Influence of Clastic Dikes on Vertical Migration of Contaminants in the Vadose Zone at Hanford – November 2001

Chris Murray, Andy Ward, Phil Long, Yi-Ju Chien, Fred Zhang, Peter Kannberg, Randy Kirkham, Glendon Gee, Duane Horton, and Mike Fayer - PNNL

John Wilson and BJ Lechler - New Mexico Institute of Mining and Technology

Bill Clement – Boise State University

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Background

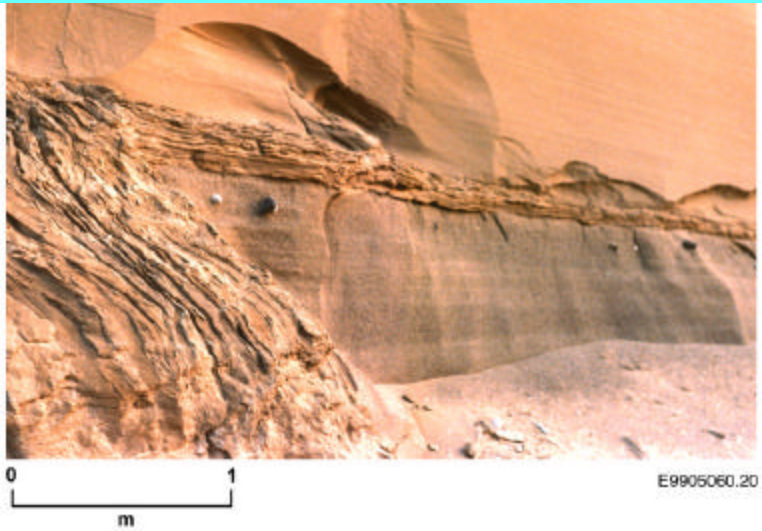
- Contaminants at Hanford have migrated more deeply than expected
- Preferential pathways could explain the discrepancy between predicted and observed travel times
- Clastic dikes are one of the principal vertical discontinuities known to exist around tank waste leak sites.

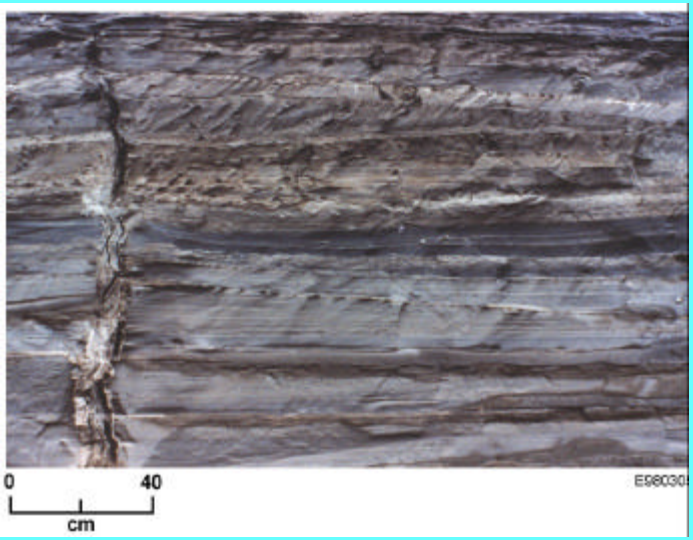
Goal

- Develop a basic scientific understanding of clastic dikes at the Hanford Site and their possible role as preferential pathways for vadose zone contaminant transport

Scientific Approach

- Determine spatial patterns
- Measure hydrogeologic properties
- Evaluate potential effects on fluid flow through the vadose zone





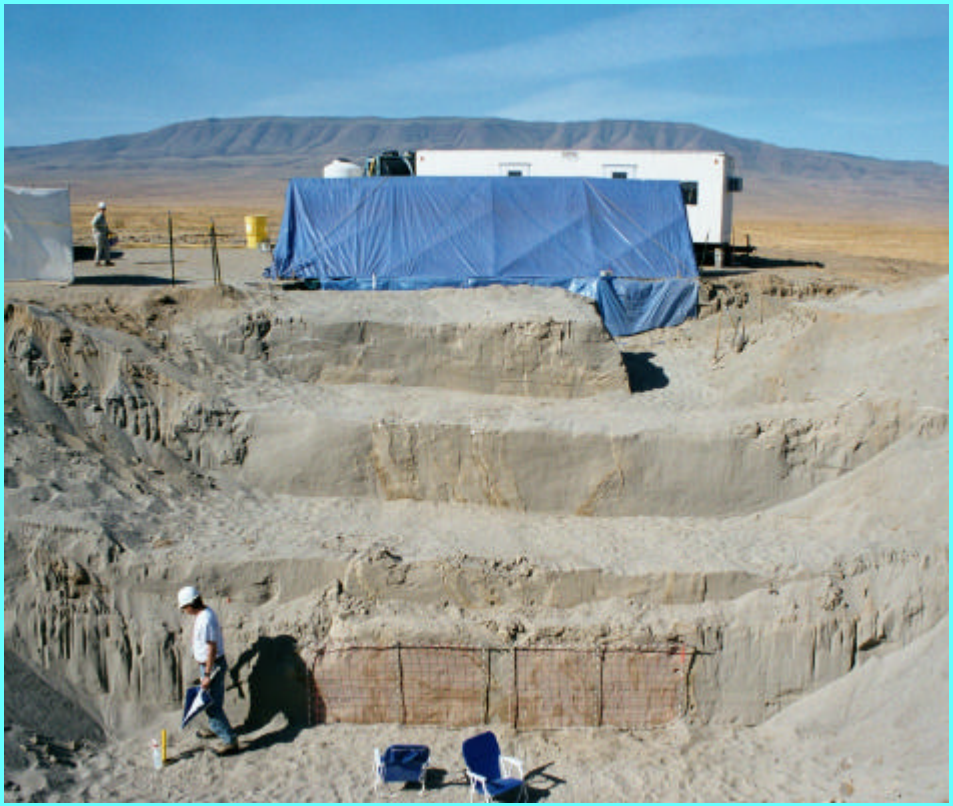
Phase 2: Measurement of Dike and Matrix Properties

