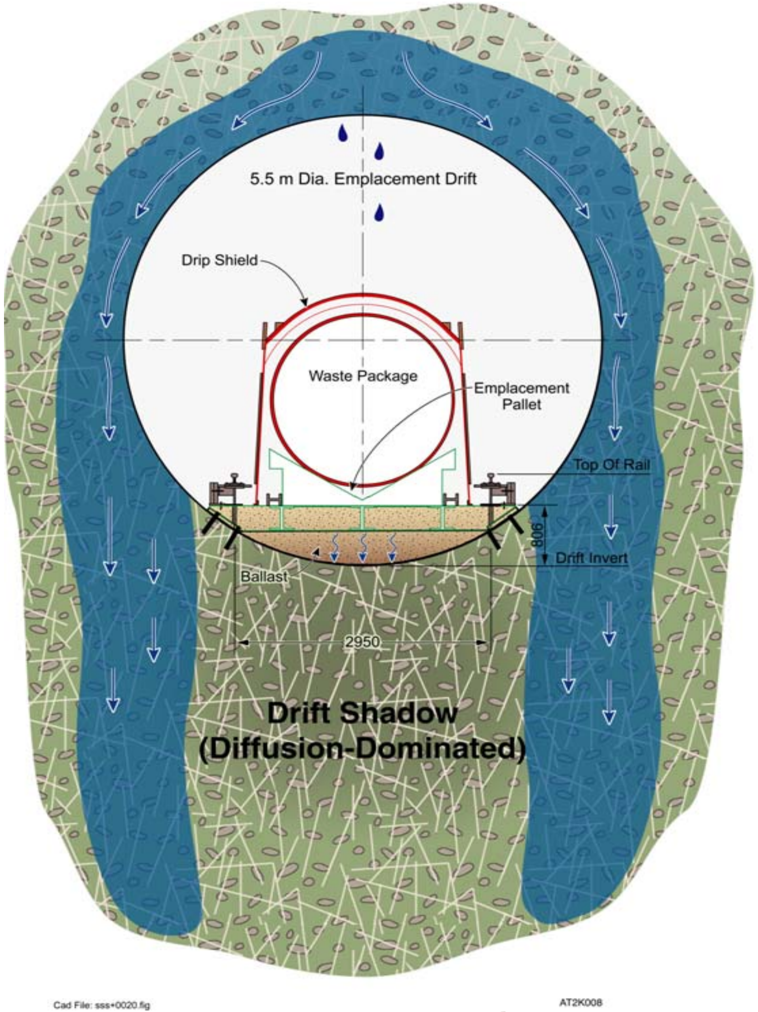
Matrix $K_d$ initial estimates for Li are 3.5 x $10^{-5}$ ($m^3$/Kg) in TpTpv1 and 8.8 x $10^{-5}$ ($m^3$/Kg) inTpTpv2, Calibrated values are 5.5 x$10^{-4}$ ($m^3$/Kg) and 9.3 x$10^{-4}$ ($m^3$/Kg) respectively (1 $m^3$/kg=$10^{-3}$ ml/g)

# Unsaturated Zone Transport Model Development

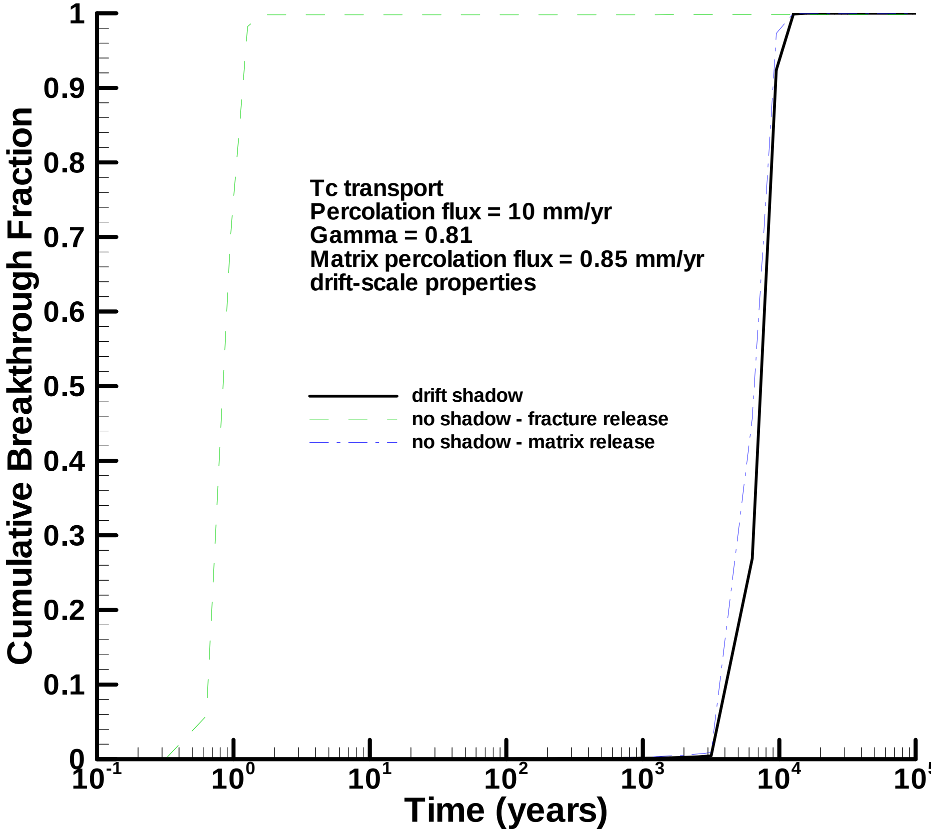
- **Radionuclide source term: drift shadow concept**
- **Geological attributes that are key to transport**
- **Numerical tools**
- **Selective UZ transport model results**

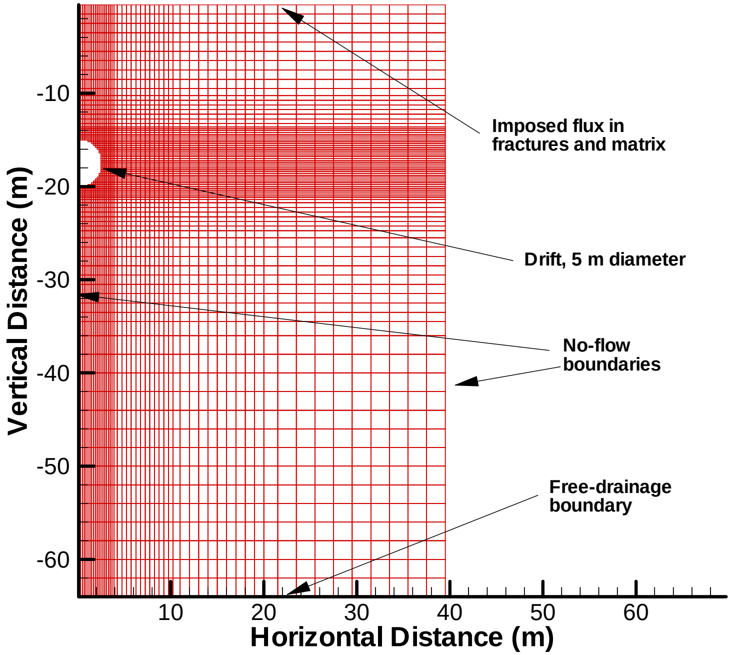
# Radionuclide Source Term:
# *Drift Shadow Concept*

- **Drift Shadow (zone of lower water saturation and flux) from seepage diversion is expected to exist in 50 to 90% of drifts**
- **Radionuclides primarily enter the rock matrix by diffusion**



