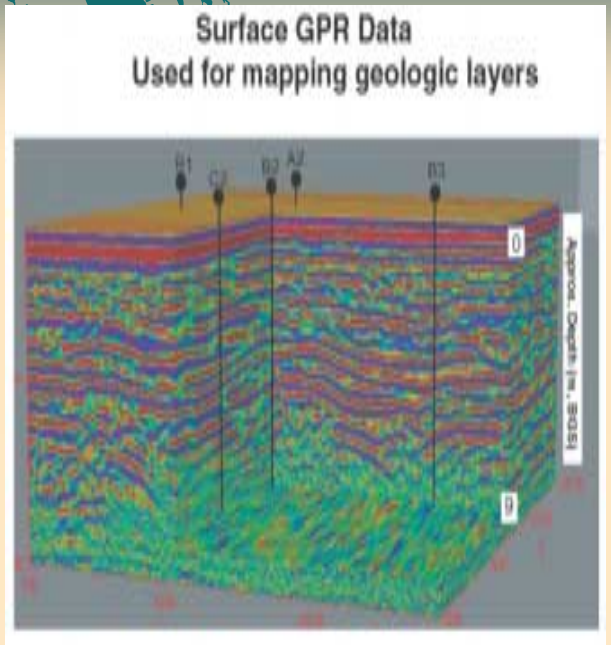
Geophysical Studies at the FRC

Susan S. Hubbard, Ken Williams, Jinsong Chen
Lawrence Berkeley National Laboratory

- **BACKGROUND**: Previous Geophysical Research associated with Biostimulation/Bioaugmentation Projects
  - Characterization
  - Monitoring during biostimulation: Lab and Field-Scale
- **FRC GEOPHYSICS: Area 3**
  - Geophysical Data Acquisition
    - Preliminary
    - Proposed
  - Characterization and Monitoring

Field-Scale Characterization using surface and crosshole GPR data and flowmeter data

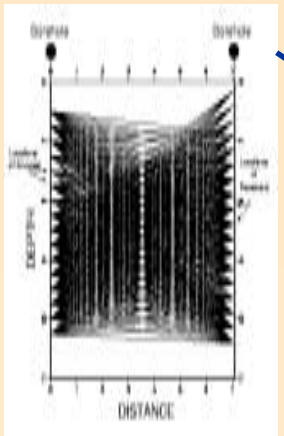


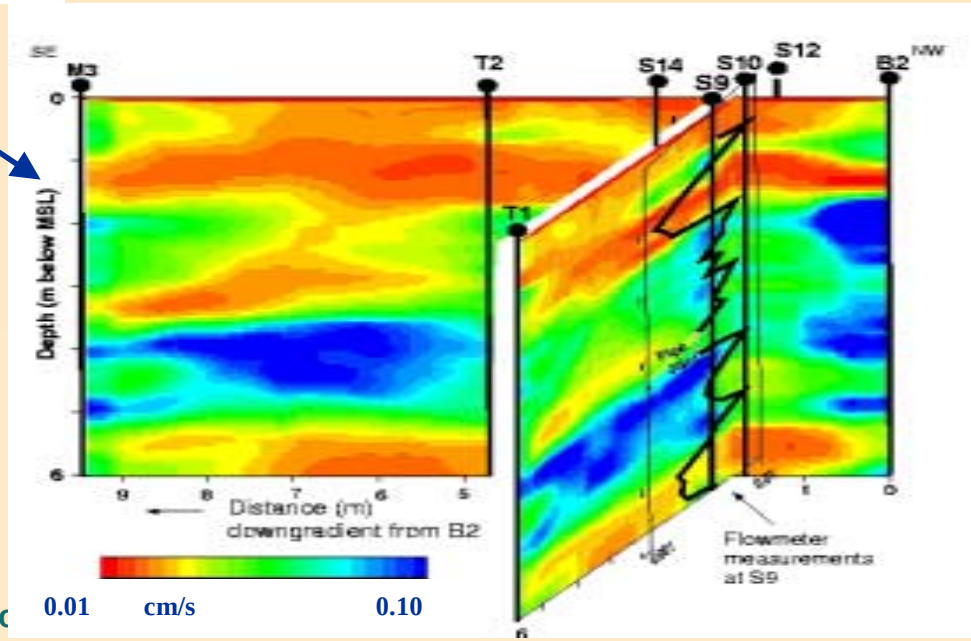
Hubbard, Chen, Rubin et al.

WRR 37(10), 2001

Estimation of:

1. Geological Units
2. Hydraulic Conductivity (K)
3. Spatial Correlation Parameters
4. Injected Plume Moments
5. Geochemical Parameters
6. Monitoring Biostimulation





Earth Sciences Divisi

NABIR

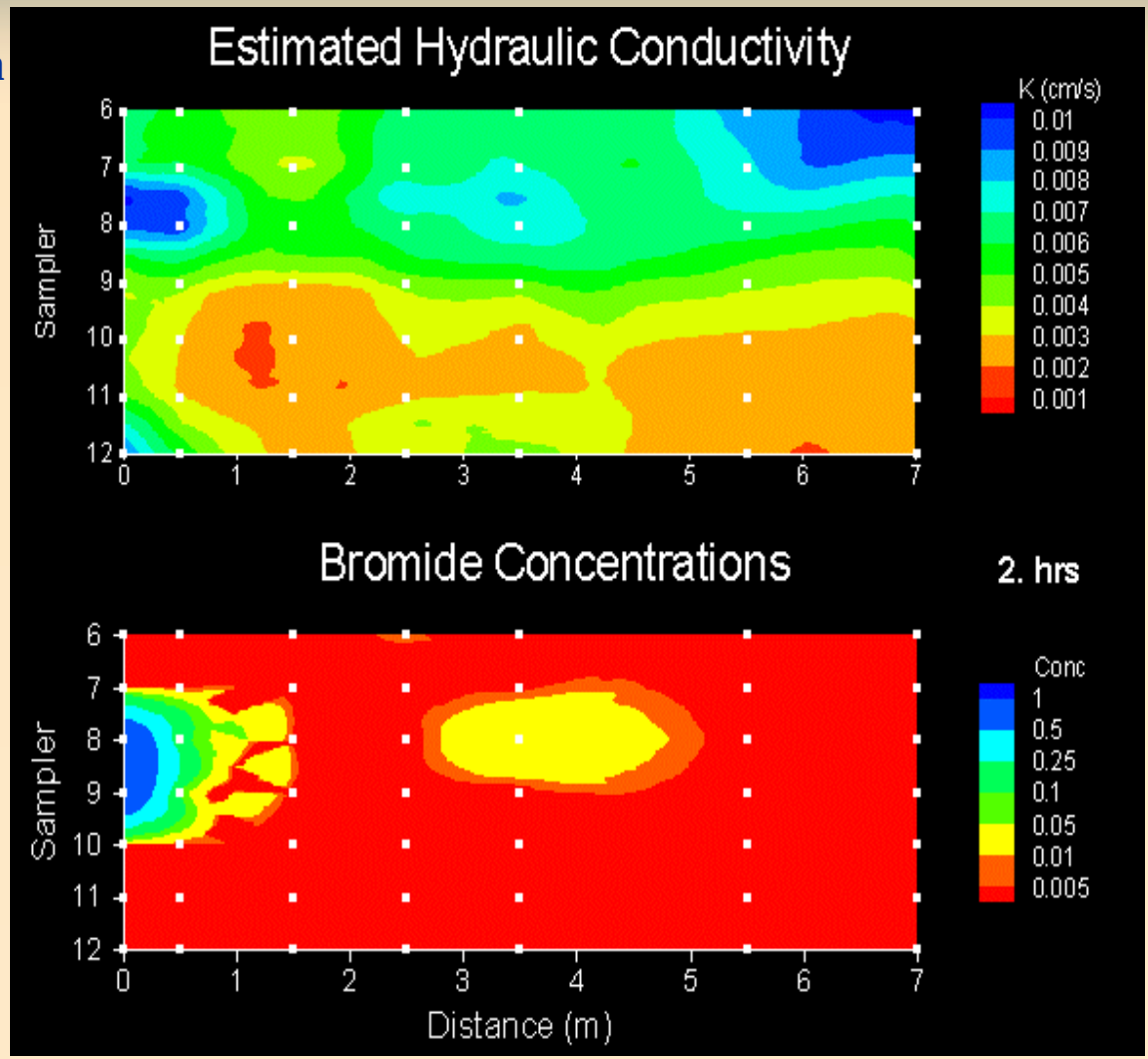
Field-Scale Estimation of Hydraulic Conductivity using Crosshole GPR

