Characterization and Monitoring at the FRC using Geophysical Methods

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LBNL

In Collaboration with:
Craig Criddle and Area 3 team
Jack Istok and Area 1 team
Tim Scheibe and Area 2 team
David Watson, Phil Jardine, and Tonia Mehlhorn ORNL

Needed:

•Hydrogeological property information for predicting flow and transport;

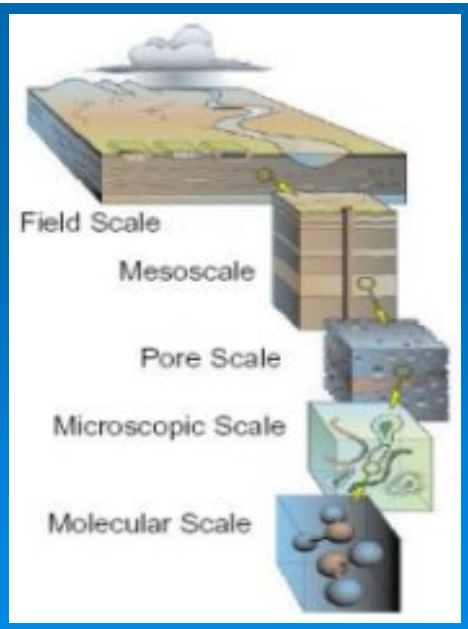
•Better understanding of spatiotemporal biogeochemical-hydrological changes that occur during remediation

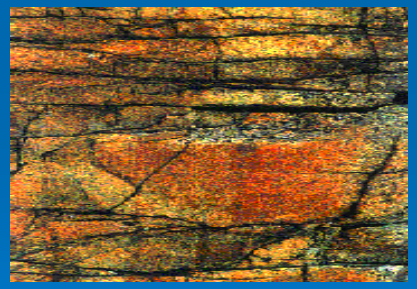
Problem:

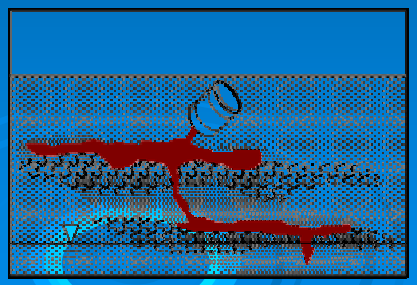
Large spatial and temporal variability of parameters in natural systems renders characterization/monitoring of subsurface parameters and processes difficult using conventioal measurements.

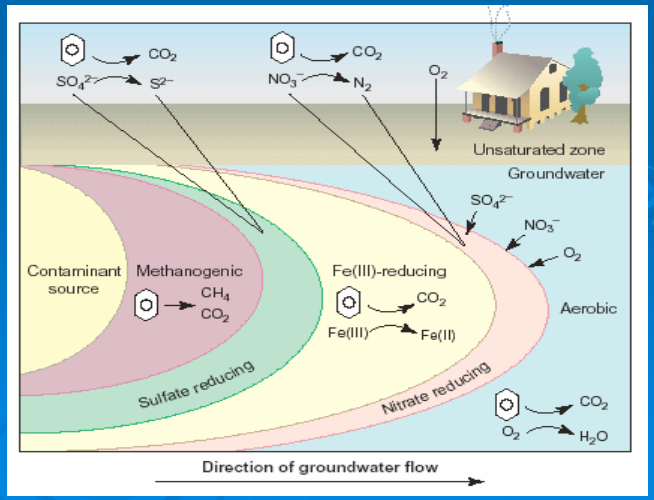
Approach:

Investigate the use of multi-scaled geophysical data to provide data that can assist in environmental characterization and monitoring





