



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

# Update of Unsaturated Zone Transport Test at Busted Butte

Presented to:

**Nuclear Waste Technical Review Board (NWTRB)**

Presented by:

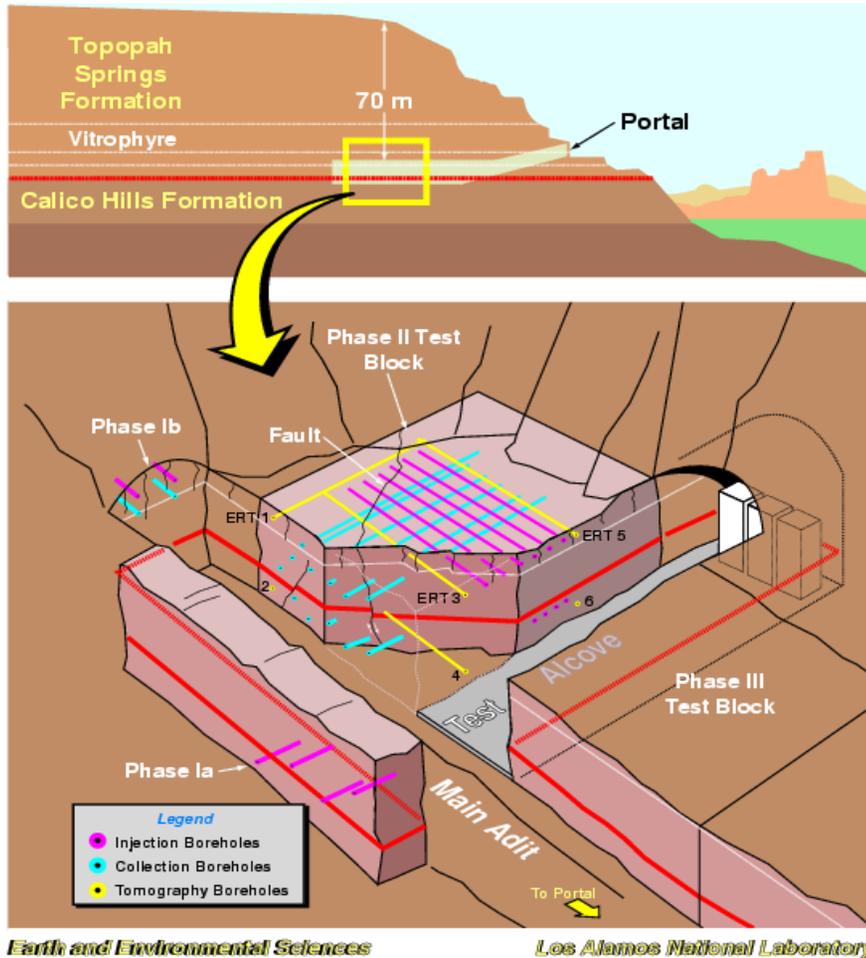
**Paul R. Dixon**

**Los Alamos National Laboratory**

**Las Vegas, Nevada  
January 25-26, 2000**

YUCCA  
MOUNTAIN  
PROJECT

# UZTT Test Goals



- 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 flow and transport model
- Address scaling issues

# Progress Towards Test Goals

- **Phase 1 testing provided insight to flow and transport heterogeneities, indicating strong capillarity, matrix-dominated flow regimes and changes in flow properties at unit and sub-unit contacts**
- **Phase 2 is expected to provide additional insights to flow and transport heterogeneities as migration results near fault are analyzed**
- **Phase 2 will provide larger-scale, three dimensional comparisons to Phase 1 results**

# Progress Towards Test Goals

- **Analytical technique to detect microspheres (colloids surrogate) nearing completion. Phase 1 and 2 analysis scheduled to begin 2/2000**
- **Insights to sorption parameters and site scale model validation obtained through analyses of reactive (Li) and non-reactive tracers. Reactive metals (radionuclide analogs) have not yet been detected**
- **Scaling issues continue to be addressed in both Phase 1 and 2 analyses**

# Deliverables

- **Busted Butte data, modeling predictions, and modeling results presented in:**
  - **Revision 00 of UZ/SZ Transport Properties AMR currently in checking**
  - **Revision 01 of UZ/SZ Transport Properties AMR scheduled for completion FY 2000**
  - **Revision 01 of UZ Colloids AMR scheduled for completion FY 2000**

# Applicability

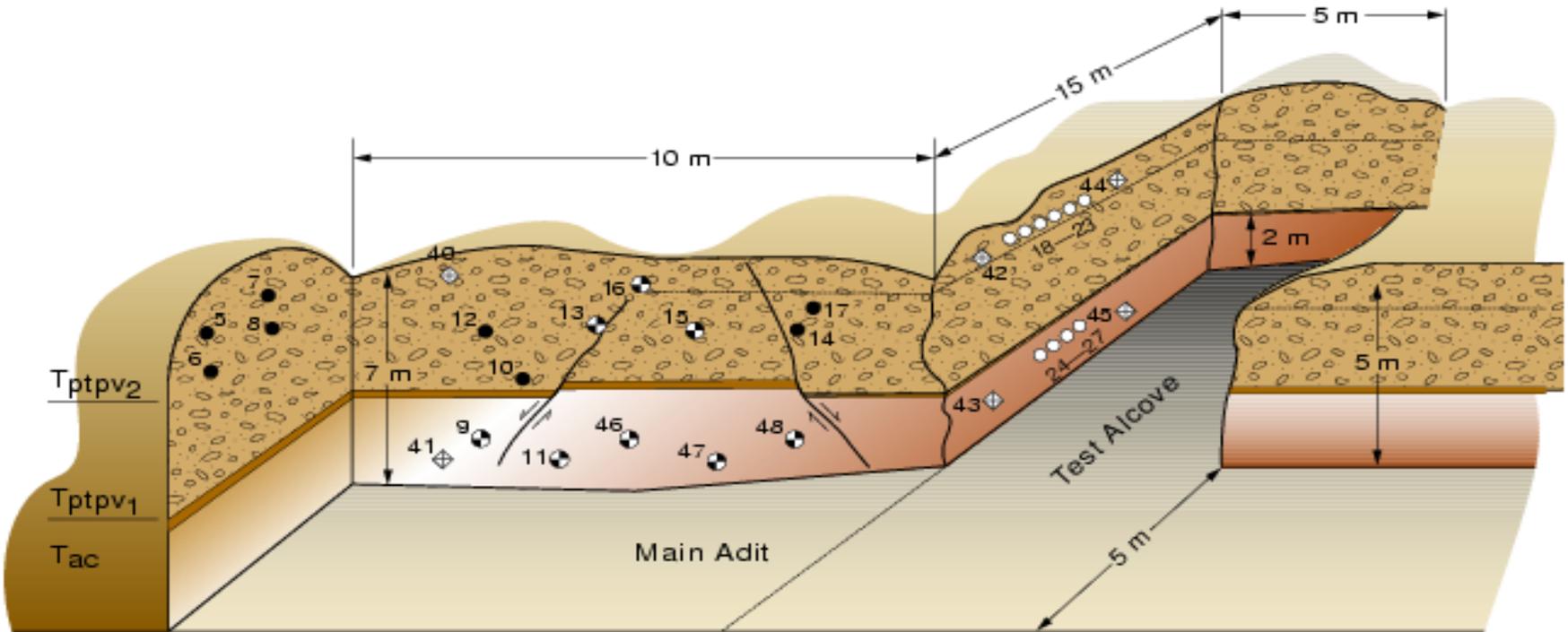
- **Calico Hills unit under the repository is variable, ranging from vitric/non-zeolitized rocks in the southern portion to completely zeolitized rocks in the northern portion**
  - **Busted Butte is vitric with a relatively low abundance of clay and/or zeolite alteration**
  - **Busted Butte section most resembles the lower Topopah Spring/upper Calico Hills section observed in H-5 and SD-6**
  - **Relative proportions of glass and zeolites are similar to H-5**

# Applicability

- **Retardation in the Calico Hills unit under the repository can occur due to sorption, fracture-matrix interactions, and to matrix diffusion processes**
- **Busted Butte studies are quantifying retardation mechanisms in the vitric portion of the Calico Hills**
- **Flow and transport models developed for SR and LA will be consistent with Busted Butte results**

# Busted Butte Test Layout

Legend	
Collection Boreholes	10 ●
Boreholes Used for GPR	9 ⊕
Injection Boreholes	18 ○
ERT Boreholes	40 ◇



# Time Step Animation of GPR Results

- Ground Penetrating Radar (GPR)

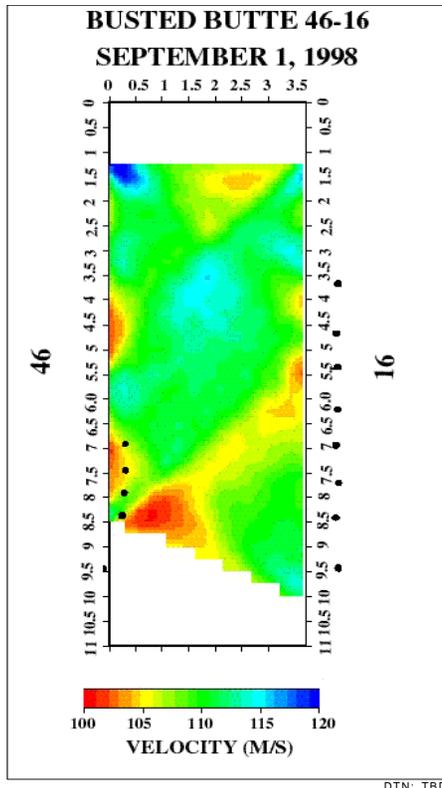
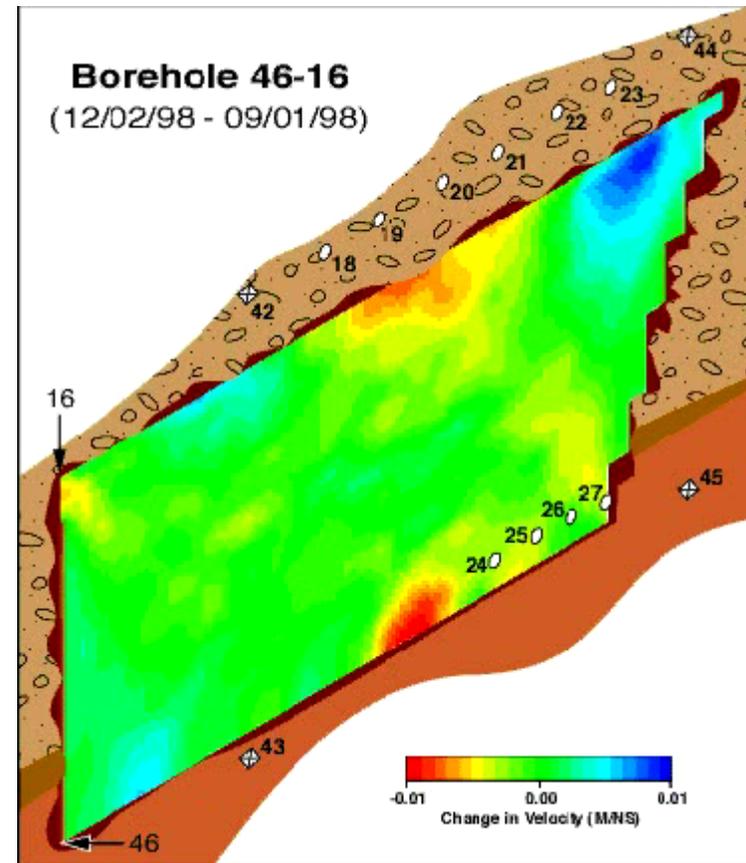
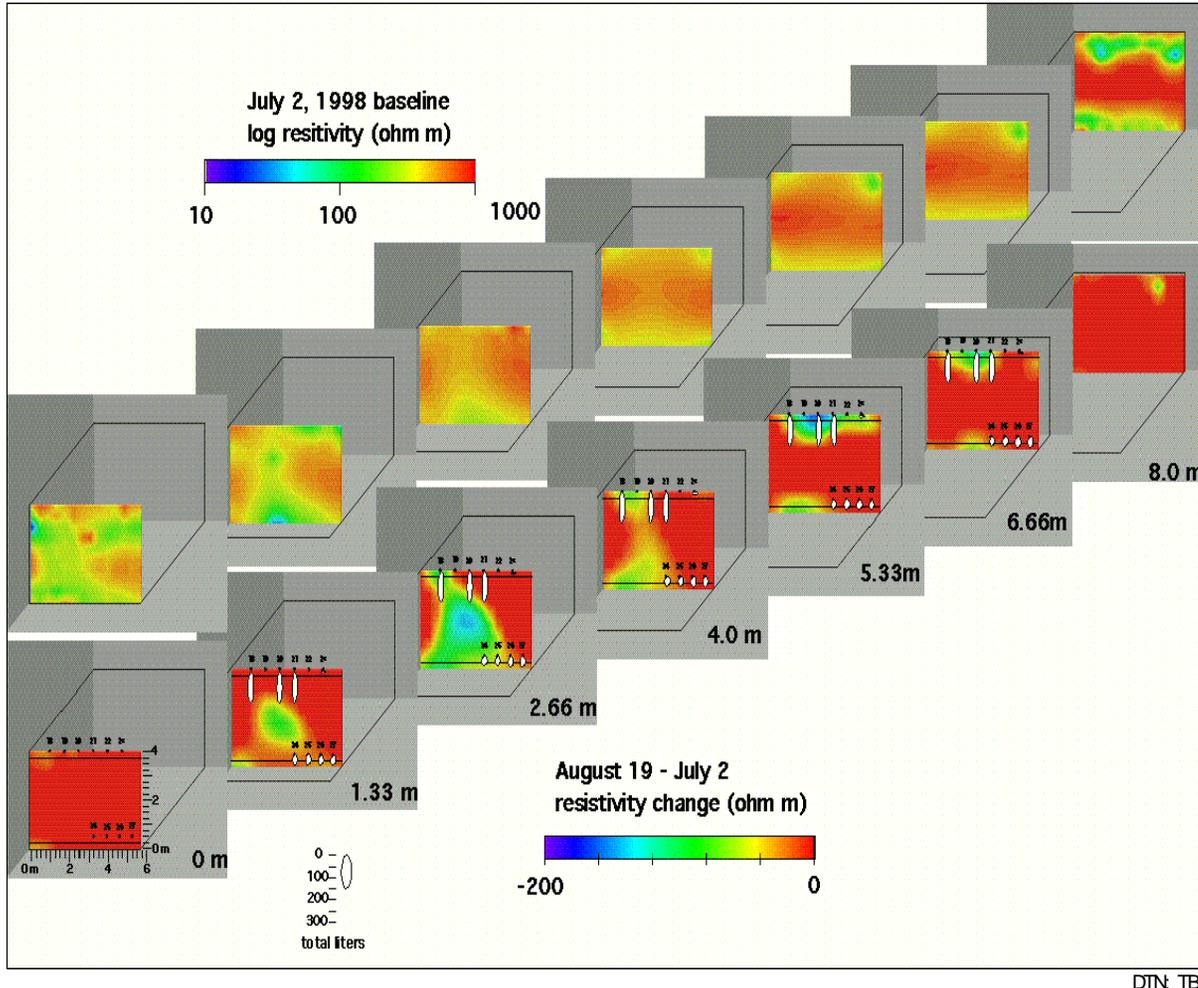


Figure 83. GPR Pair 46-16

NOTE: The plot is a vertical section with the top representing the right rib of the Main Adit. The four dots to the left represent the intersection of the Phase 2B injection holes. The eight dots to the right of the image represent the intersection with injection holes from Phases 2A and 2C and ERT holes 3 and 5.



# ERT Images



- 3-D snap shot of tracer migration
- Covers entire test block
- Half meter resolution

Electrical-Resistance Tomography Images of Test Block Viewed from Test Alcove: Baseline and August Differences

NOTE: The diagram shows vertical slices through block at 0, 1.33, 2.66, 4.0, 5.33, 6.66, and 8.0 m. The top series is an absolute image (baseline, July 2), and the bottom series is the August 19–July 2 difference images.

# Busted Butte Tracers for Phase I and Phase 2

## Phase I:

- Lithium Bromide
- Potassium Iodide
- Fluorescent polystyrene latex microspheres (two sizes)  
Plutonium Analogs, (colloidal form)
- Sodium Fluorescein
- Pyridone
- 2,4-difluorobenzoic acid
- 2,6-difluorobenzoic acid
- 2,4,5-trifluorobenzoic acid
- 2,3,4,5-tetrafluorobenzoic acid
- Pentafluorobenzoic acid

## Phase 2 (Same as Phase I plus):

- Neptunium Analogs (Np5+):
  - Nickel (II) chloride hexahydrate
  - Cobalt chloride hexahydrate
  - Manganese chloride tetrahydrate
- Plutonium Analog, (Pu3+):
  - Samarium Chloride hexahydrate
- Americium Analogs (Am3+):
  - Cerium (III) chloride heptahydrate
- Rhodamine WT
- Potassium Iodide replaced microspheres on 8/18/99

# Sorption

- **Measured sorption values for Busted Butte (vitric) rocks are greater than are currently used in models**
- **Preliminary sorption results indicate smectite is potentially important to performance**
  - **Pu has a strong relationship**
  - **Am shows only a weak variation**

# Preliminary Comparisons of Busted Butte and J-13 Waters

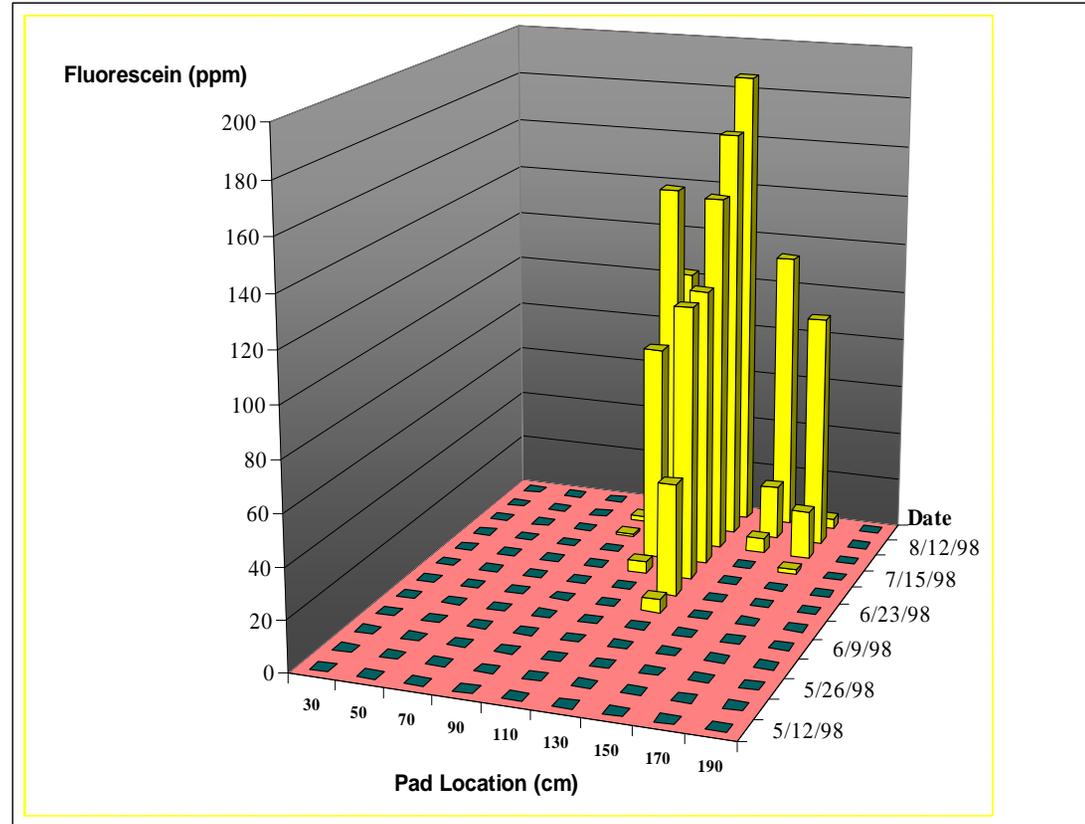
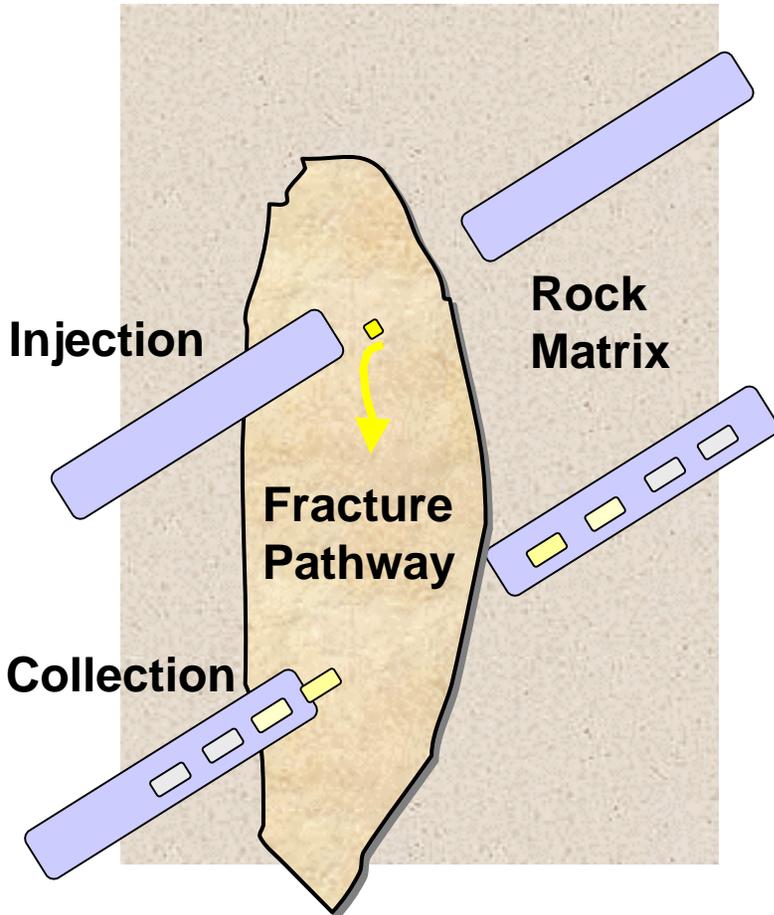
Chemical Composition of Busted Butte Pore Water,  
with J-13 Groundwater for Comparison

Constituent	Concentrations (mg L <sup>-1</sup> )					
	Sample 3B	Sample 3N	Sample 3Q	Sample 3U	Average 3N – 3U	J-13 water
Br	0.06	0.07	0.06	0.06	0.06	—
Ca	17.73	24.35	21.16	19.81	21.77	12.5
Ce	< 0.5	< 0.5	< 0.5	< 0.5	< 0.6	—
Cl	16.13	19.06	17.71	16.74	17.84	6.5
Co	< 1.0	< 1.0	< 1.0	< 1.0	< 1.1	—
F	2.36	1.82	1.85	1.41	1.69	0.53
Fe	< 0.1	< 0.1	< 0.1	< 0.1	< 0.2	< 0.05
HCO <sub>3</sub> (est.)	33.0	52.7	45.6	40.6	46.3	137.2
K	4.14	3.35	3.37	3.44	3.39	4.5
Li	0.11	0.11	0.10	< 0.1	0.10	< 0.1
Mg	3.20	4.13	3.64	3.19	3.66	2.1
Mn	< 0.5	< 0.5	< 0.5	< 0.5	< 0.6	< 0.01
Mo	< 1.0	< 1.0	< 1.0	< 1.0	< 1.1	—
Na	17.67	21.36	19.63	17.89	19.63	44.6
Ni	< 1.0	< 1.0	< 1.0	1.34	1.34	—
NO <sub>3</sub>	22.76	26.48	22.62	20.99	23.36	1.3
PO <sub>4</sub>	< 0.1	< 0.1	< 0.1	< 0.1	< 0.2	—
Re	< 1.0	< 1.0	< 1.0	< 1.0	< 1.1	—
Si	29.69	31.85	34.10	31.00	32.32	29.6
Sm	< 0.5	< 0.5	< 0.5	< 0.5	< 0.6	—
SO <sub>4</sub>	31.29	33.63	31.36	30.08	31.69	18.6
Sr	0.37	0.49	0.42	0.38	0.43	—
TDS	178.5	219.4	201.6	186.9	203.6	257.4
pH	8.20	8.48	8.45	8.28	8.40	7.3–8.4
Gravimetric moisture content:	0.123	0.134	0.158	0.109	0.133	n/a

DTN: LA9909WS831372.015, LA9909WS831372.016, LA9909WS831372.017, LA9909WS831372.018

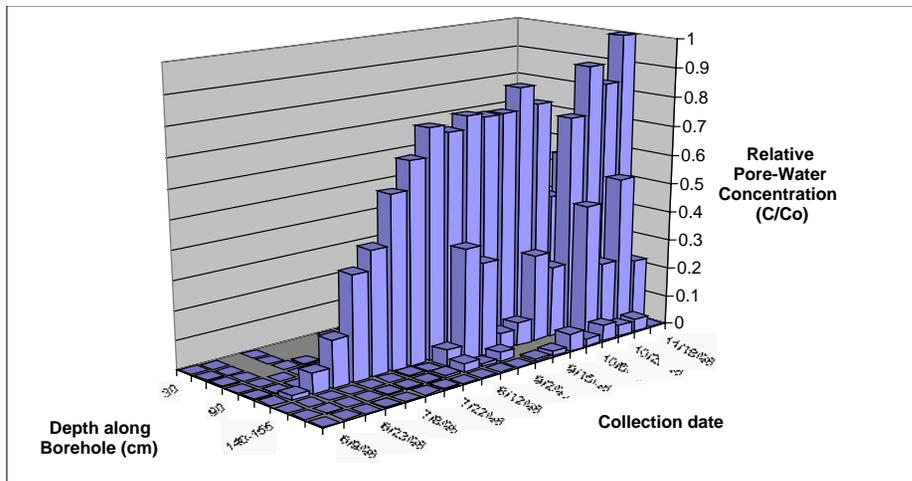
- **Butted Butte pore waters differ from J-13 waters**
- **Work may be extended to include pore water measurements in other units**
- **Significance to lab studies will be determined**

# Phase IB Results



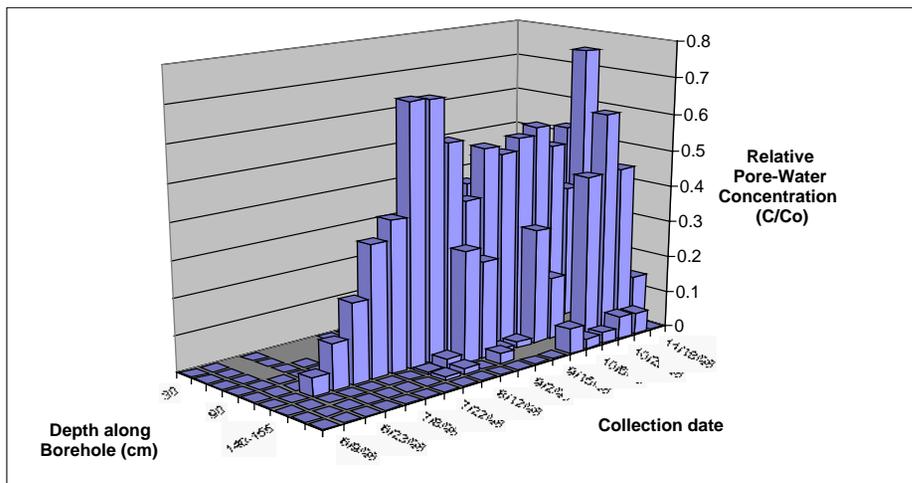
**Water is readily imbibed into the rock matrix even when injected directly into the fracture.**

# Phase 1B Results



DTNS: LA9909WS831372.001; LA9909WS831372.002

Bromide Concentrations in Borehole 6

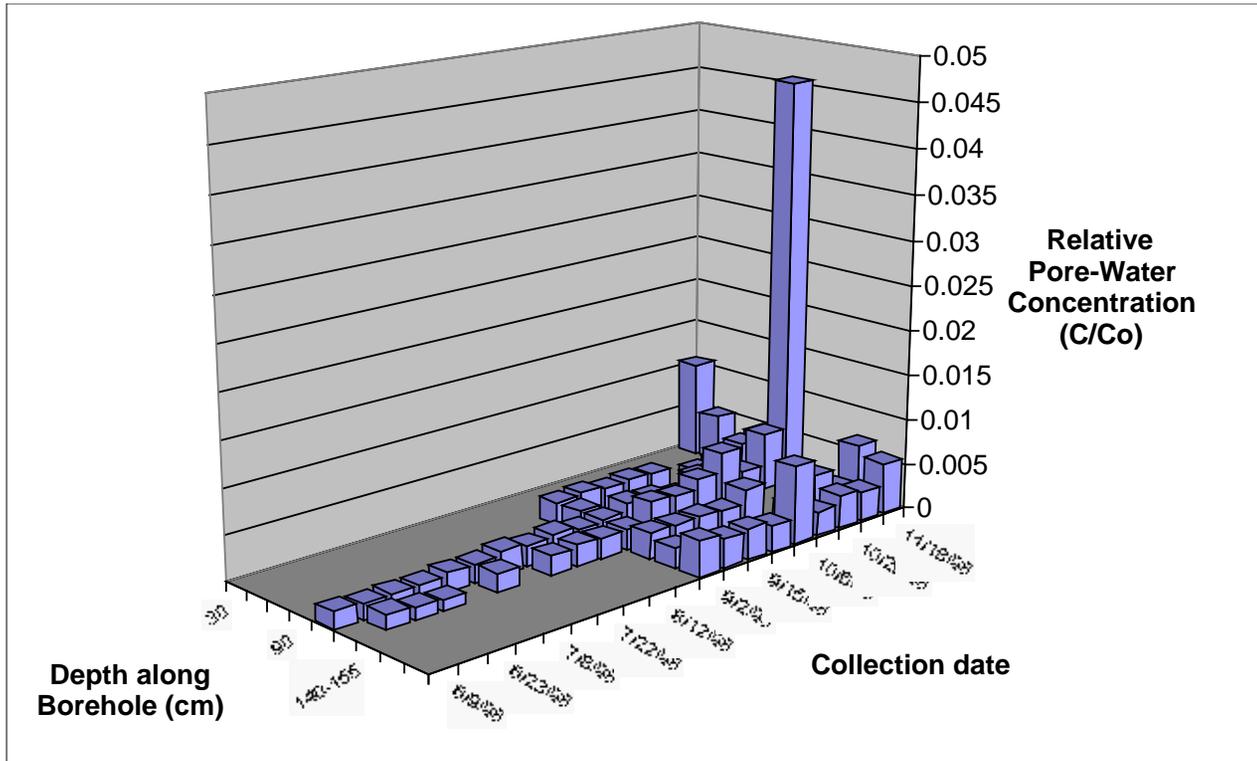


DTNS: LA9909WS831372.001; LA9909WS831372.002

2,6-DFBA Concentrations in Borehole 6

- Tracers show strong, expected breakthrough patterns during Phase 1B injection
- Breakthrough is slightly ahead of predicted matrix flow only
- Tracer shows matrix-driven lateral spreading
- Lithium (next slide) is retarded as expected