1/4m by 1/4 resolution

High K →

Low K →

High K →



Bayesian Estimation Method

(Chen, Hubbard and Rubin WRR 2001)

Earth Sciences

*Bacteria followed similar paths at NC to Bromide

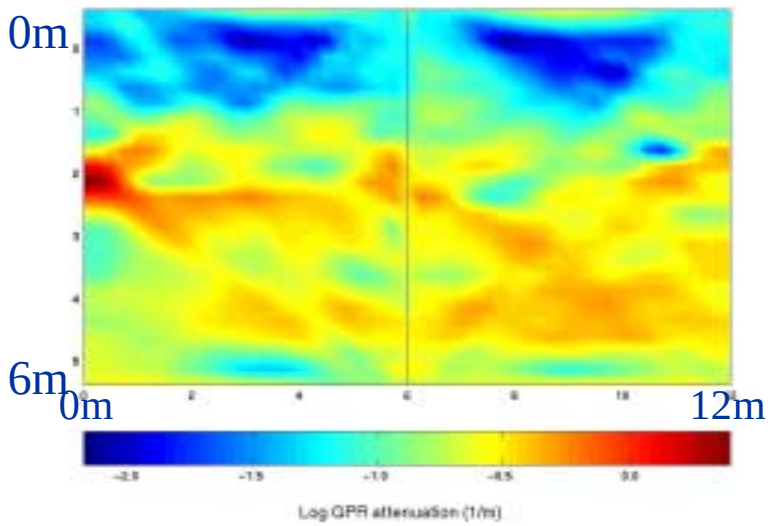
*Tomography Estimates useful for improving numerical flow and transport model (Scheibe et al., Ground Water, 2002)

J. Chen et al., in preparation for ES&T, 2002

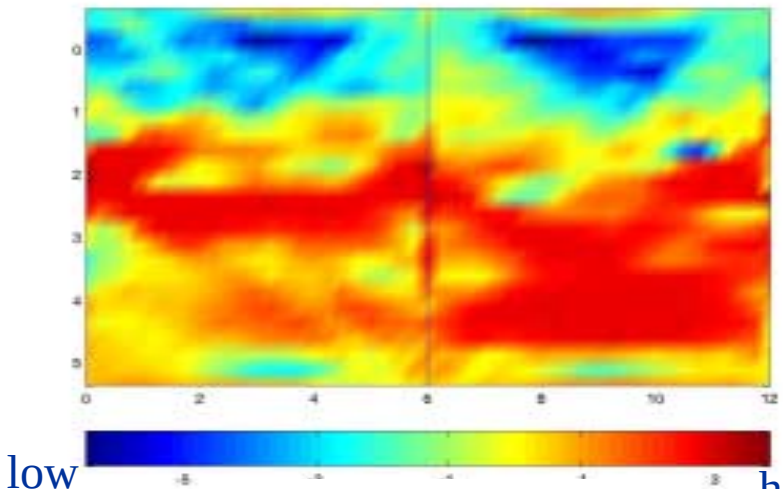
*Iron data provided by **Chris Murray** (PNNL) and **Eric Roden** (University of Alabama)*

Field-Scale Geochemical Parameter Estimation using MCMC

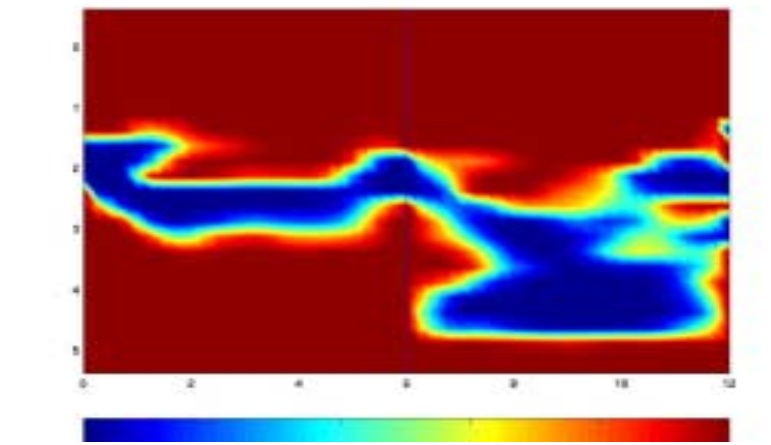
Radar Attenuation



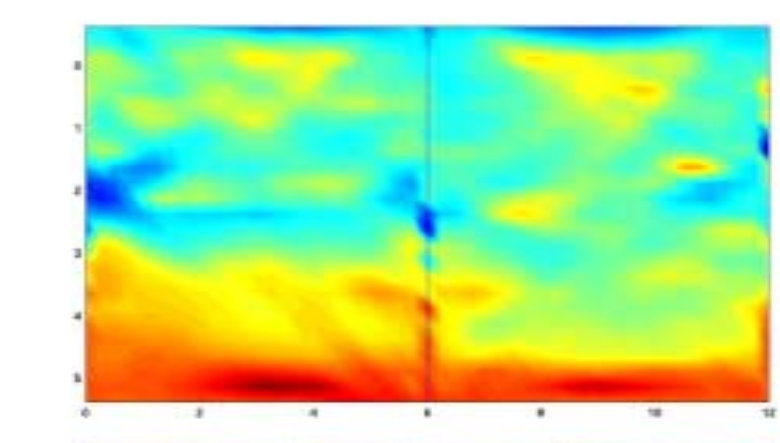
Estimated Fe2



Estimated Lithology

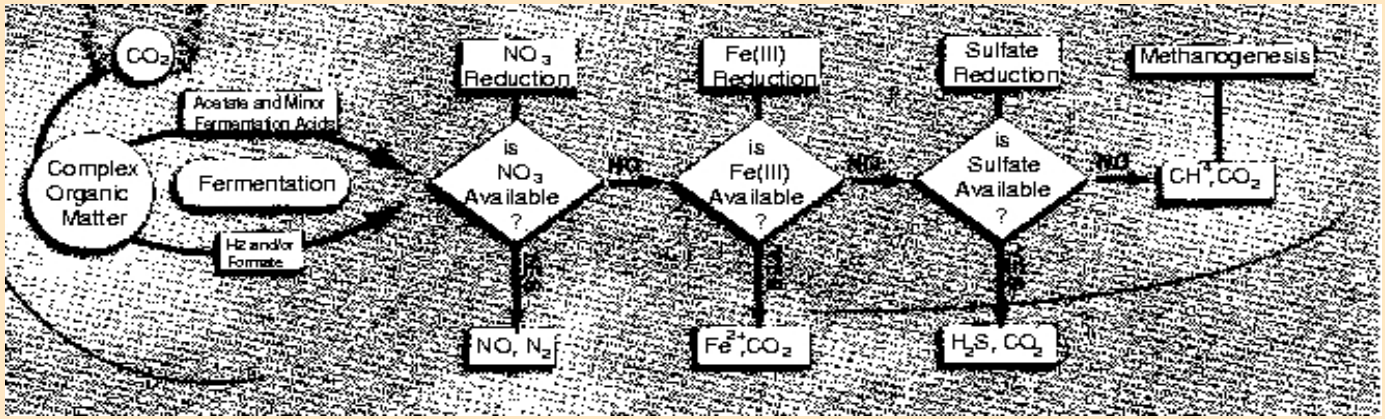


Estimated Fe3



Background: Geophysical Monitoring of Bacterial-Induced Phenomena

- Biostimulation induces **system transformations** that can be **dynamic, complex, and coupled**



Chapelle, 2000

- Extremely difficult to understand using wellbore data
- ***Investigate utility of geophysical methods for providing information about system transformations over space and time: Gas Generation, Biofilm development & Precipitation***
  - **Seismic Amplitudes: Lab Scale**
  - **Radar Velocity: Lab Scale**
  - **Seismic Amplitudes: Field Scale**

Lab Experiment: using Seismic Amplitudes to detect gas generation

Reduction of NO_3^- ⟶ N_2

Electron Acceptor: Nitrate, Initial Concentration ~300mg/L

Carbon Source: Acetate

Microbe: *Pseudomonas Stutzeri* (courtesy PNNL)

Grown to ~2 x 10^7 cells/gram sand and suspended in a nutrient depleted growth media