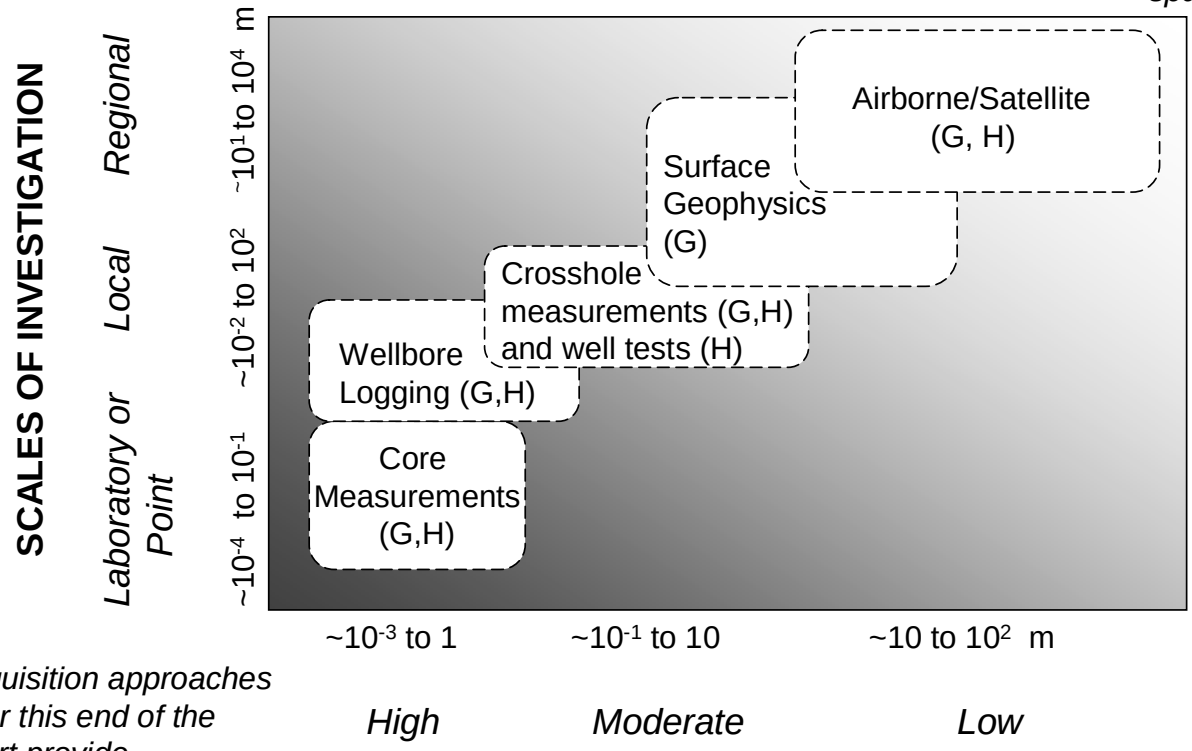




Advantages of Using Geophysical Data

- Minimally invasive
- Multi-dimensional
- Varied spatial resolution

Acquisition approaches near this end of the chart provide low resolution information over large spatial extents



Acquisition approaches near this end of the chart provide high resolution information over small spatial extents

Challenges

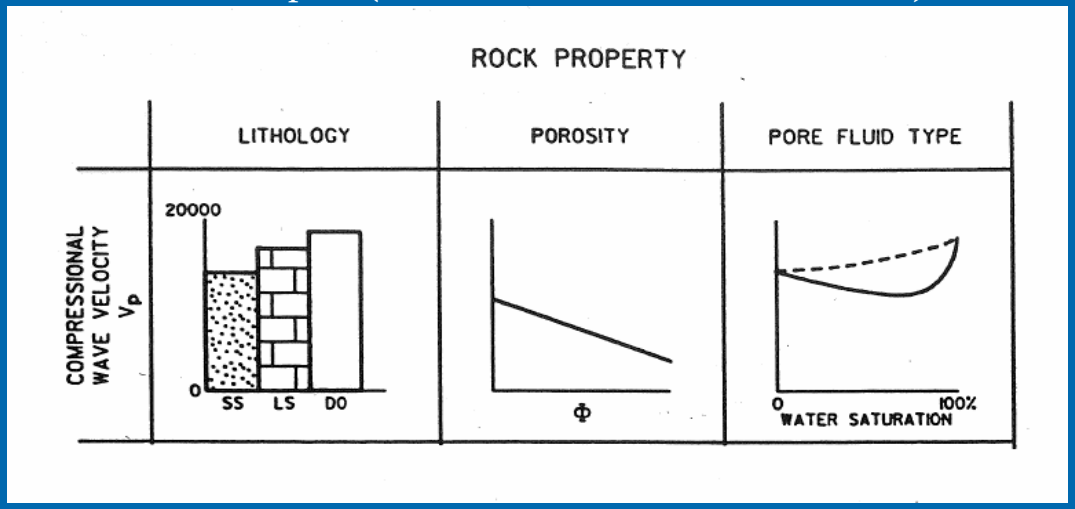
Geophysical Measurements are:

1) Indirect;

2) Effective (volume averaged), and sample with a different support scale than most hydrological measurements;

3) Often sensitive to several different hydrogeological properties.