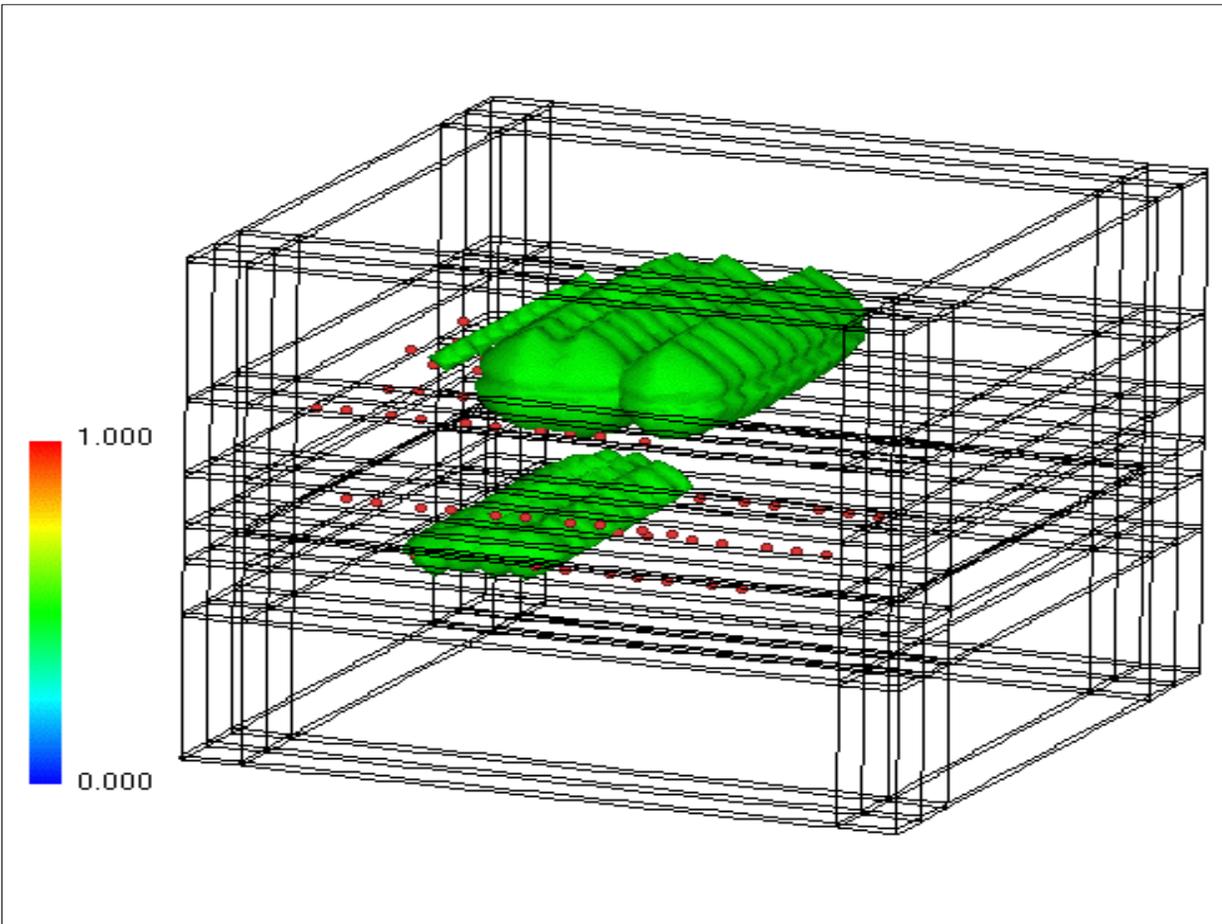
# Phase 1B Results



DTNS: LA9909WS831372.001; LA9909WS831372.002

Lithium Concentrations in Borehole 6

# Model Simulations of Phase 2 Conservative Tracers



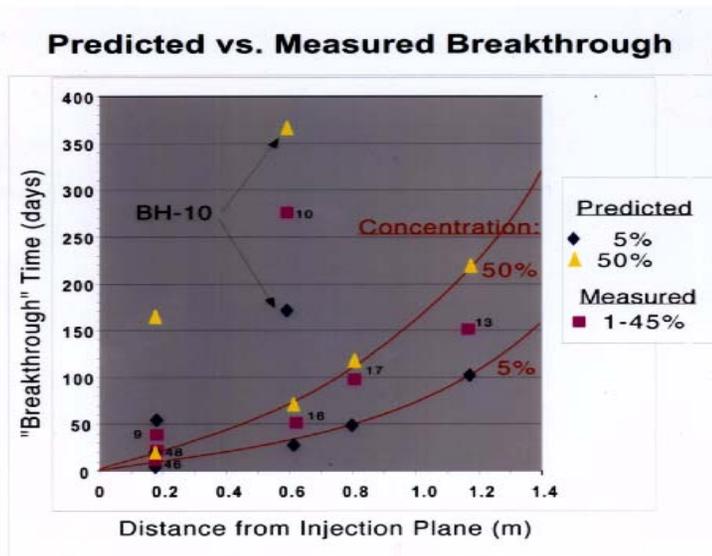
DTN: LA9909WS831372.022

Conservative Tracer Concentration Plume

- **Concentration of conservative tracer Time = 1yr @ Concentration = 0.5**
- **These predictions are compared with pad results to build confidence in models**

NOTES: <sup>a</sup>The figure depicts the concentration plume after 1 yr of conservative-tracer injection. The green isosurface represents a normalized concentration of 0.5; the red dots represent the sampling points along the collection boreholes.

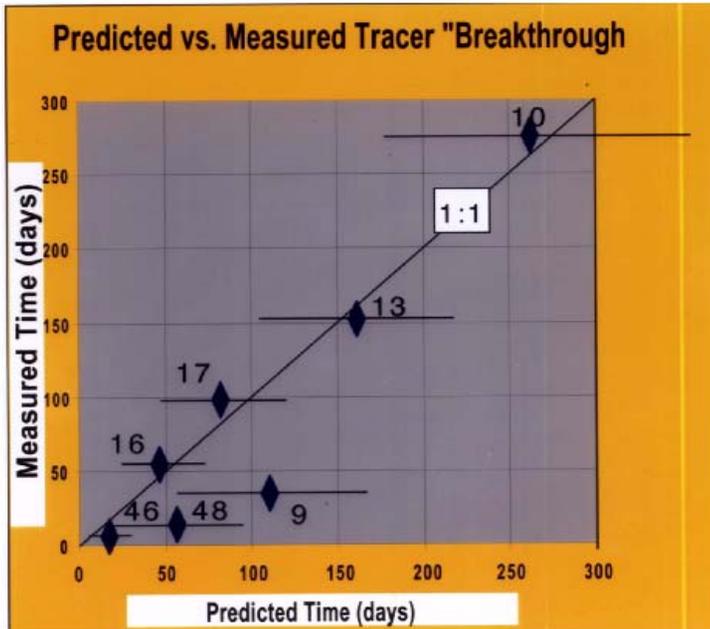
# Measured Vs. Predicted Breakthroughs



Phase 2 Model Predictions

- **Spatial comparison of model prediction of conservative tracer against observed fluorescein breakthrough**
- **Predictions match well with observations**

# Measured Vs. Predicted Breakthroughs



Phase 2 Model Predictions

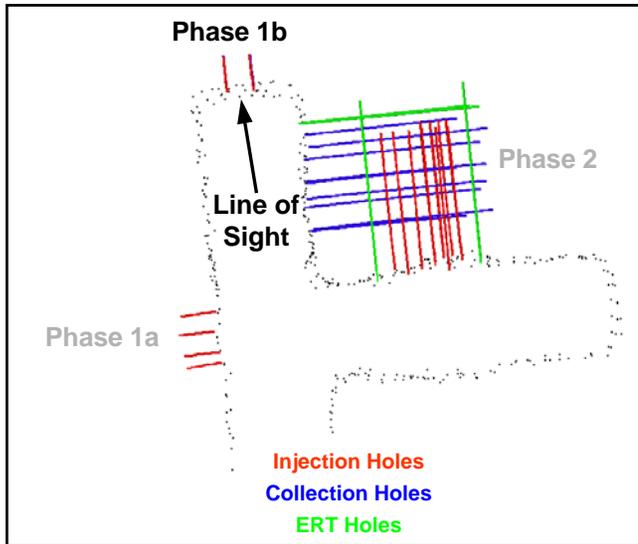
- Temporal comparison of model prediction against observed fluorescein breakthrough
- Predictions match observations for high injection rate boreholes
- Boreholes 46 and 48 precede prediction due to inter-borehole damage

Note: 1:1 curve drawn for illustrative purposes only and is not intended as best fit to data.

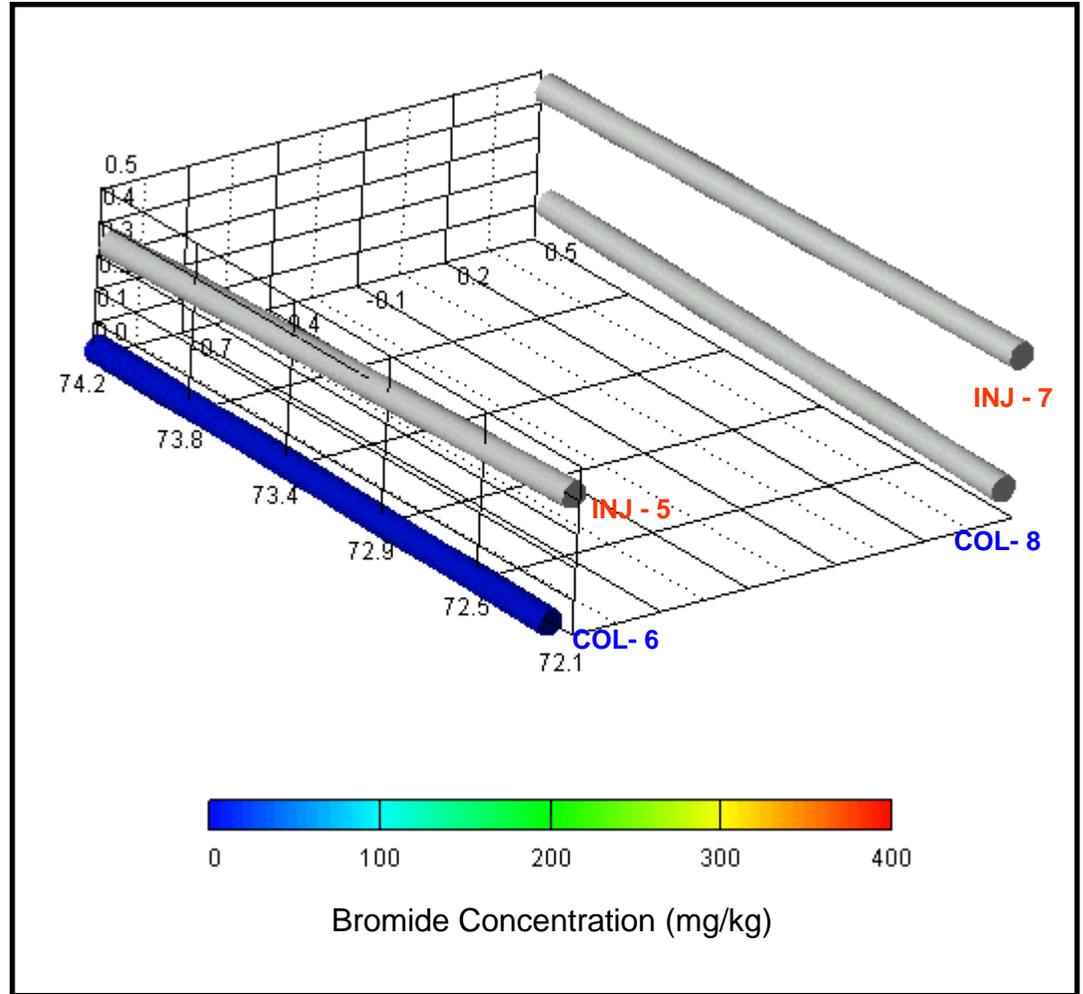
# **Time Step Animation of Total Moisture, Bromide, and Tracer Breakthrough**

# Busted Butte Unsaturated Zone Transport Test

## Phase 1b Bromide Data

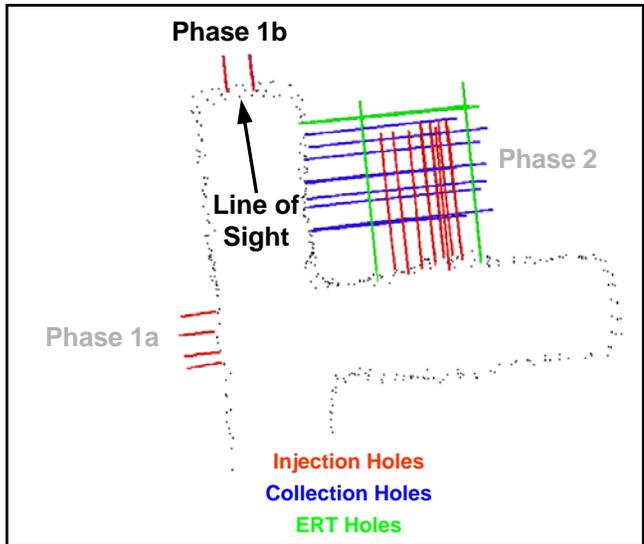


**June 9, 1998**

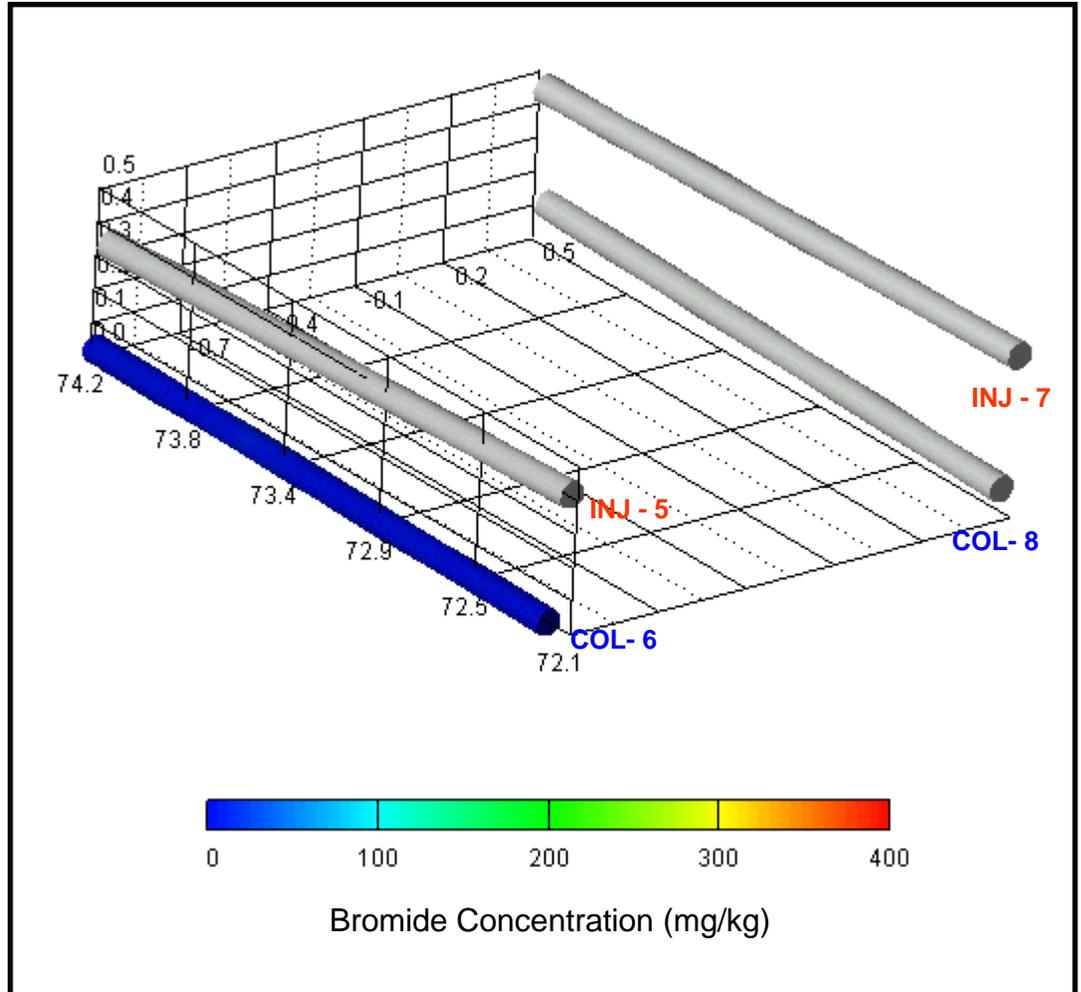


# Busted Butte Unsaturated Zone Transport Test

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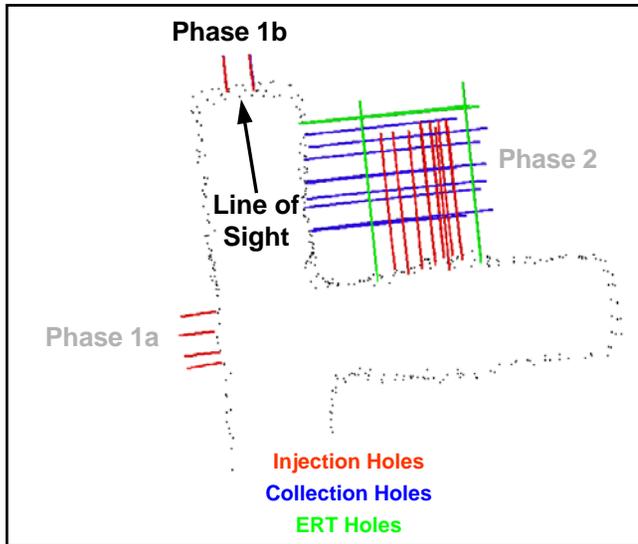


June 16, 1998

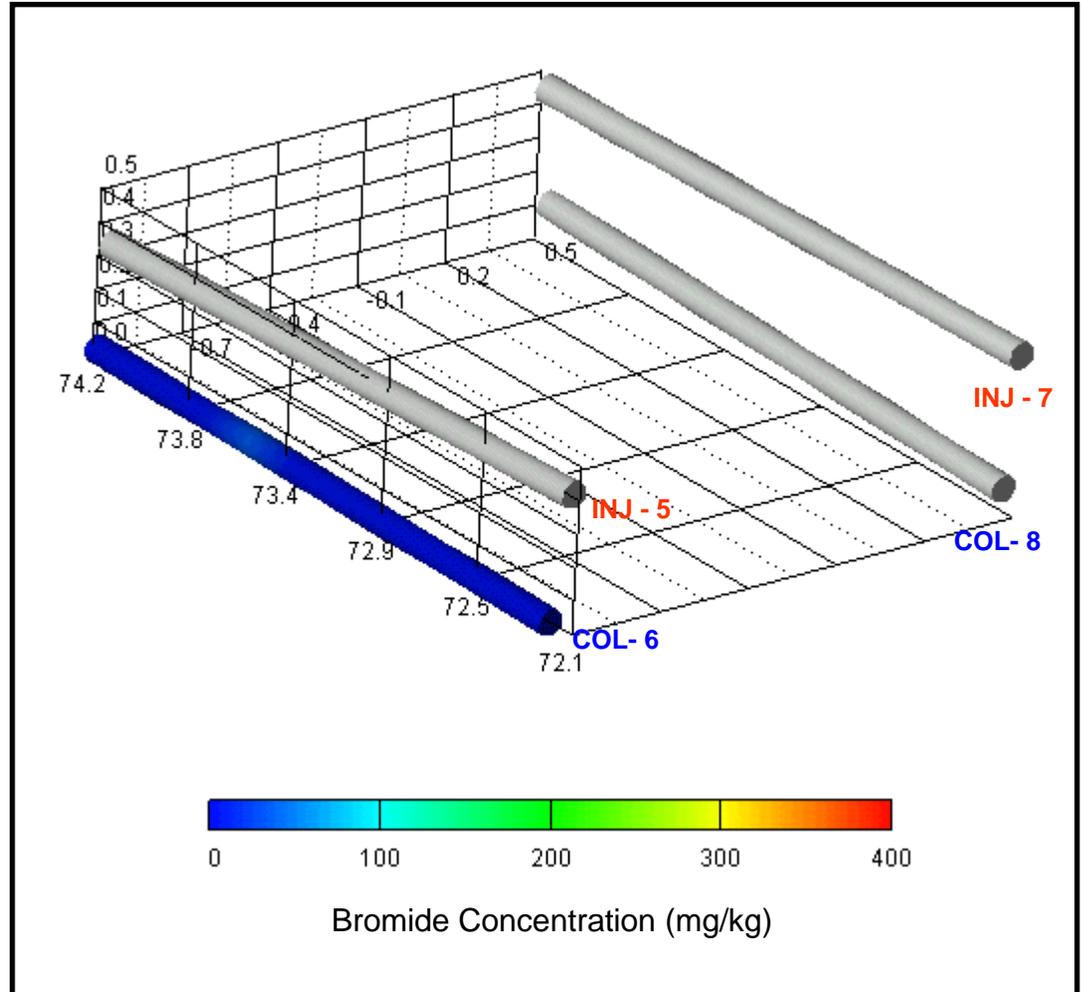


# Busted Butte Unsaturated Zone Transport Test

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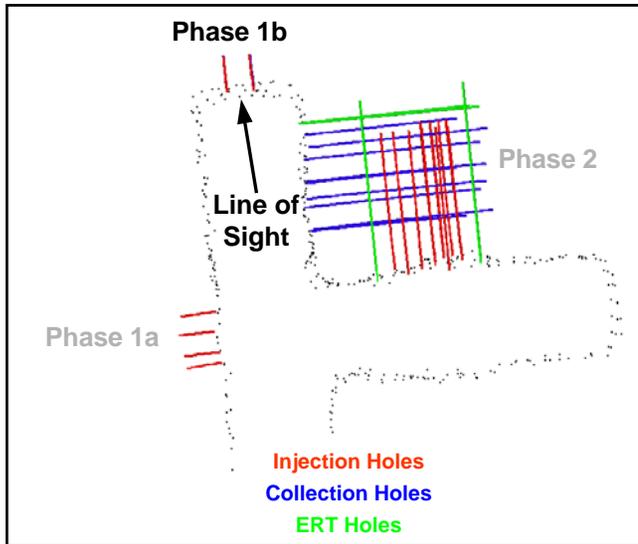


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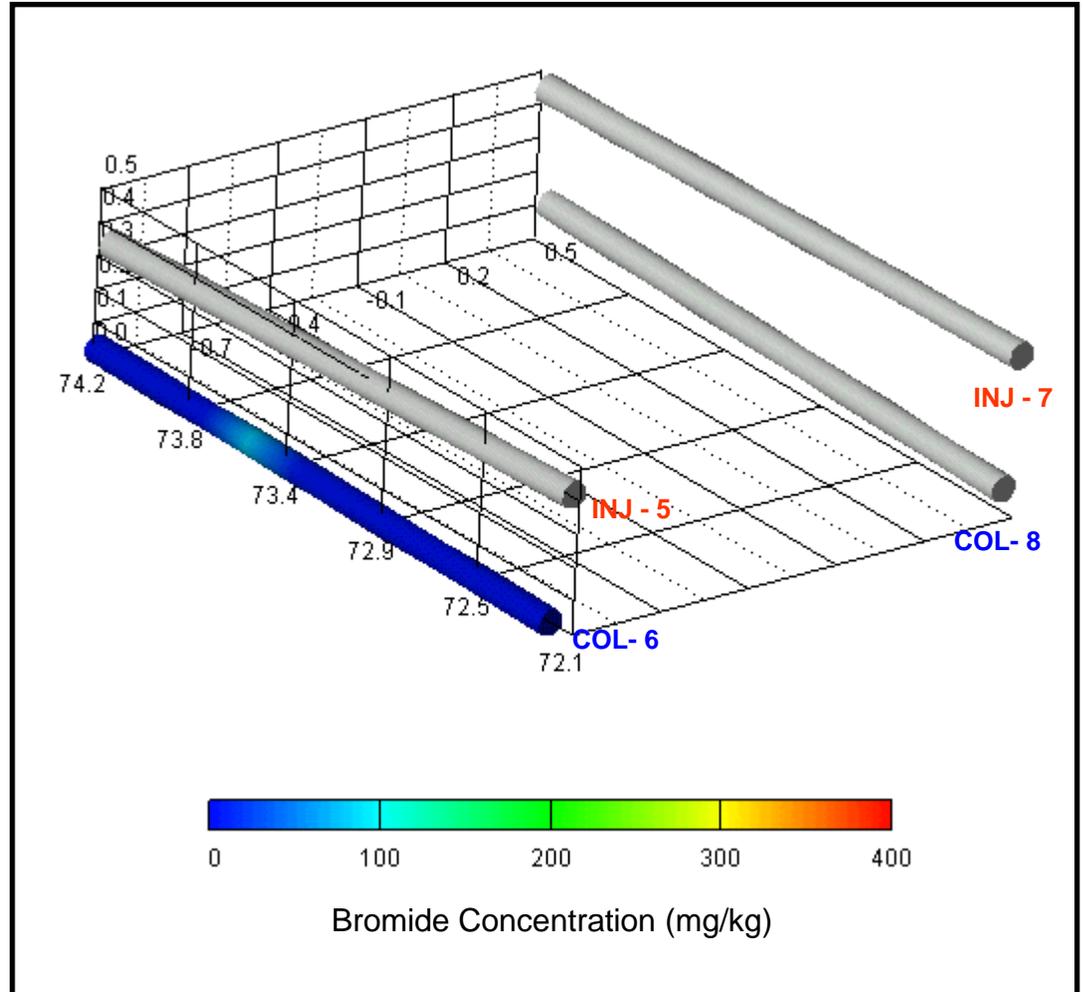


# Busted Butte Unsaturated Zone Transport Test

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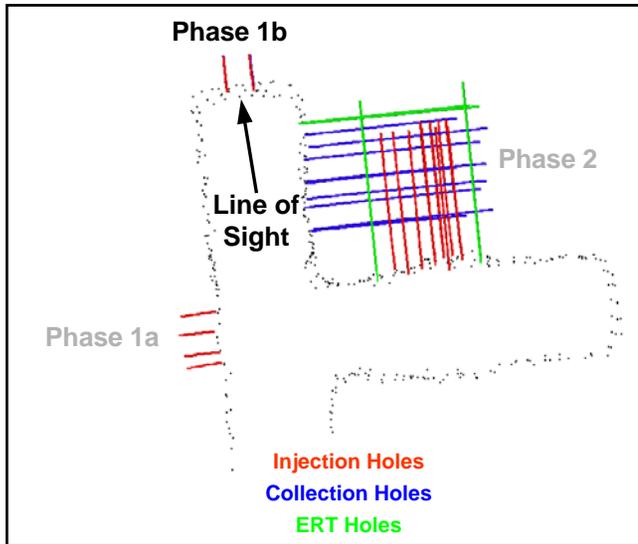


July 1, 1998

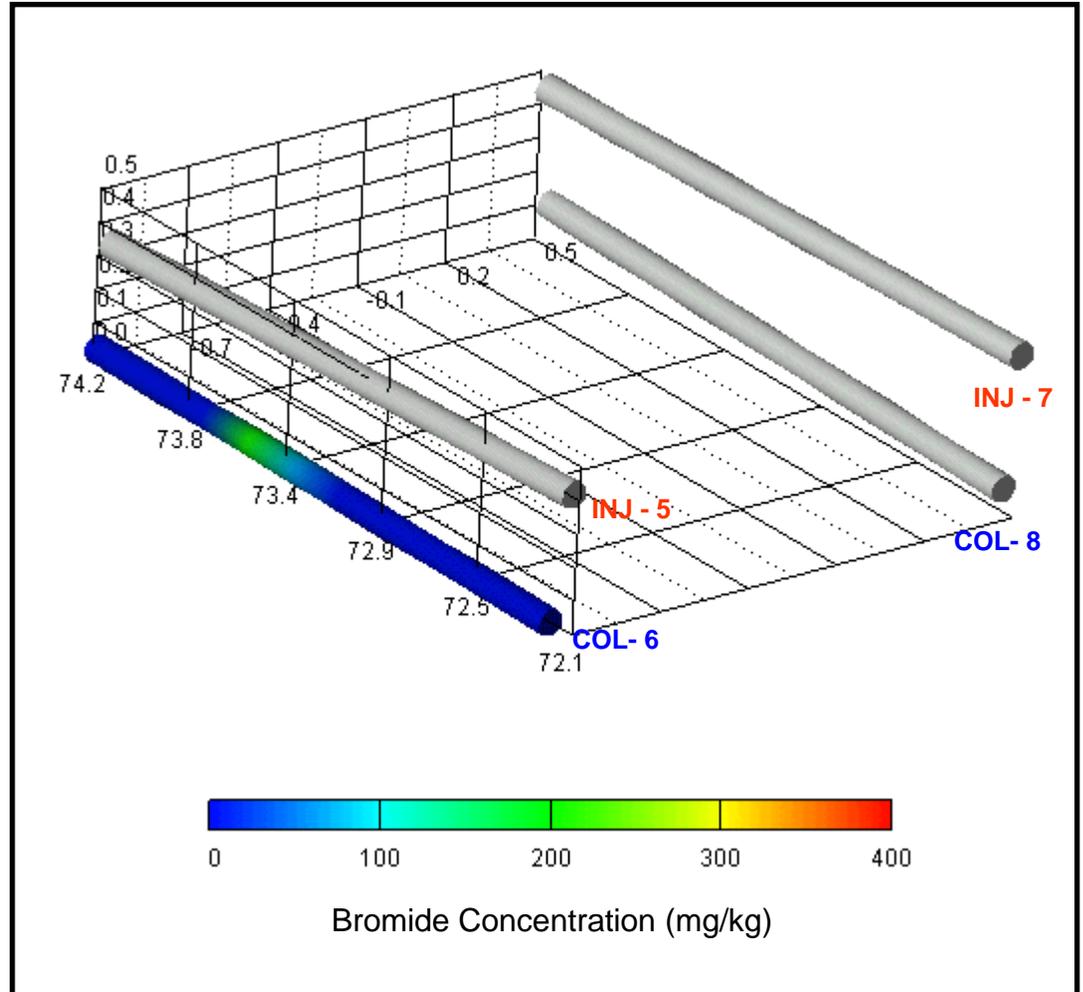


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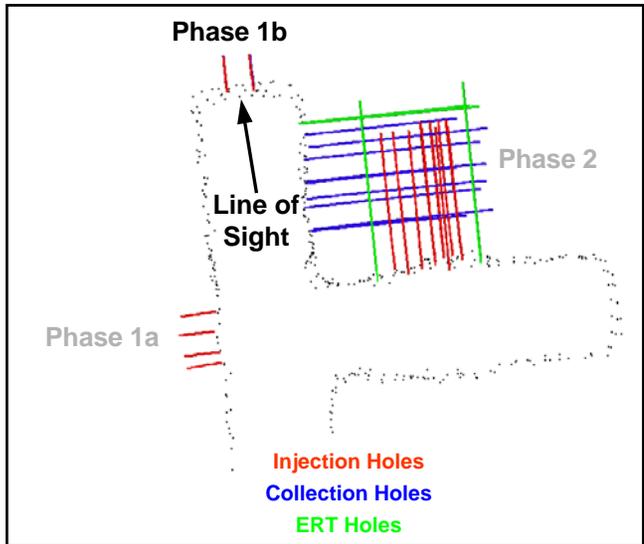