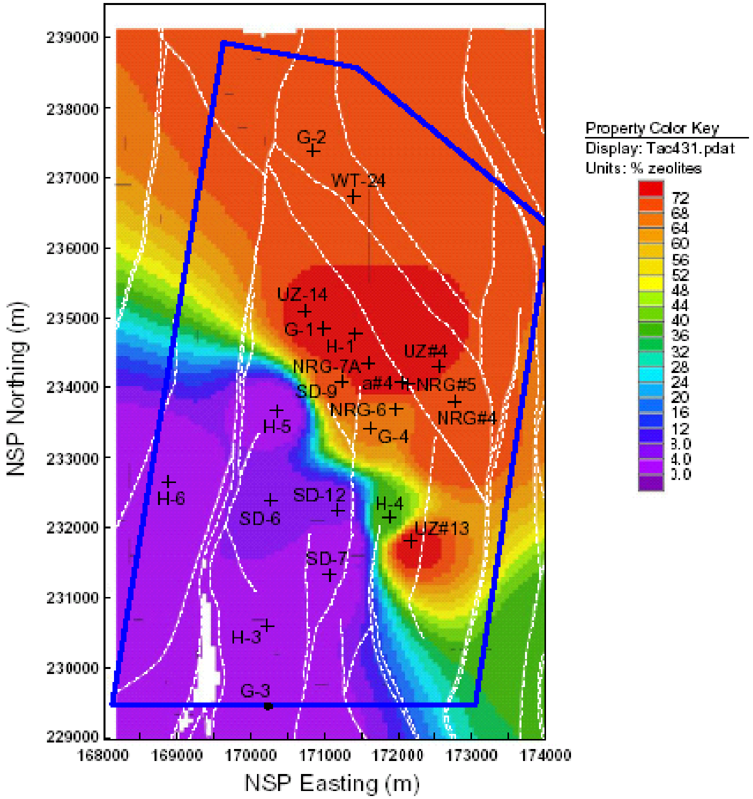
# Drift Shadow: Impact on Radionuclide Transport – (preliminary)

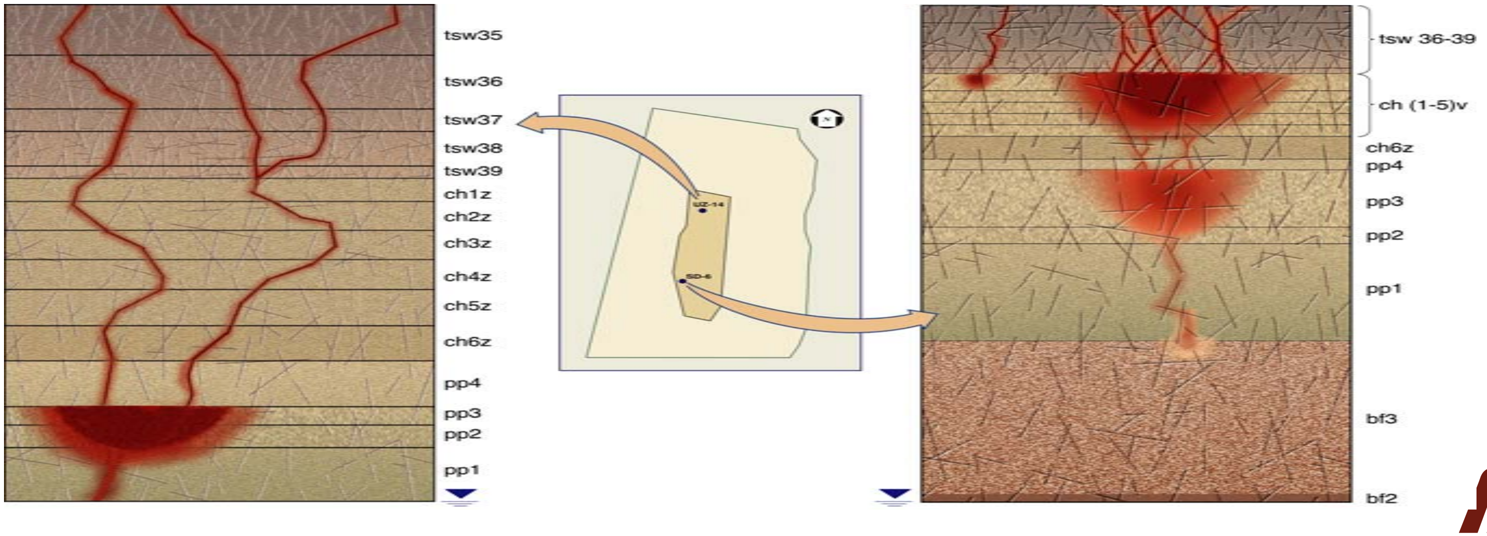




**Transport time (to 45 m below emplacement drift) of thousands of years calculated, compared with a few years for release into the unperturbed flow**

# Vitric and Zeolitic in CH Play Dominant Role in Radionucllide Transport



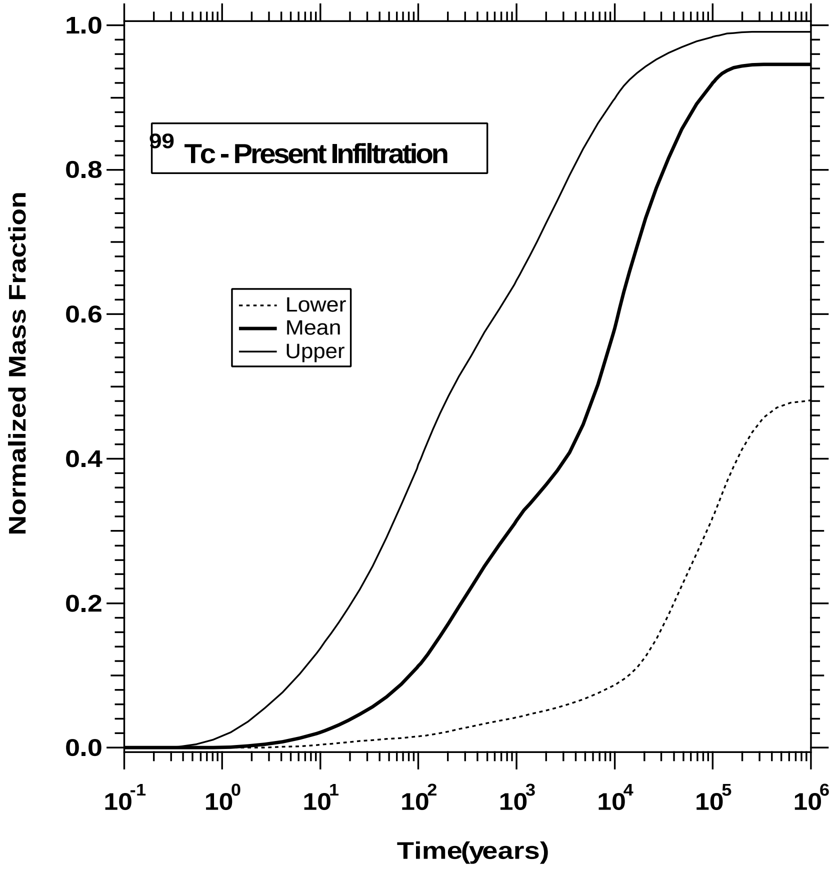


# Numerical Tools Specific to UZ Transport Modeling

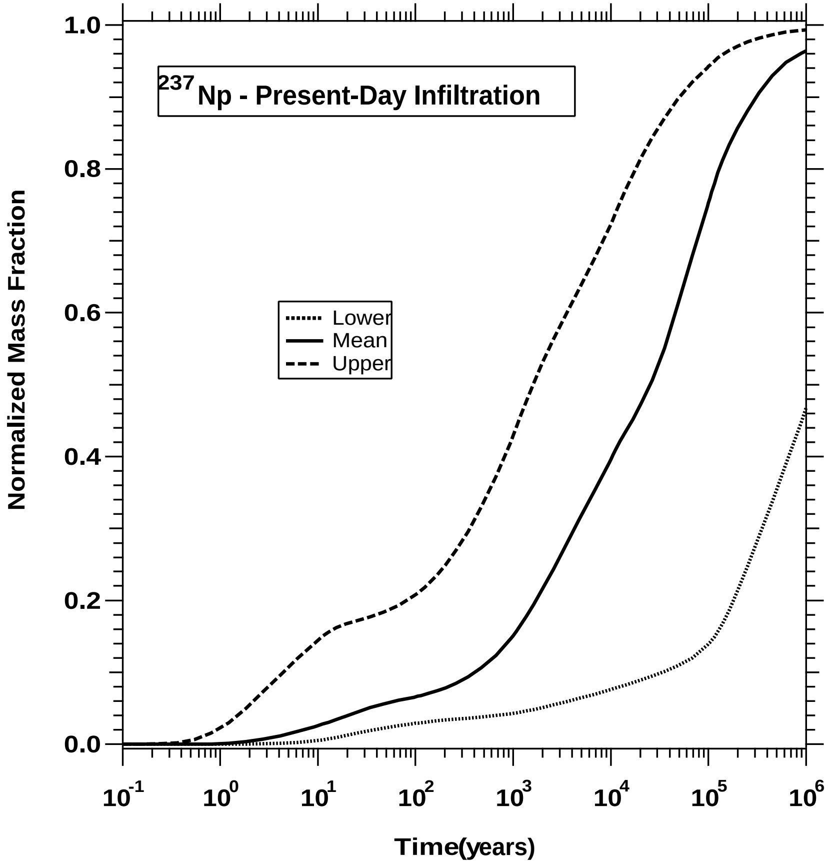
- **TOUGH2 family of codes**
  - **TOUGH2 V1.11 Module EOS9nT simulates flow and the transport of multiple radioactive solutes and/or colloids (parents and daughters)**
  - **TOUGH2 V1.4 (Module EOS9 V1.4)**
  - **T2R3D V1.4 simulates flow and the coupled transport of a single radioactive solute tracer**
- **DCPT V1.0 and V2.0 involves the particle-tracking method to simulate transport in a single radioactive tracer**
- **FRACL V1.0 provides semianalytical solutions to the problem of 2-D transport of multiple radioactive solutes and /or colloids**