- Small Scale Measurement and Estimation
  - Measure dike and matrix exposed in excavation
    - Small scale (1 to 100 mm)
    - Large sample size
    - Variability
  - Air-minipermeameter
    - large, but limited, number of accurate permeability measurements
  - Infrared imaging
    - continuous imaging of exposure
    - cm-scale resolution
- Field Infiltration Experiments
  - Large scale (0.1 to 10 m)

Measure Properties (cont.)

- Grain Size and Mineralogy
  - XRD of non-clay fraction indicates normal Hanford mineralogy
    - Quartz, feldspar, pyroxene, mica, chlorite, amphibole, calcite
    - No readily discernible difference between dike and host
  - Grain size analysis indicates higher clay content present in dike
    - 3 to 8 percent in matrix
    - 6 to 16 percent in clastic dike
  - XRD of clay fraction
    - smectite, chlorite, illite, and kaolinite, with a small amount of quartz and feldspar

Clastic Dike Excavation – Army Loop Road



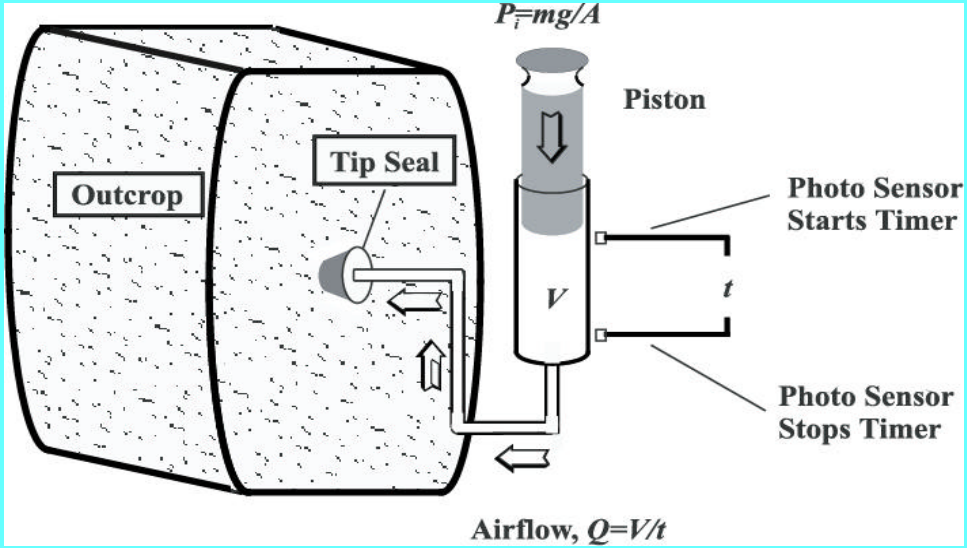
- Excavation in June 2001
  - ~ 4 m of vertical exposure
  - 3 working levels
  - Logistical support from Groundwater/ Vadose Zone Integration Project
- Characterization
  - Geologic mapping
  - Air permeability
  - Infrared imaging
  - Grain size
  - Moisture
  - Mineralogy (XRD)
  - Infiltration/tracer experiments

Extension of Air Mini-Permeameter Range

- The LSAMP II air mini-permeameter developed by New Mexico Tech had a practical range of $1x10^{-10}$ - $5x10^{-13}$ m^2
  - ~ $9.7x10^{-04}$ to $4.9x10^{-06}$ m/sec, corresponding to fine to medium sand
  - measuring less permeable material took too long
- How can the LSAMP II be modified to measure the less permeable facies of the clastic dikes?

Permeameter Modifications by NMT

Only control on measurement time is P_i, the inner tip seal pressure.