July 15, 1998

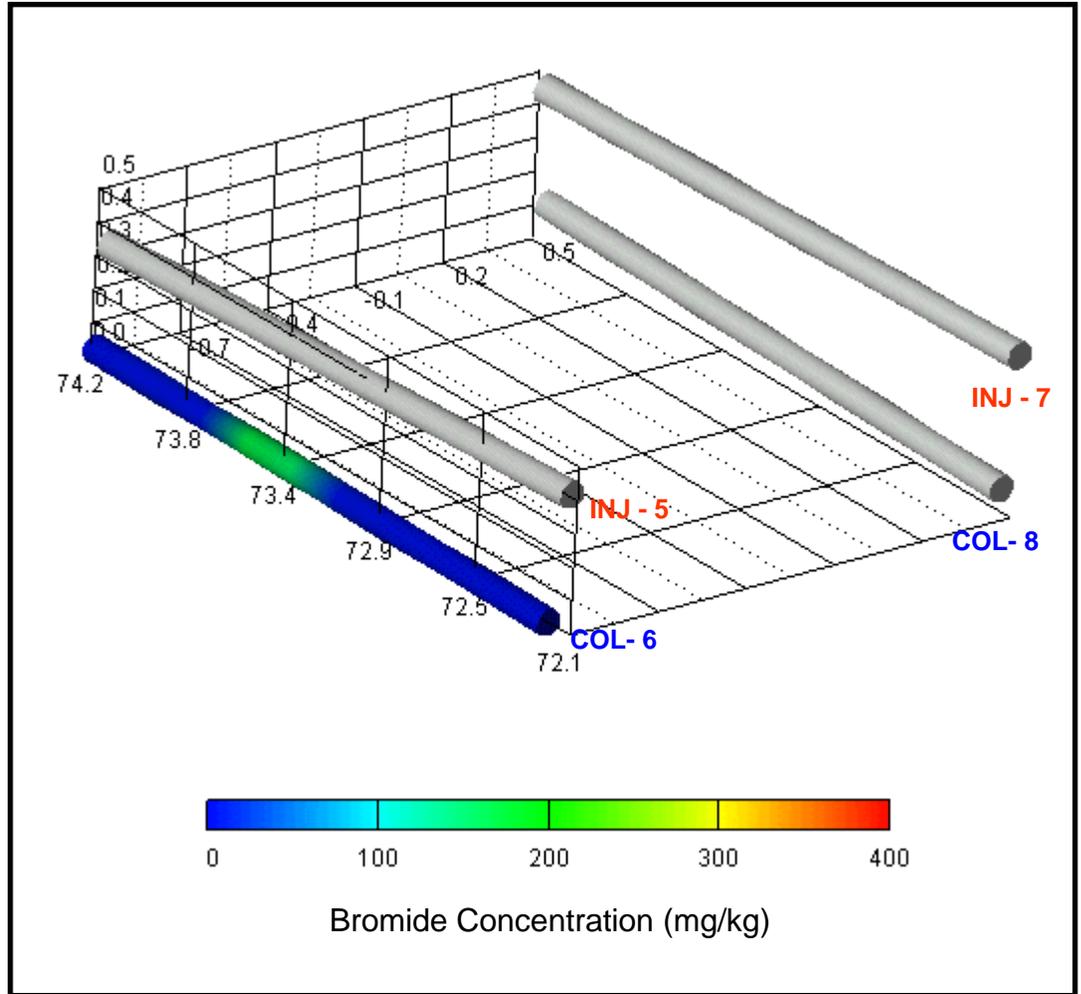


# Busted Butte Unsaturated Zone Transport Test

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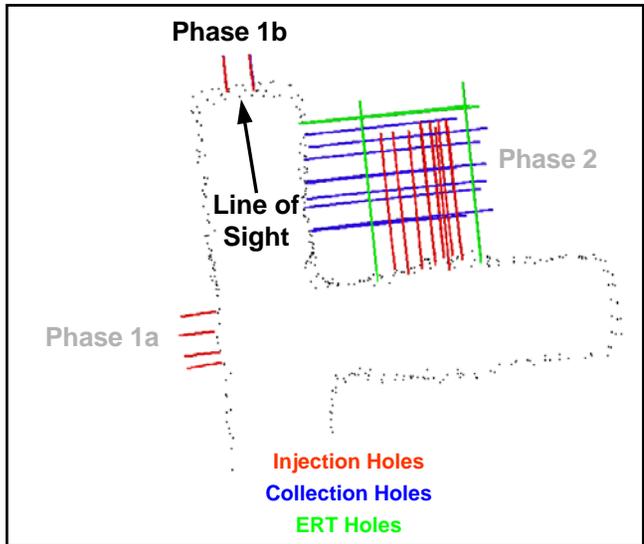


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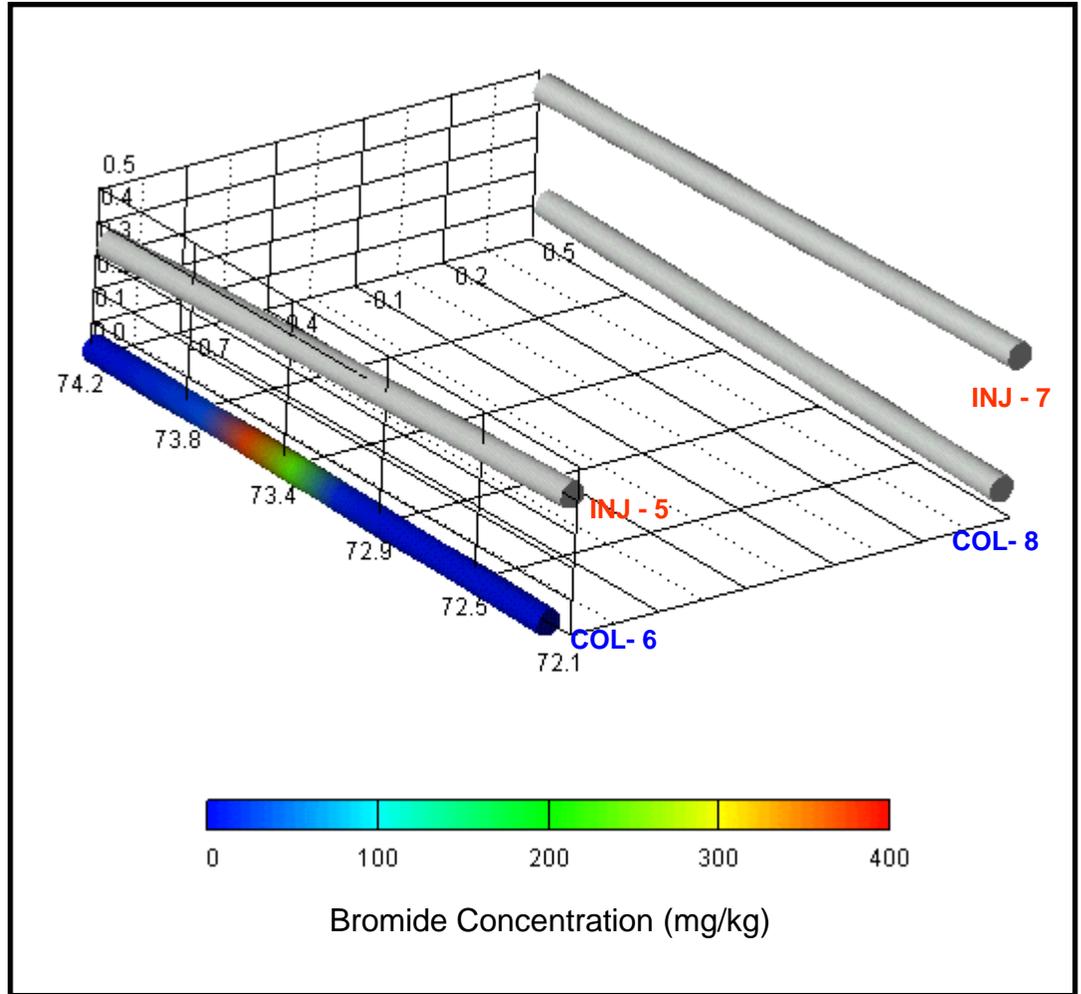


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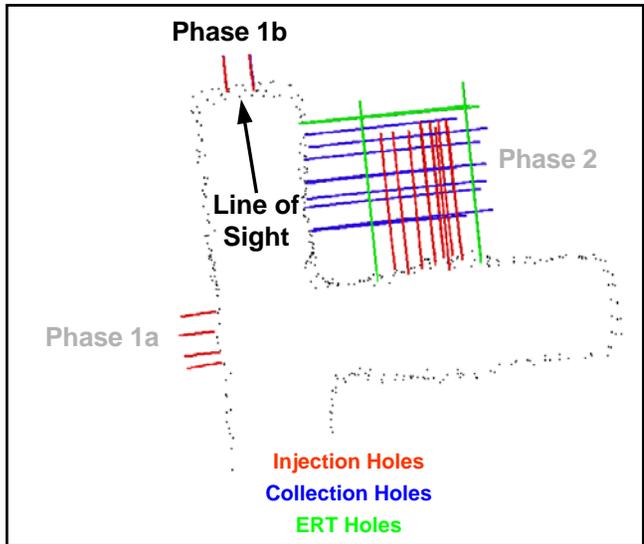


August 12, 1998

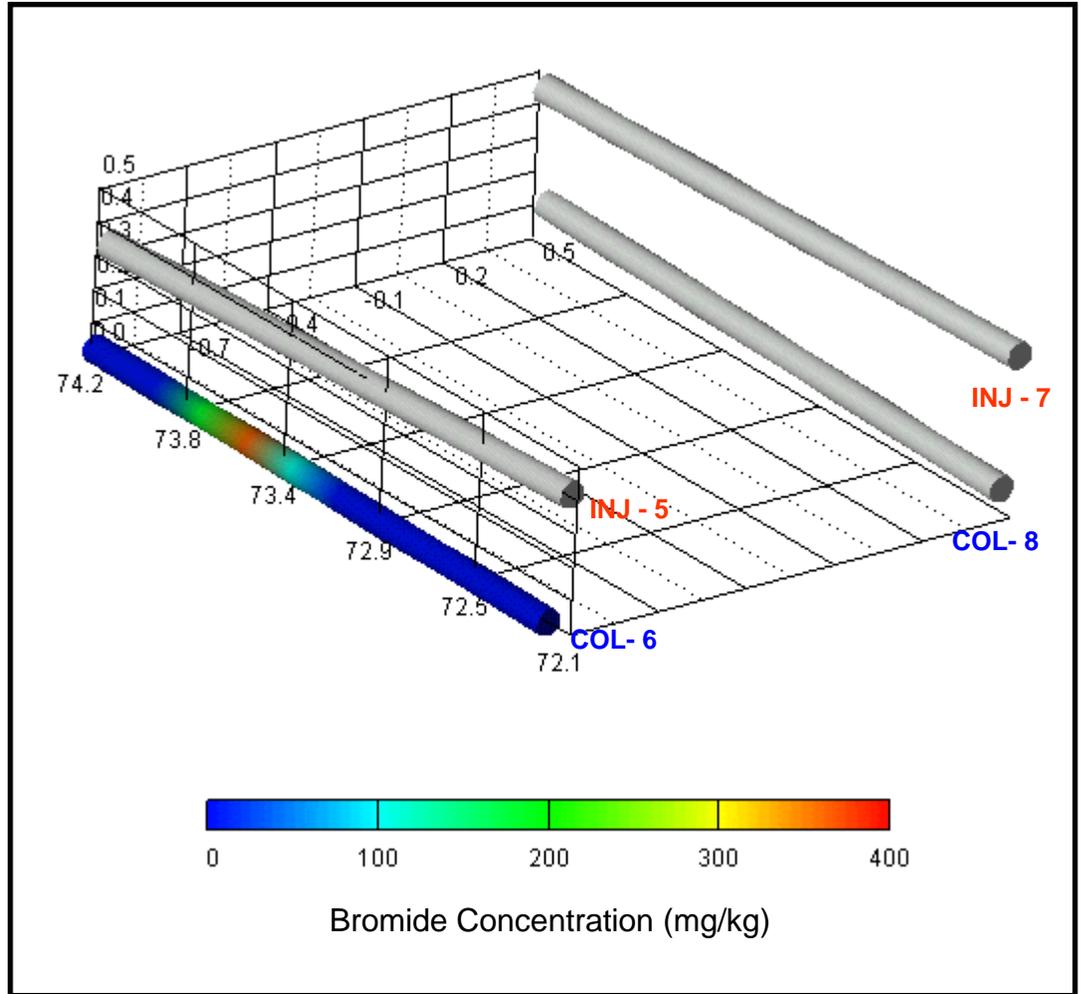


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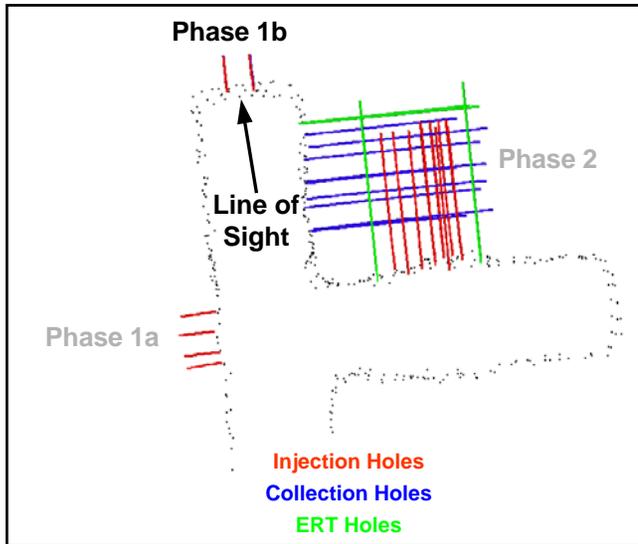


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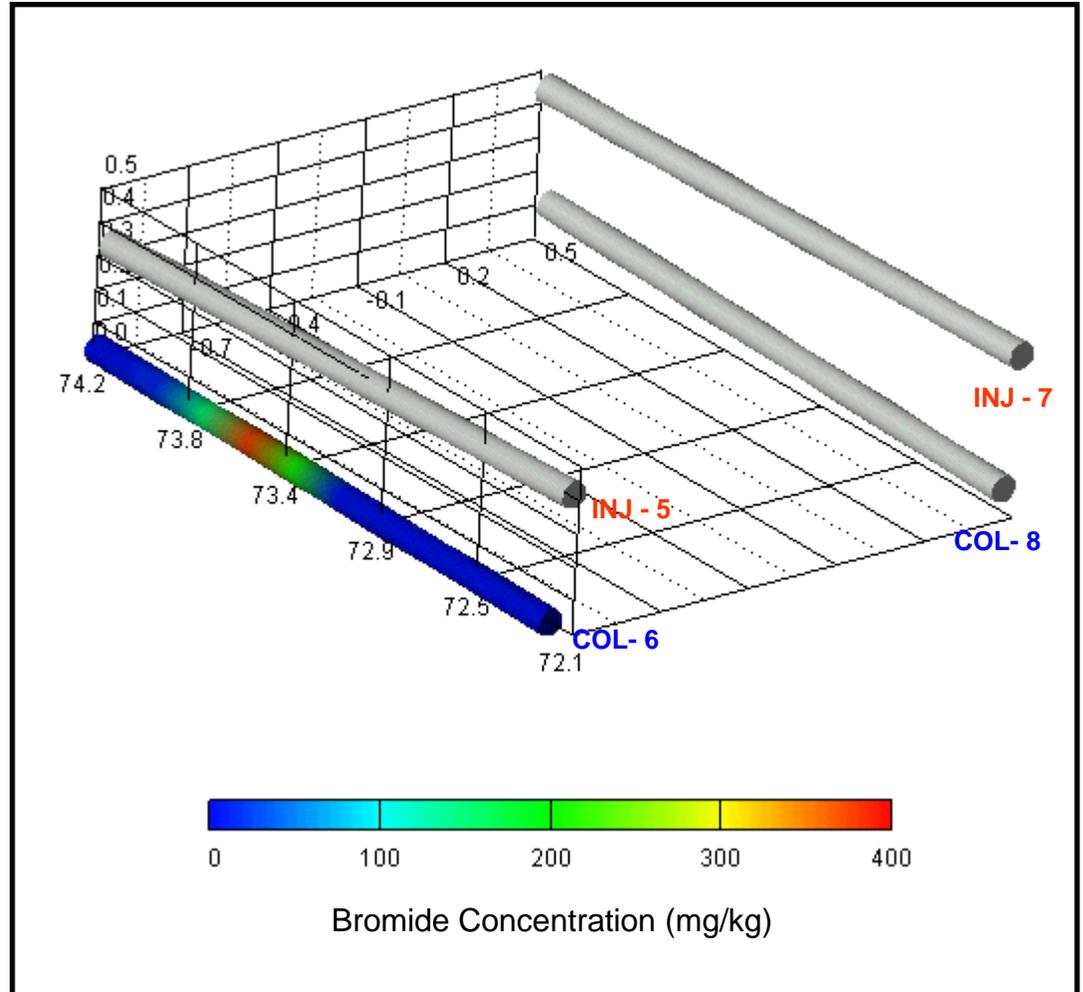


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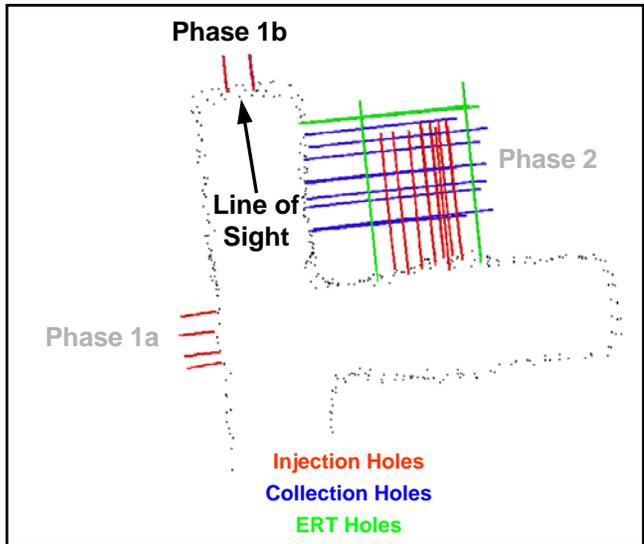


September 2, 1998

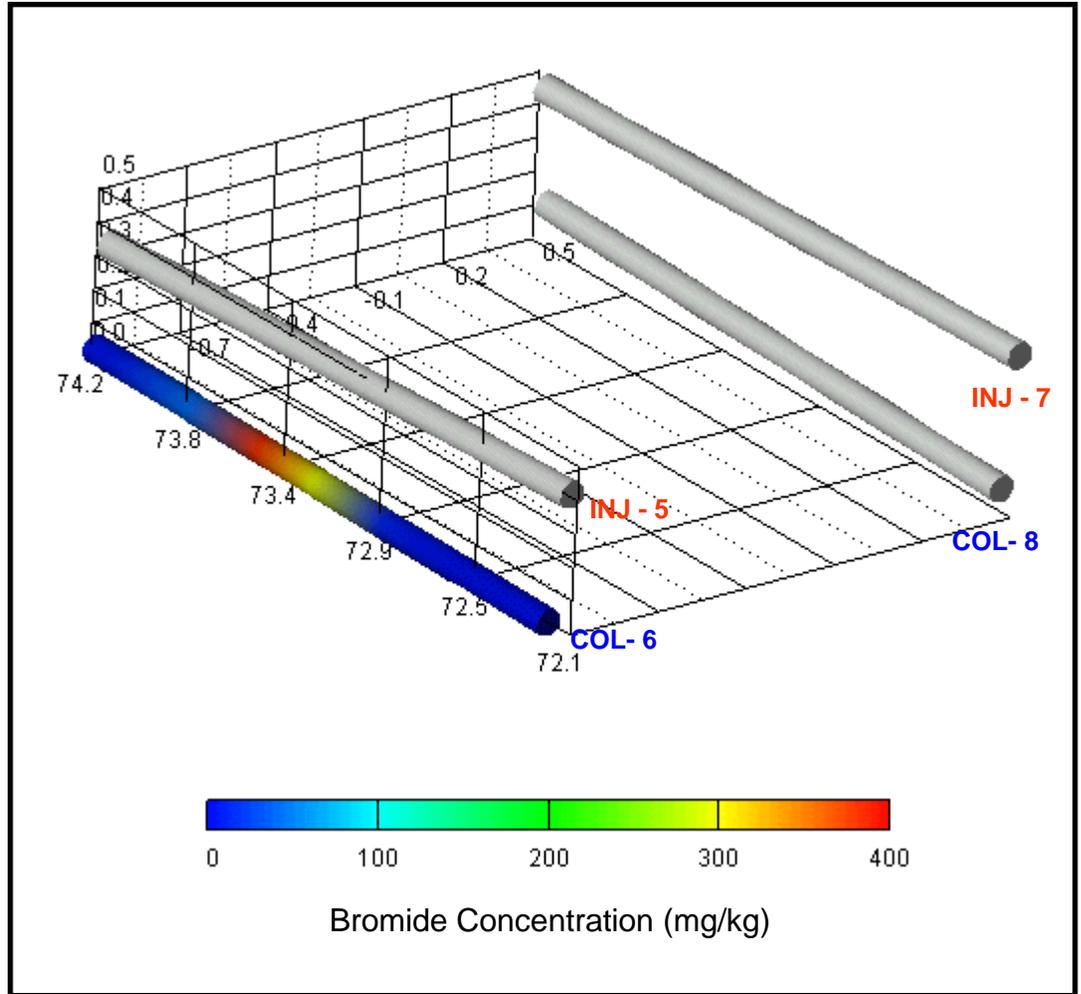


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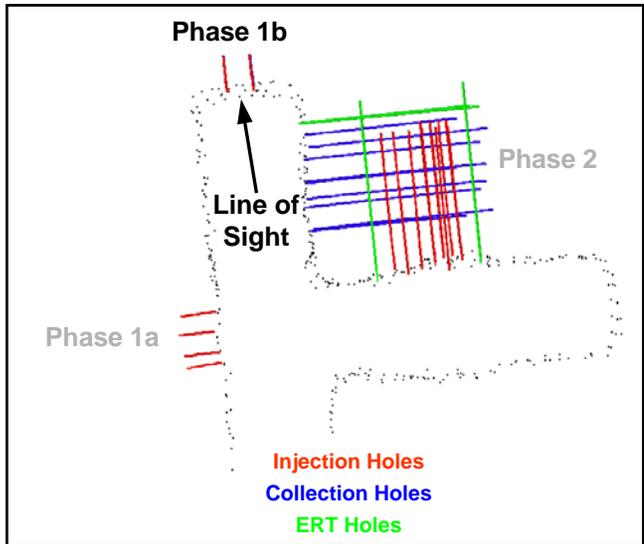


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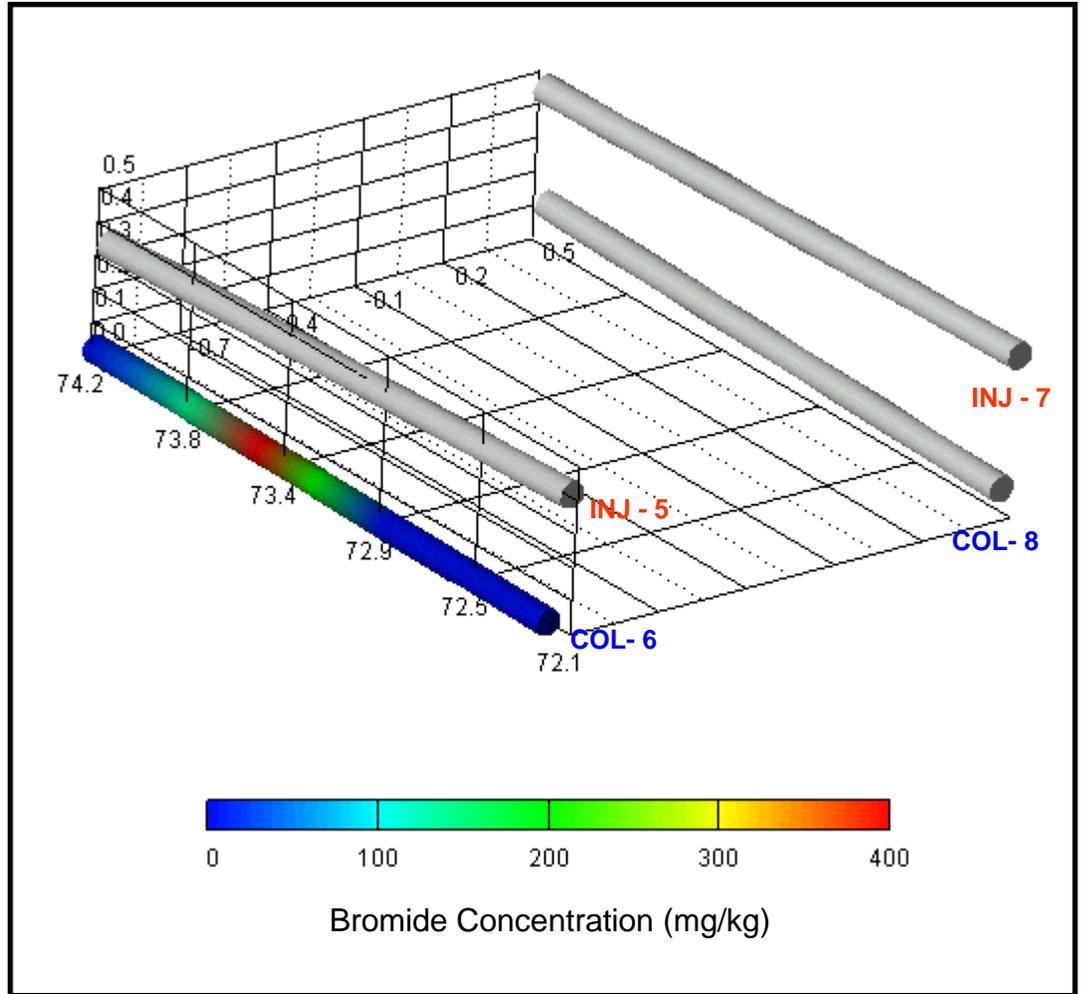


# Busted Butte Unsaturated Zone Transport Test

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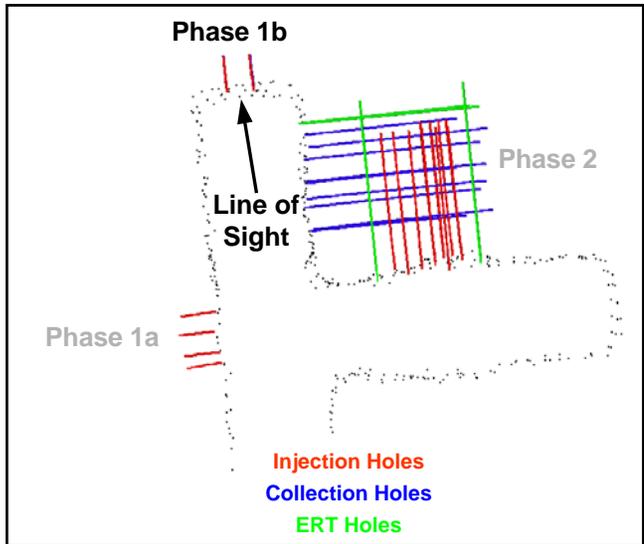


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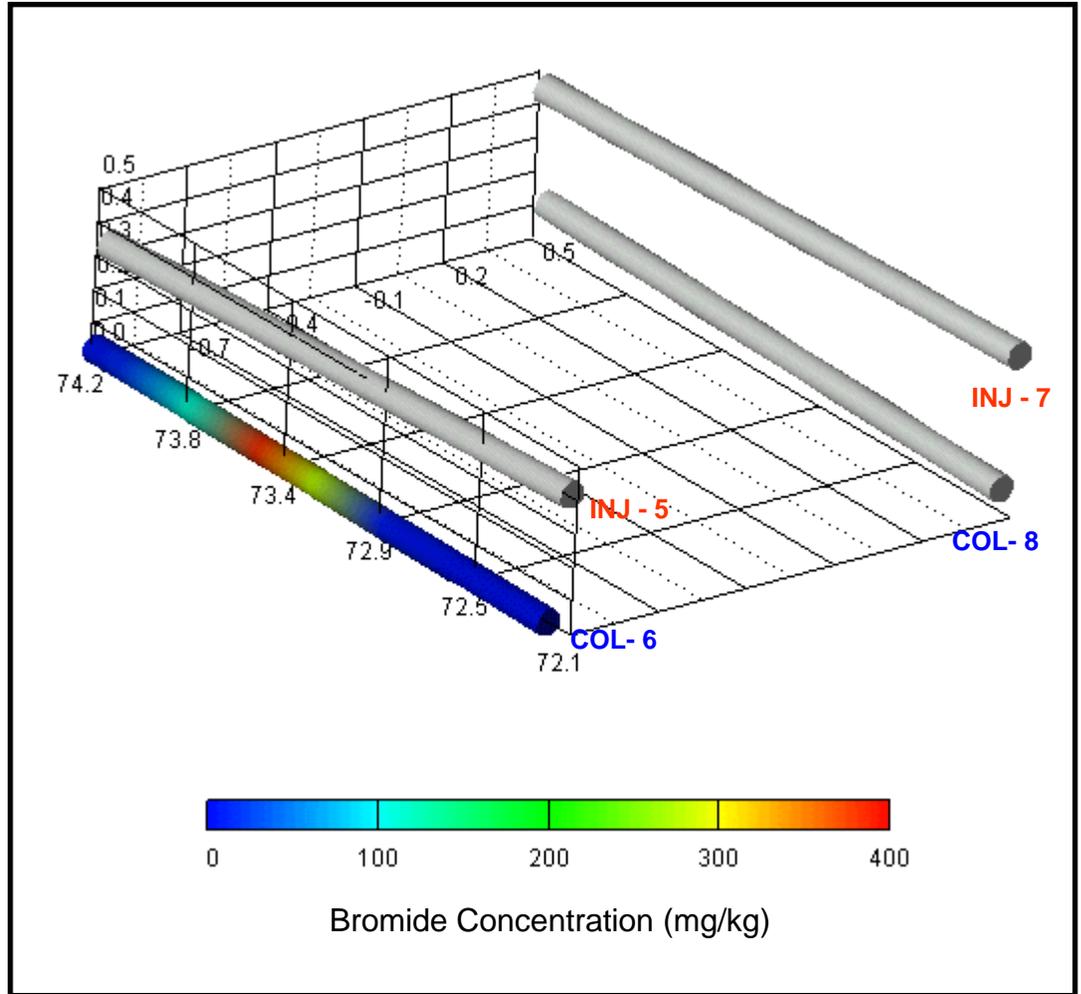