# Breakthrough at Water Table
# *(Present-Day Infiltration scenarios)*
## *(preliminary)*

$^{99}$Tc

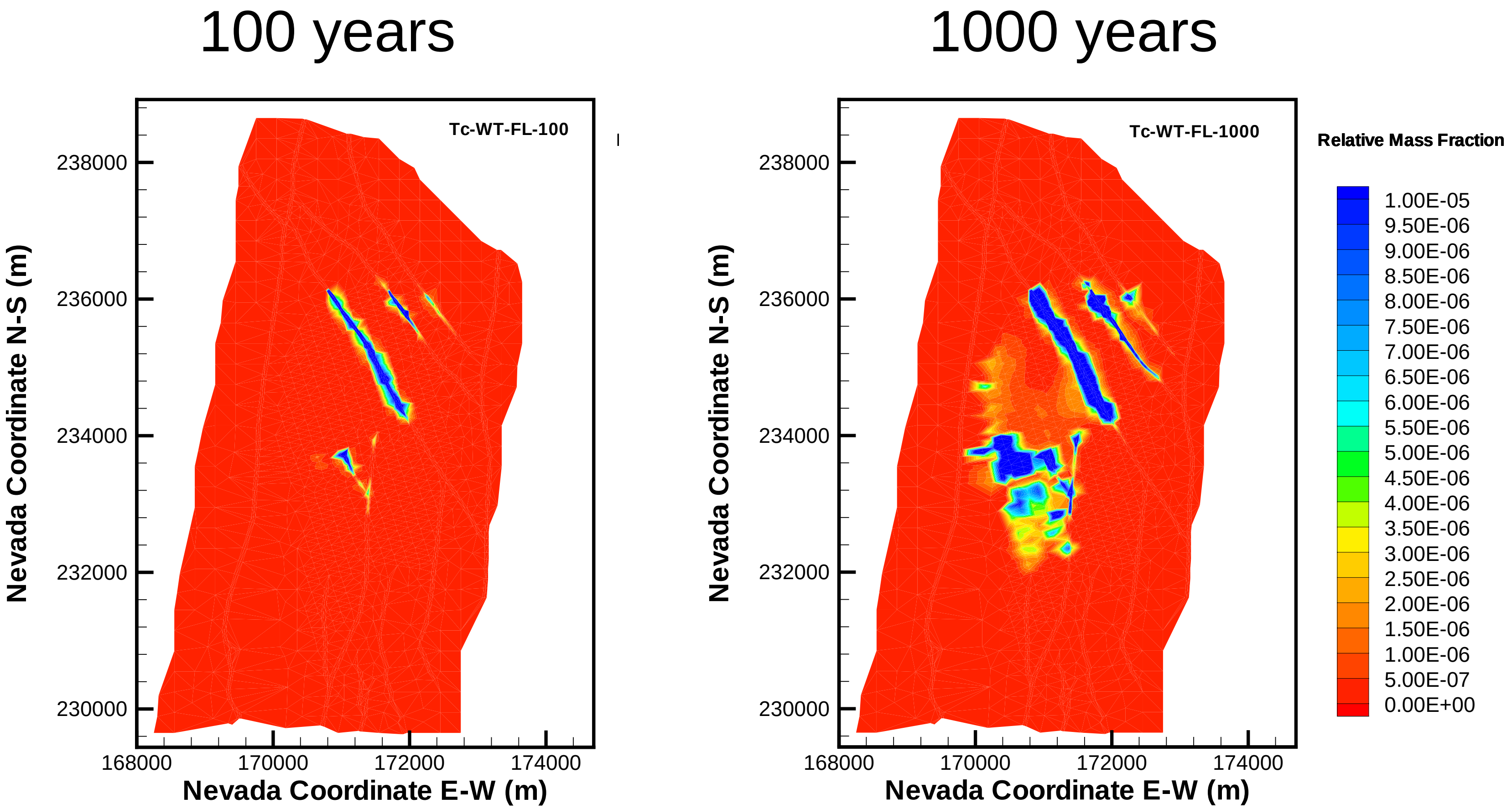


$^{237}$ Np



# Non-sorbing Radionuclide: *Relative Mass Fraction of $^{99}$Tc in the Fractures Immediately above the Water Table*

## *(preliminary)*

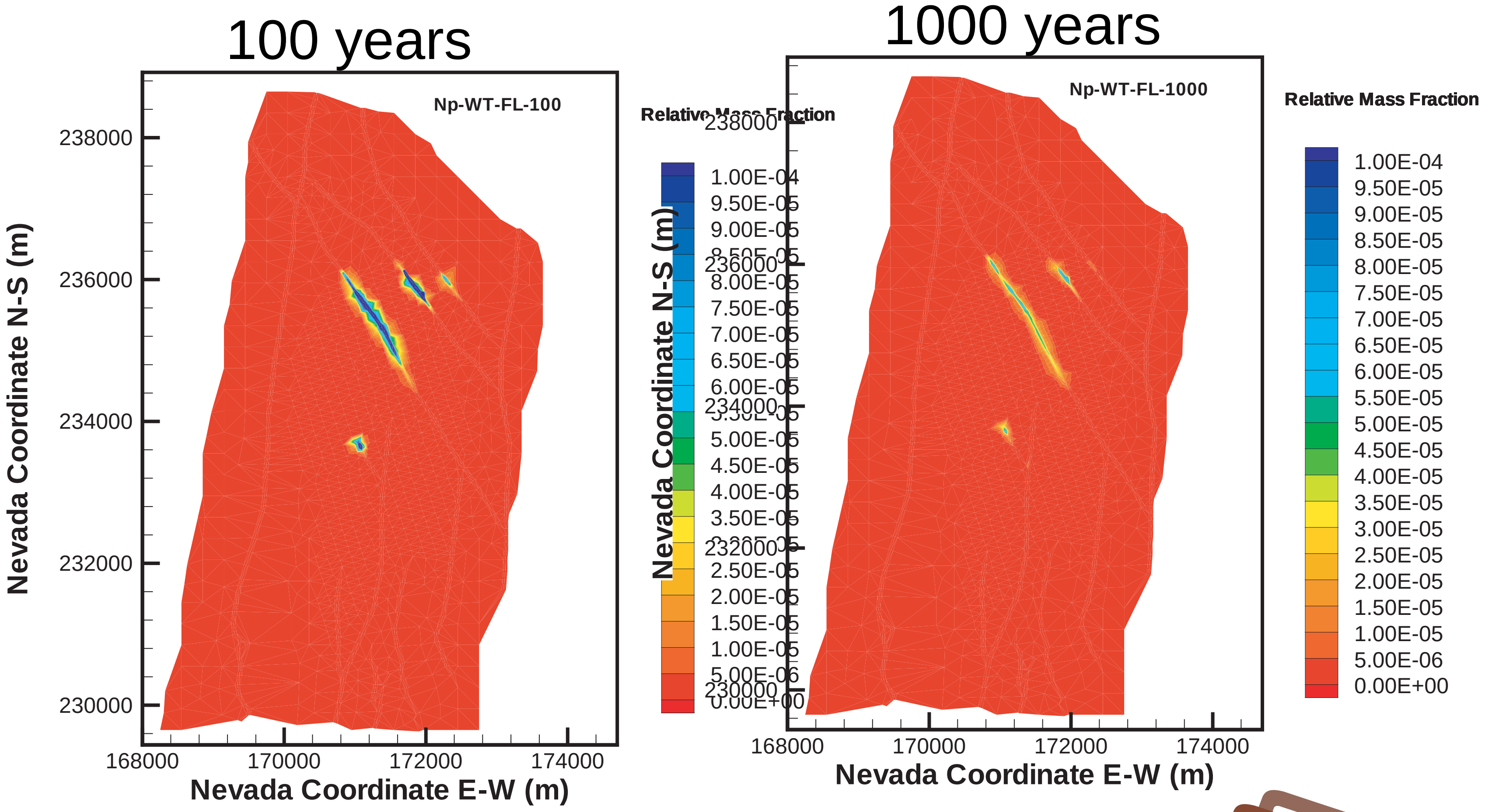


100 years

1000 years

# Sorbing Radionuclide: *Relative Mass Fraction of $^{237}$Np in the Fractures Immediately above the Water Table*

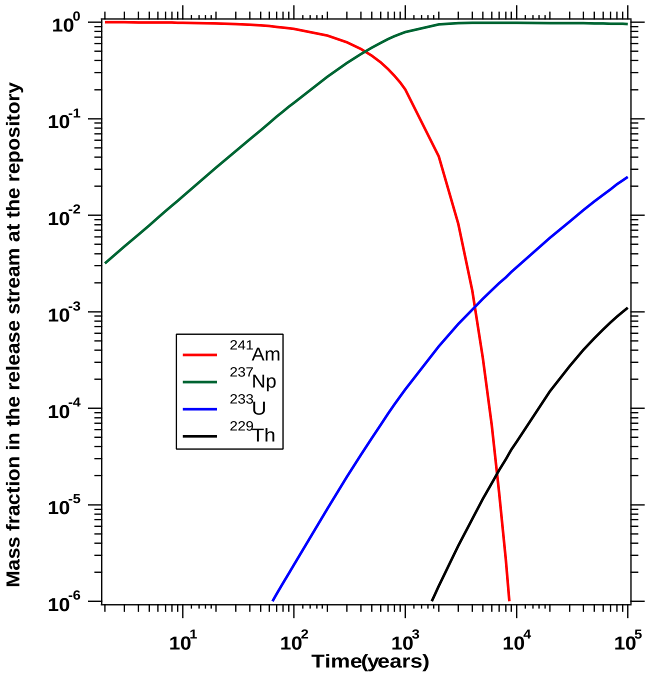