$P_i = mg/A$, to make P_i greater we have to add mass

Permeameter Modification Issues/Resolution

- Permeameter operates under assumption that piston reaches terminal velocity before it passes first photo sensor.
  - How much mass can be added before assumption is invalid?
- Permeameter calibrated in the laboratory with and without added mass of varying sizes
  - Increasing mass of piston by up to 1 order of magnitude causes max 2% error in calculated permeability
  - Range of instrument extended on lower end by 1 order of magnitude
- Good for relative comparison of dike and matrix

Air-minipermeameter

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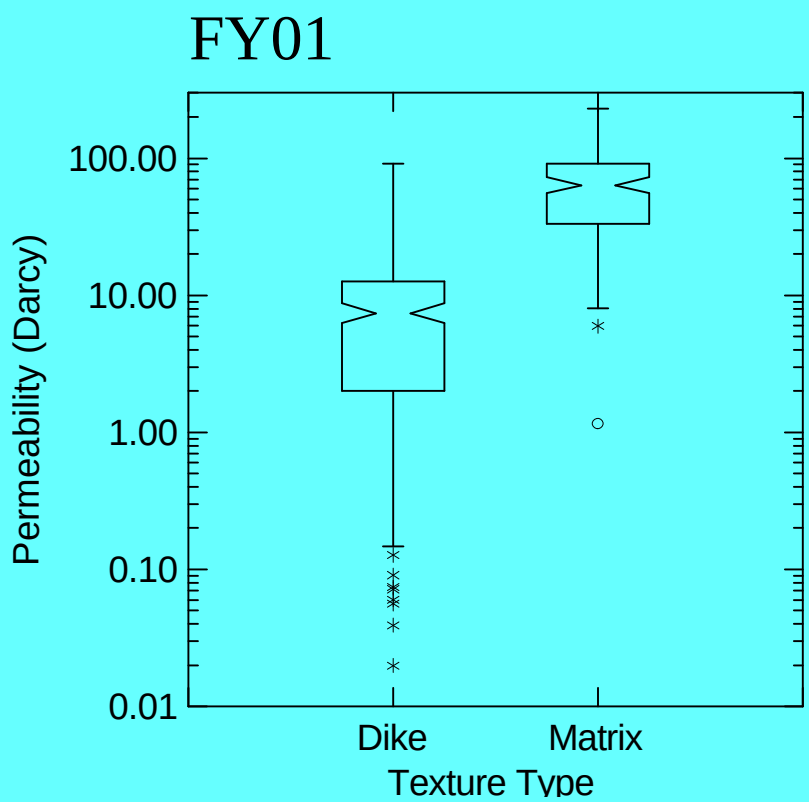
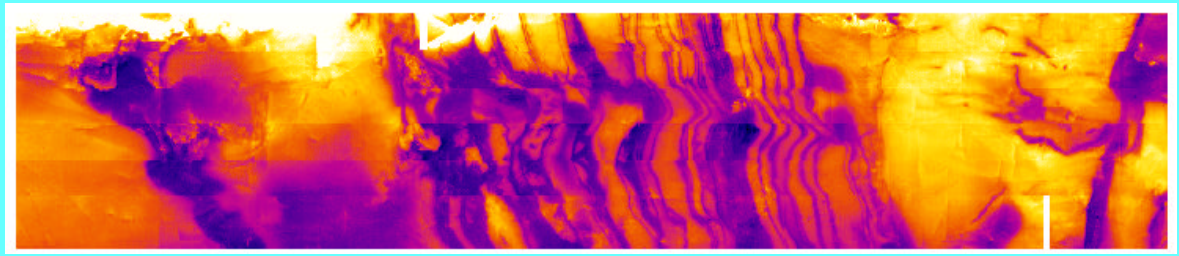
Air-minipermeameter results

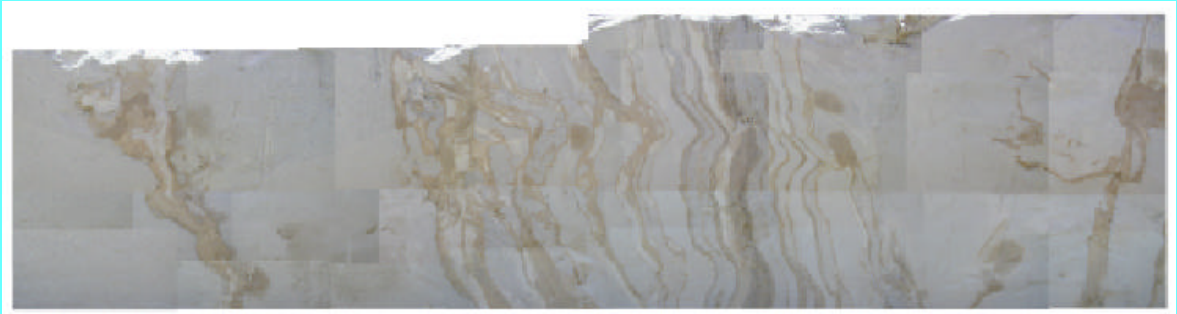


- 2 instruments employed in FY2001
  - Low-perm and standard
  - 3 times as many measurements as previous year
- 456 measurements on 3 tiers
  - 1/3 in dike
  - 2/3 in matrix
- Additional samples on horizontal exposure of dike and in matrix
- Significant difference in air permeability
  - Dike has lower perm than matrix
  - Approx 1 order of magnitude difference
  - Both fine and coarse zones occur in both dike and matrix
  - Dike has coefficient of variation twice that of matrix (1.2 vs 0.6)

Infrared Imaging

- Complex moisture pattern seen in IR (top)
  - coarser grained (light/low moisture)
  - finer grained (dark/high moisture)
- IR data will be correlated with air perm data