# Busted Butte Unsaturated Zone Transport Test

## Phase 1b Bromide Data

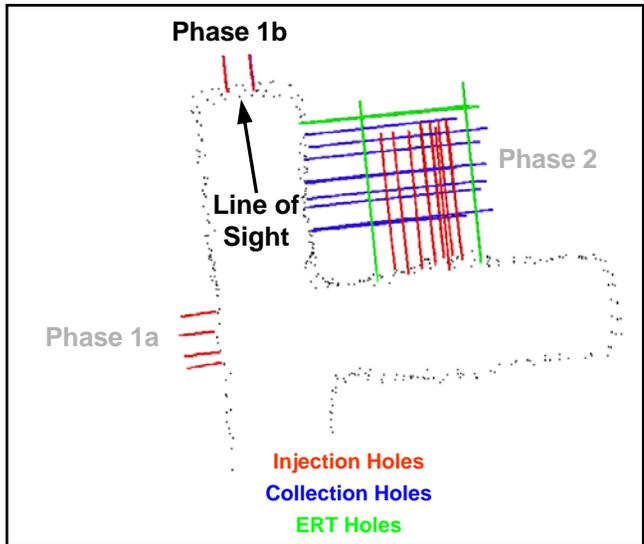


**October 6, 1998**

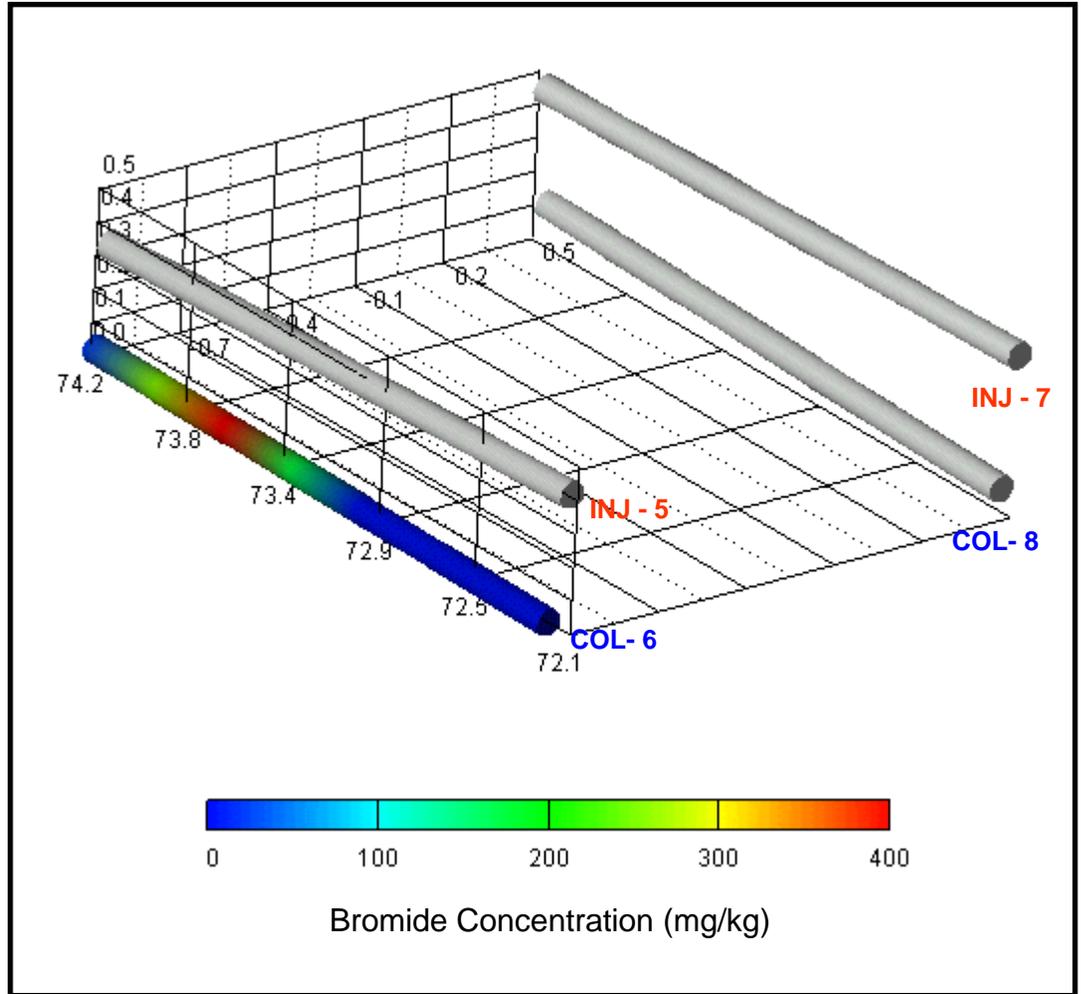


# Busted Butte Unsaturated Zone Transport Test

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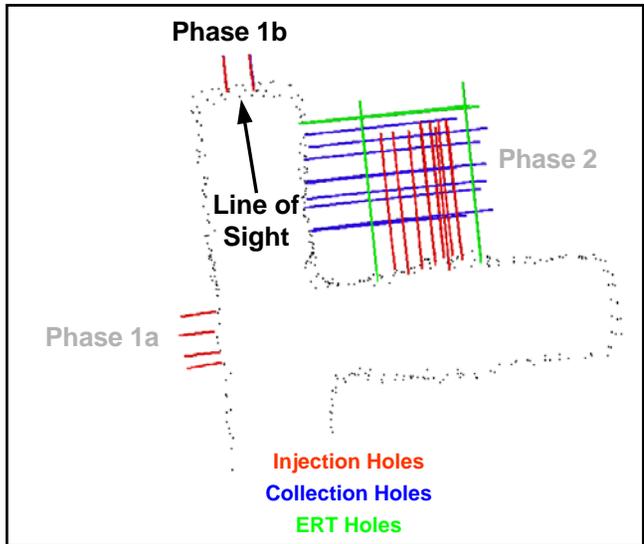


October 27, 1998

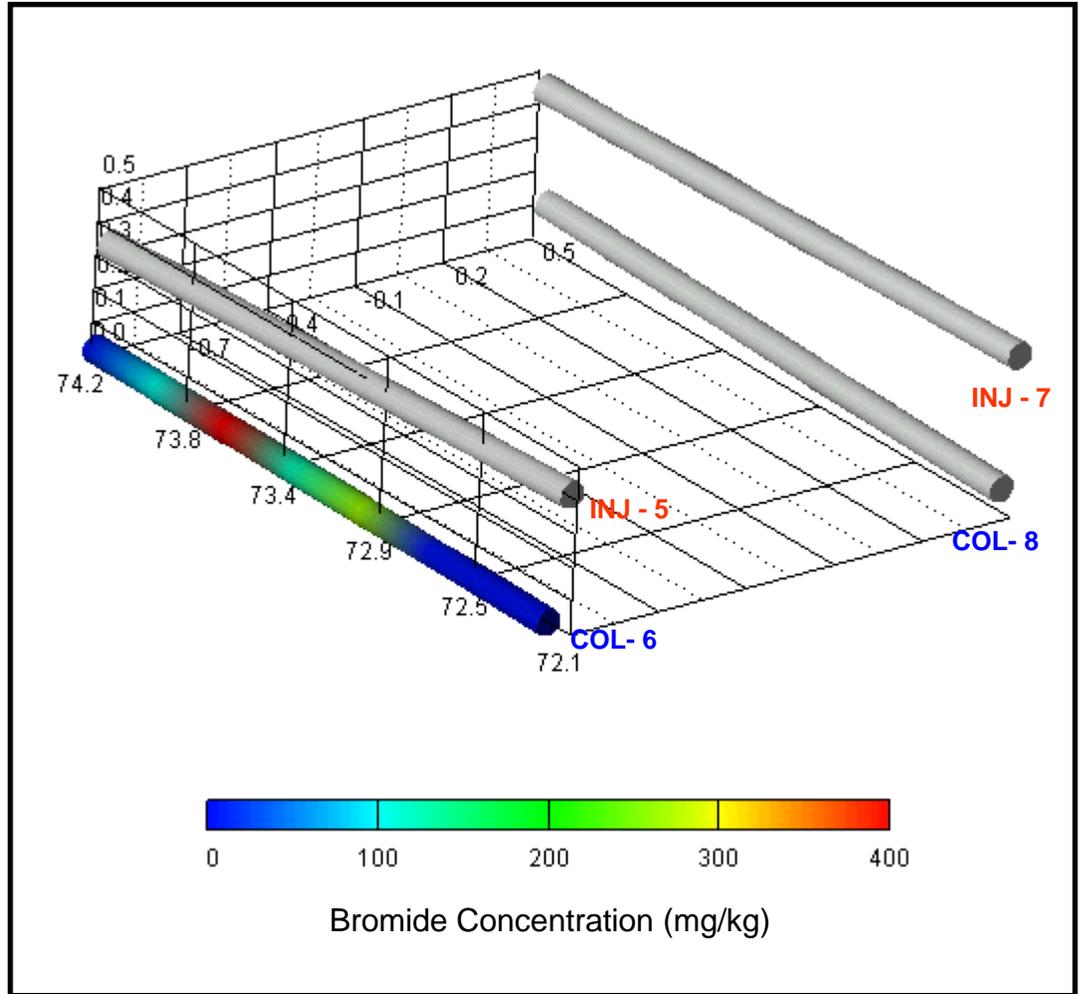


# Busted Butte Unsaturated Zone Transport Test

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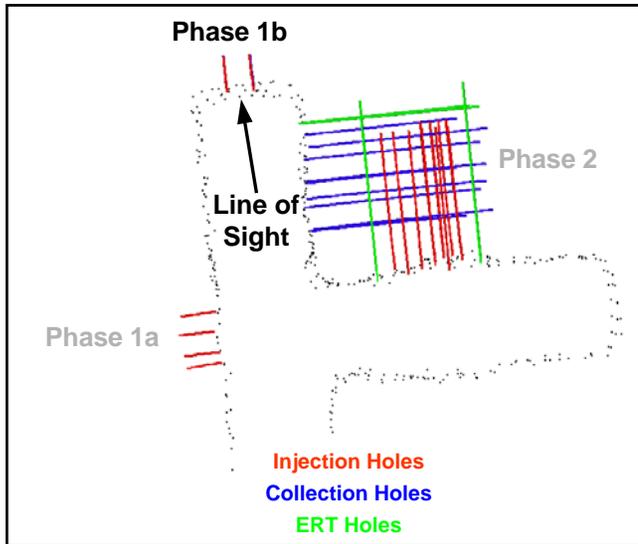


**November 18, 1998**

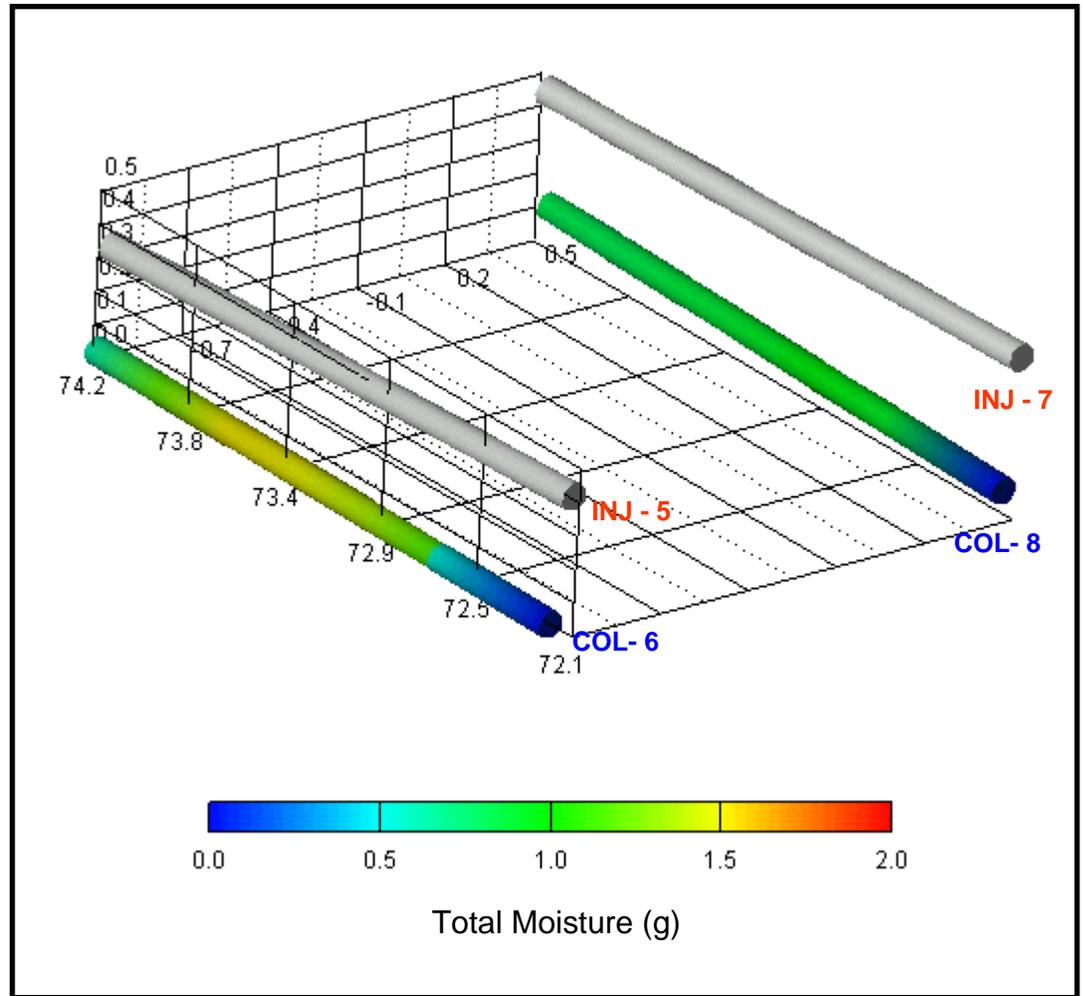


# Busted Butte Unsaturated Zone Transport Test

## Phase 1b Total Moisture Data

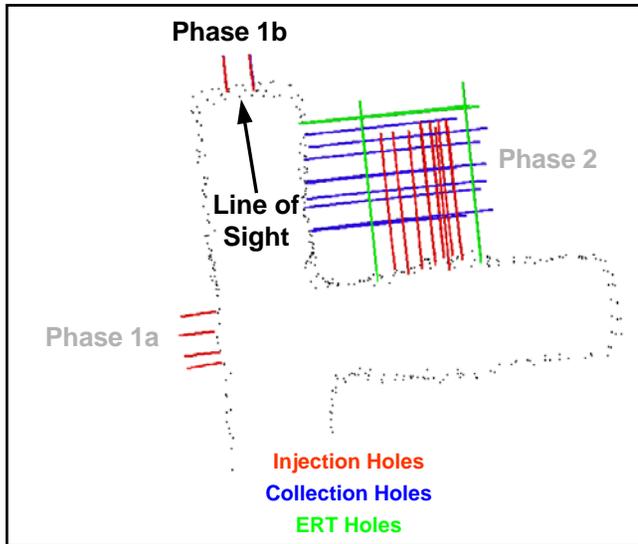


**June 6, 1998**

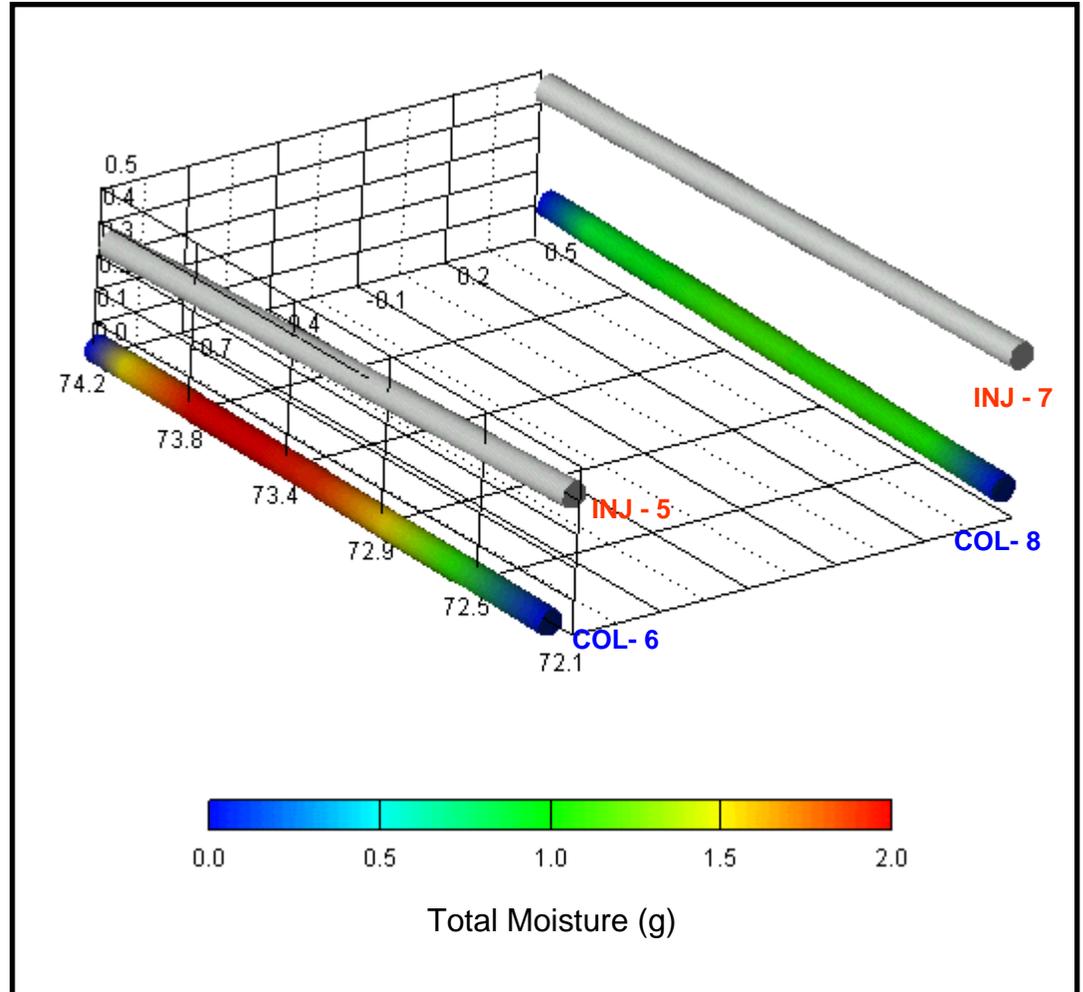


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## Phase 1b Total Moisture Data

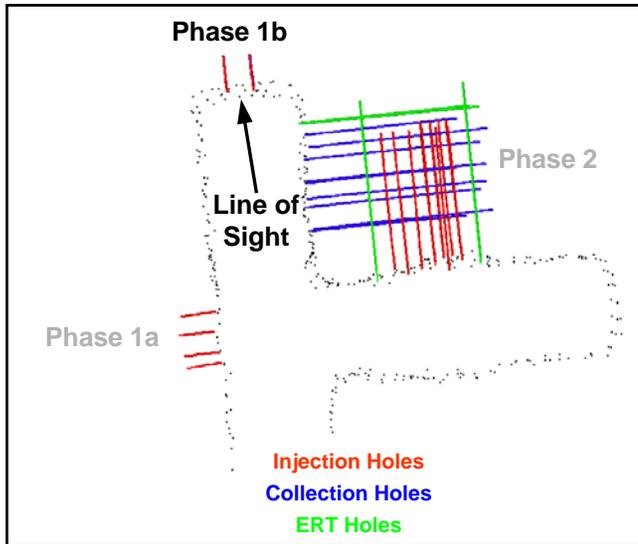


August 26, 1998

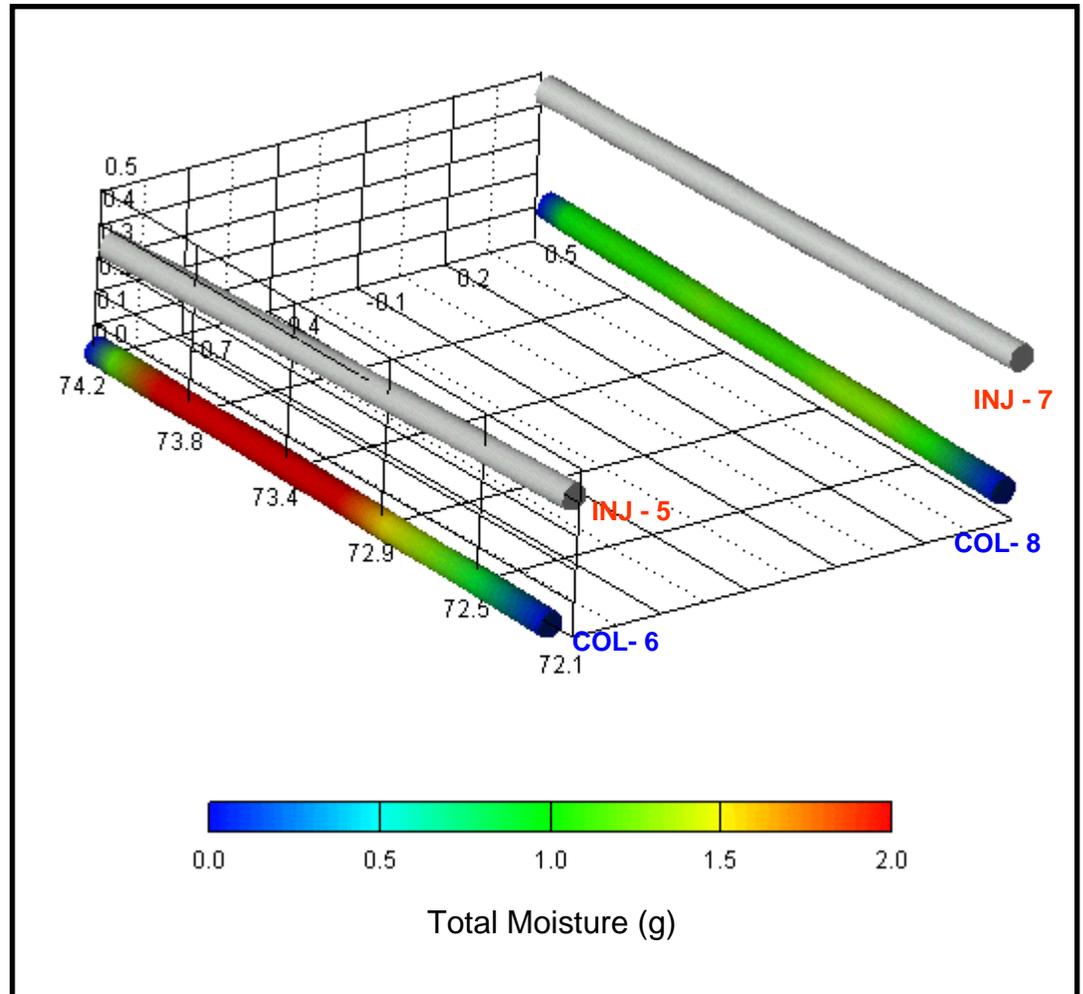


# Busted Butte Unsaturated Zone Transport Test

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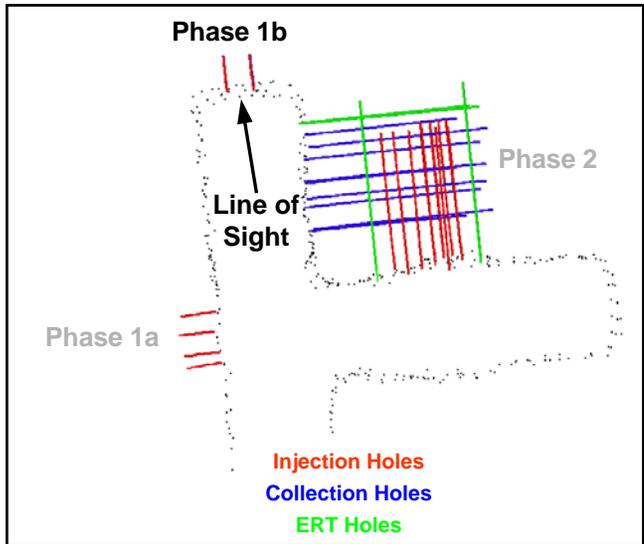