## *(preliminary)*

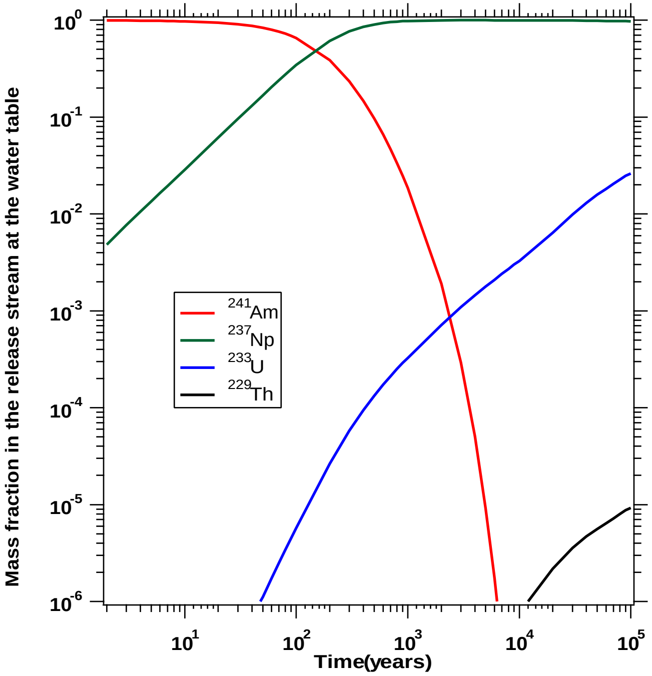


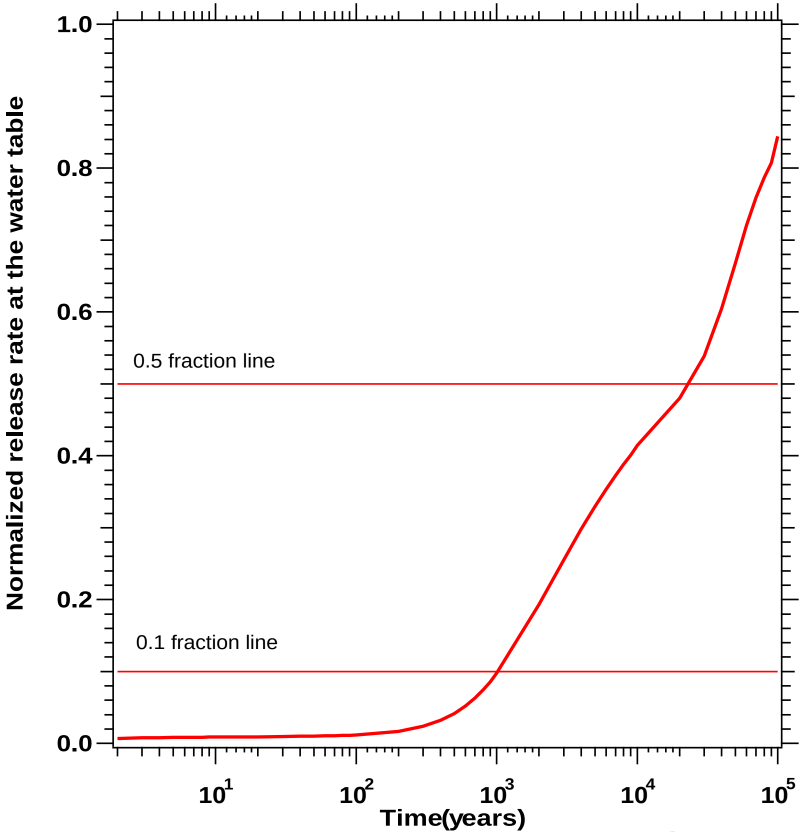
100 years

1000 years

# Parent-Daughter Decay Transport: *Mass Fractions of Each Member of the $^{240}$Am Chain (preliminary)*



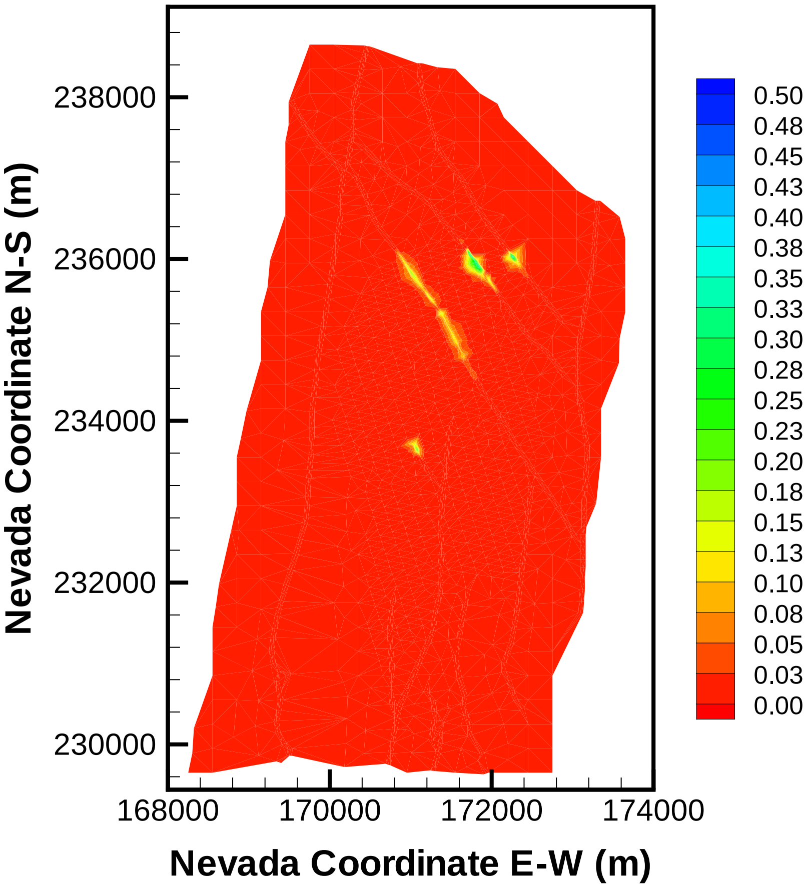




# Colloidal Transport: *Relative Mass Fraction in the Fracture Immediately above the Water Table for 6 nm $PuO_2$ (preliminary)*