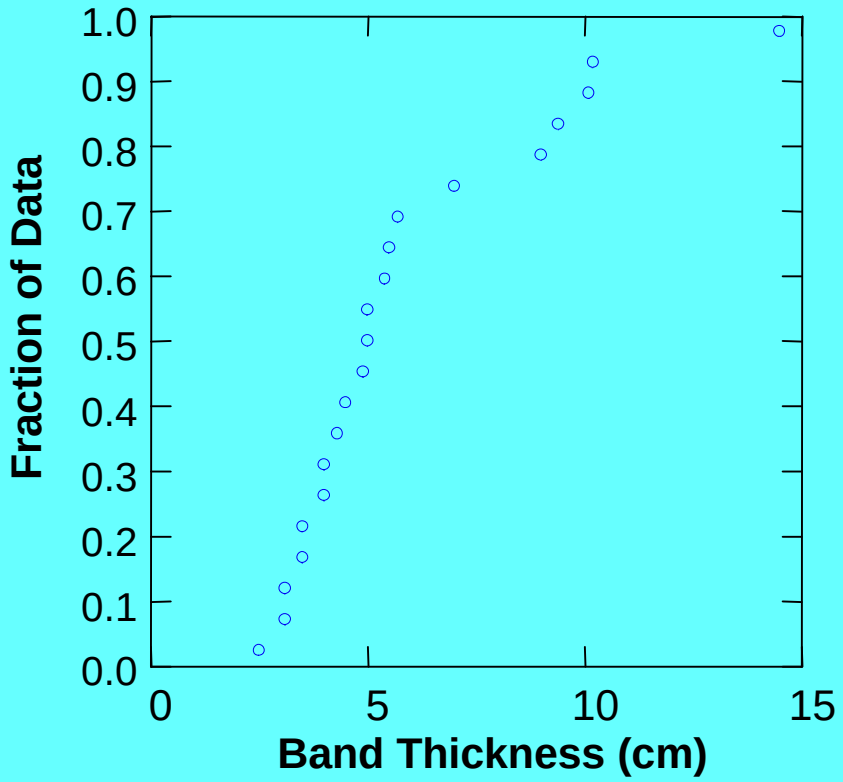


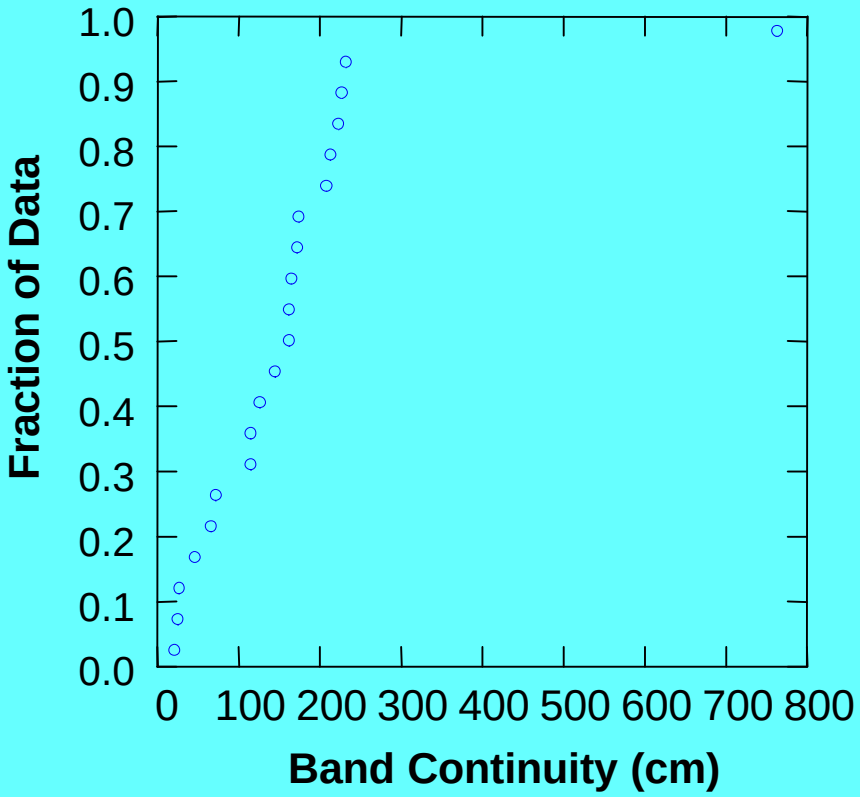
2 m

Band Thickness and Continuity

- Measured transect across dike
- 21 bands measured
- Band thickness
  - Range from 2.5 to 14 cm
  - Median thickness of 5 cm
- Band continuity
  - Measure distance along excavation face until band pinches out or cut off
  - Range from .2 m to 7.6 m
  - Median continuity = 1.6 m
  - Dimensions uncertain – 3D problem
  - Implications for transport along dike