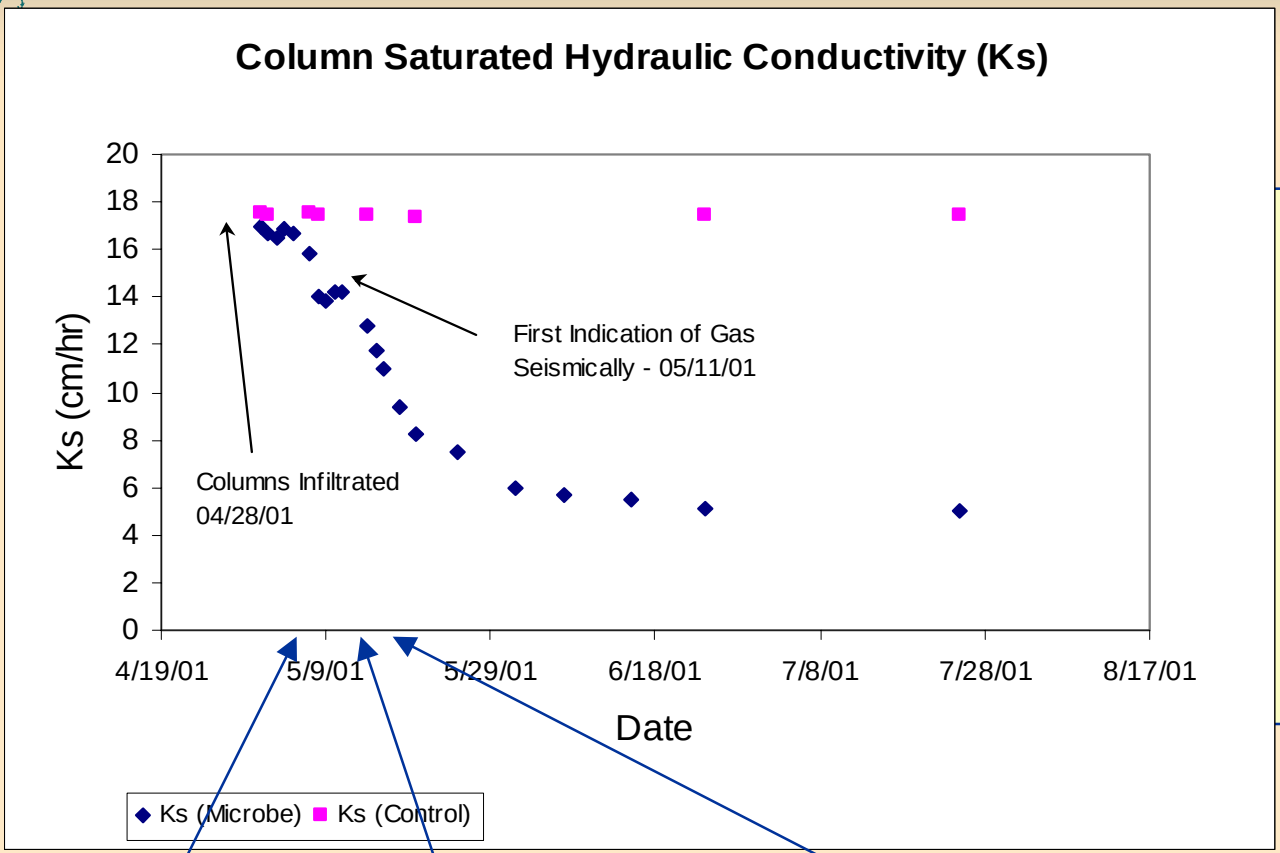
***Cross-column seismic measurements**
Evaluate seismic signal amplitude as a function of gas production

***K measured using constant head tests**

*** Gas sampling of evolved N_2**

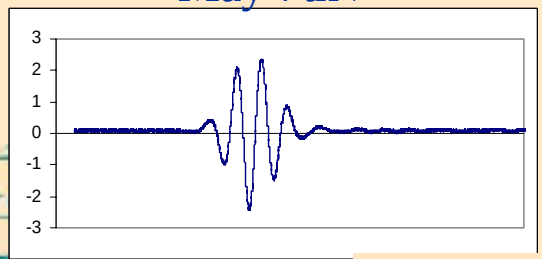
Ken Williams with assist from Mary Firestone (UCB) and Fred Brockman (PNNL). In preparation for *ES&T*

Hydraulic Conductivity and Seismic Amplitude Responses during Stimulation

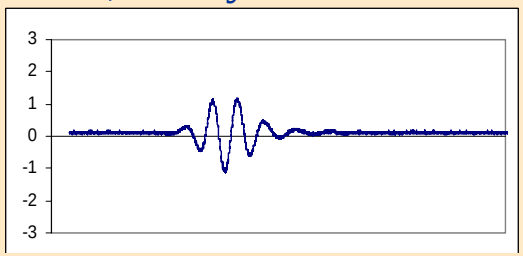


N2 production coincident with reduction in hydraulic conductivity and in seismic amplitude