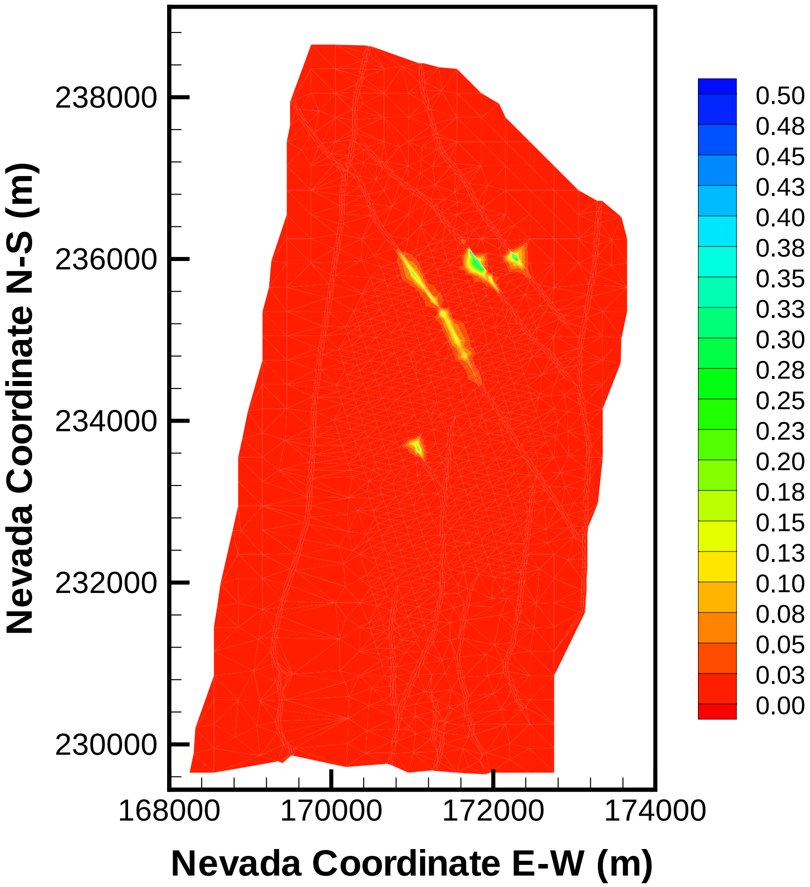
**Fracture Mass Fraction at Water Table**

**(for Co006 at 100 years)**

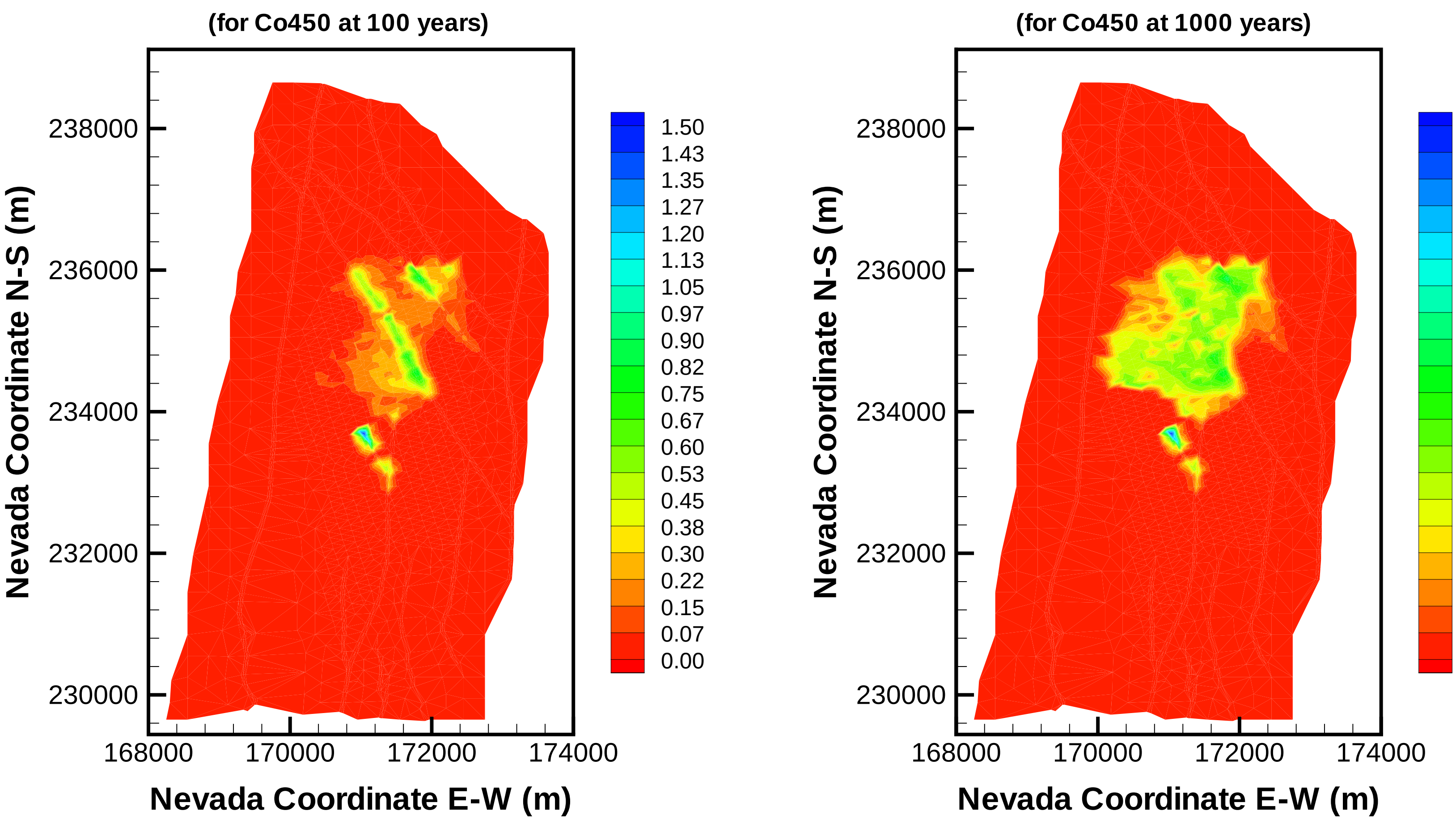


**Fracture Mass Fraction at Water Table**

**(for Co006 at 1000 years)**



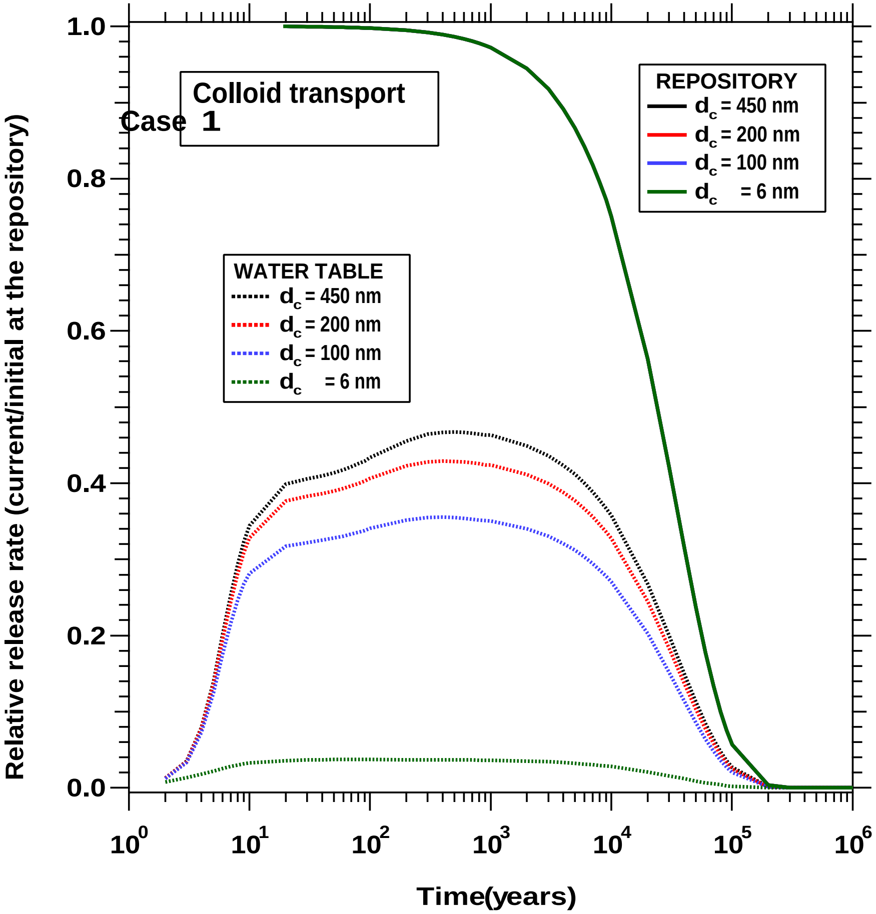
# Colloidal Transport: *Relative Mass Fraction in the Fracture Immediately above the Water Table for 450 nm $PuO_2$ (preliminary)*