September 2, 1998

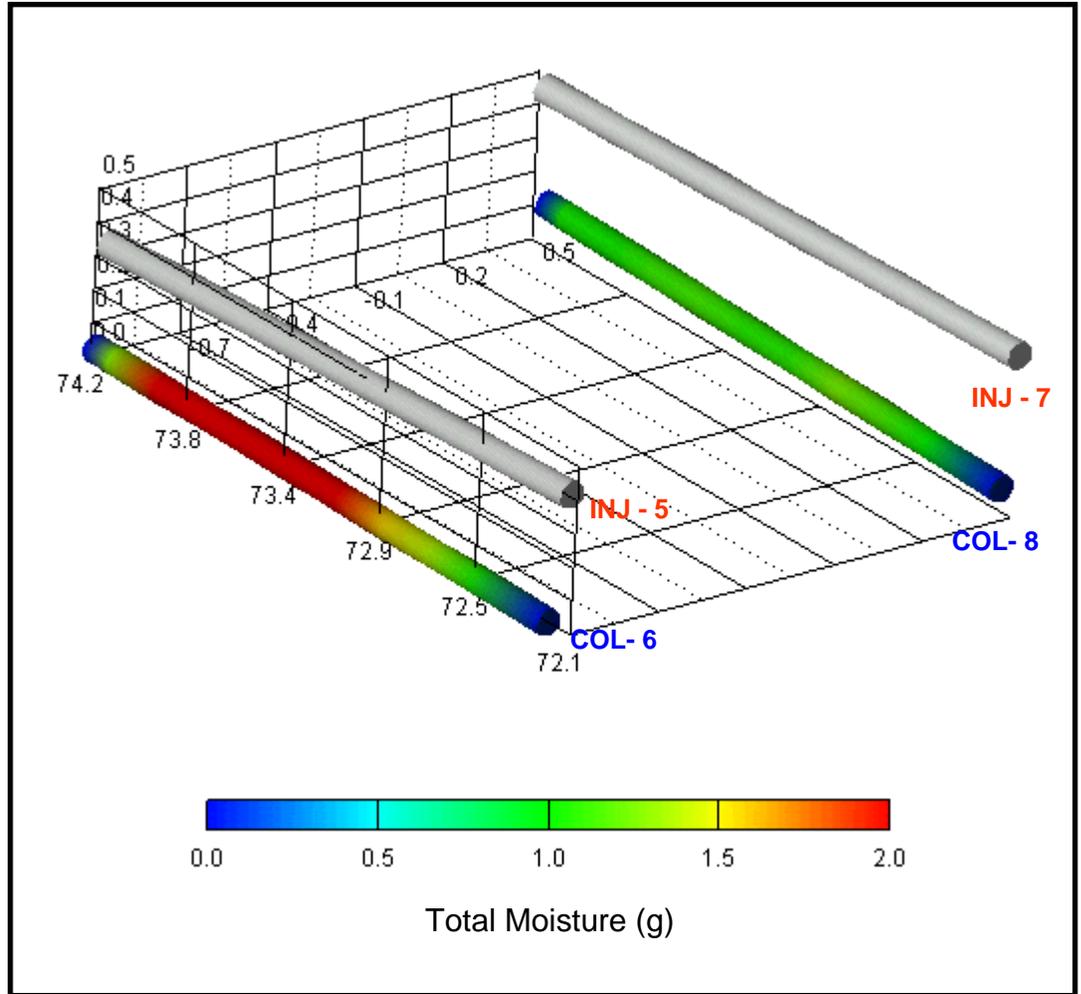


# Busted Butte Unsaturated Zone Transport Test

## Phase 1b Total Moisture Data

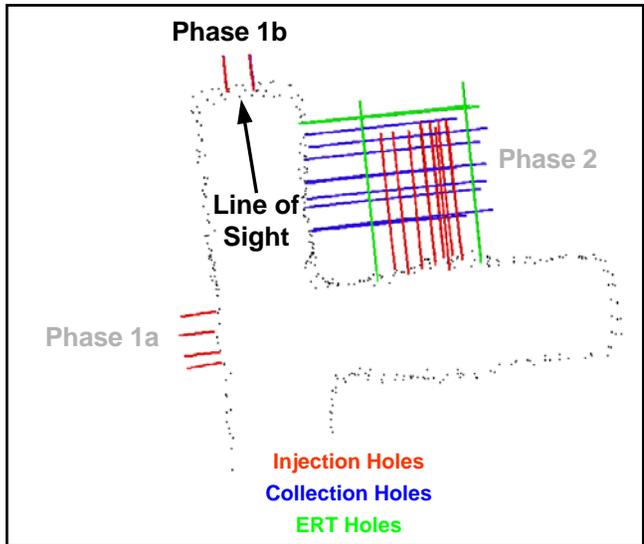


September 24, 1998

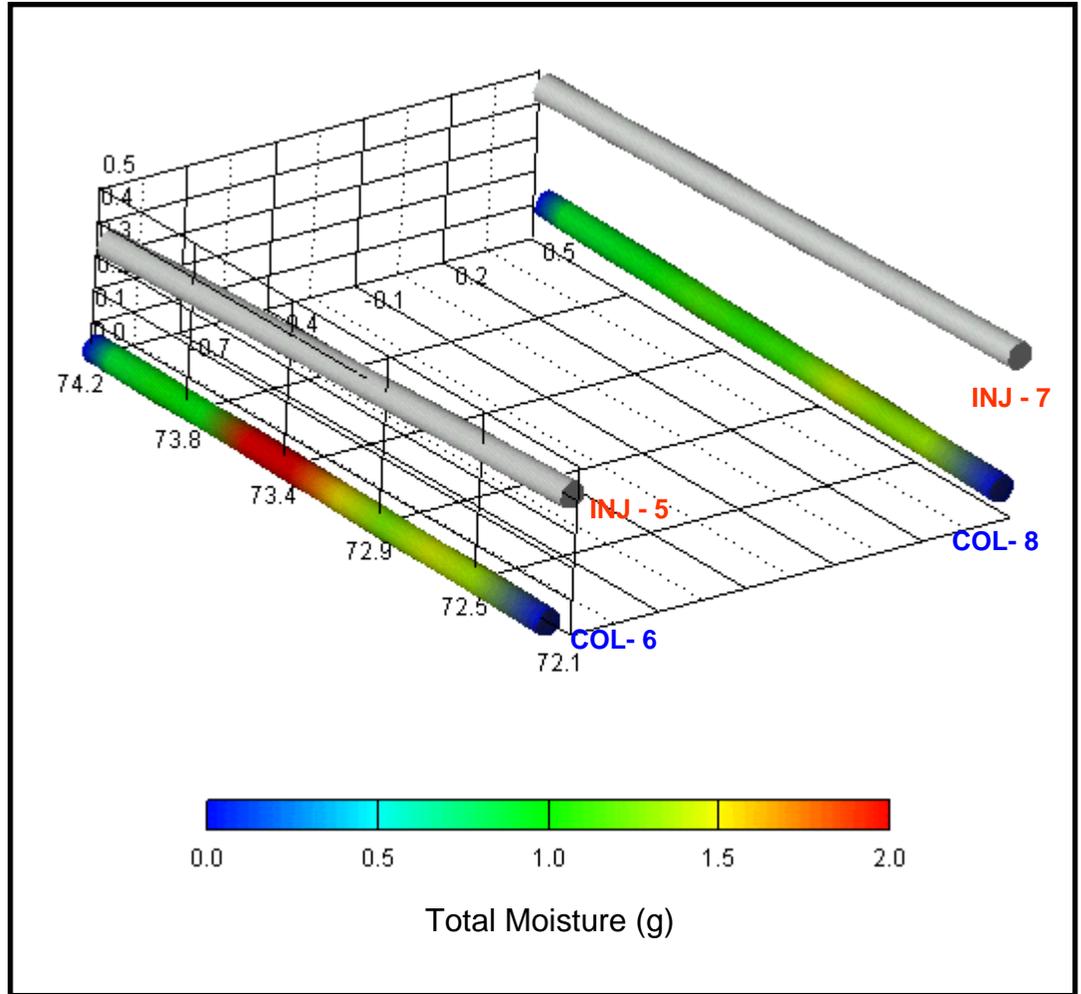


# Busted Butte Unsaturated Zone Transport Test

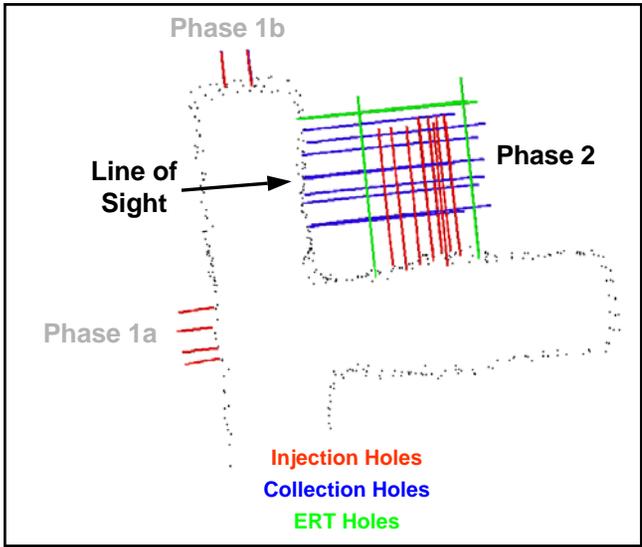
## Phase 1b Total Moisture Data



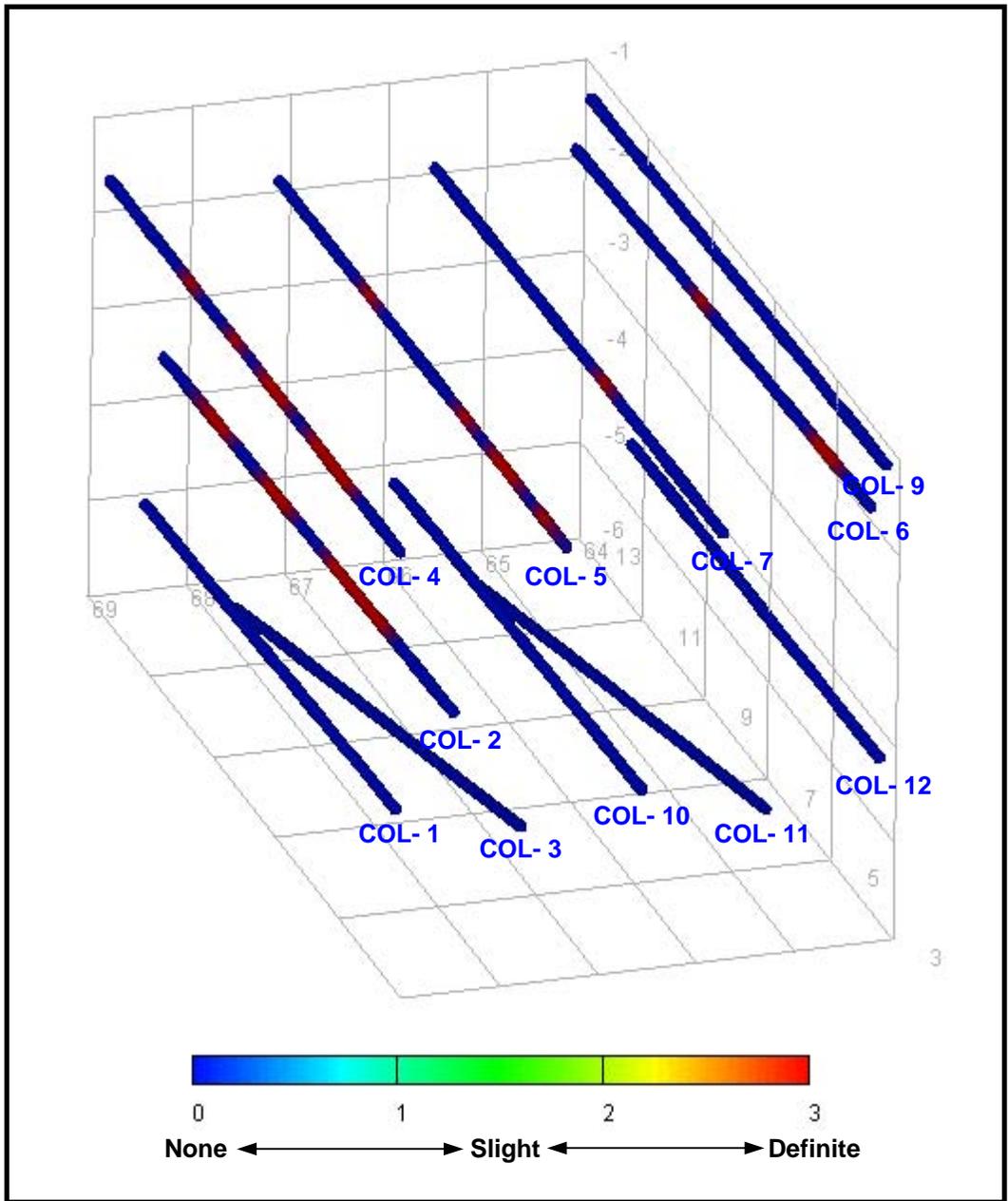
November 18, 1998



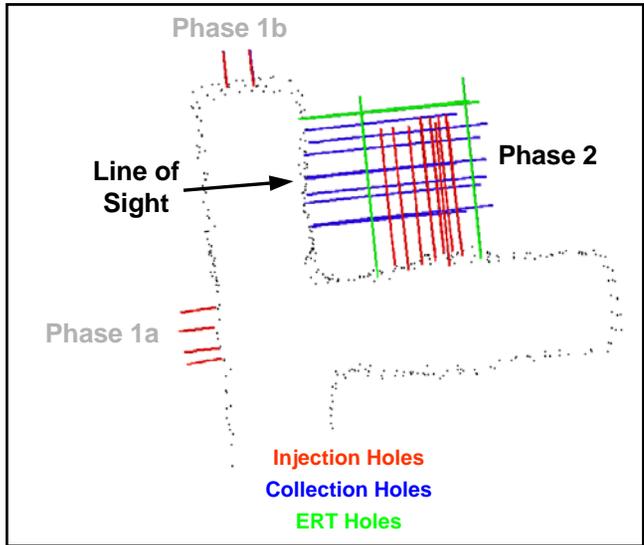
# Busted Butte Unsaturated Zone Transport Test - Phase 2 Breakthrough Data



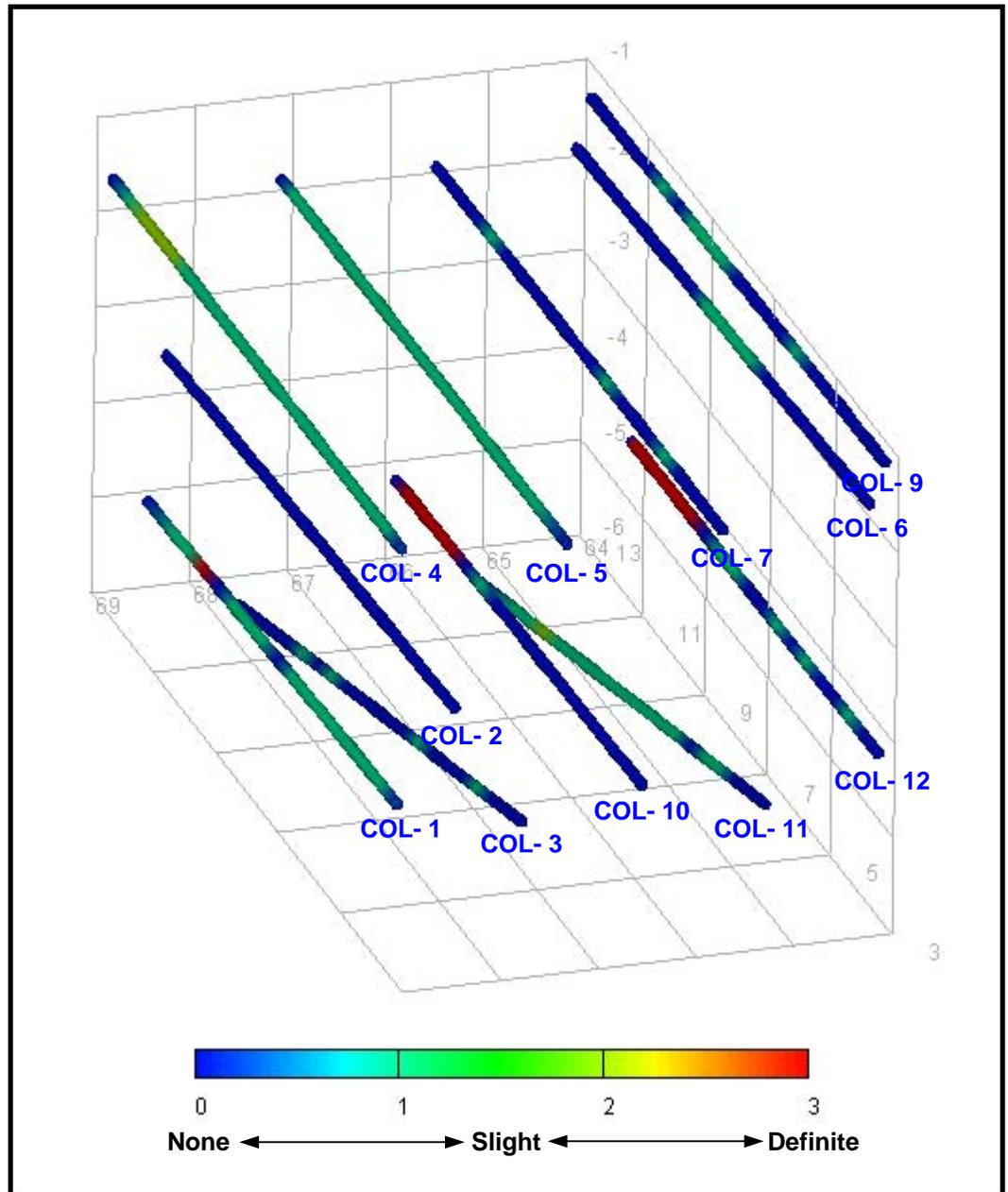
August 1998



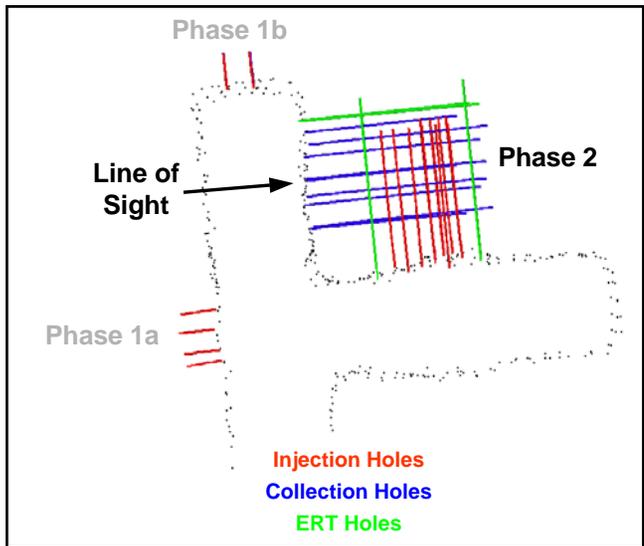
# Busted Butte Unsaturated Zone Transport Test - Phase 2 Breakthrough Data



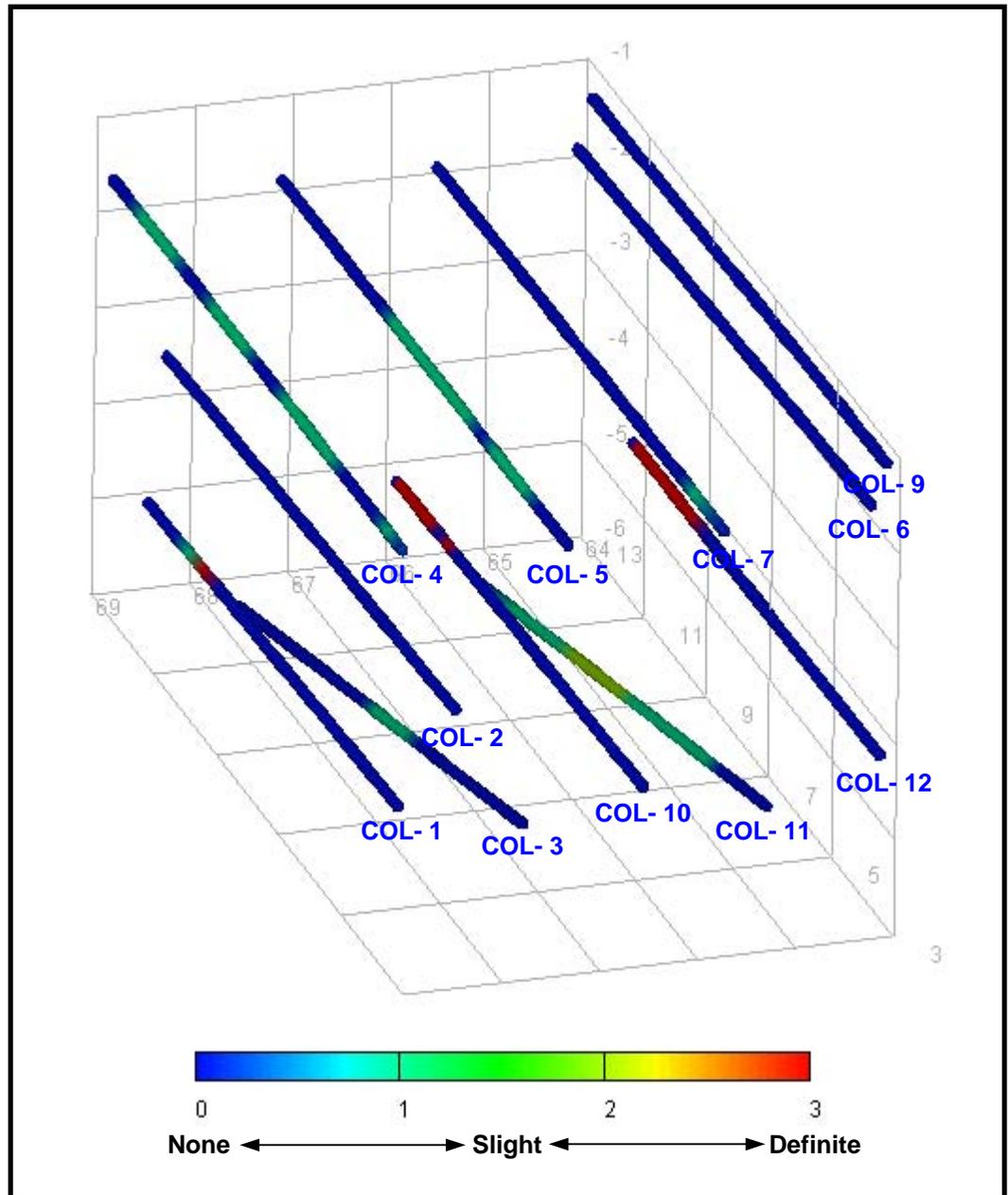
September 1998



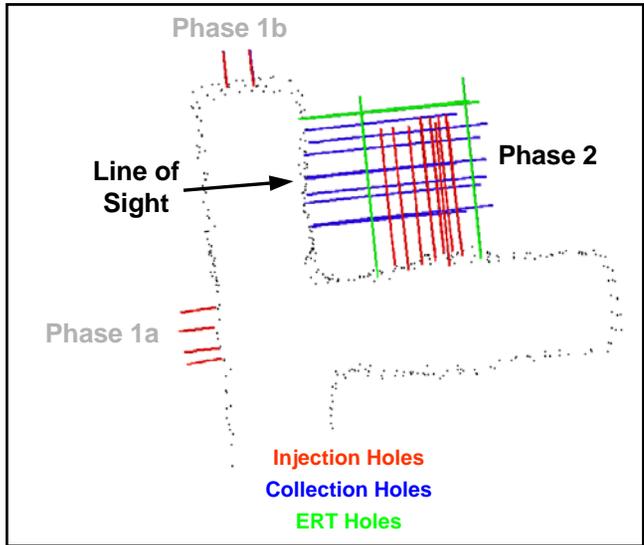
# Busted Butte Unsaturated Zone Transport Test - Phase 2 Breakthrough Data



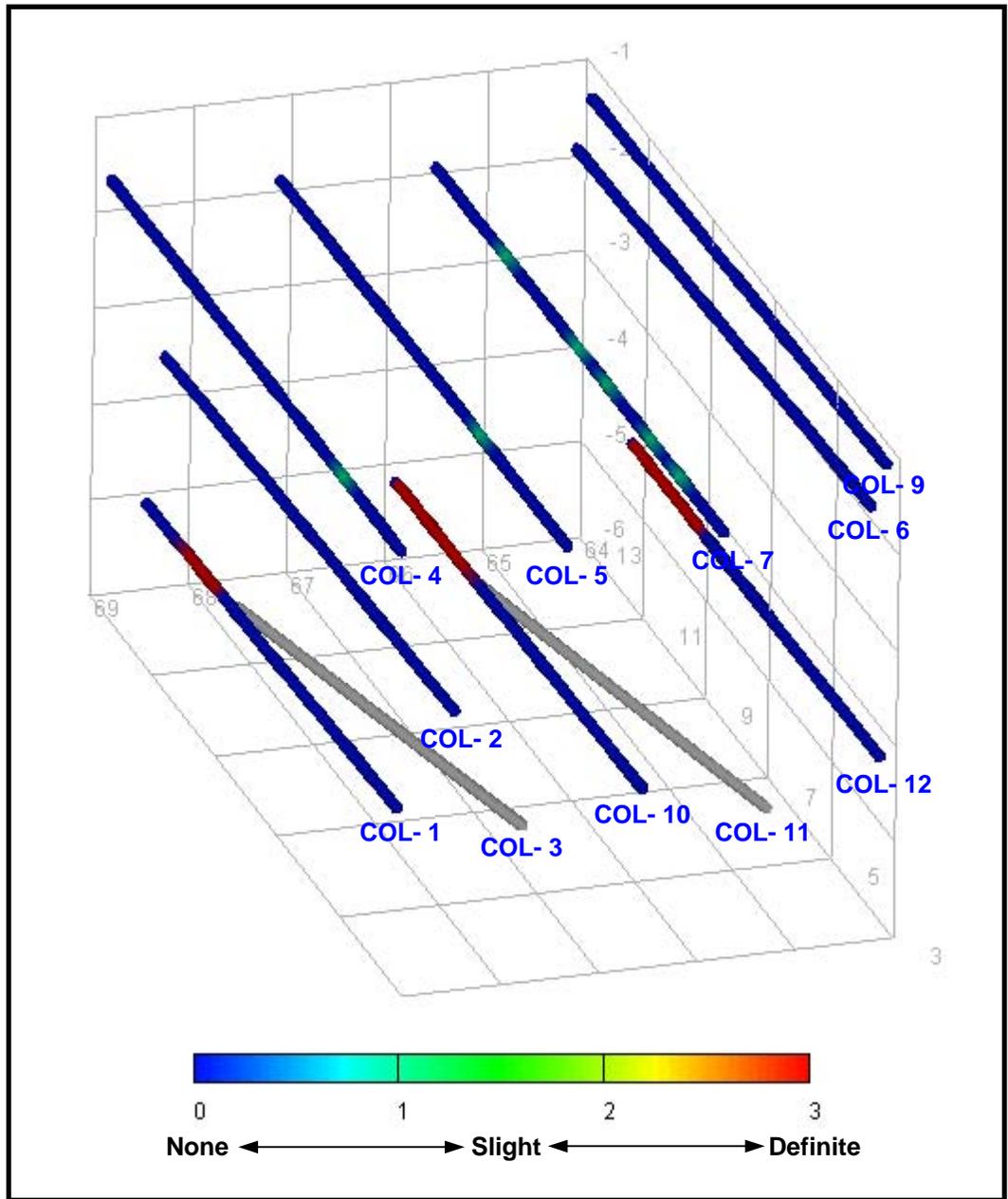
October 1998



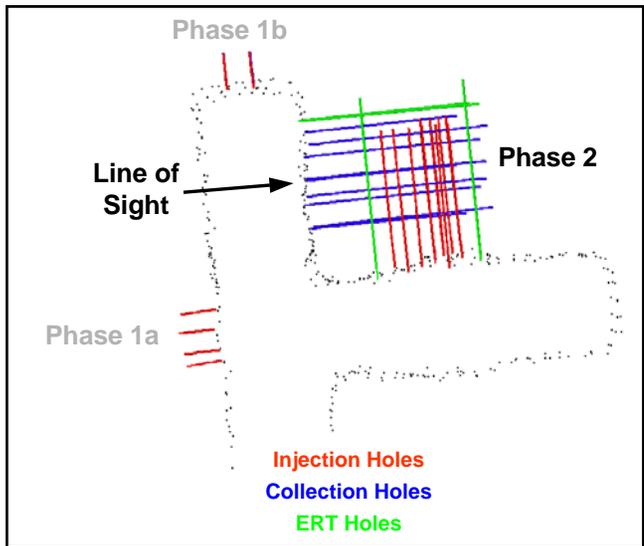
# Busted Butte Unsaturated Zone Transport Test - Phase 2 Breakthrough Data



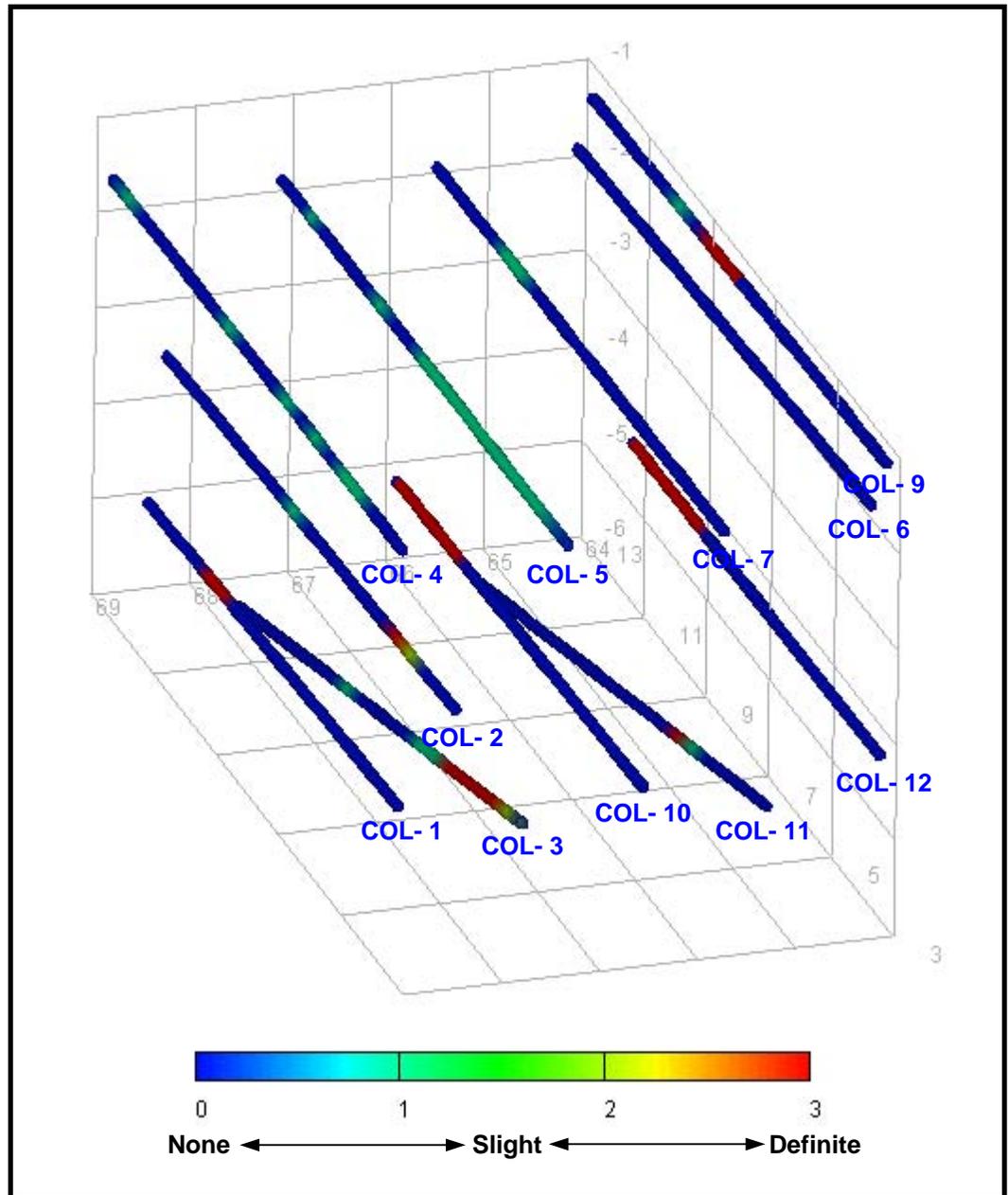
November 1998



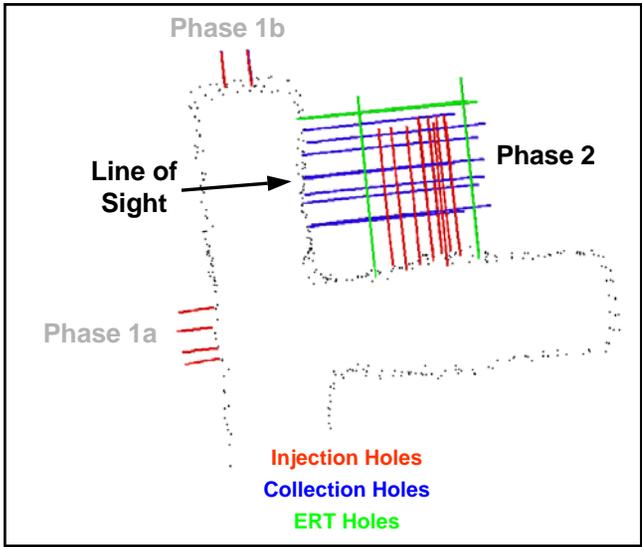
# Busted Butte Unsaturated Zone Transport Test - Phase 2 Breakthrough Data



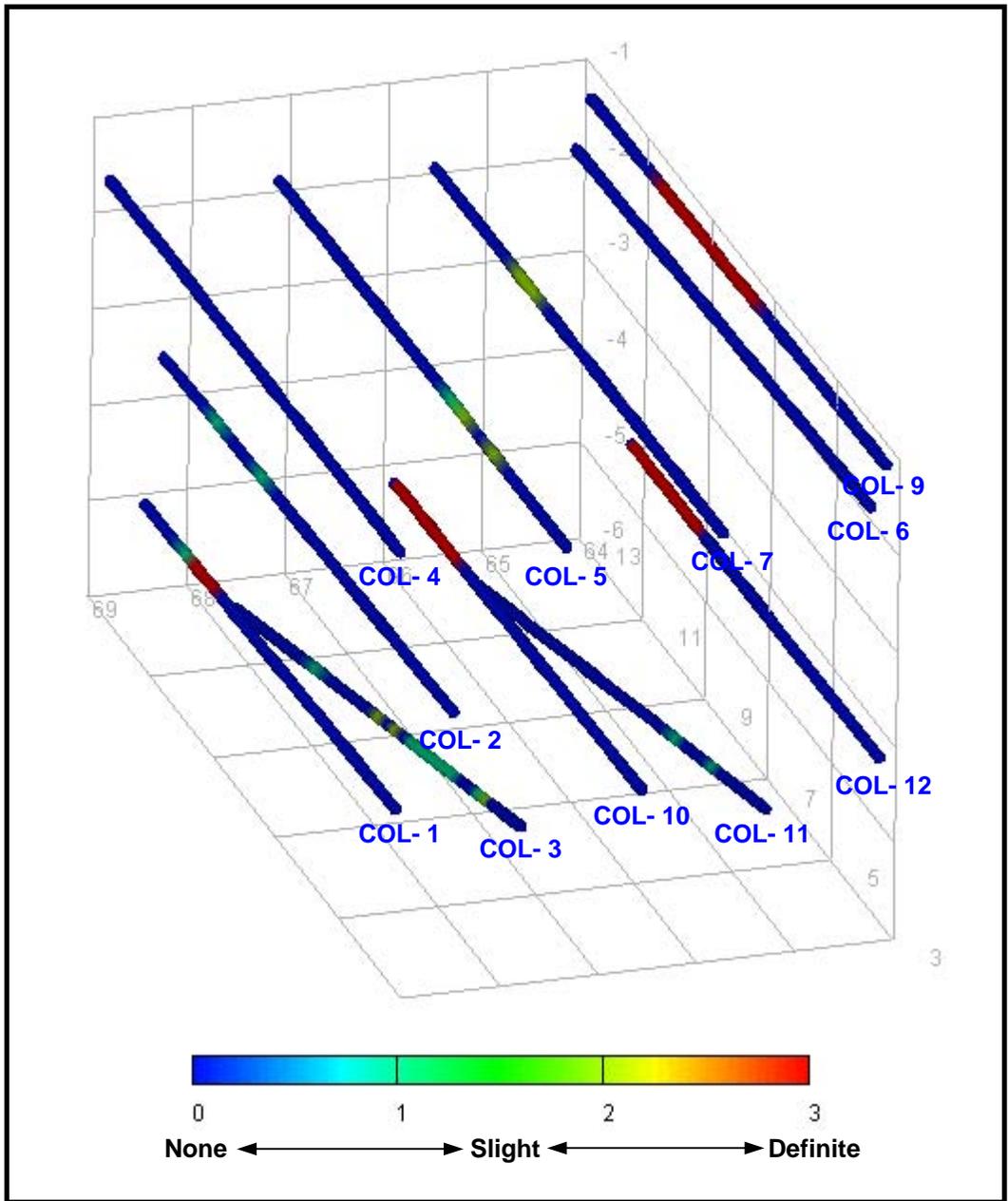
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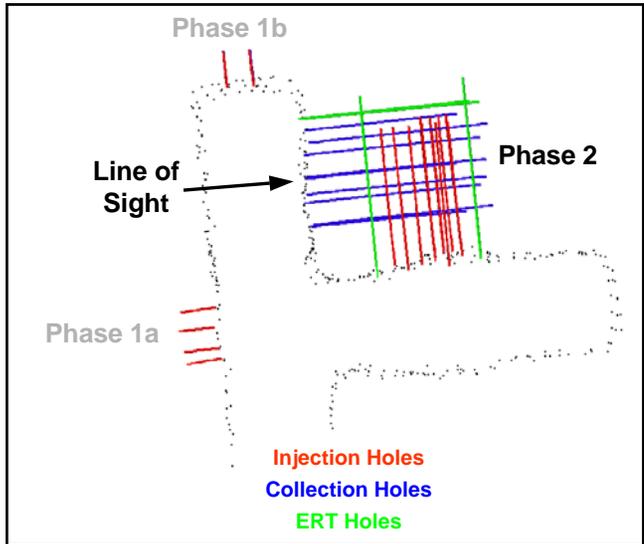
# Busted Butte Unsaturated Zone Transport Test - Phase 2 Breakthrough Data