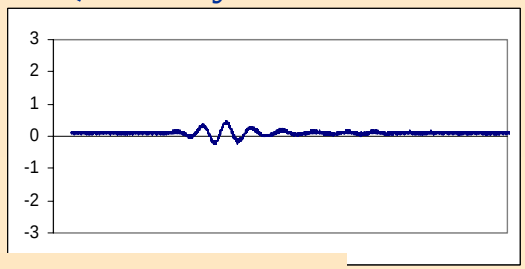
May 7th



May 11th

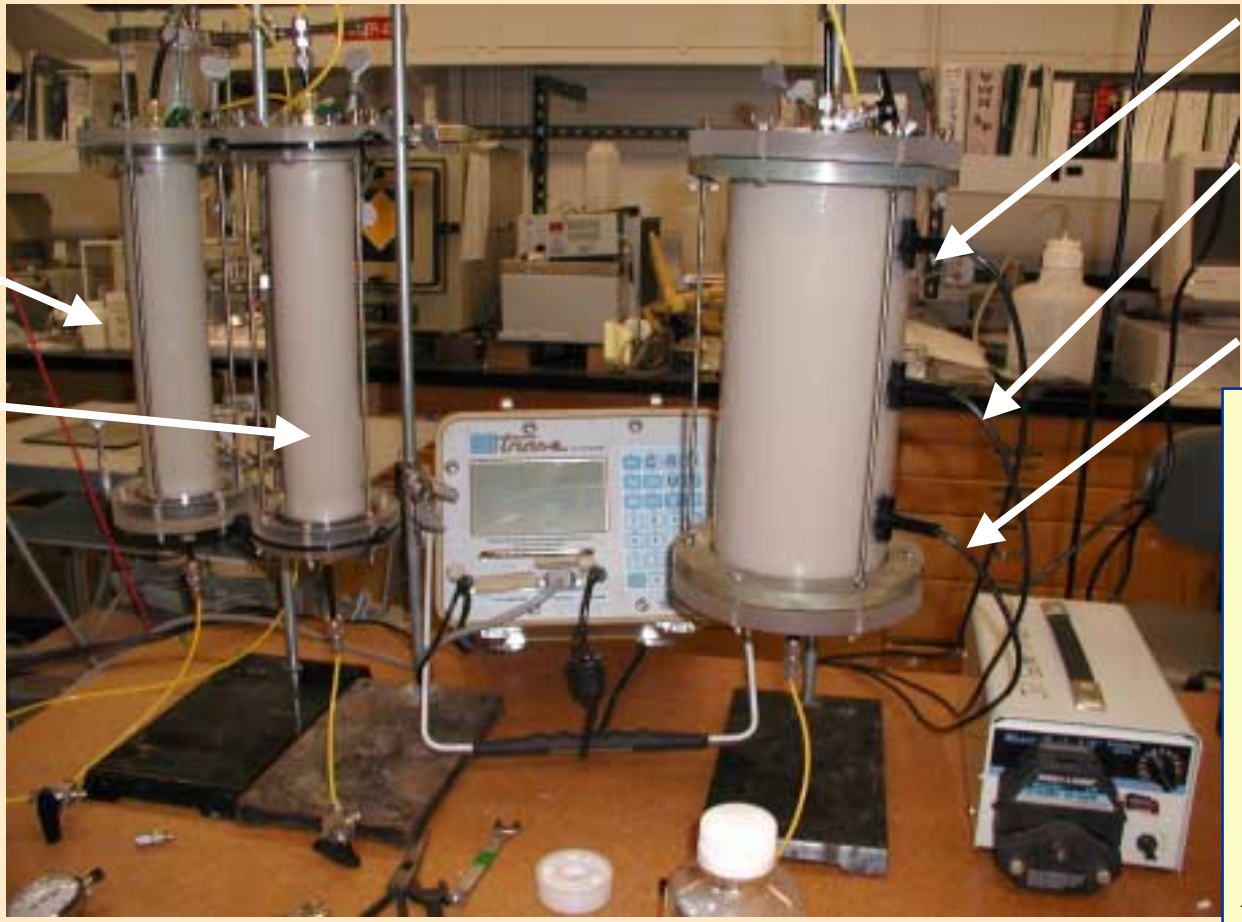


May 15th



Examples of decreases in Seismic Amplitudes

Radar Monitoring of Gas Evolution during biostimulation of OY-107



Electron Acceptor: Nitrate, Initial Concentration ~300mg/L

Carbon Source: Acetate

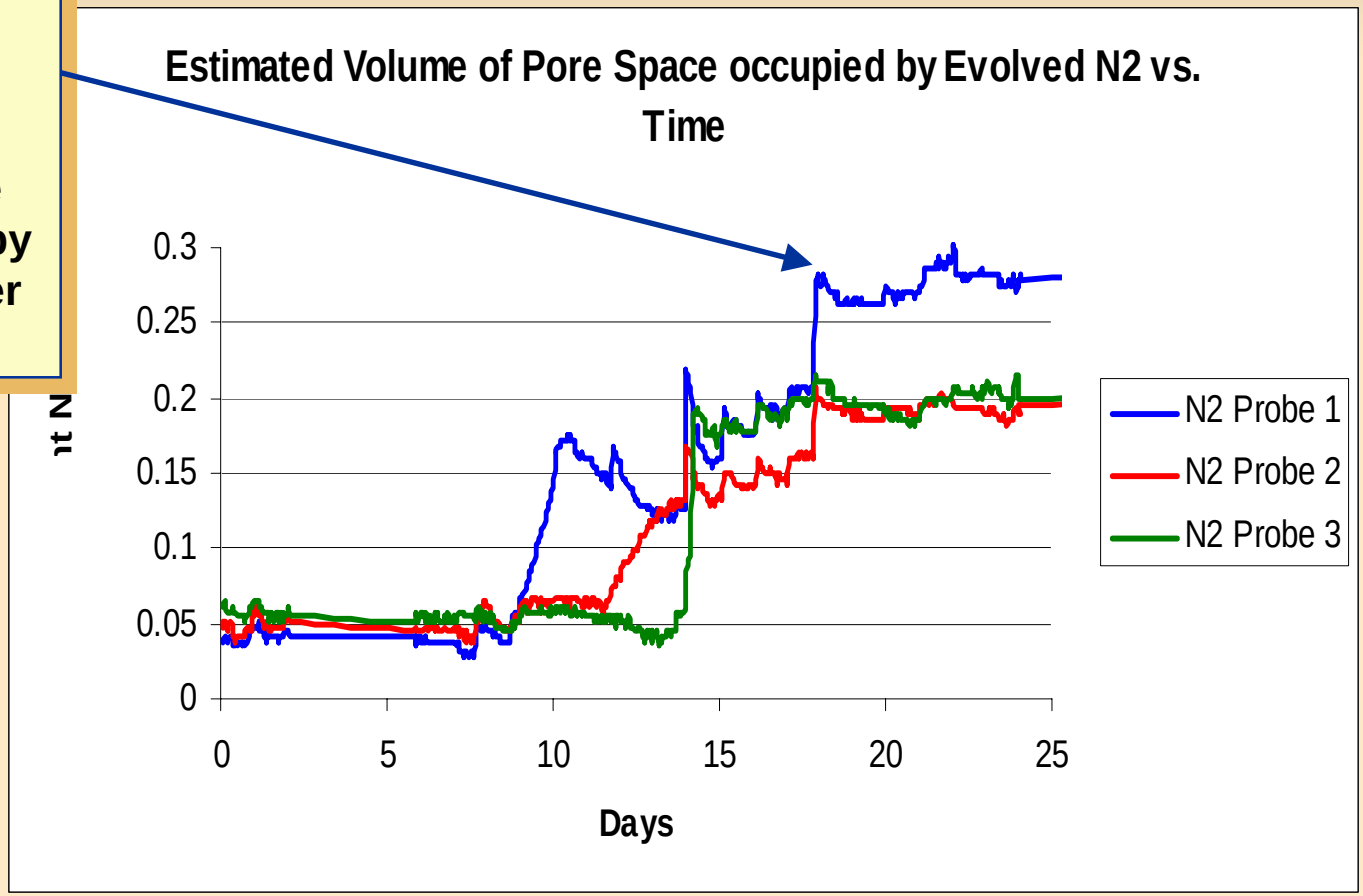
Microbe:*OY107 Acidovorax*

Grown to ~2 x 10^7 cells/gram in sand and suspended in a nutrient depleted growth media

Dielectric measurements collected every hour at each probe for 40 days

Radar Lab-Scale N_2 Estimation Results

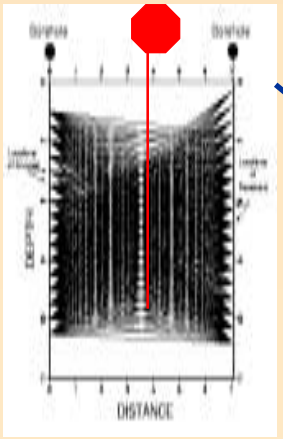
Radar Velocities suggested ~30% of pore space was filled by N2 gas after ~20 days

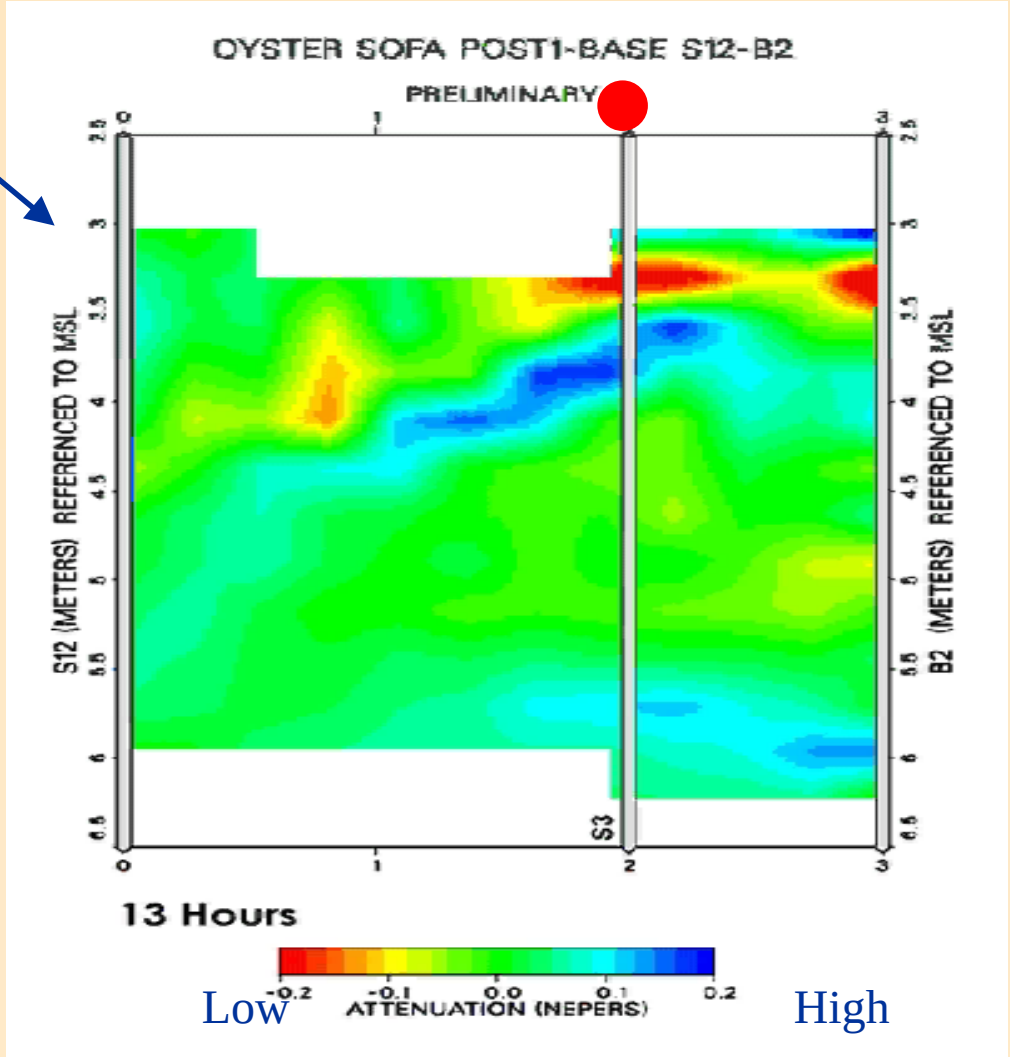


- Final estimates corroborated by column weight loss, K_s and seismic amplitude measurements