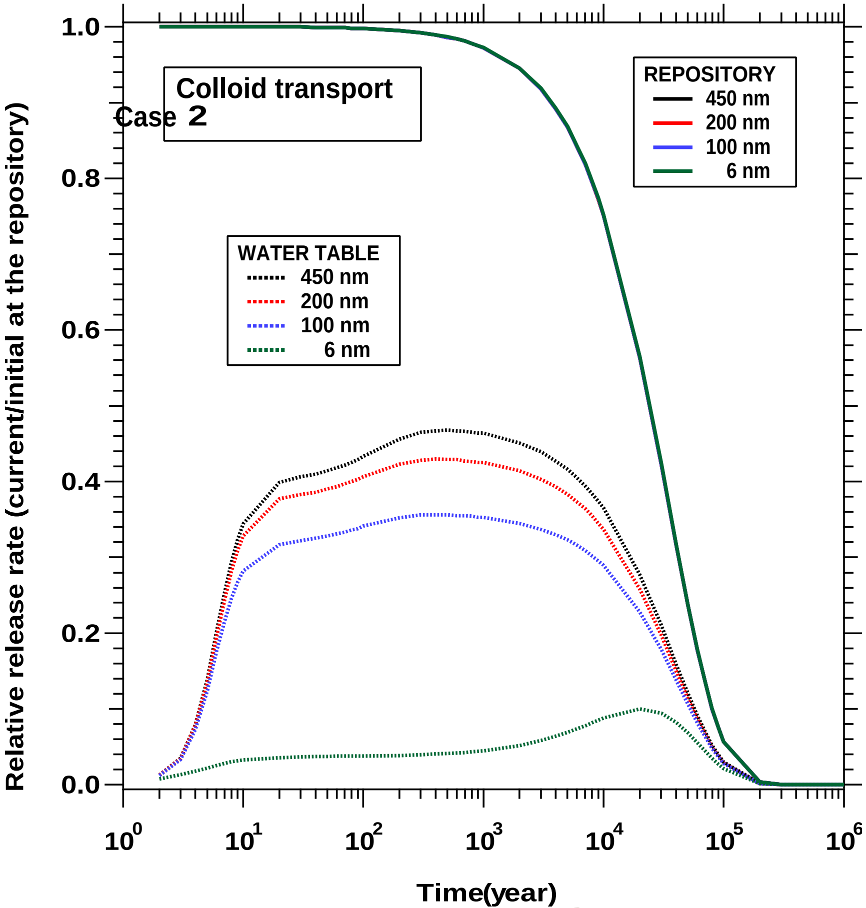


# Colloidal Transport Declogging Models

*(preliminary)*

## Similarity of Normalized Release at the Water Table for Case 1 - No Declogging, and Case 2 - Strong Kinetic Declogging Indicates Dominant Role of the Fractures



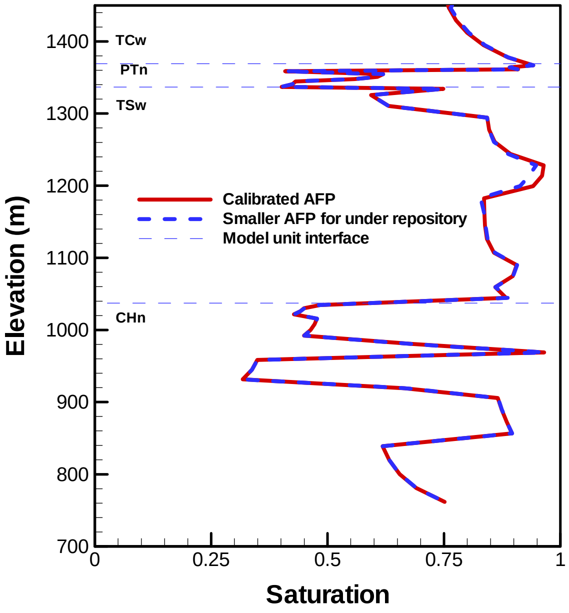


# UZ Transport Model Uncertainties

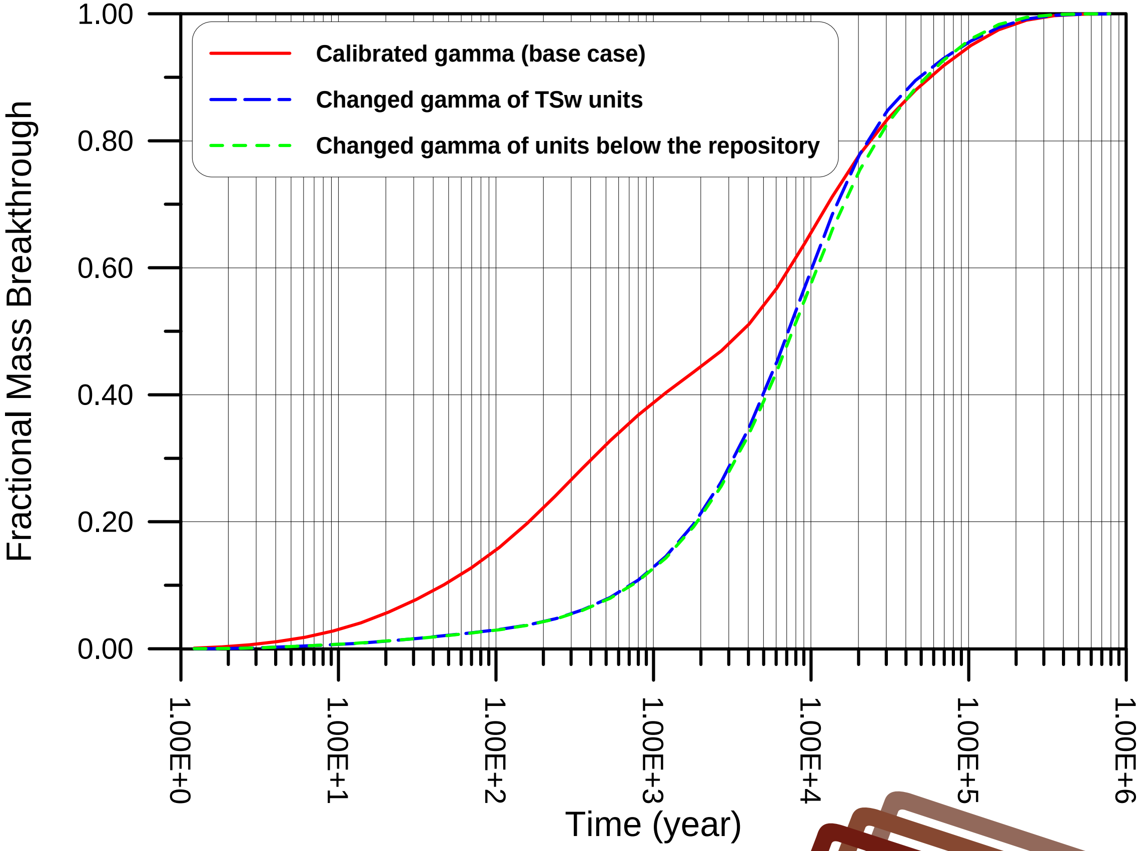
- Uncertainties in the flow conceptual model and the corresponding parameters
- Climate uncertainties
  - assessed by estimating transport under nine climatic scenarios
- Uncertainties in matrix diffusion
- Uncertainties in sorption
- Uncertainties in filtration