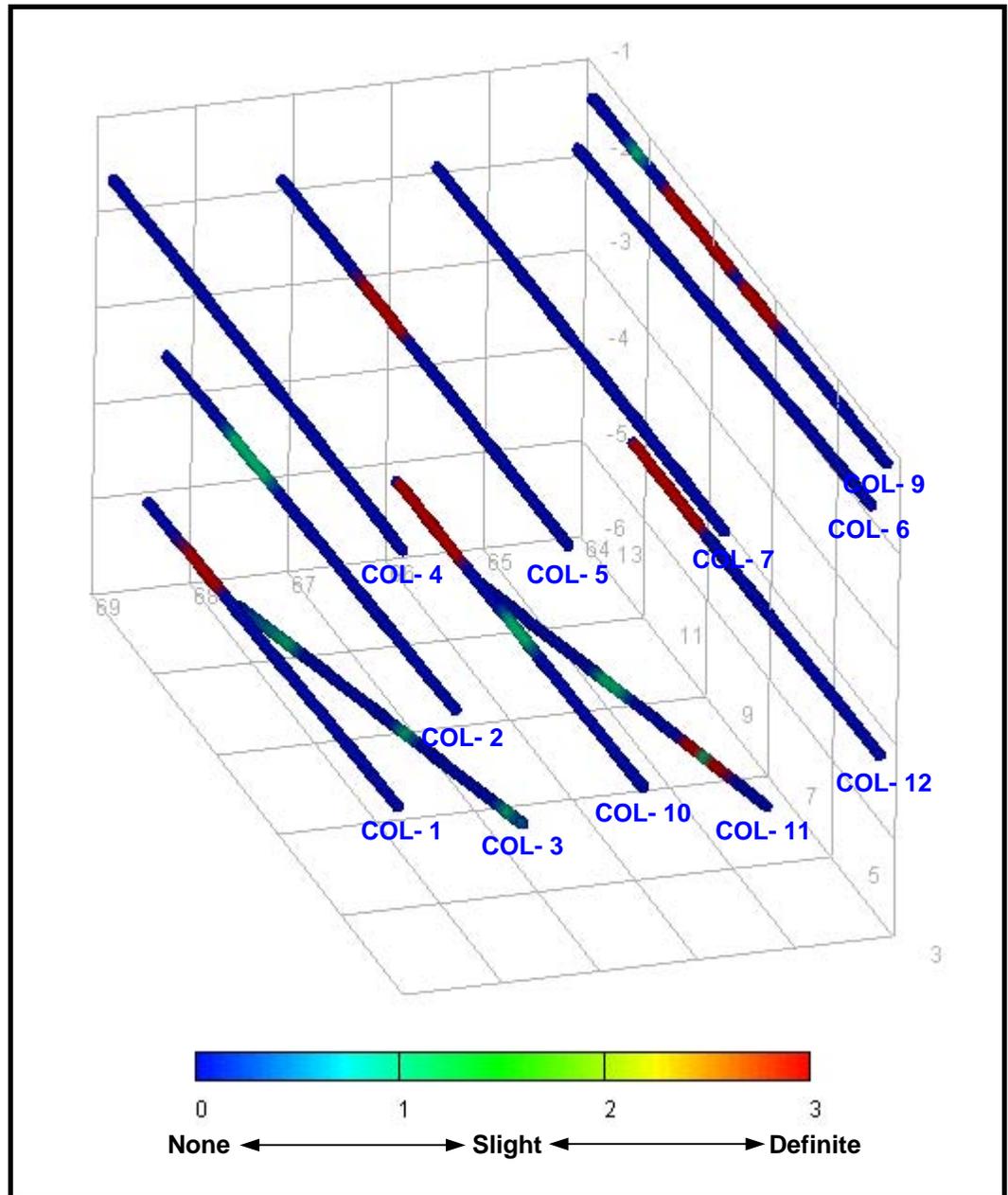
January 1999



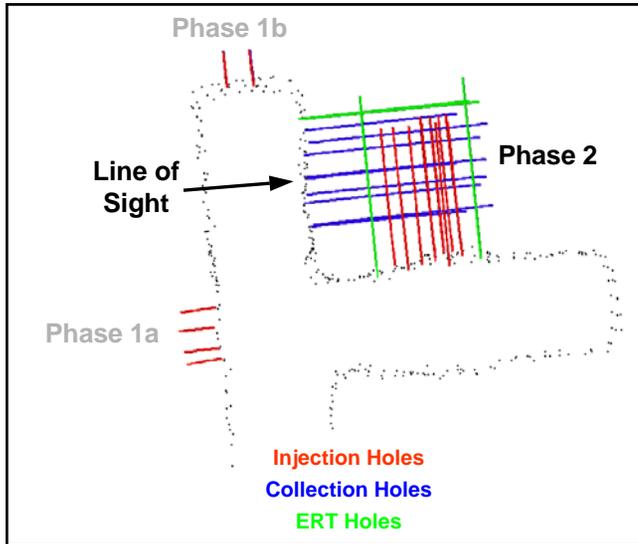
# Busted Butte Unsaturated Zone Transport Test - Phase 2 Breakthrough Data



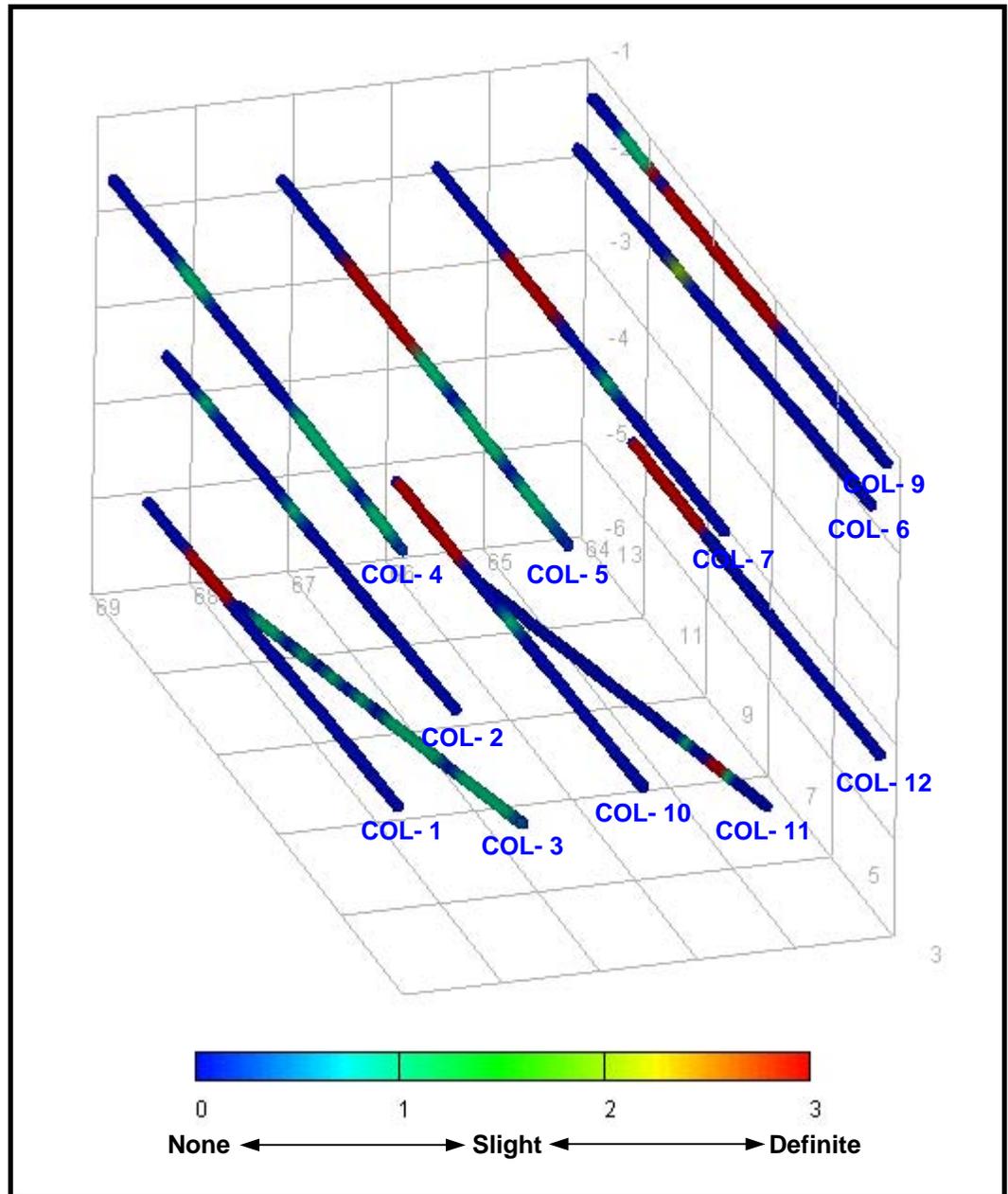
February 1999



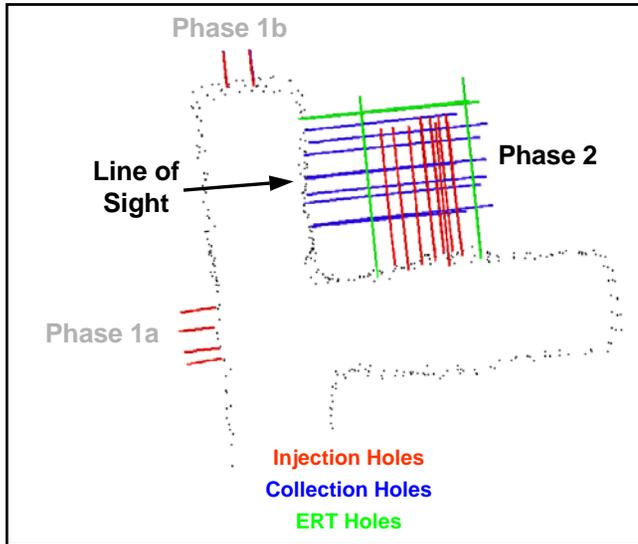
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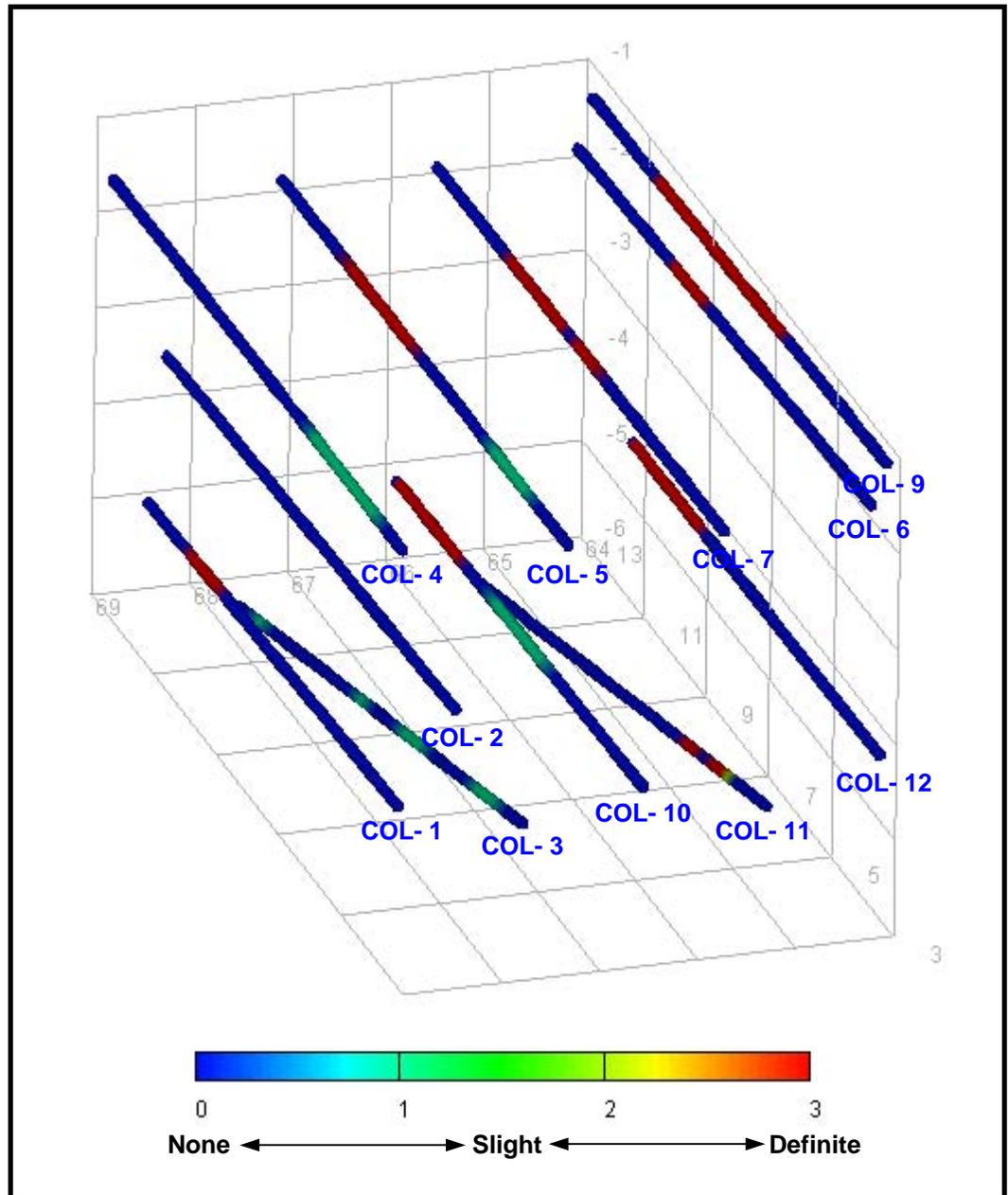
March 1999



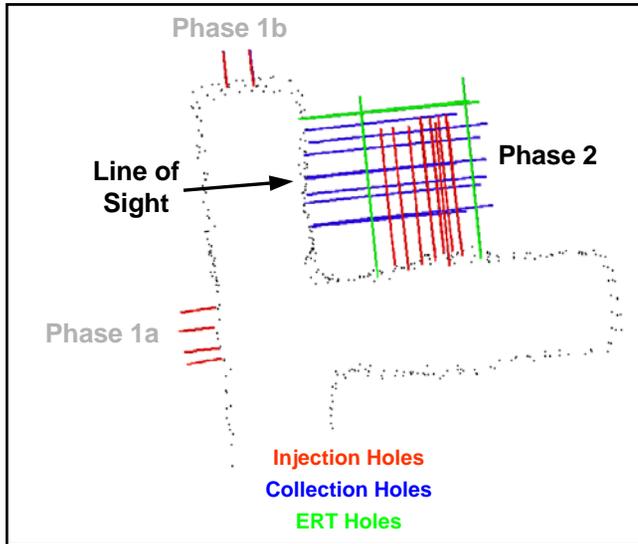
# Busted Butte Unsaturated Zone Transport Test - Phase 2 Breakthrough Data



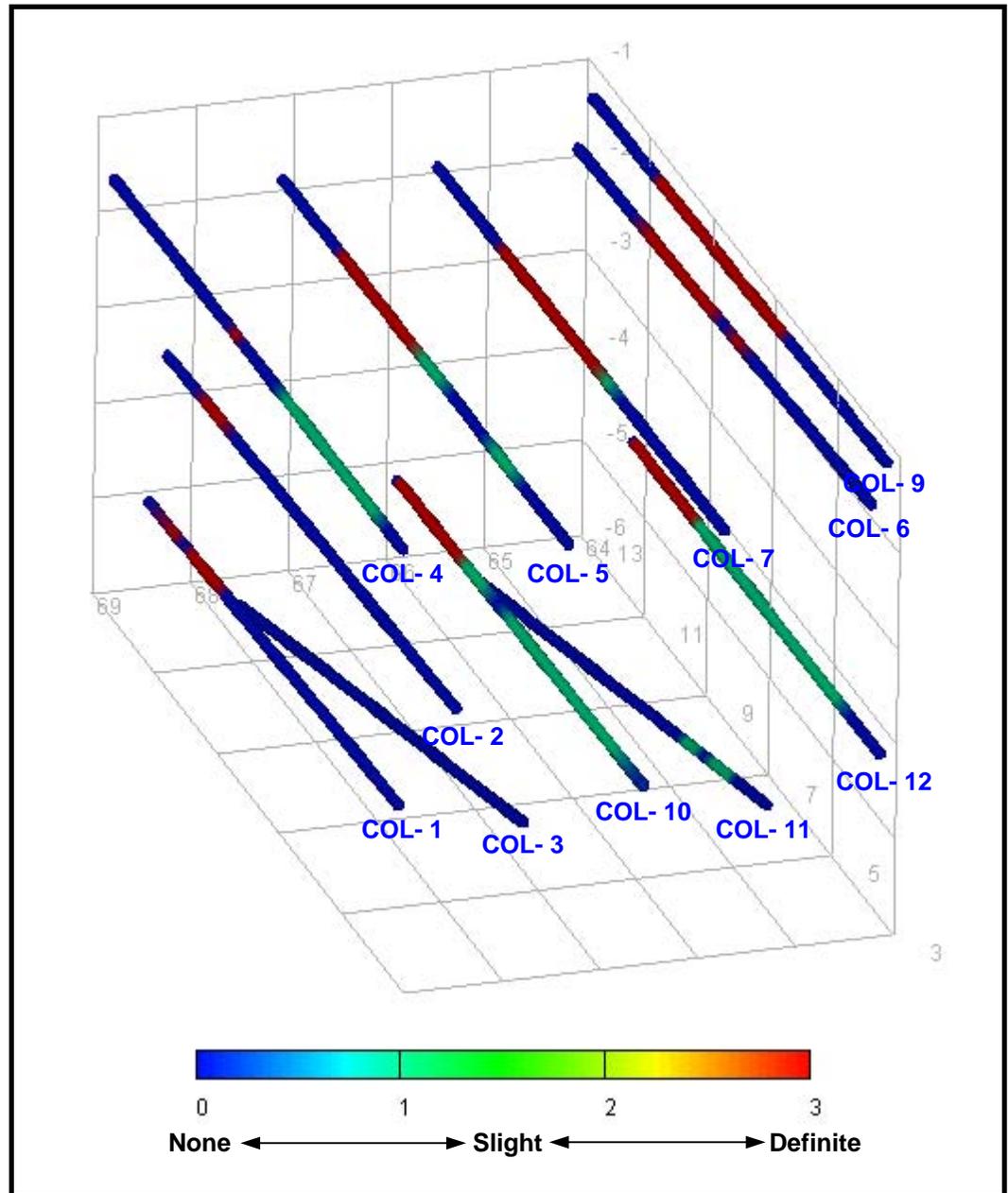
April 1999



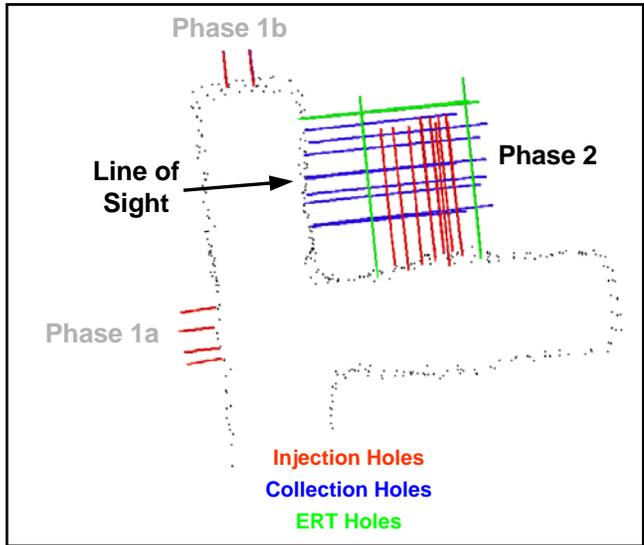
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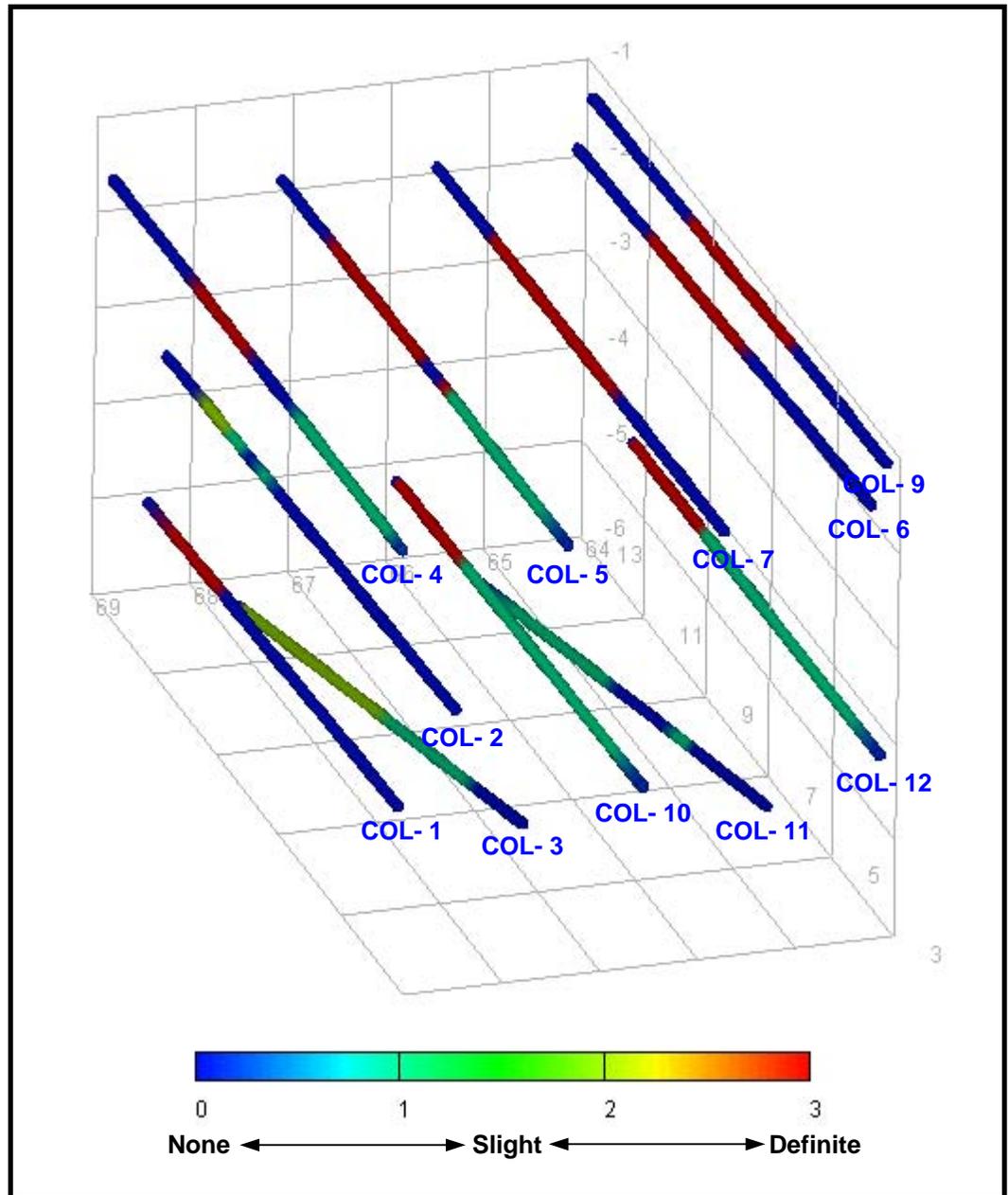
May 1999



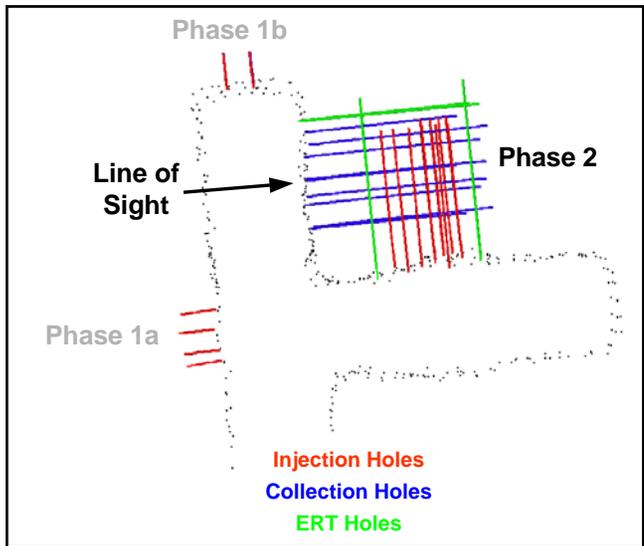
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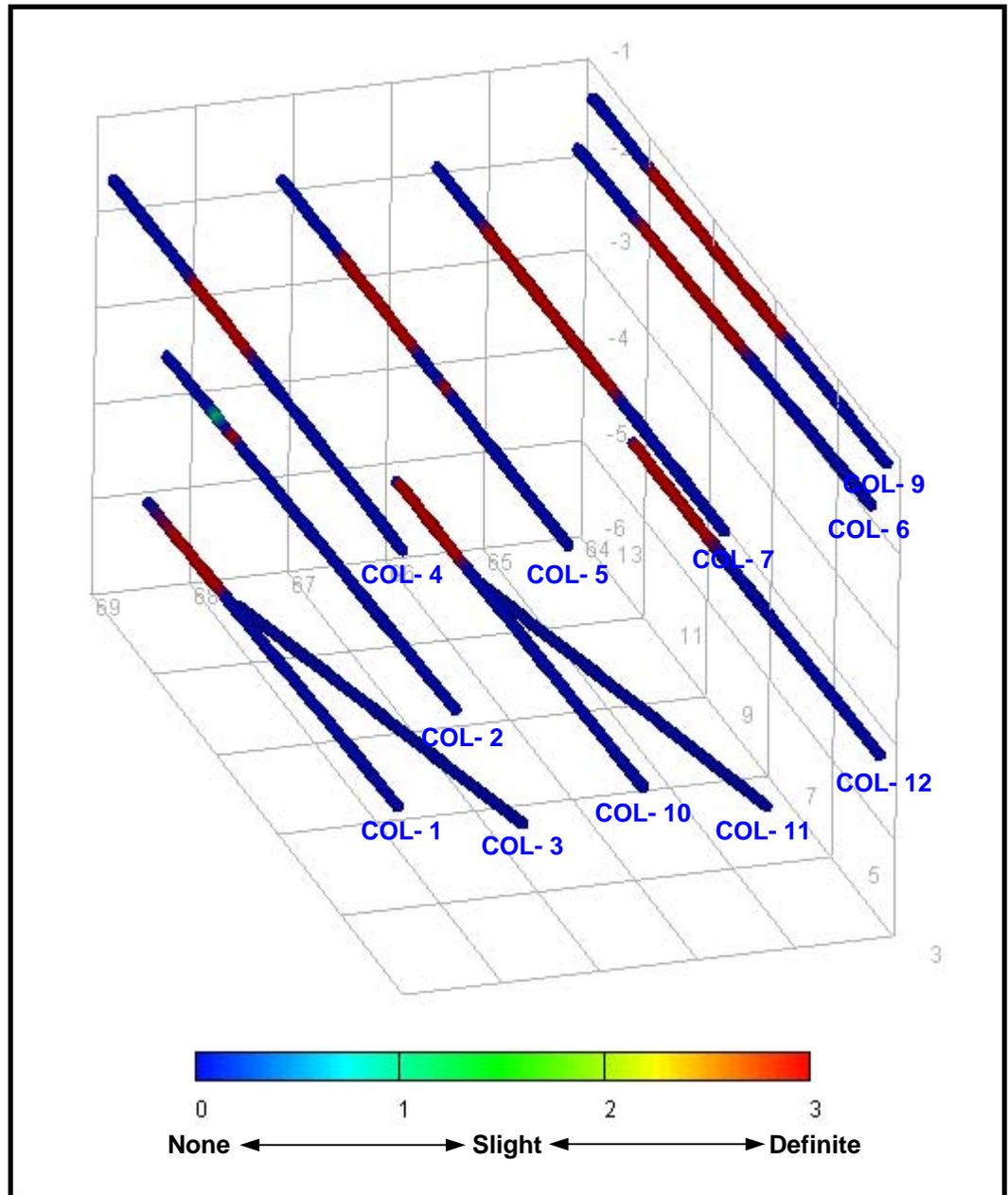
June 1999



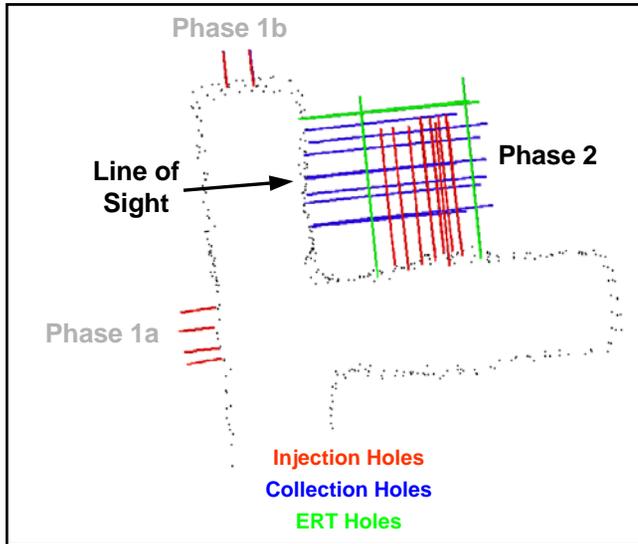
# Busted Butte Unsaturated Zone Transport Test - Phase 2 Breakthrough Data