Field-Scale Biostimulation Monitoring using Time-Lapse Seismic Tomography

Lactate Injection Well





Oyster Biostimulation Experiment. Nitrate Initial Concentration <12 mg/L (avg. 7mg/L)

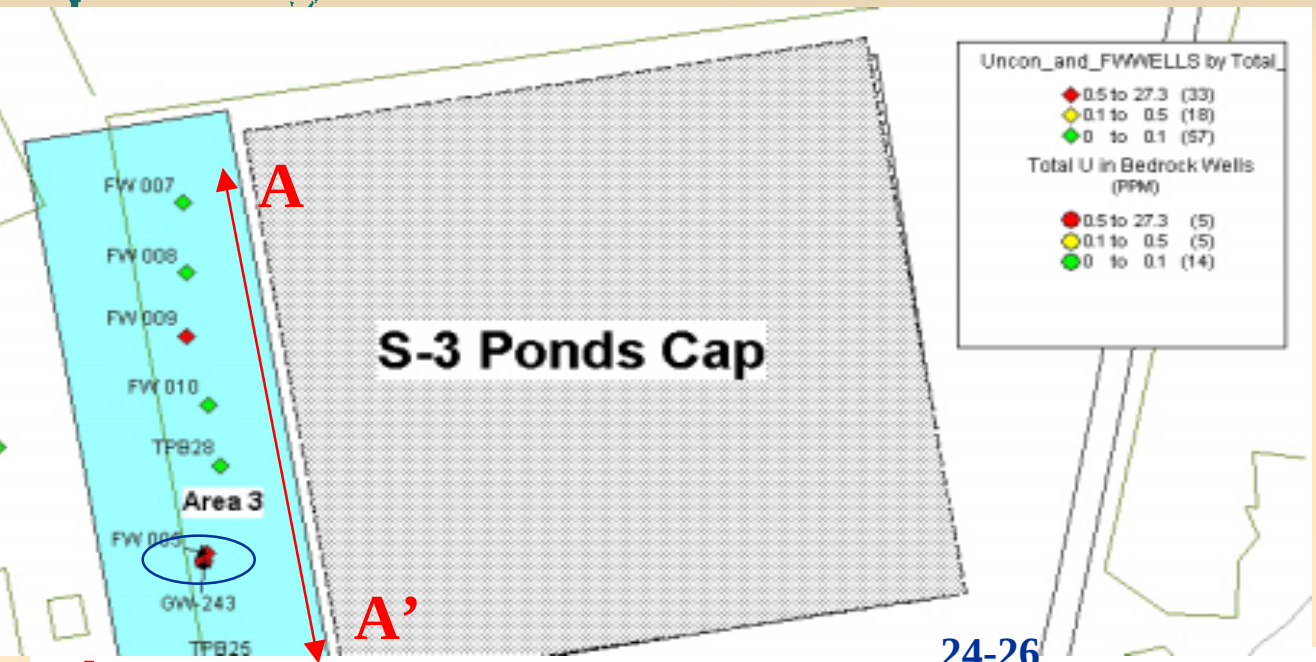
Mailloux et al., *Fall AGU*, 2002

Spatio-temporal variations in seismic amplitude correlated with N2 production near the wellbore AT THE FIELD SCALE!

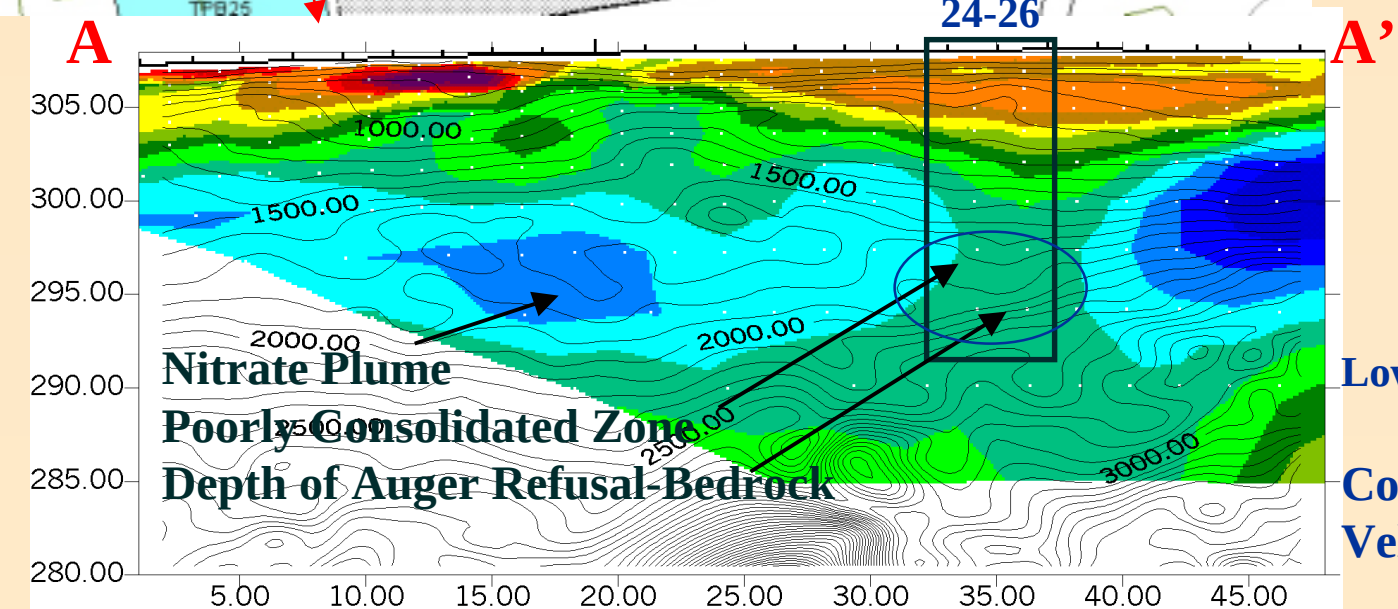
FRC Area 3 Geophysics

- Seismic and Radar Data Preliminary Analysis
- Plans for new Data Acquisition
- Estimation Approach and Objectives

Geophysical Characterization at the FRC



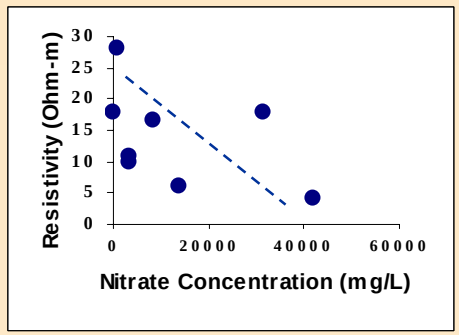
S-3 Ponds Cap Surface Seismic/Electrical (Bill Doll et al., *SAGEEP*, 2002 and David Watson et al., *Spectrum*, 2002).