# Example of Model Uncertainty: Active Fracture Model Parameter γ

**Halving the calibrated γ does not affect saturation (flow)**



**Breakthrough (transport) is greatly affected by halving the calibrated γ**



# Conclusions – UZ Flow

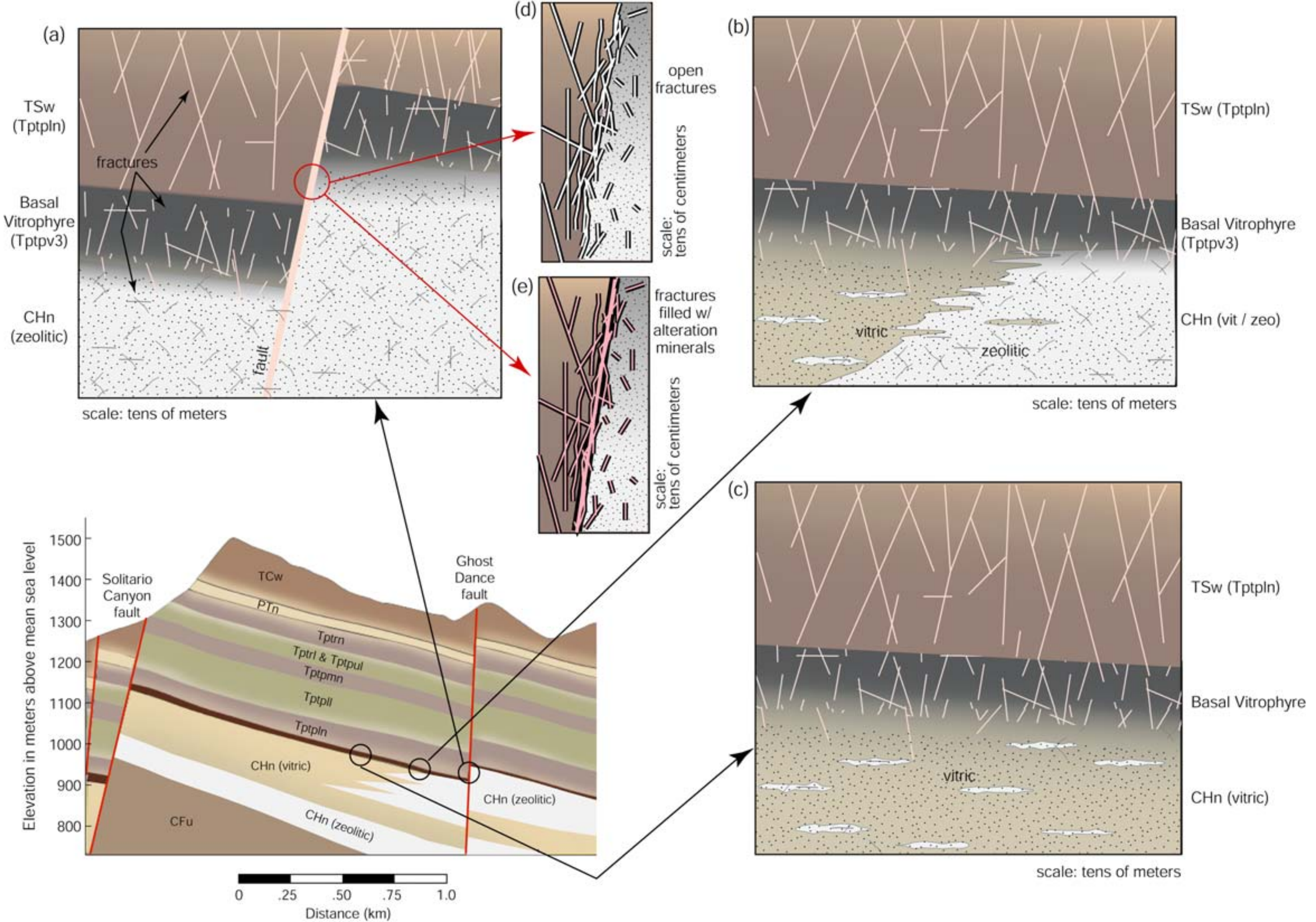
- Available data, including geophysical, geochemical and hydrological data, provide significant constraints on the UZ flow model
- The UZ flow model is well calibrated using pneumatic, saturation/moisture tension, perched water, total chloride, strontium, calcite and temperature data
- The UZ flow model is validated using data from the Cross Drift (ECRB), in particular geology, fault and total chloride data
- The global water flow is well represented in the UZ flow model, and there is much confidence in those models results
- The local (detailed) water flow patterns (spacing and magnitude distribution) are poorly understood (represented by the active fracture model and flow focusing)
- Other major uncertainties relate to the van Genuchten formulation and  fault properties and their effect on flow, especially below the repository horizon

# Conclusions – UZ Transport

- **On-going and completed tests provide input data that constrain the UZ transport model and allow the Project to take substantial credit for this important barrier**
- **Tracer tests using Alcove 1 and Alcove 8/Niche 3 provide clear evidence of matrix diffusion and provide essential data for the calibration of the UZ transport model**
- **Tracer tests conducted in the Busted Butte facility have clearly confirmed the porous medium nature of the vitric Calico Hills and verified sorption values for some important radionuclides**
- **Colloidal transport is significantly affected by the colloid size, but not much by kinetic declogging (reverse filtering)**
- **Daughter products of some important radionuclides, such as $^{239}$Pu and $^{241}$AM must be considered in the UZ transport model**
- **Greatest uncertainties in the UZ transport model relate to the detailed characteristics of flow, the active fracture model and the efficiency of matrix diffusion. It is expected that significant additional benefits of this barrier can be achieved by full implementation of the shadow zone in the process models and TSPA.**

# Back-up Slides

# Vitric/Zeolitic: Geology Important for Transport to the Water Table



# Lessons Learned from Site Characterization Studies

# Testing Update: *Geochemical Studies of Fracture Minerals (USGS)*

## (preliminary)

- **Conducting microbeam analyses of calcite at UCLA to determine carbon and oxygen isotope variability and implications for subsurface influence of Pleistocene/Holocene climate changes**
- **Continued microdigestion and TIMS analyses of youngest opal to evaluate depositional rates in the latest Pleistocene and Holocene**
  - **U-series ages range from 3,000 to 140,000 years in recently analyzed sample**

# Use of Construction Water Migration to Validate Fast Flow through Fractures

## Observation

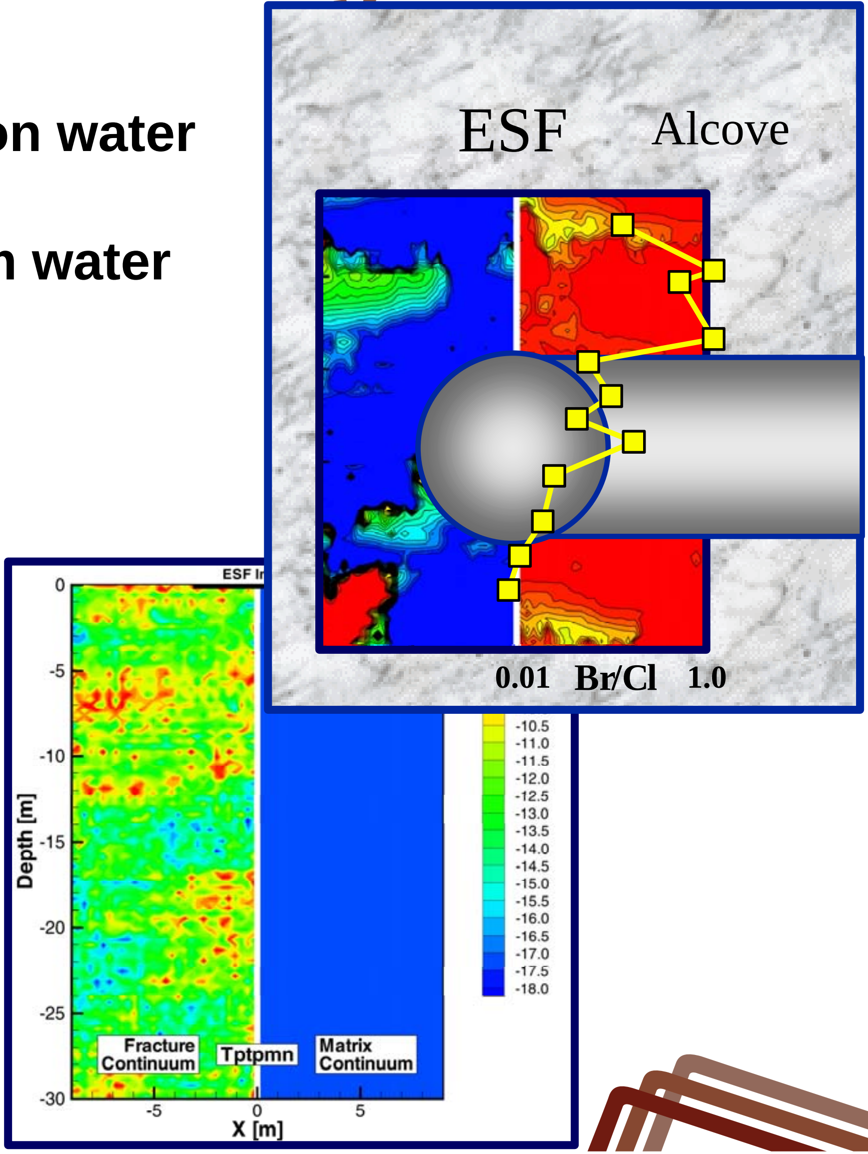
- Ponded release of construction water (tagged with LiBr)
- Br/Cl ratios with distance from water source