Example: (Tatham and McCormack, 1993).



Our Work has focused on overcoming these challenges to use geophysical data to:

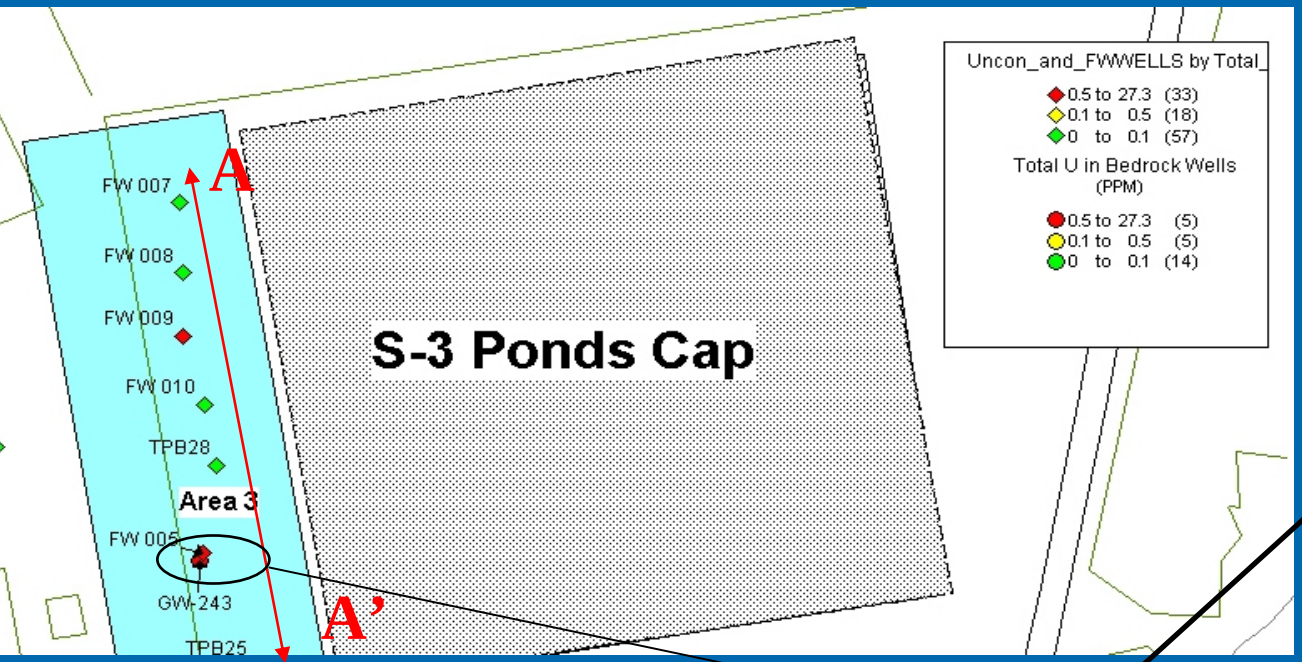
1) Estimate hydrogeological parameters that can be used as input to numerical flow and transport models (Part 1);