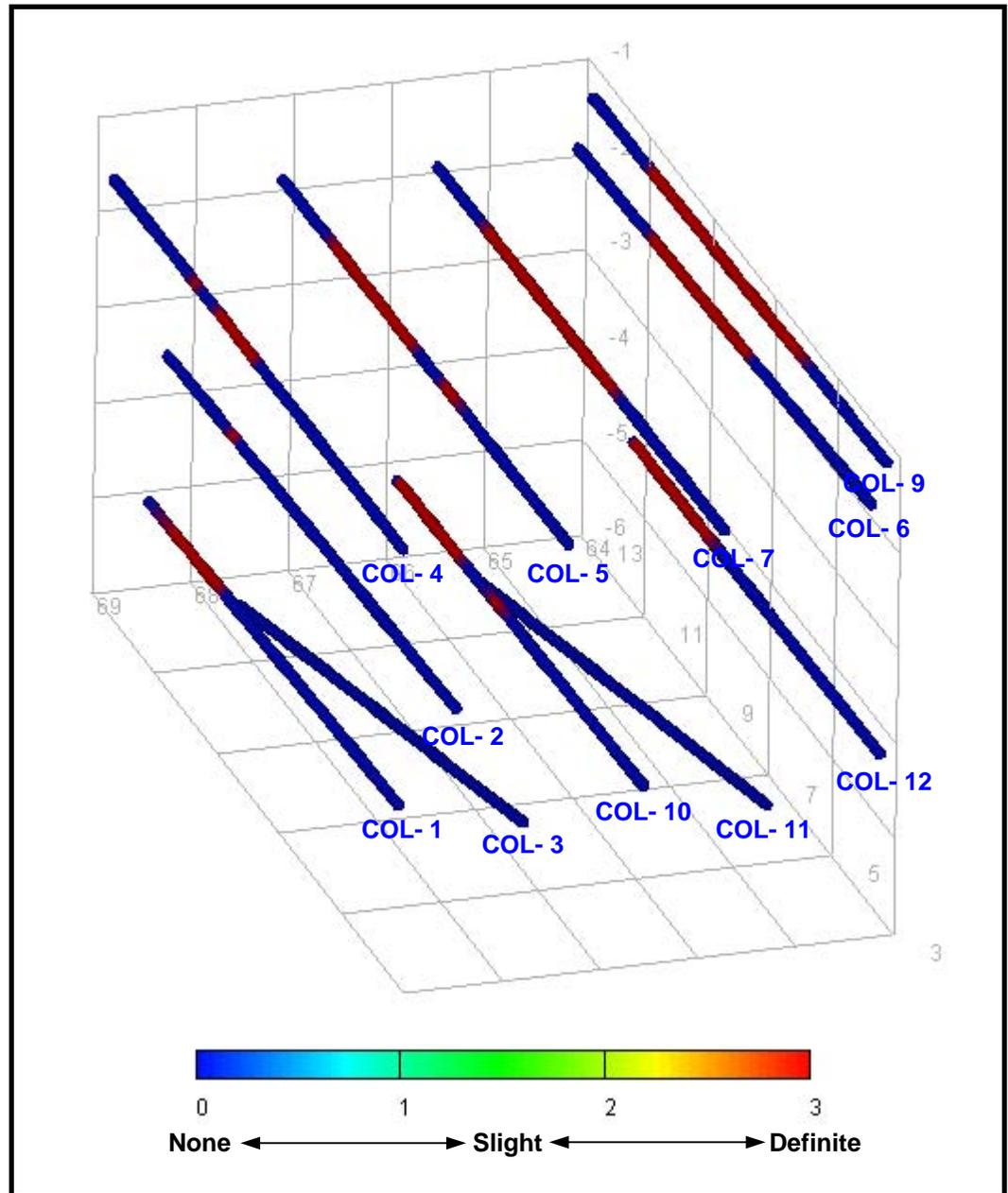
July 1999



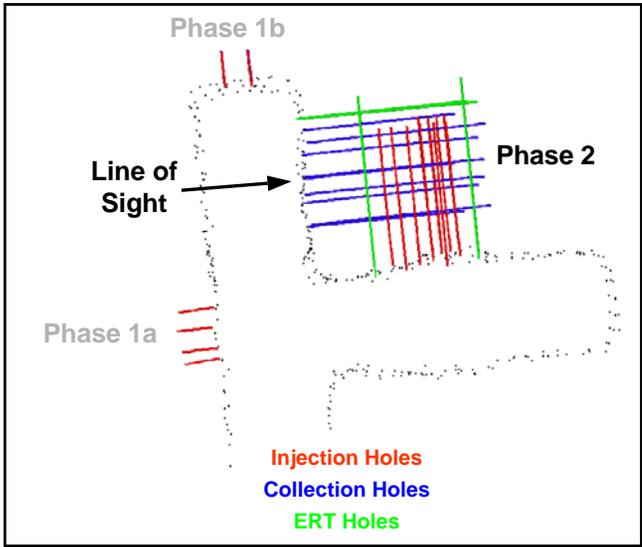
# Busted Butte Unsaturated Zone Transport Test - Phase 2 Breakthrough Data



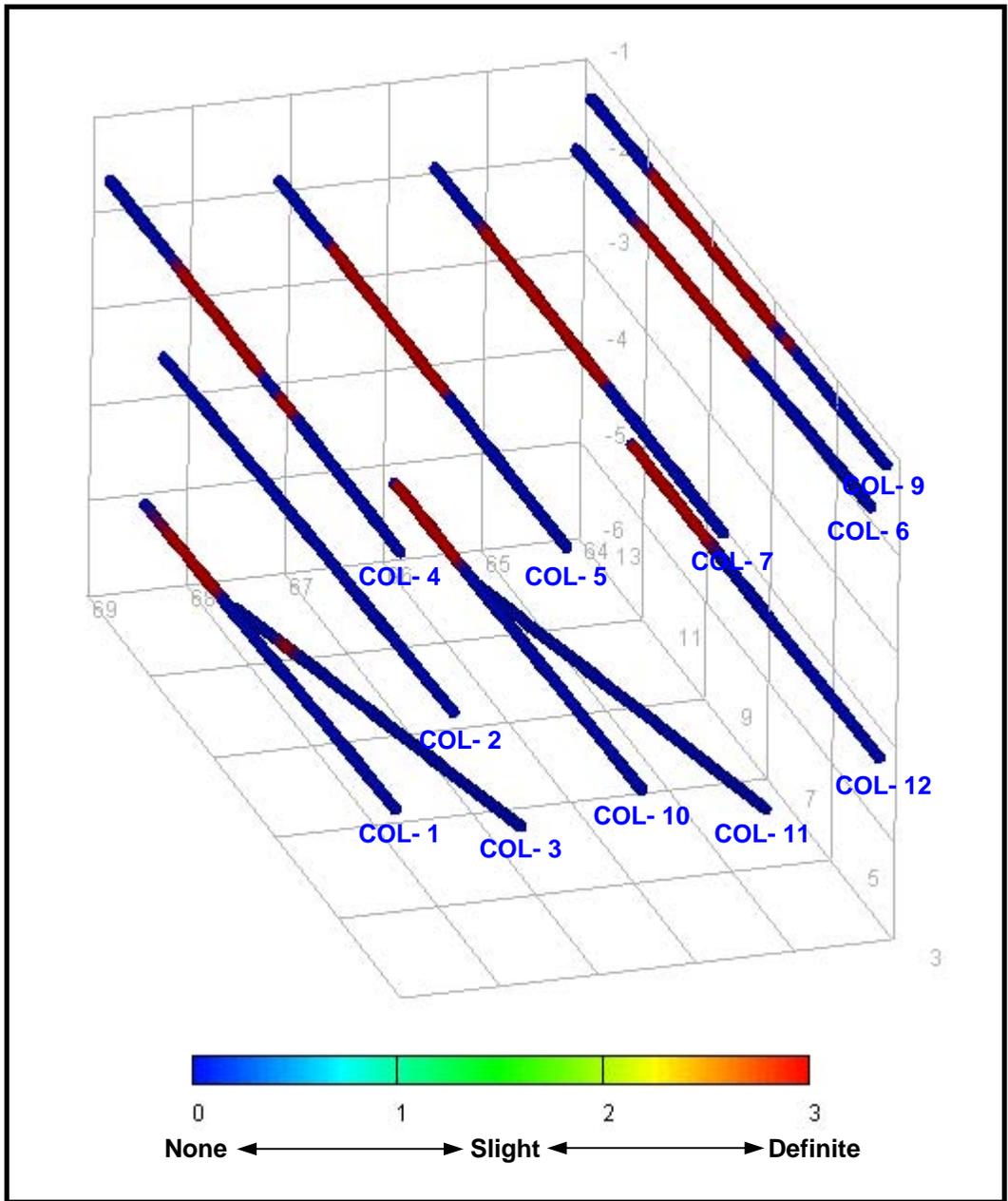
August 1999



# Busted Butte Unsaturated Zone Transport Test - Phase 2 Breakthrough Data



September 1999



# Proposed Phase 2 Test Plan for FY 2000/FY 2001

- **Reactive metals (radionuclide surrogates) have not been detected on collection pads**
  - **Injection continues through FY 2000, in parallel with limited coring**
  - **Limited cores located via predictive modeling and with least potential to disrupt test**
  - **Early retrieval of reactive metals data via rock analyses**
  - **Continued pad analyses for all tracers**
  - **Post-Test characterization via coring and/or mineback in FY 2001**

# Phase 2 Post-Test Characterization Goals

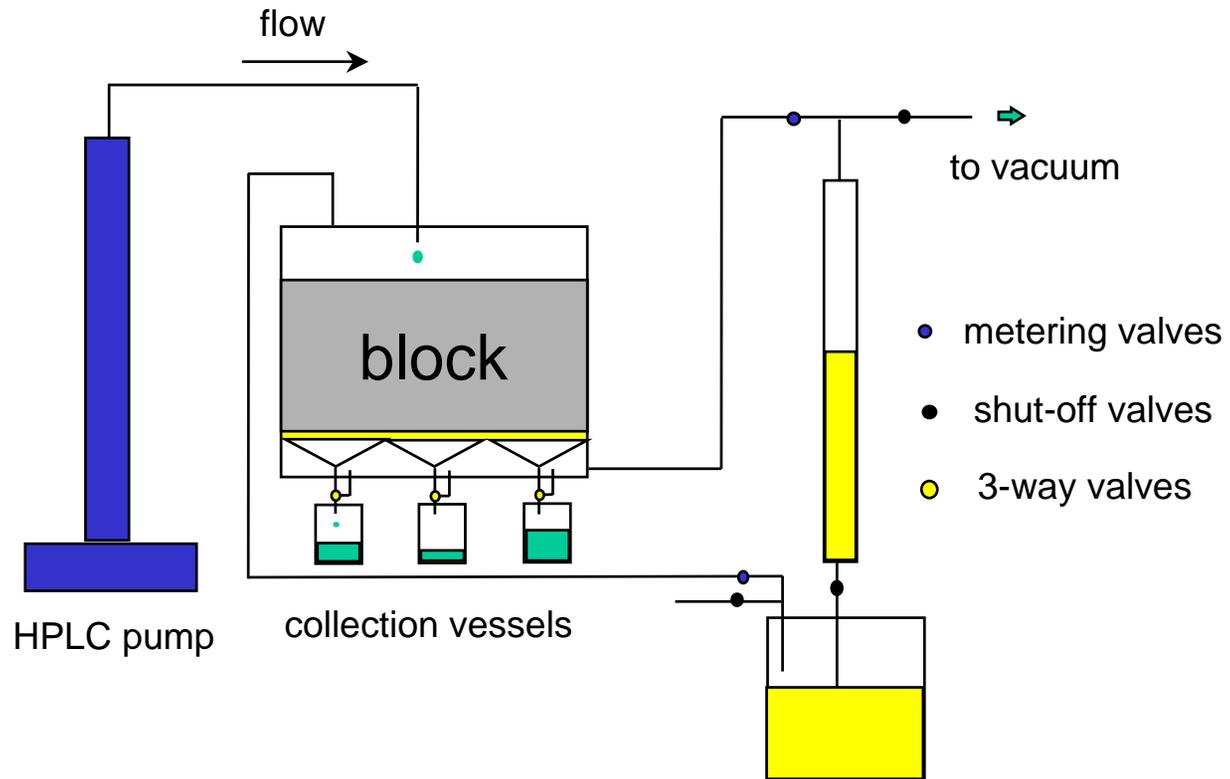
- **Rock sample analyses will be used to:**
  - **Confirm reactive metals (radionuclide analogs) transport data derived from pad analyses (if breakthrough has occurred)**
  - **Confirm and calibrate geophysical results**
  - **Explore effects of faults on matrix-dominated flow regime**
  - **Confirm non-reactive tracer breakthrough (pad) data**
  - **Characterize effects of capillary forces on matrix-dominated flow via samples collected above injection points**

# Conclusions

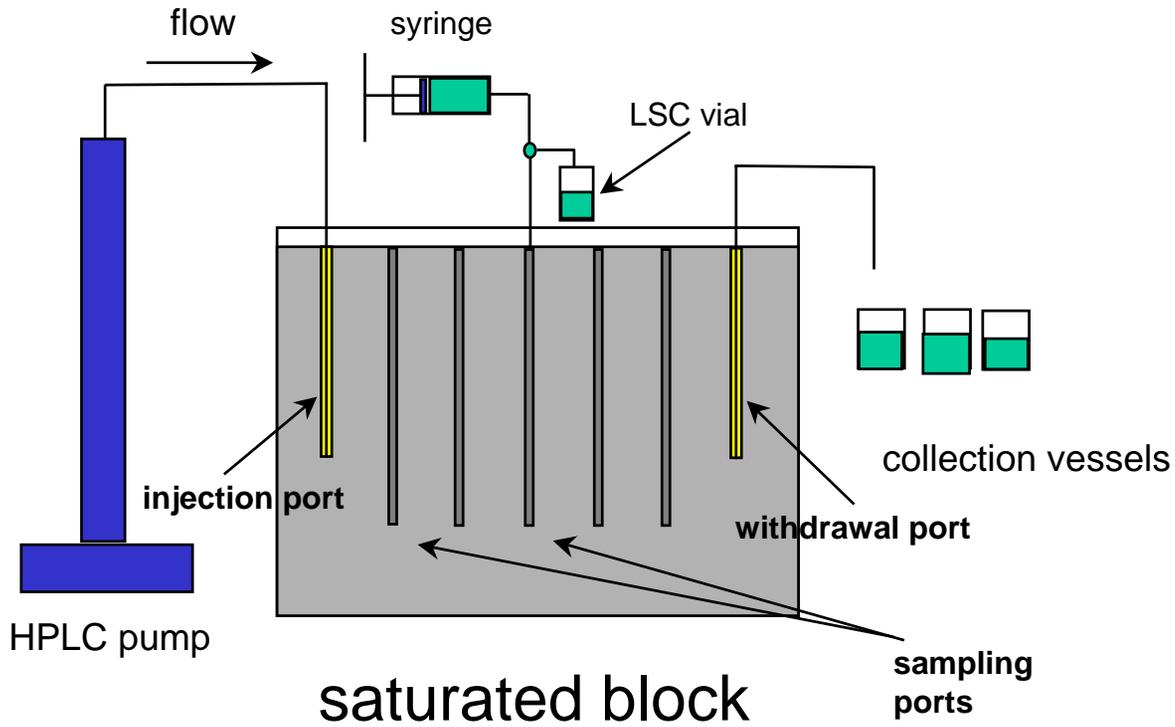
- **Porous media flow dominates in the vitric Calico Hills**
- **Data from boreholes surrounding the repository and results from Busted Butte are expected to build confidence in UZ flow and transport models**
- **Preliminary sorption results indicate smectite is potentially important to performance**
- **Measured sorption values for Busted Butte (vitric) rocks are greater than are currently used in models**
- **Data and analyses from the test will continue to be considered as part of the basis for the preparation of the Site Recommendation Consideration Report and License Application**

# **AECL Work on Busted Butte Calico Hills**

# Schematic for Unsaturated Flow

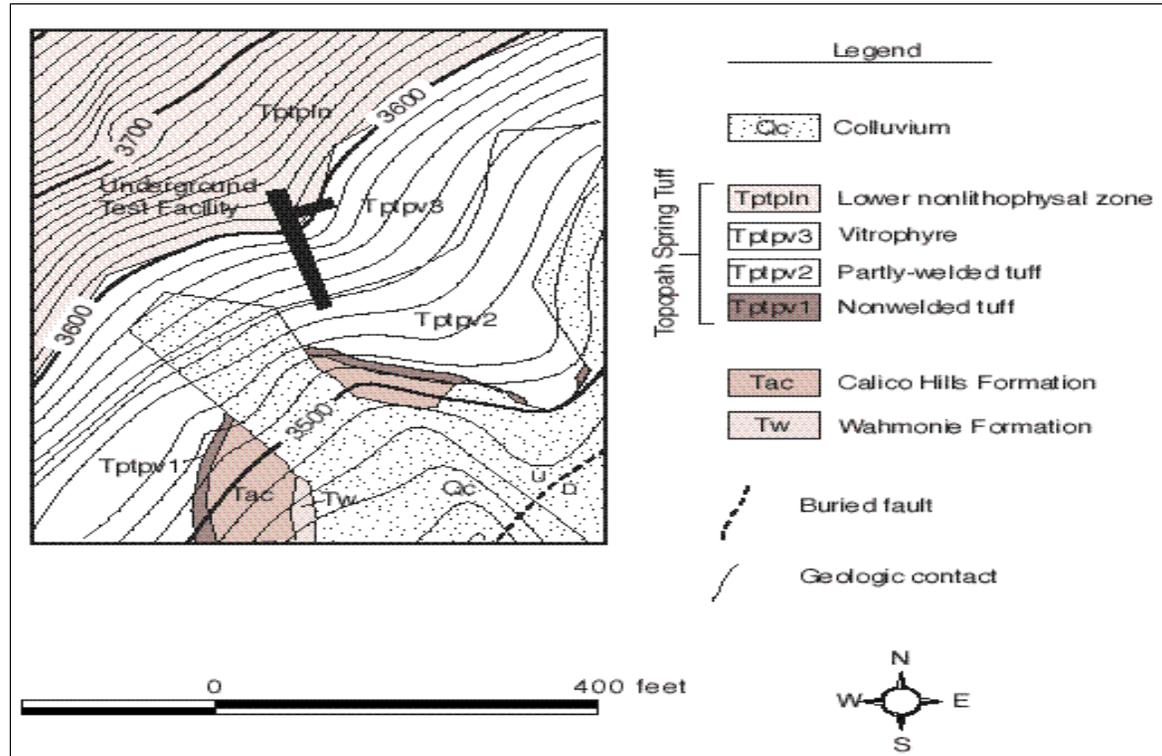


# Schematic for Saturated Flow



# Backup Materials

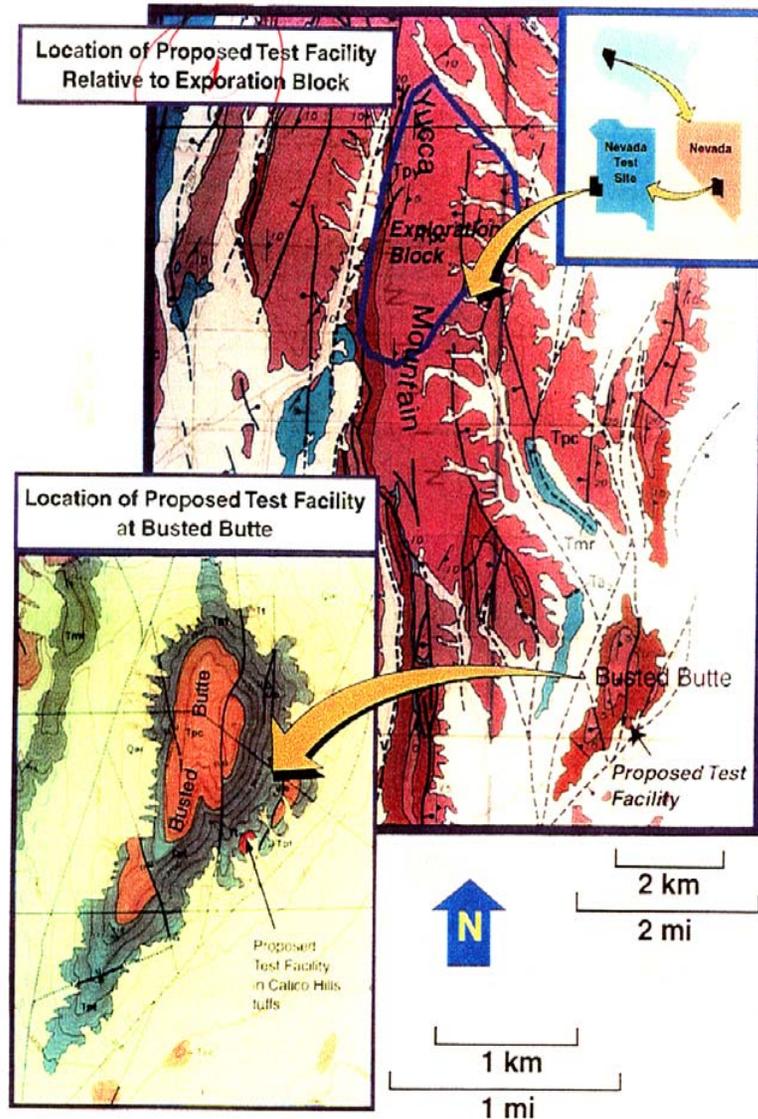
# Busted Butte Geologic Map



Busted Butte Geologic Map

NOTE: The plot is a geologic map of the area around the underground test facility in the southeastern part of Busted Butte.

# Location Map



# Laboratory Sorption Studies of Radionuclides and BB Tracers

## Summary of Radionuclide Sorption Results (Radionuclide)

Sample	Approximate Average $K_d$ ( $\text{g g}^{-1}$ )		
	Np	Am	Pu
PH1-3	20	380	19
PH1-4	21	470	2500
PH1-7	21	450	1100

DTN: LA9909WS831372.003

## Preliminary Measured Sorption Coefficients (Tracer)

Rock sample	Measured $K_d$ ( $\text{mL g}^{-1}$ )			
	Li	Mn	Co	Ni
Tac (Ph. 1, BH #4)	= 1	16	38	34
Tptpv2 (Ph. 1, BH #7)	= 1	6	14	13

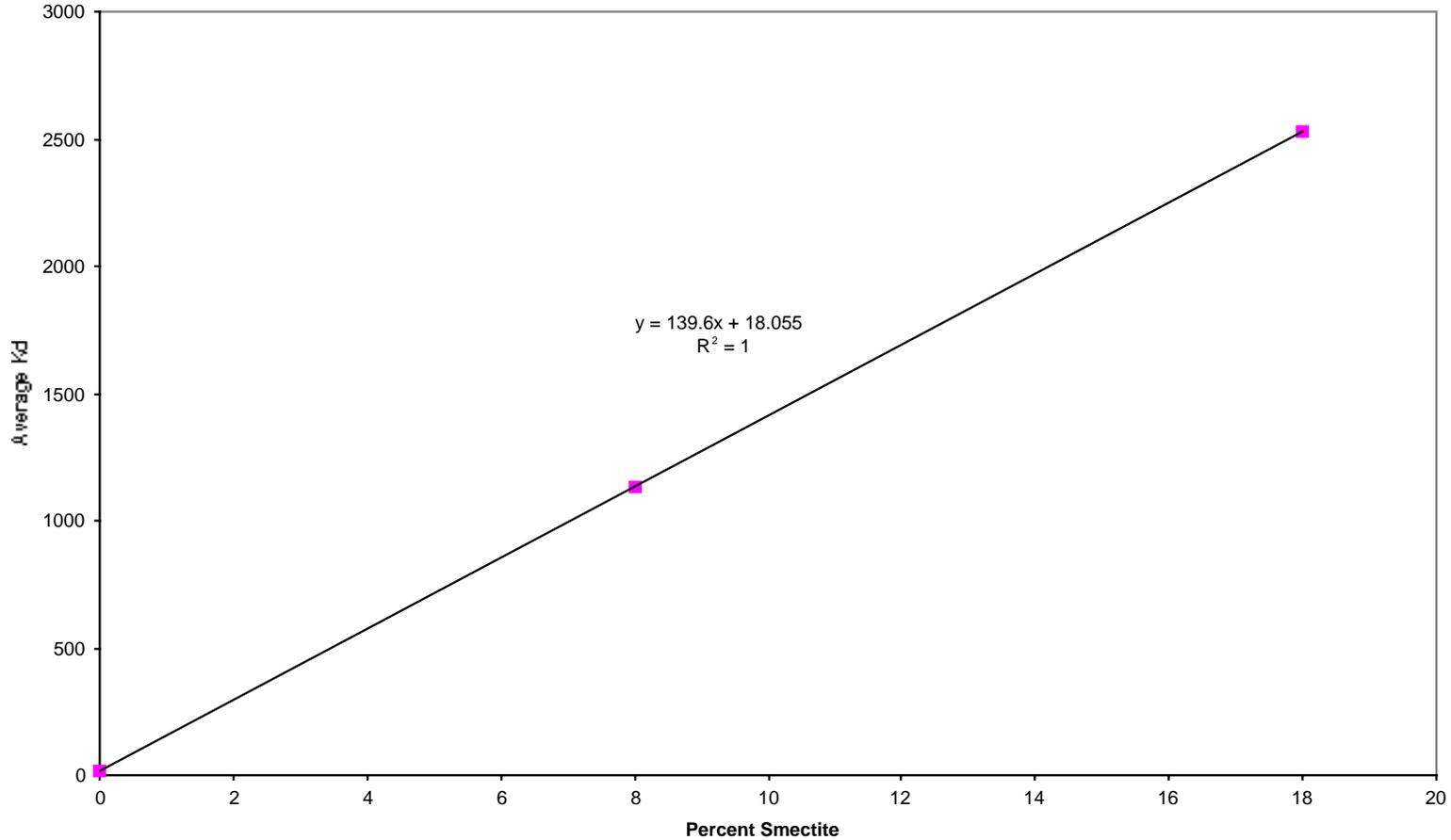
DTN: LA9909WS831372.011

PH1-3 = (Tptpv1) Ph 1A BH#3; PH1-4 = (Tac) Ph 1A BH#4; PH1-7 = (Tpdtpv2) Ph 1B BH#7

Mn, Co, Ni are analog tracers for Np.

# Preliminary Data on the Effects of Smectite on Sorption in Vitric Calico Hills

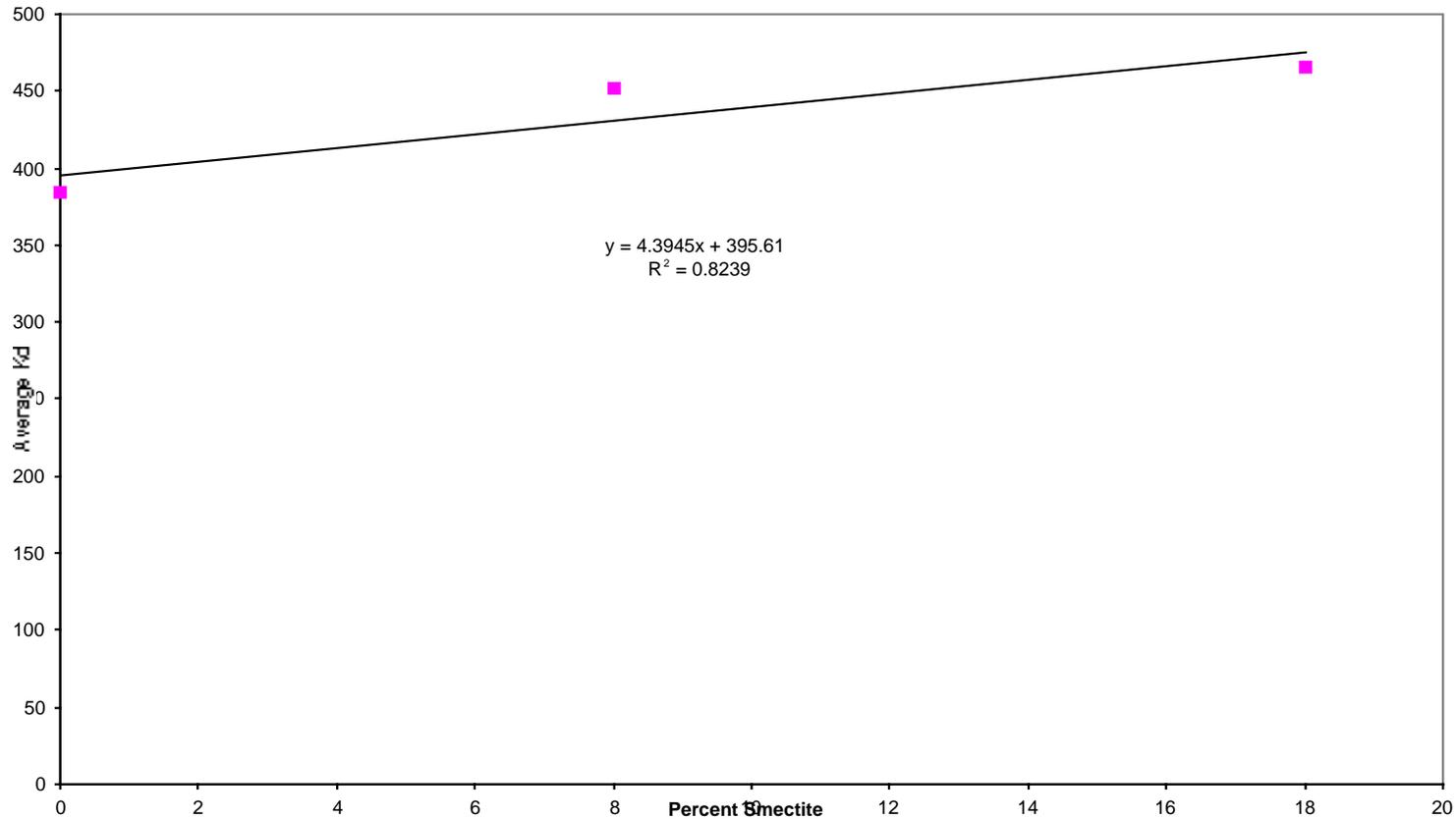
Pu Sorption to BB Vitric Tuffs



P  
P  
M

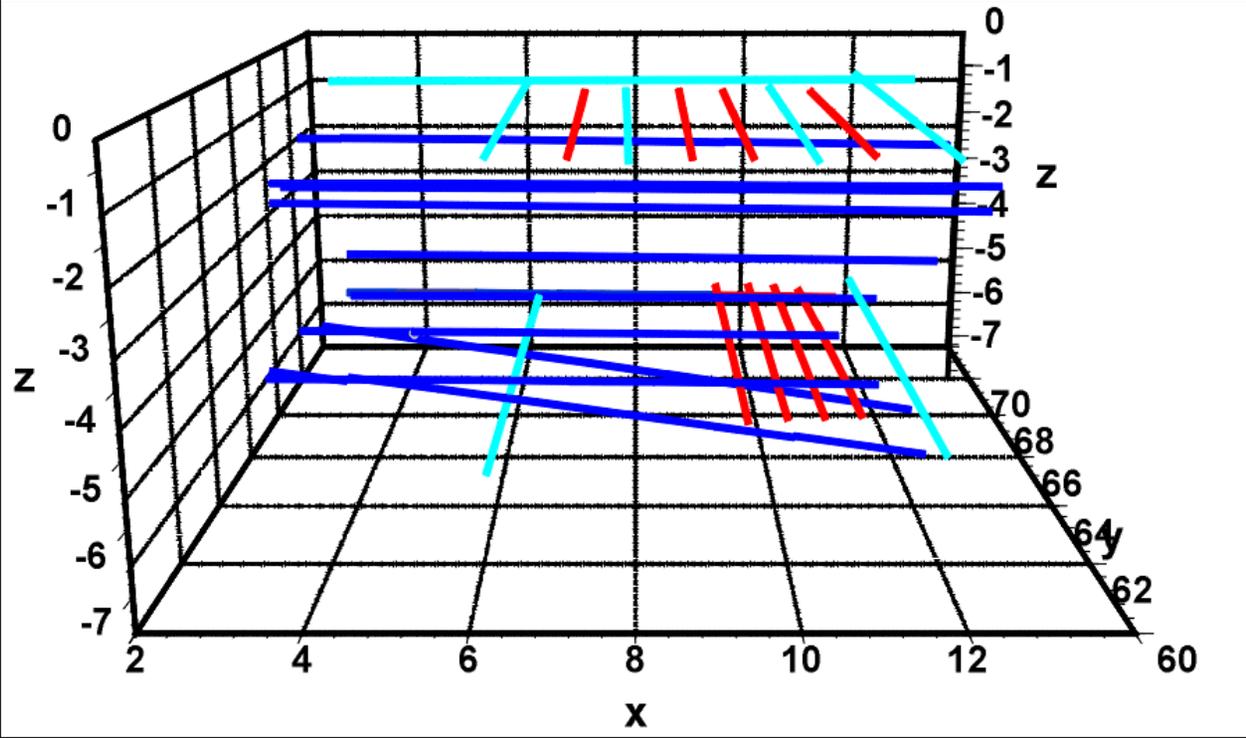
# Preliminary Data on the Sorption Effects of Smectite in Vitric Calico Hills

Am Sorption to BB Vitric Tuffs



P  
P  
M

# 3 Dimensional Collection Borehole Layout

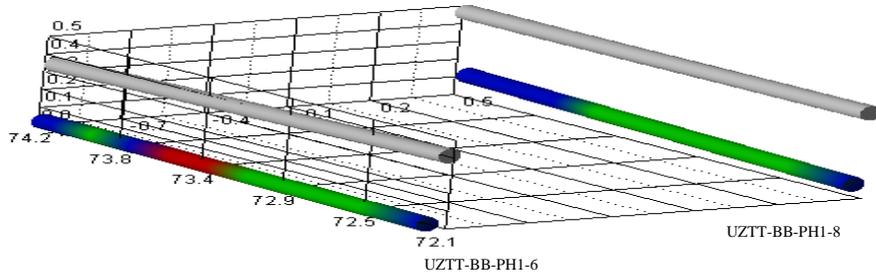


DTN: LA9909WS831372.022

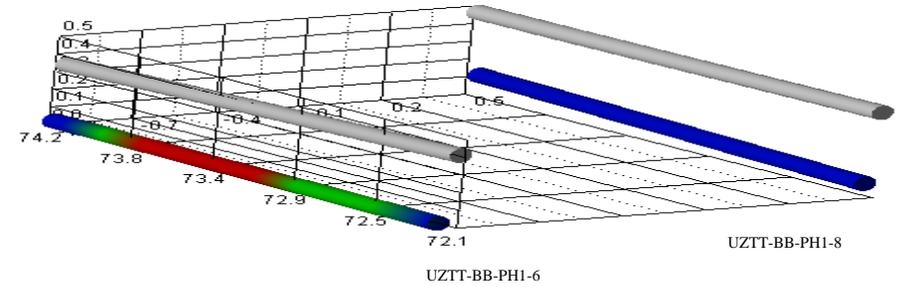
Three-Dimensional View of the Injection and Collection Boreholes

NOTE: The red lines represent injection boreholes, the dark blue lines collection boreholes, and the light blue lines are devoted to tomography. In this view, the Test Alcove is located in front of the figure, and the Main Adit is to the left of the figure (beyond the  $x = 2$  plane).