## Modeling Approach

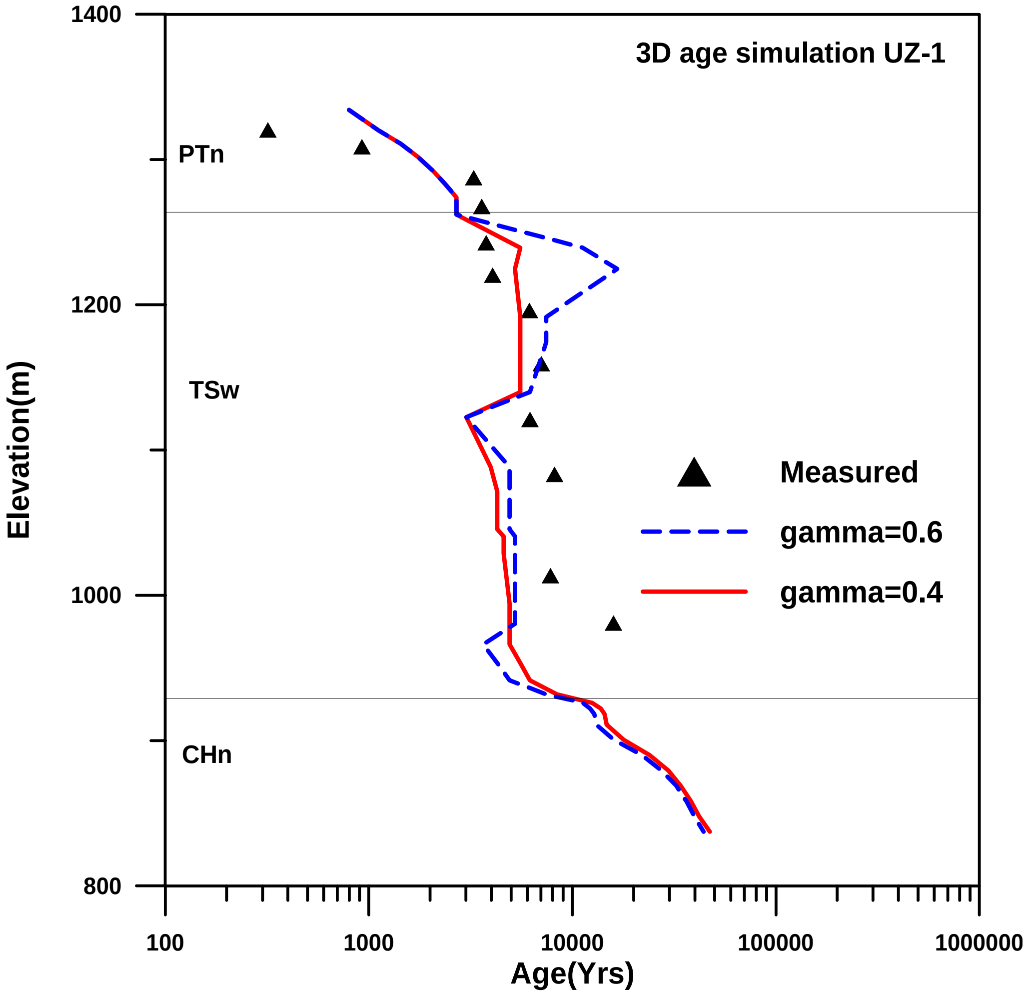
- Heterogeneous fracture-matrix system (MINC)
- Interpretation of geochemical data
- Variability and uncertainty

## Results

- Fast flow through fractures
- Saturation changes consistent with Br/Cl ratios



# Use of Carbon-14 Age to Evaluate Active Fracture Model – Model Confidence Building



# Transport Simulations for Suite of Radionuclides: *Different Lab-Determined $k_d$’s*

*(preliminary)*

| Species | Unit/Analysis | Distribution | Coefficients describing distribution[a] (ml/g) |
|---|---|---|---|
| U | Zeolitic | Cumulative | (Kd value, probability) (0, 0) (**0.5**, 0.5) (30, 1.0) |
| | Devitrified | Cumulative | (Kd value, probability) (0, 0) (**0.2**, 0.5) (4, 1.0) |
| | Vitric | Cumulative | (Kd value, probability) (0, 0) (**0.2**, 0.5) (3, 1.0) |
| Np | Zeolitic | Cumulative | (Kd value, probability) (0, 0) (**0.5**, 0.5) (6, 1.0) |
| | Devitrified | Cumulative | (Kd value, probability) (0, 0) (**0.5**, 0.5) (6, 1.0) |
| | Vitric | Cumulative | (Kd value, probability) (0, 0) (**1.0**, 0.5) (3, 1.0) |
| Pu | Zeolitic | Cumulative | (Kd value, probability) (10, 0) (**100**, 0.5) (200, 1.0) |
| | Devitrified | Cumulative | (Kd value, probability) (10, 0) (**70**, 0.5) (200, 1.0) |
| | Vitric | Cumulative | (Kd value, probability) (10, 0) (**100**, 0.5) (200, 1.0) |
| Am | Zeolitic | Uniform | Range = 100- 1000 (**500**) |
| | Devitrified | Uniform | Range = 100- 2000 (**1,000**) |
| | Vitric | Cumulative | (Kd value, probability) (100, 0) (**400**, 0.5) (1,000, 1.0) |
| Pa | Zeolitic | Uniform | Range = 1000 – 20,000 (**10,000**) |
| | Devitrified | Uniform | Range = 1000 – 20,000 (**10,000**) |
| | Vitric | Uniform | Range = 1000 – 20,000 (**10,000**) |
| Cs | Zeolitic | Cumulative | (Kd value, probability) (425, 0) (**5,000**, 0.5) (20,000, 1.0) |
| | Devitrified | Uniform | Range = 1 – 15 (**7.5**) |
| | Vitric | Cumulative | (Kd value, probability) (0, 0) (**2**, 0.5) (100, 1.0) |
| Sr | Zeolitic | Uniform | Range = 50 – 2000 (**1000**) |
| | Devitrified | Uniform | Range = 10 – 70 (**40**) |
| | Vitric | Uniform | Range = 0 – 50 (**25**) |
| Ra | Zeolitic | Uniform | Range = 1000 – 5,000 (**2,500**) |
| | Devitrified | Uniform | Range = 100 – 1,000 (**500**) |
| | Vitric | Uniform | Range = 50 – 600 (**300**) |
| Th | Zeolitic | Uniform | Range = 1,000 - 30,000 (**15,000**) |
| | Devitrified | Uniform | Range = 1,000 - 10,000 (**5,000**) |
| | Vitric | Uniform | Range = 1,000 - 10,000 (**5,000**) |

Output-DTN: LA0302AM831341.002 TDIF: 314028 (UZ)

NOTE:[a] The numbers in boldface were used in the simulations.

# UZ Transport Model Summary (1)

- **Transport is dominated and controlled by faults (e.g. Drillhole Wash fault and Pagany Wash fault)**
  - **Provide fast paths to downward migration**
  - **Limit lateral migration across the fault walls into the formation**
- **Faster transport over a larger area in the northern part of the repository**
  - **Consistent with the geological model for UZ, which is characterized by the highly fractured zeolitic CHZ layers in that area**

# UZ Transport Model Summary (2)

- Transport patterns follow the infiltration and percolation distributions
  - Water flow pattern dictates the advective transport pattern
- Fractures are the main pathways of radionuclide transport
- Diffusion from the fractures into the matrix is one of the main retardation processes in radionuclide transport

# UZ Transport Model Summary (3)

- Transport to the water table is strongly dependent on the sorption affinity of the radionuclide to the geohydrologic units it encounters in the UZ
  - Lower $k_d$ (quantifying weaker sorption) leads to faster radionuclide transport
- In considering transport of $^{239}$Pu and $^{241}$Am, contribution to the breakthrough of daughter products is important

# UZ Transport Model Summary (4)

- For continuous colloid release under a mean present-day infiltration regime, the transport of radioactive true colloids is not appreciably influenced by the kinetic declogging(reverse filtering).
- The colloid size has a significant effect on transport.
- The UZ of Yucca Mountain is an effective barrier to the transport of the strongly sorbing radionuclides