Electrical Resistivity

Low (~4 Ohm-m)

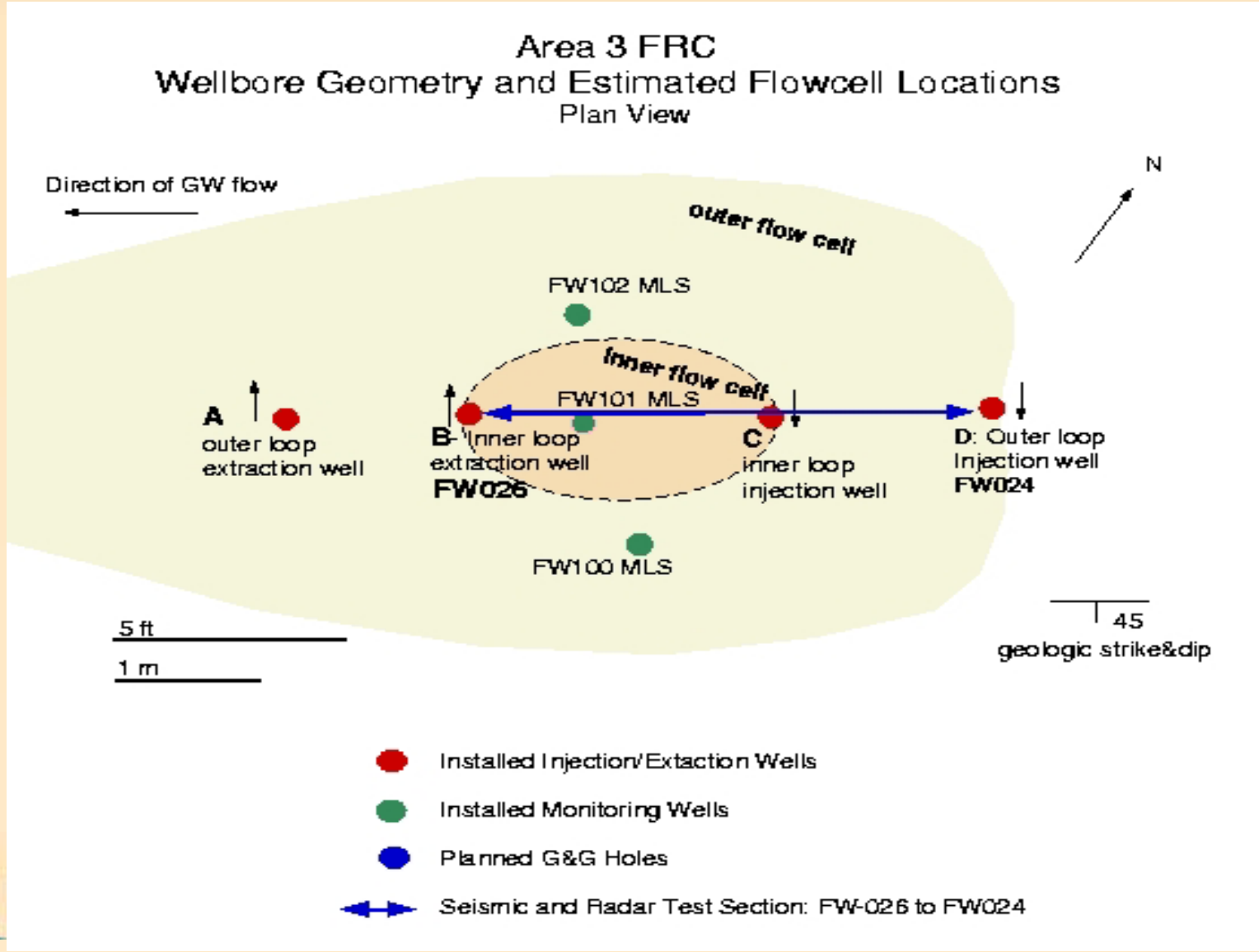
High (~150 Ohm-m)

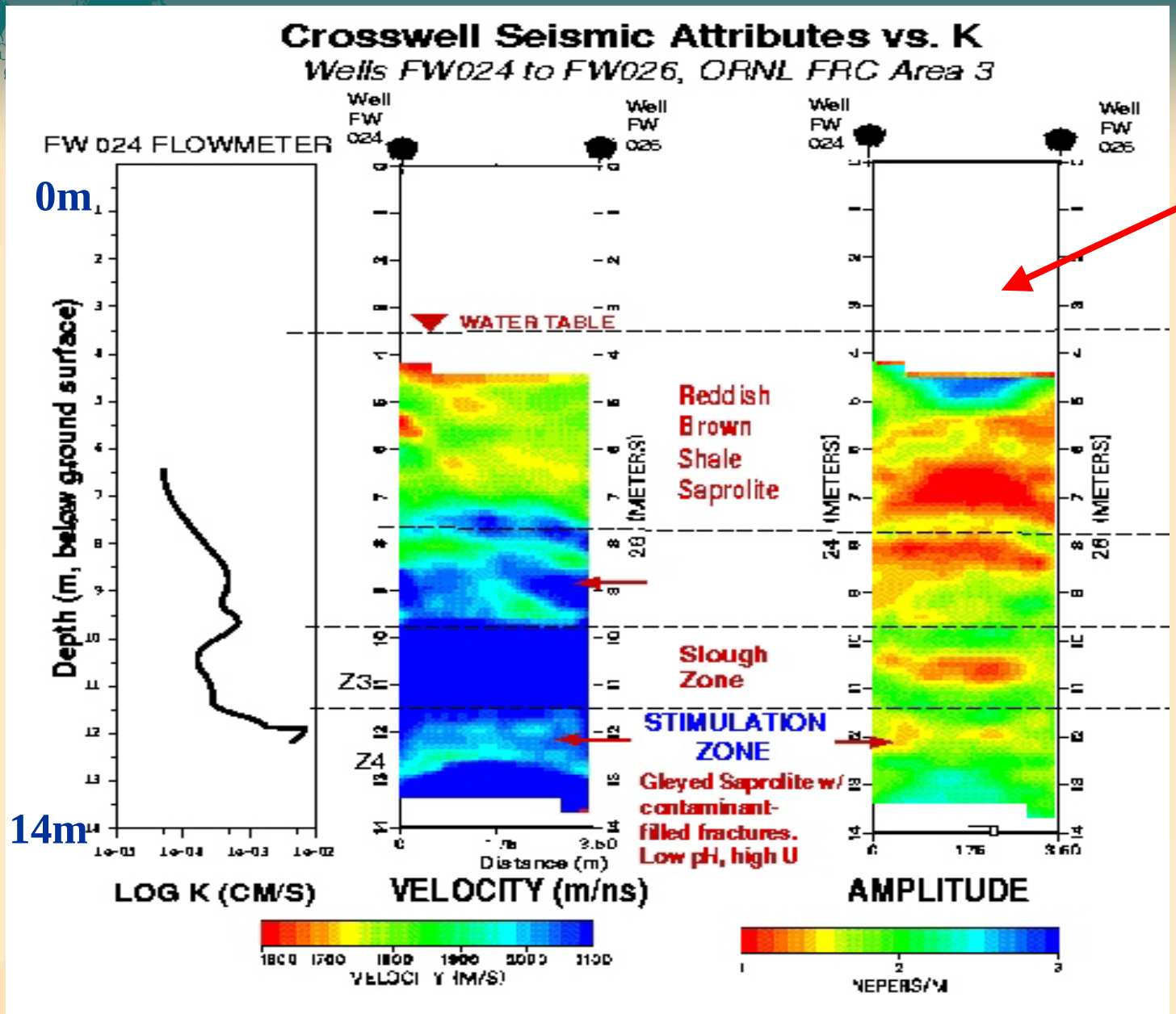


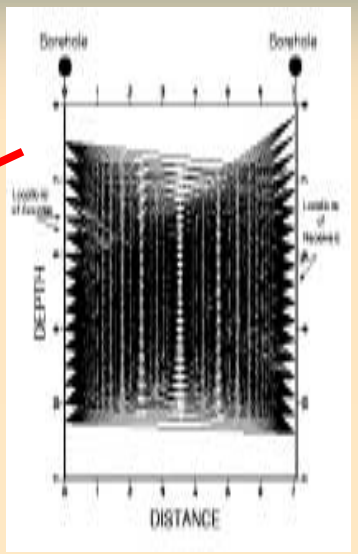
Low Resistivity ~ High Nitrates

Contour Lines: Seismic Velocity (m/s)