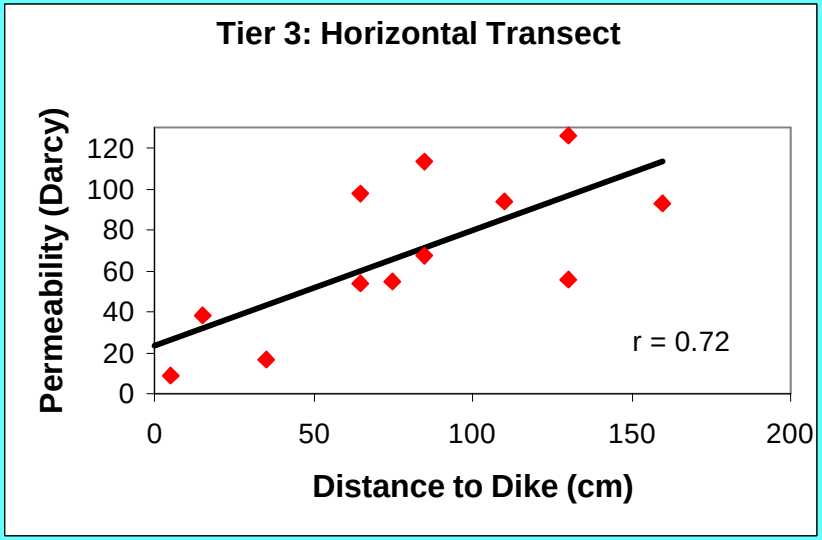
Clastic Dike Band Analysis (contd)





Permeability Variations Near Dike

- Previous field observations suggested decreased permeability near dike
- Five horizontal transects sampled in matrix
  - Air perm measurements
  - Hypothesis verified
    - About 80% drop in perm near dike
  - Sediment samples taken at air perm locations
  - Samples being analyzed for grain size, mineralogy, carbonate content



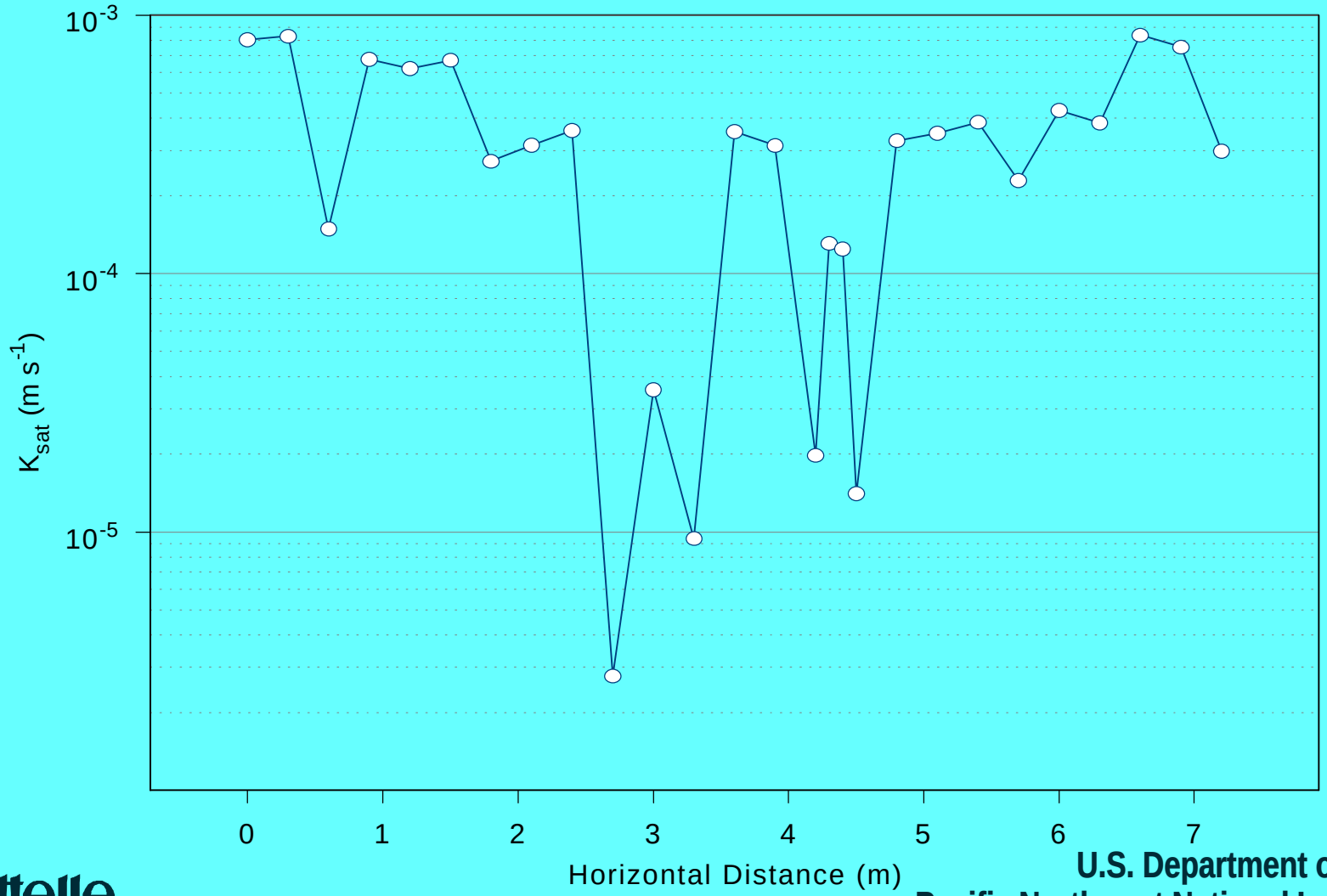
2001 Infiltration Test

- Army Loop Road site
- Drip irrigation array used to apply moisture
  - 3 flux rates (~10^{-3}, 10^{-4}, and 10^{-5} cm/s)
- Monitor to depth of 7 m using 8 CPT boreholes
- Geophysical monitoring array
  - Measure water content, matric potential, and electrical conductivity
  - Neutron probe, x-borehole GPR, tensiometers, and TDR
- Dye (Brilliant Blue FCF) and KBr tracers applied
  - Once steady state achieved on 3rd flux rate
- Followed by excavation
  - GW/VZ Project support
  - Air Perm and Infrared surveys outside wetted zone
  - Excavate into wetted zone
    - sample dike and matrix
    - image tracer distribution