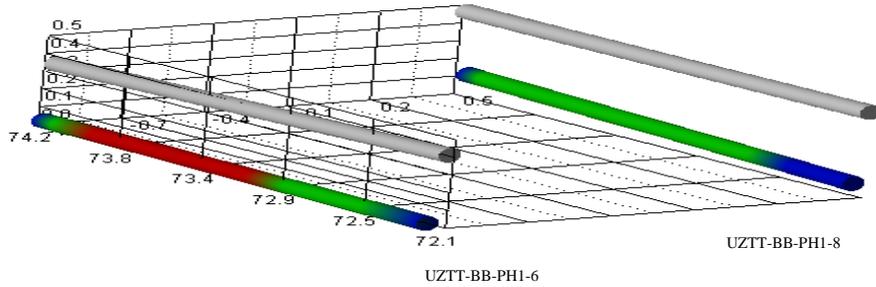
# Busted Butte Unsaturated Zone Test Phase 1B Total Moisture (g)



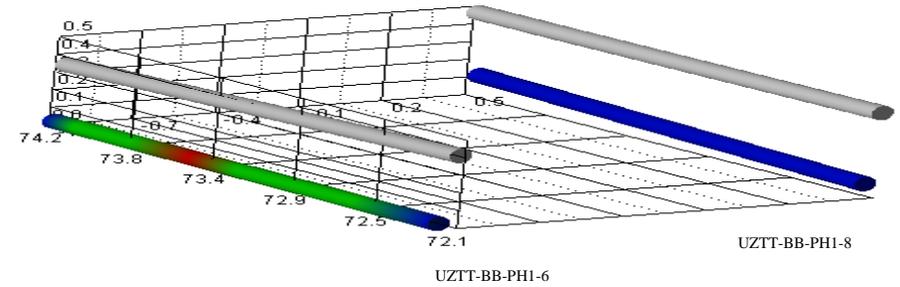
**June 9, 1998**



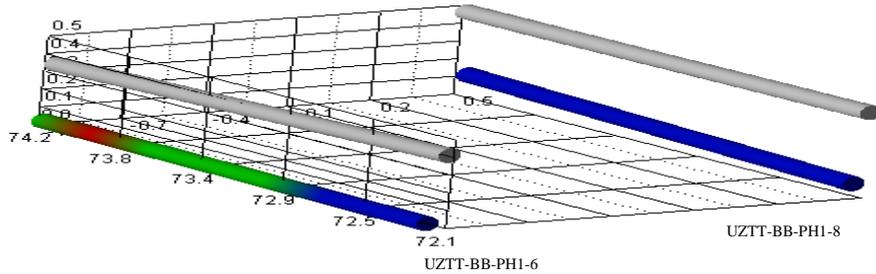
**July 15, 1998**



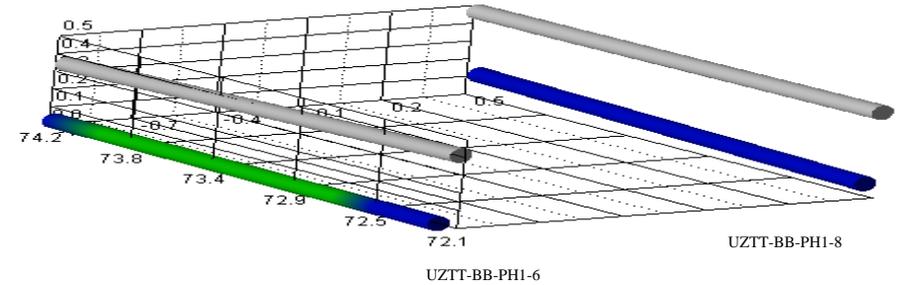
**August 26, 1998**



**September 29, 1998**



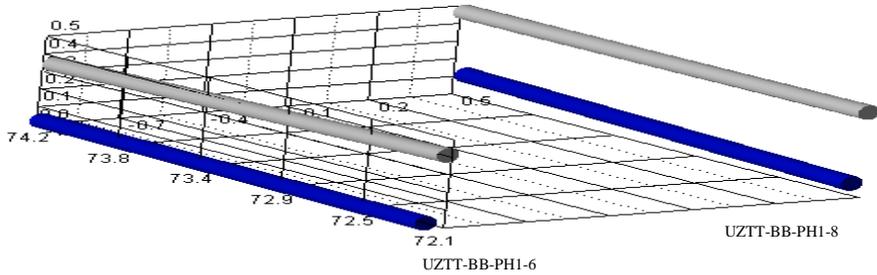
**October 27, 1998**



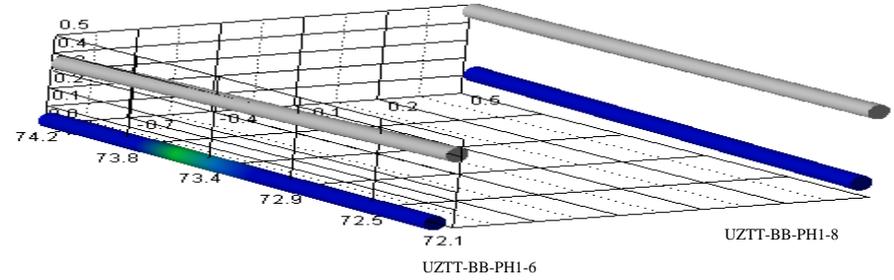
**November 18, 1998**



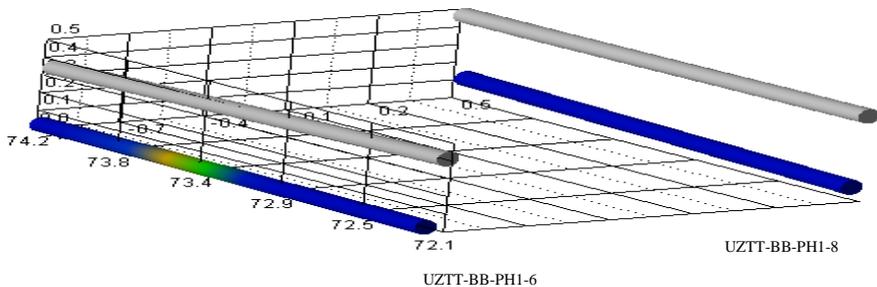
# Busted Butte Unsaturated Zone Test Phase 1B Bromide (mg/kg)



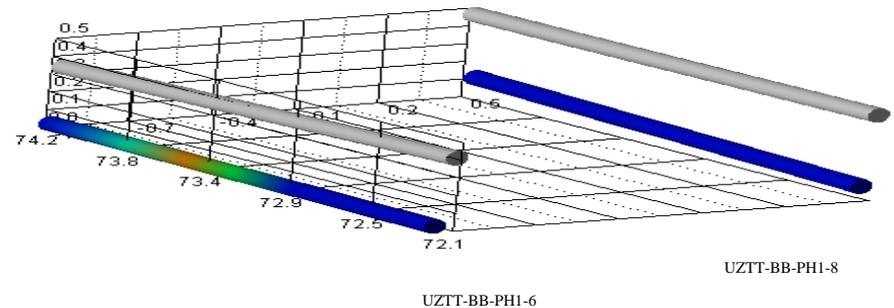
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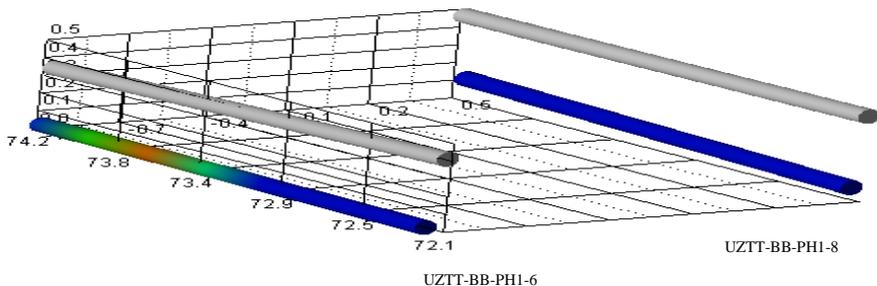
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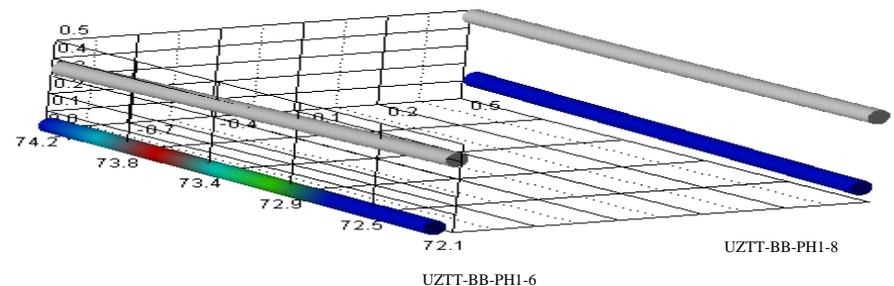
**August 12, 1998**



**September 29, 1998**



**October 27, 1998**

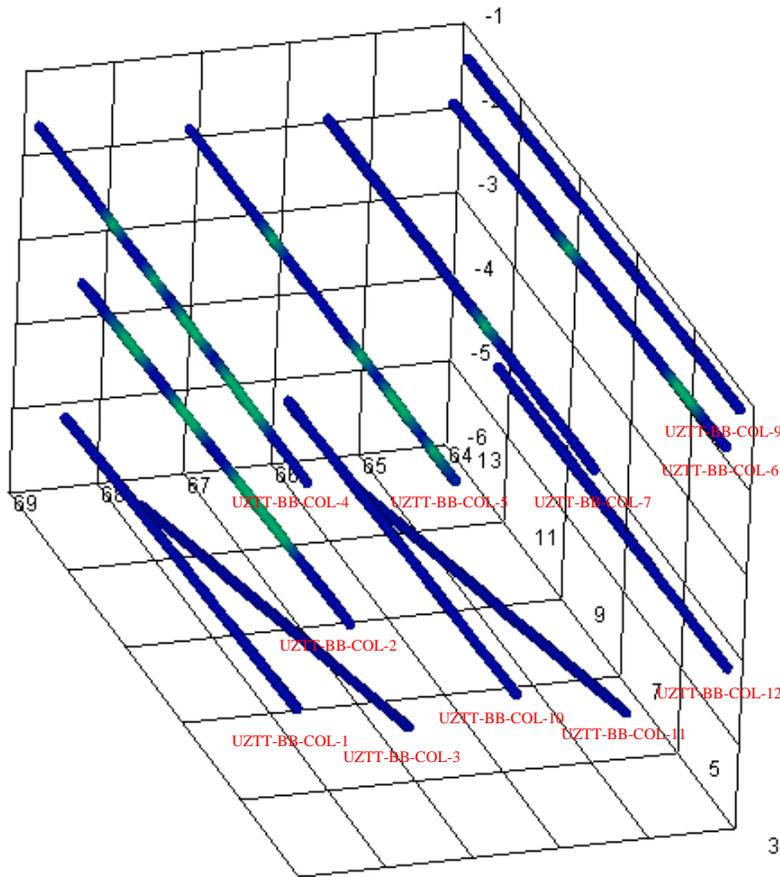


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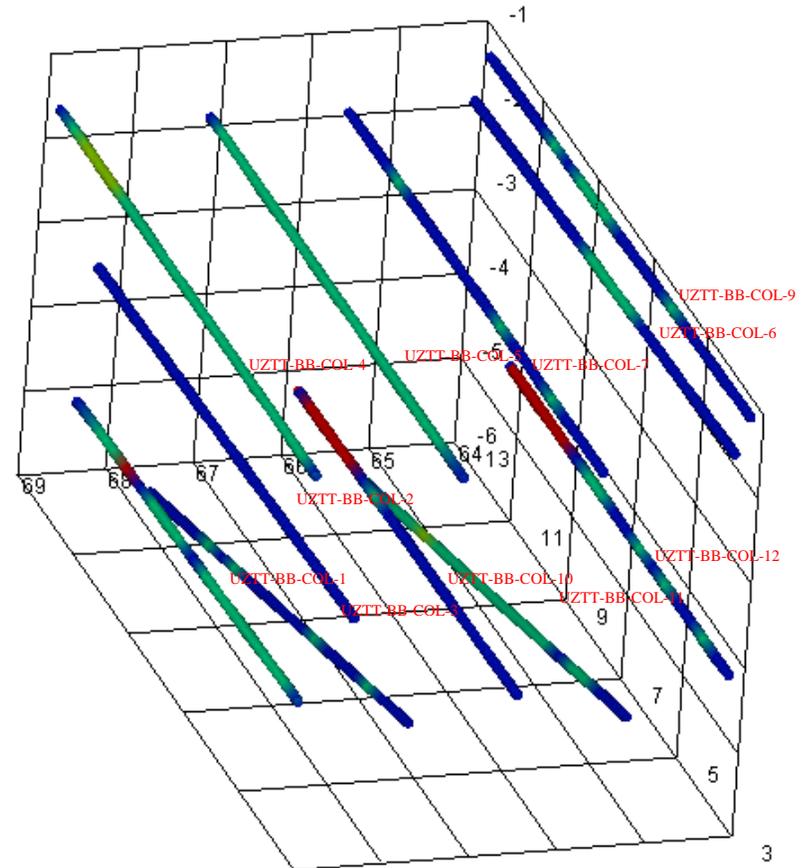


# Busted Butte Unsaturated Zone Transport Test

Phase 2 Collection Breakthrough Data (scale from 0 to 3, 0 = no breakthrough)



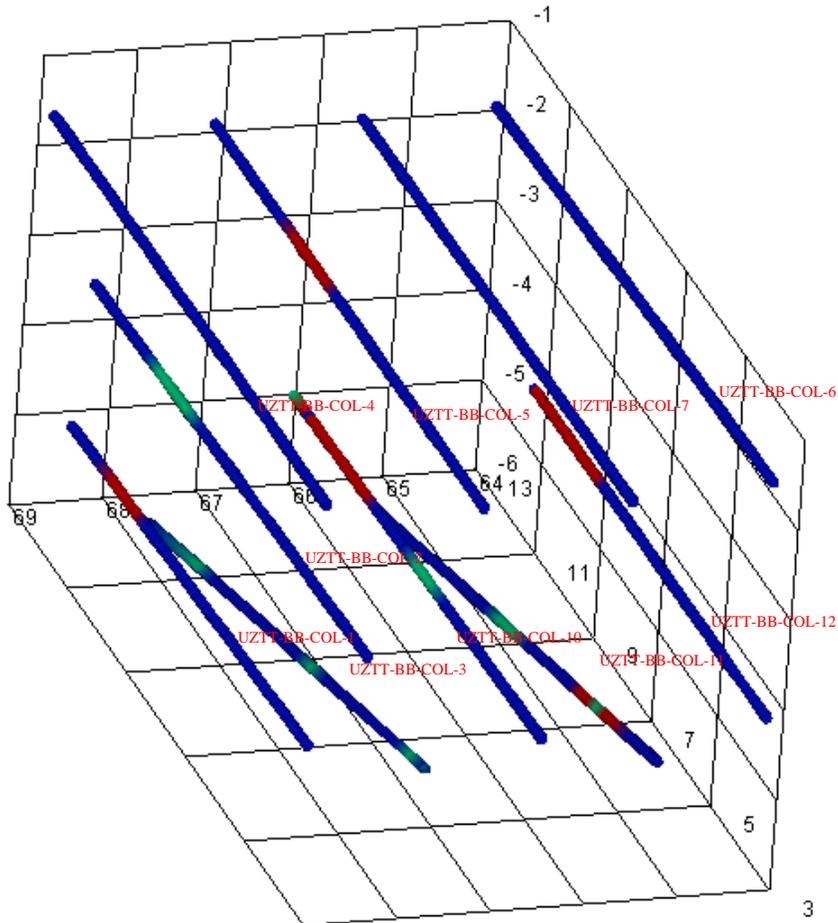
August 1998



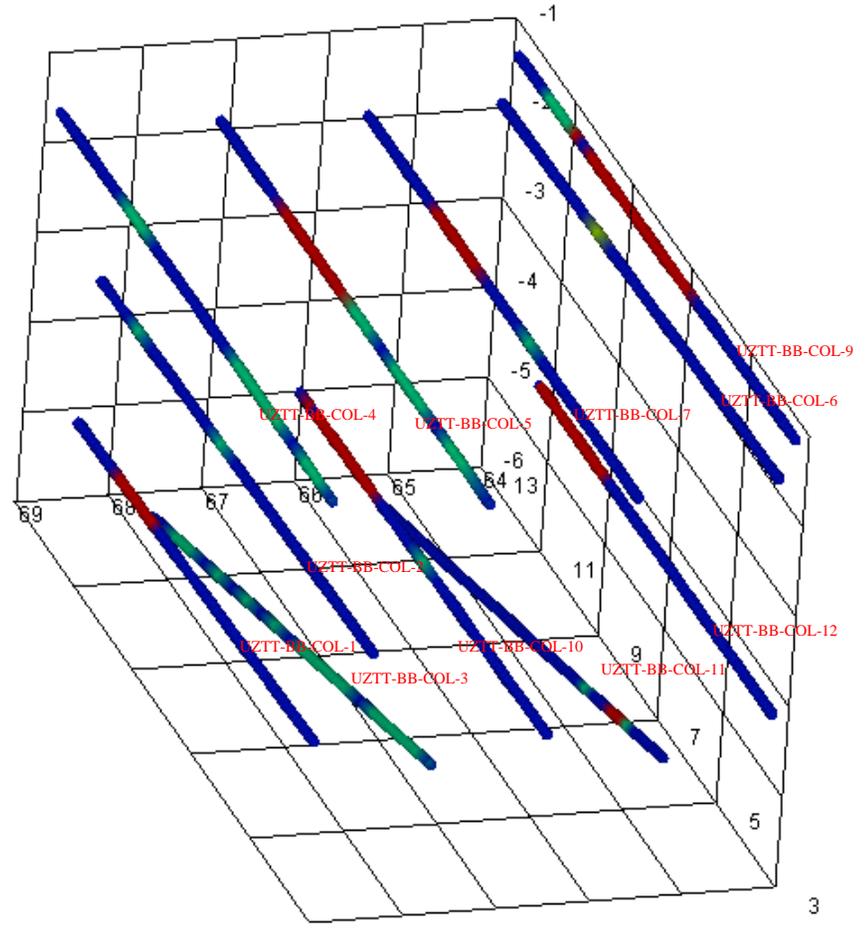
September 1998

# Busted Butte Unsaturated Zone Transport Test

Phase 2 Collection Breakthrough Data (scale from 0 to 3, 0 = no breakthrough)



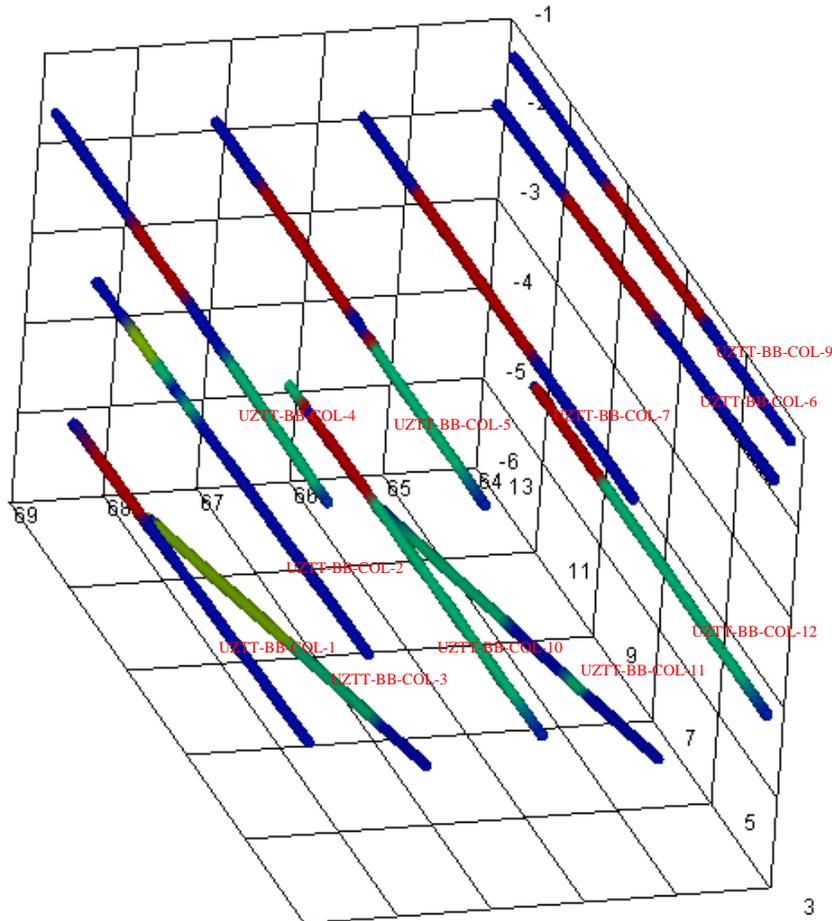
February 1999



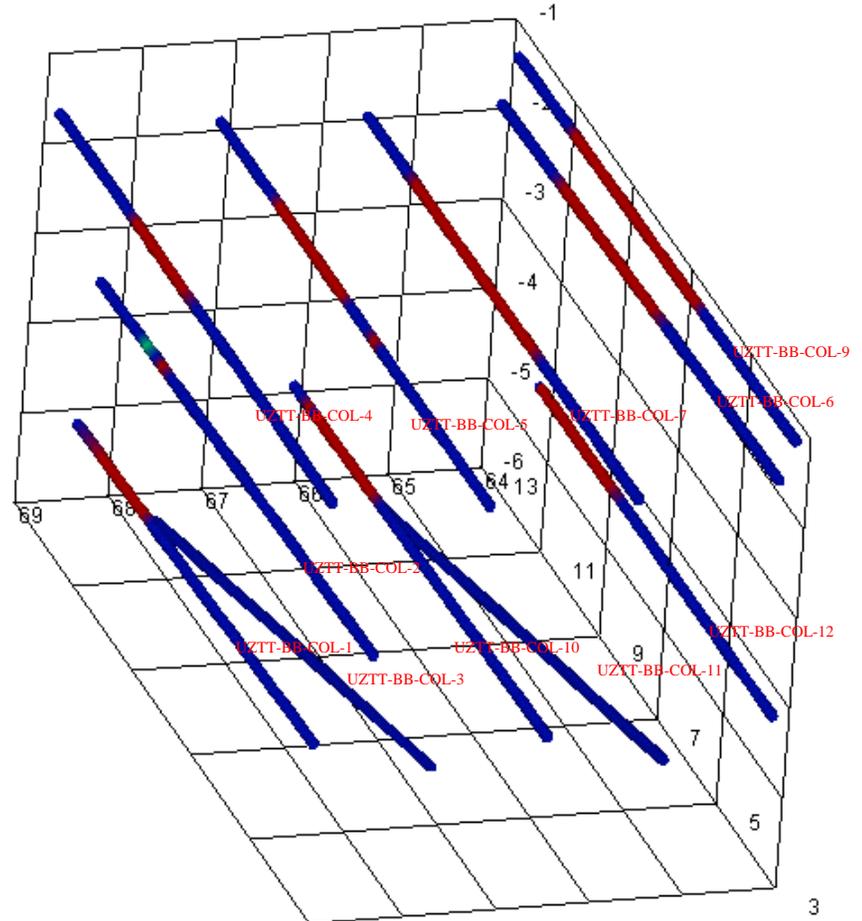
March 1999

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Phase 2 Collection Breakthrough Data (scale from 0 to 3, 0 = no breakthrough)



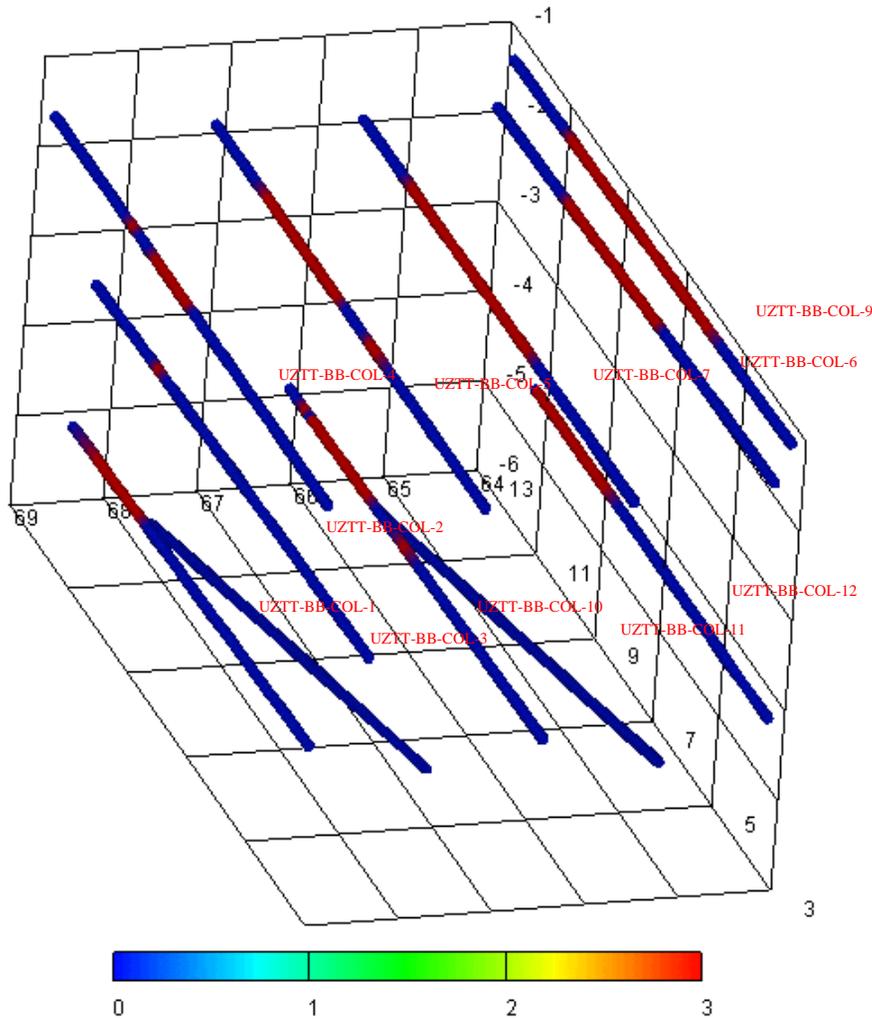
June 1999



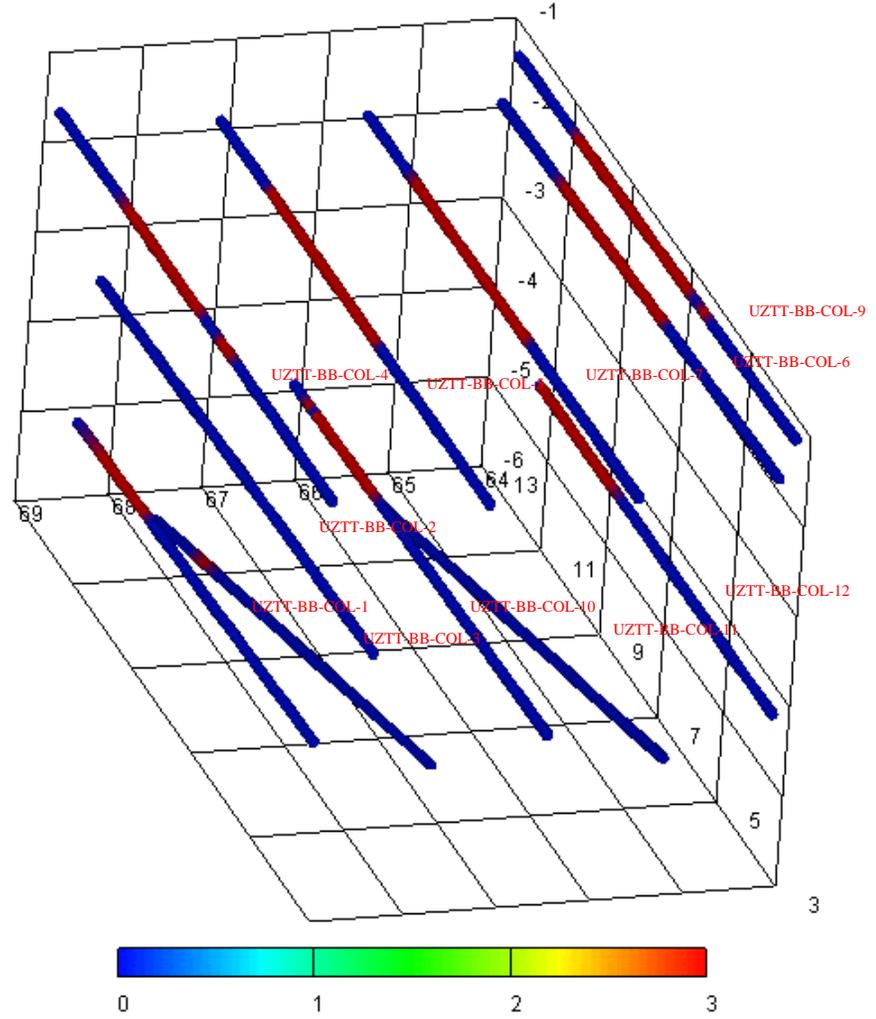
July 1999

# Busted Butte Unsaturated Zone Transport Test

Phase 2 Collection Breakthrough Data (scale from 0 to 3, 0 = no breakthrough)



August 1999



September 1999