Crosshole Seismic/Radar Acquisition Test
FW024-FW026 FRC Area 3





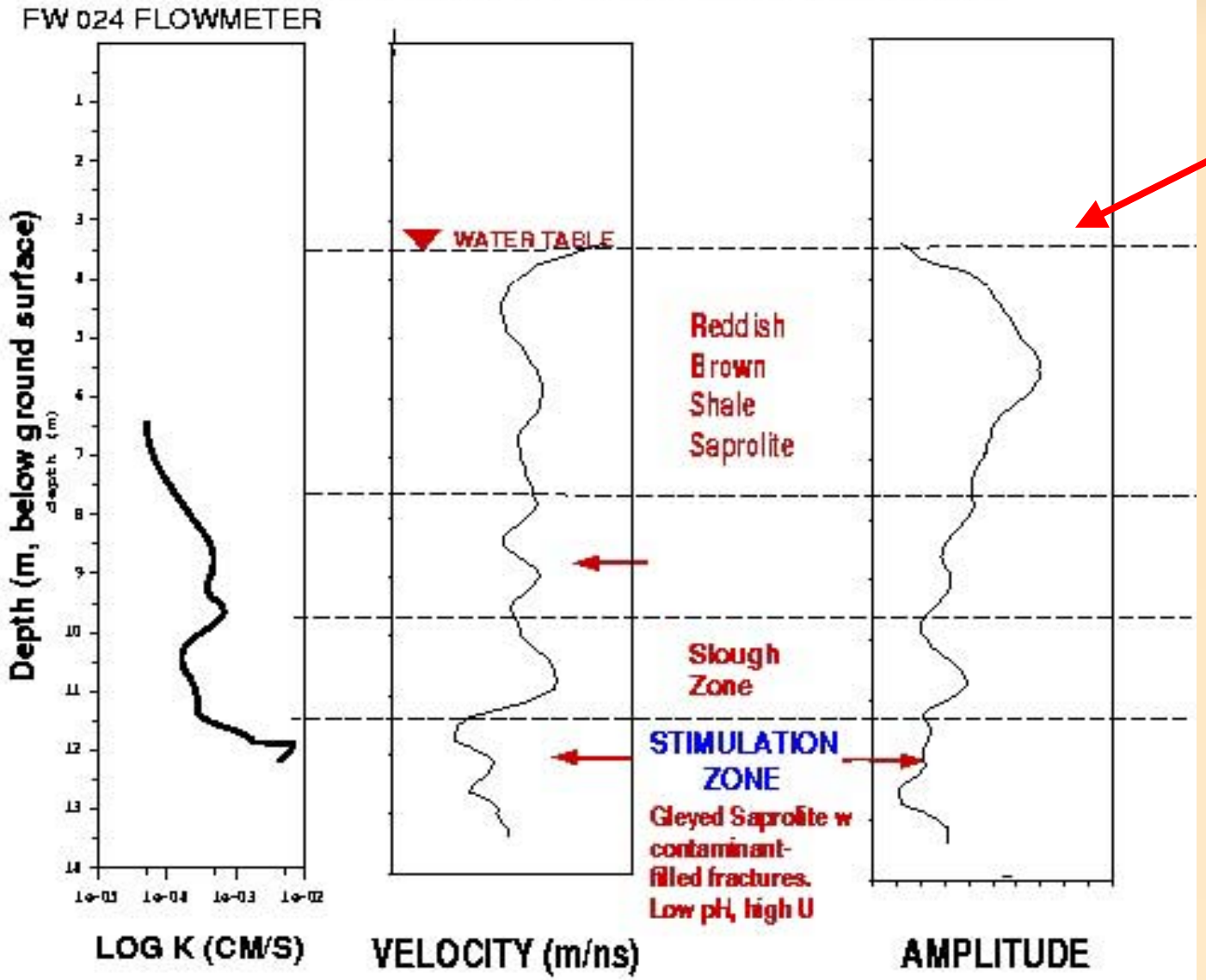


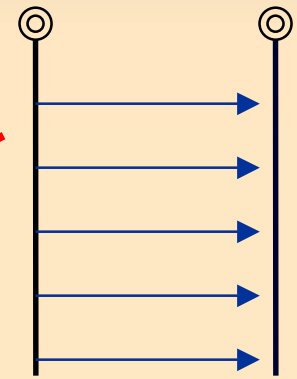
Tomographic Data Acquisition: Yields 2-D estimates of geophysical attribute between boreholes

Log Data: David Watson
Flowmeter Data: Mike Fienen and Peter Kitanidis

Crosswell RADAR Attributes vs. K

Wells FW024 to FW026, ORNL FRC Area 3

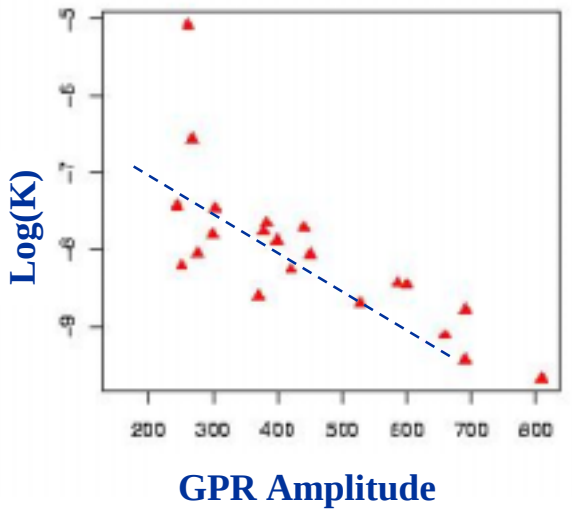


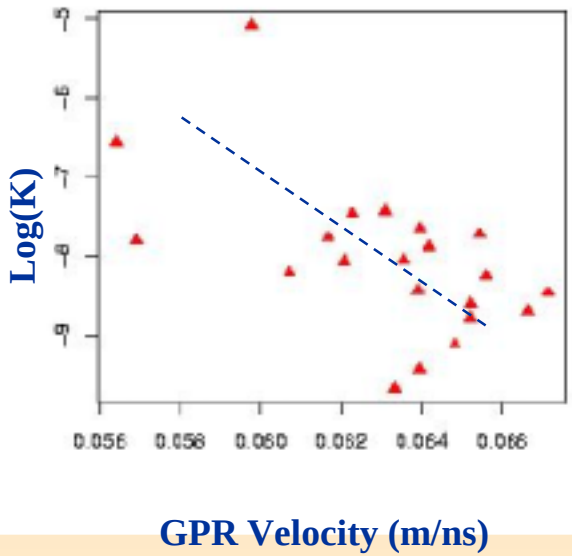


"Zero Offset" Data Acquisition: Yields 1-D horizontal average between boreholes

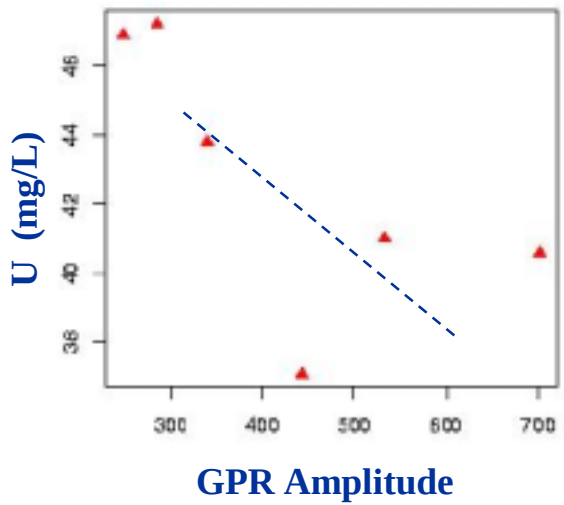
Trends: Radar Attributes vs. K and U at FW024

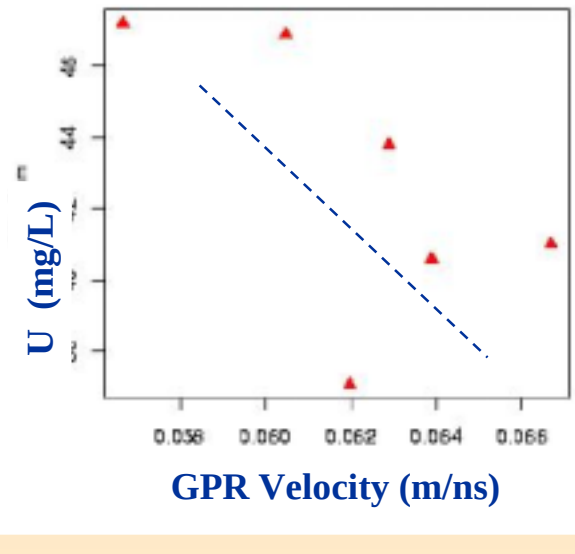
Hydraulic Conductivity (flowmeter) and GPR Attributes