Variability in Hydraulic Conductivity

Tier No.	X (m)	K_{fs} (m s^{-1})	$\overline{K}_{fs}$ ($m s^{-1}$)	s_{fs}
1	1.0	3.04×10^{-4}		
2	0.3	3.97×10^{-5}		
2	5.5	3.43×10^{-4}	2.29×10^{-4}	1.65×10^{-4}
1	3.0	4.51×10^{-5}		
2	2.2	4.38×10^{-6}		
2	3.8	1.83×10^{-5}		
2	6.8	1.39×10^{-5}	2.04×10^{-5}	1.74×10^{-5}
Sill		5.90×10^{-6}		
All Measurements			9.68×10^{-5}	1.41×10^{-5}
2	0 - 7.5		3.59×10^{-4}	2.67×10^{-4}

Spatial Variability in Ksat



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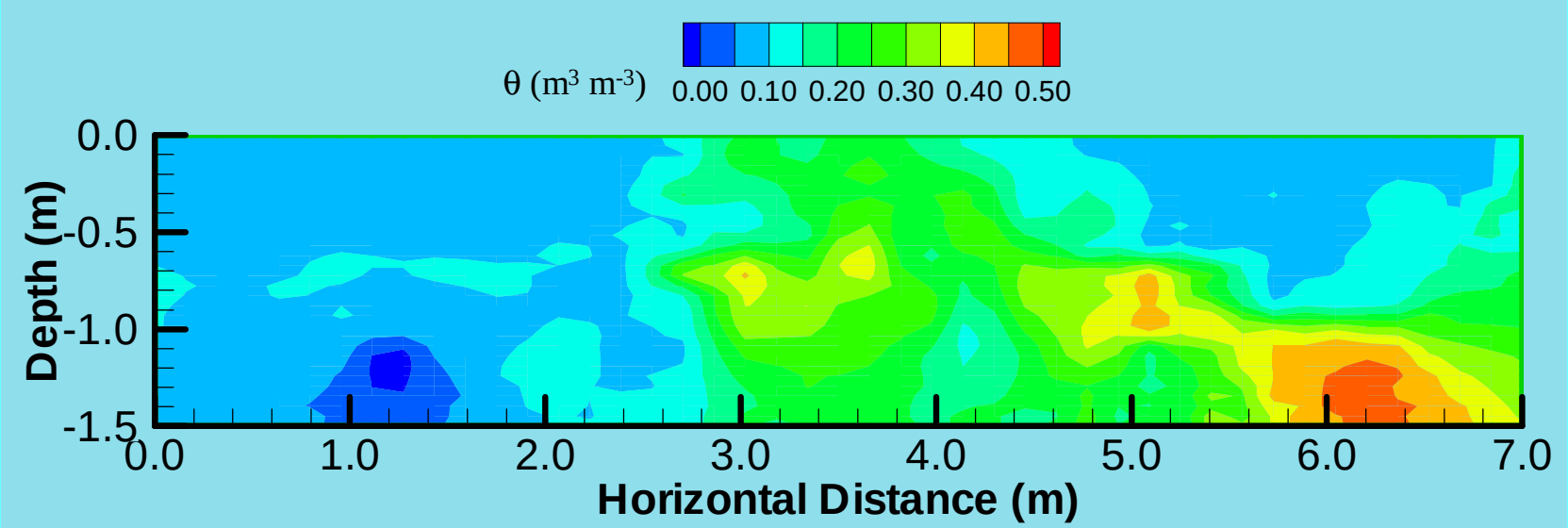
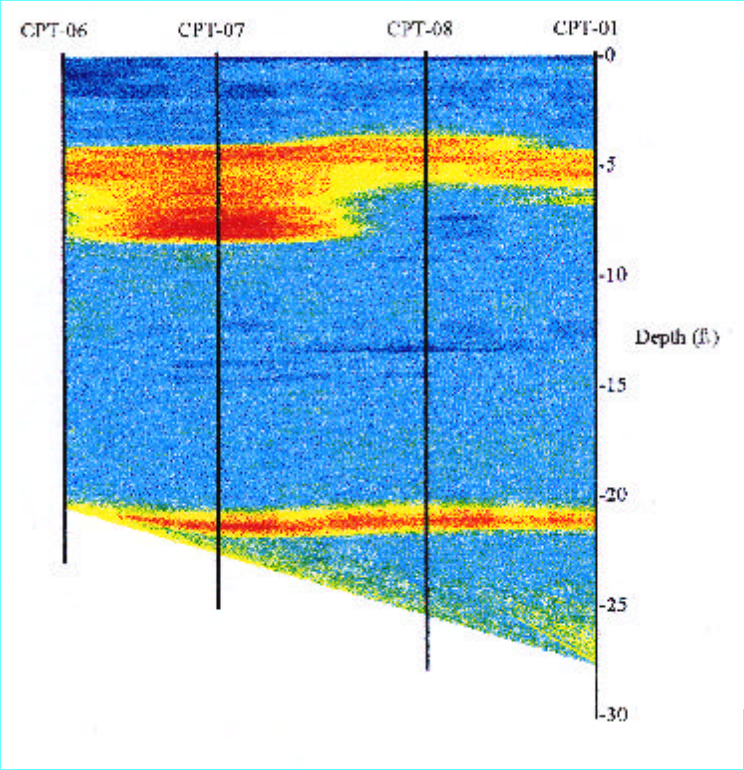
TDR-Measured q(x,z)- June 28, 2001

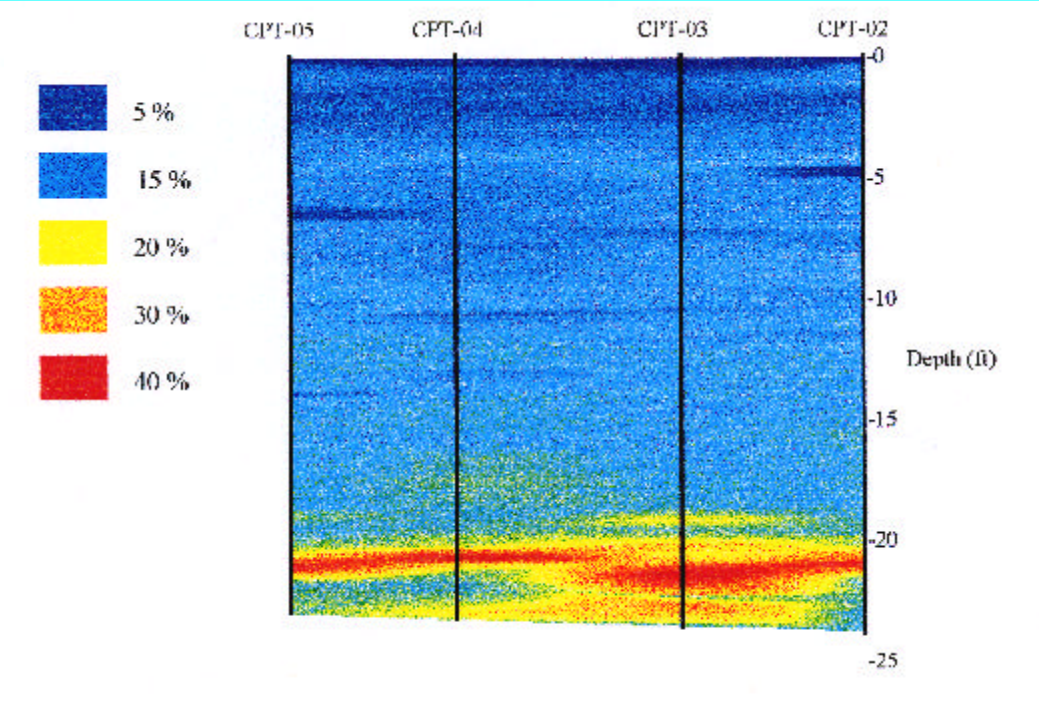


Clastic Sill – CPT Moisture Measurements

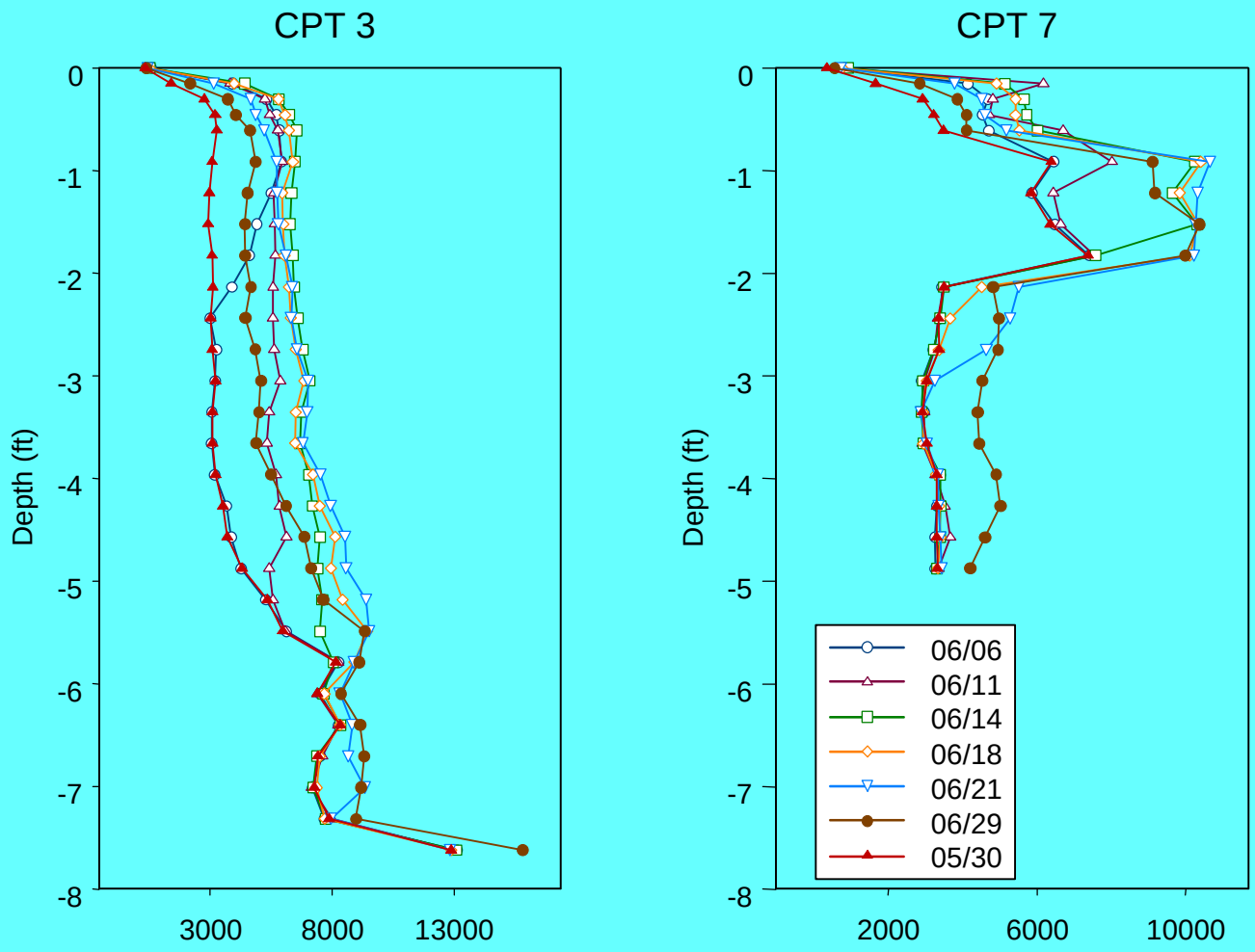
West



East



Moisture Distributions - Neutron Probe Counts



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Clastic Sill – cont'd

- Moisture migrated several meters along clastic sill
  - Conducted within sill, not above it

Phase 3: Evaluate Effects

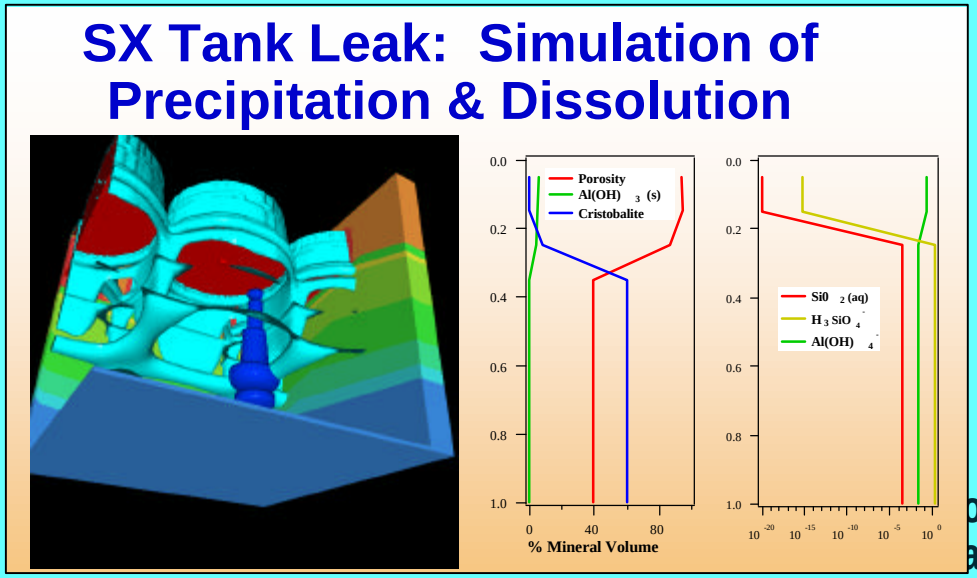
- Construct geostatistical model of experiment site
- Numerically model the infiltration experiment using multiple conceptual models

Geostatistical Model of Experiment Site

- Analyze spatial continuity of moisture and porosity
  - derived from geophysical sensors and core samples
- Variogram analysis
  - separate analysis performed for matrix sediments and clastic dikes
    - anisotropy of two systems expected to be at right angles to one another
  - anisotropy ratios of each system estimated from infrared imaging and air-minipermeametry data
- Stochastic simulation of experimental site
  - borehole measurements treated as “hard” data
  - Cross-borehole radar tomography will form more extensive “soft” data set
  - simulations performed using Markov-Bayes indicator simulation algorithm
    - reproduce expected cross-correlation between hard and soft data
  - provide detailed 3-D numerical grids of porosity and initial water contents
    - used as input to numerical flow modeling

Numerical Model of Experiment

- STOMP90
  - Fortran 90 with “parallel” directives
  - Scalar or parallel
  - Can handle as many as 10^8 nodes
  - Complex boundaries



Scientific Results

- Large-scale fractal/geostatistical models of clastic dike distribution
- Detailed models of hydraulic property distribution within clastic dikes
- Integrated field/modeling studies of moisture flux through clastic dikes
- Determination if clastic dikes provide possible preferential flow paths in the vadose zone at Hanford