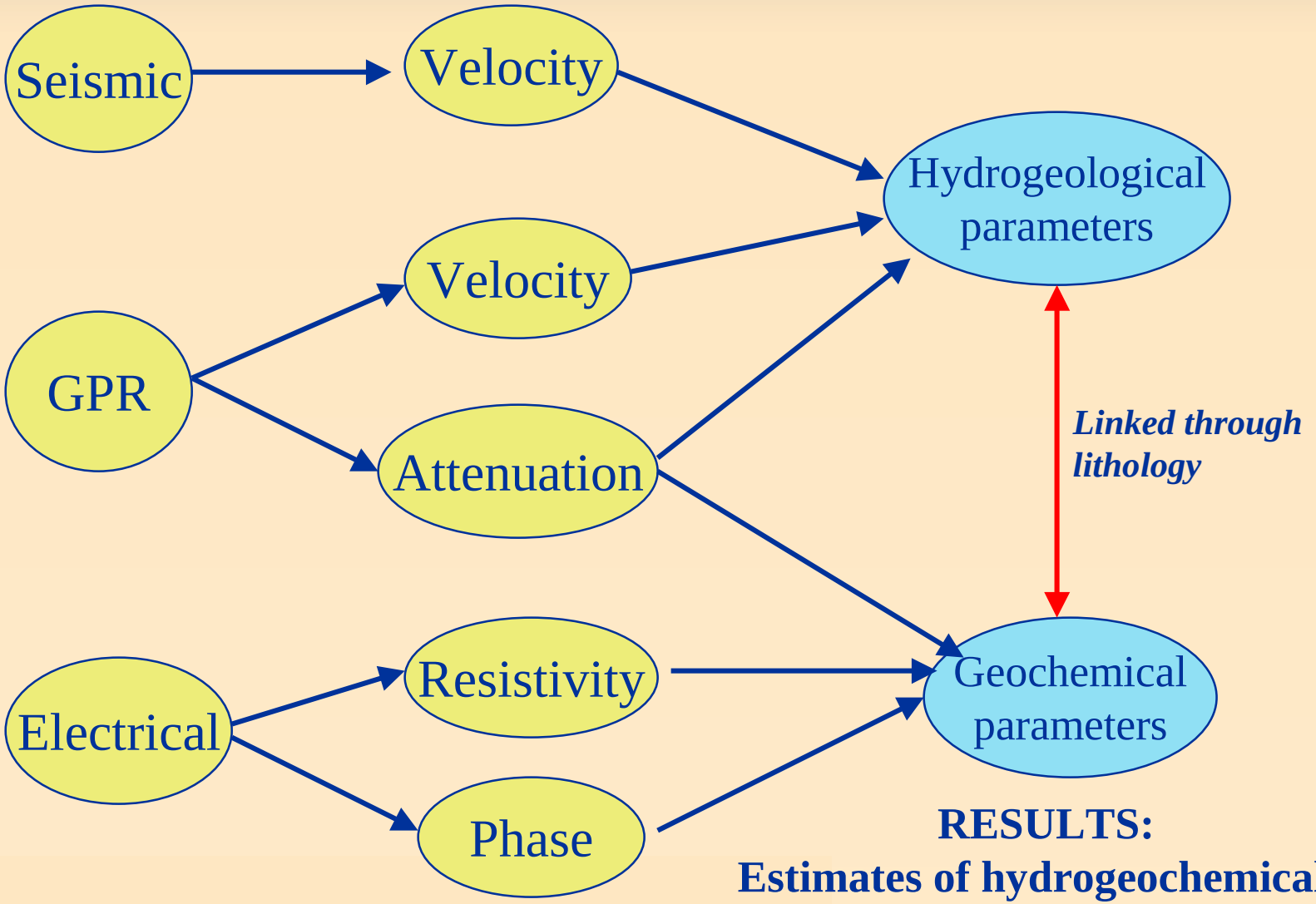
Uranium Concentration and GPR Attributes (6 points only)





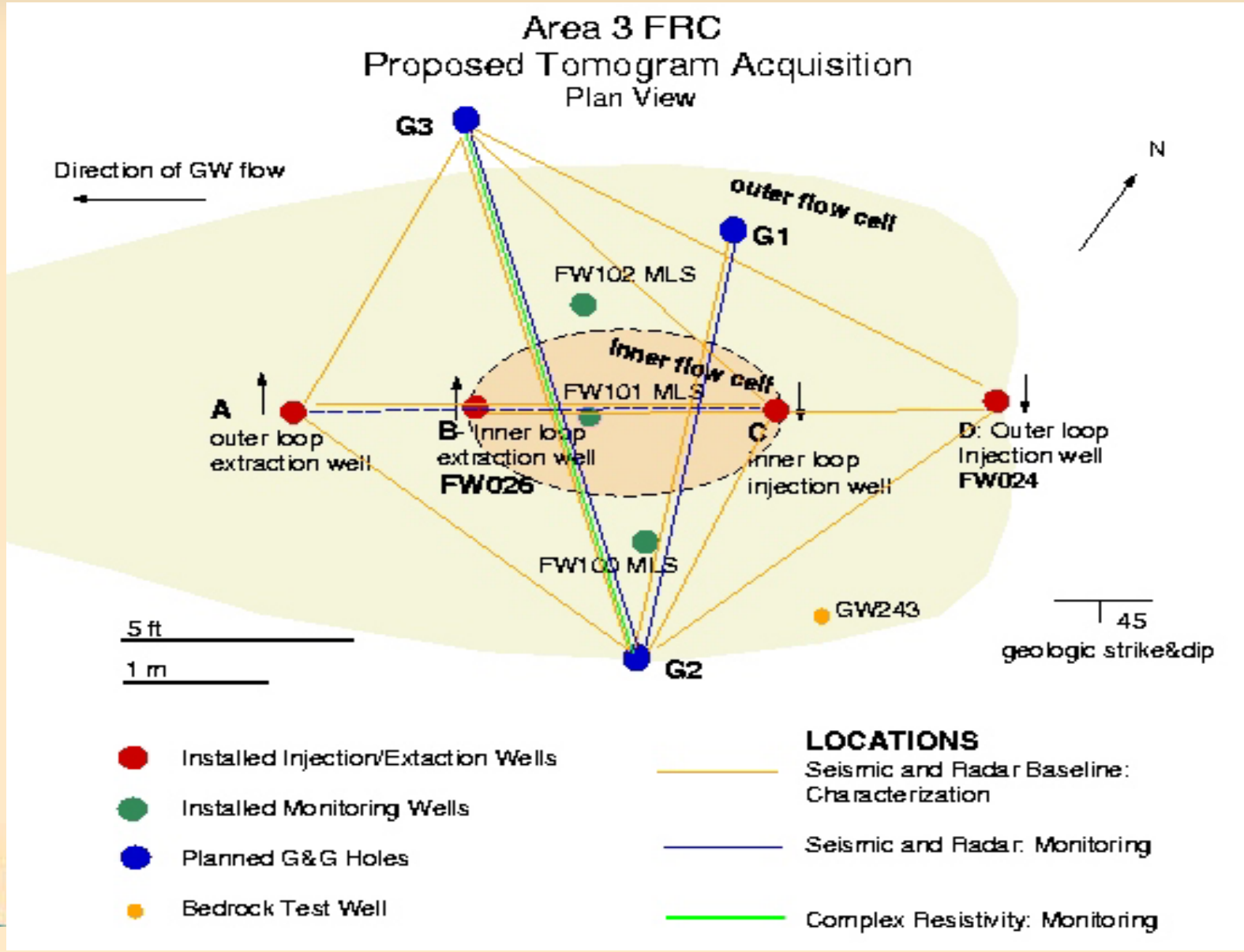
- ** *Indications: Low GPR Amplitude and Velocity~ High K and High U* **

Approach: Bayesian / Monte Carlo Markov Chain



RESULTS:
Estimates of hydrogeochemical properties and their uncertainties at each pixel along tomogram

Proposed Crosshole Acquisition



Uses of Geophysical Data at the FRC

- **Field Scale:** ***Characterization and Monitoring***
  - Use to refine field plan
  - Constrain numerical flow and transport models - boundaries & K
  - Assess efficacy of initial "Groundwater Flush"
  - Detection of any evolved N2 in inner flowcell
  - Delineate boundaries of inner and outer flowcells
  - Possible detection of urananite and aluminum hydroxide precipitation
- **Lab Scale:** ***Systematic Investigation of Geophysical Attributes***
  - Investigate geophysical responses in terms of various system transformations and heterogeneity. Perform in conjunction with Criddle et al.?

The end