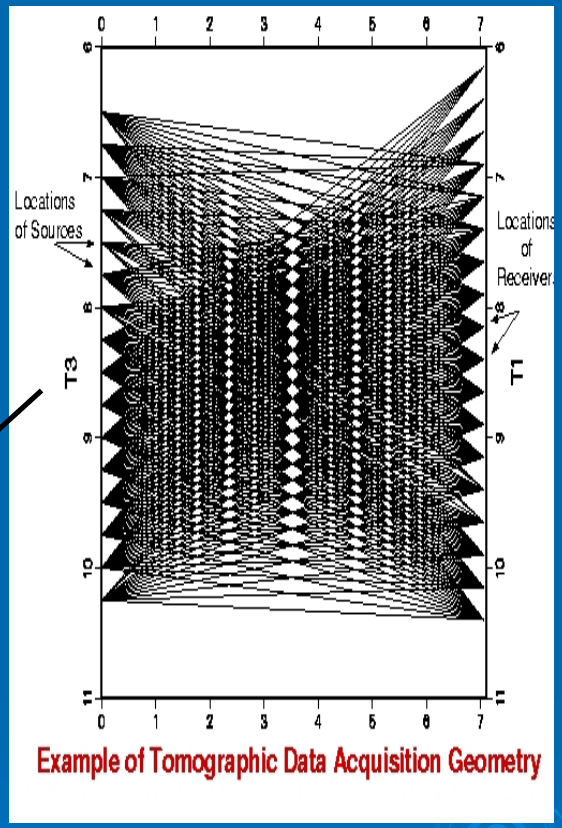
2) Monitor processes that occur in the subsurface as it is perturbed, such as the evolution of gasses, precipitates, and biofilms during biostimulation (Part 2)

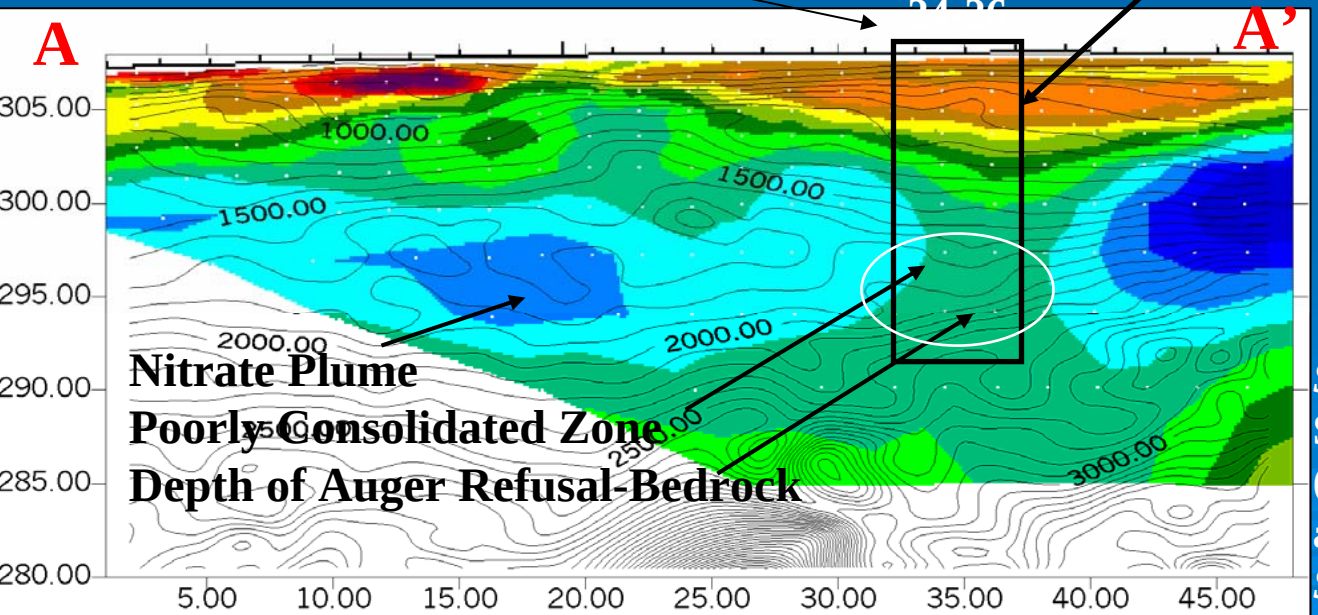
Part 1: Fracture Zonation **Characterization Area 3**

- **Seismic Velocity expected to be sensitive to stiffness – FRACTURE zones.**
- **Problems:**
  - **Seismic anisotropy,**
  - **Difference in flowmeter/tomography measurement support scales**
- **Approach: Sampling Based Bayesian (MCMC) methods for JOINT inversion of seismic travel times and hydraulic conductivity INDICATOR values.**
- **Result: Estimation of the *Probability of being in the High Hydraulic Conductivity Fracture Zone.***

High Resolution Imaging at Area 3 using Seismic Tomographic Data

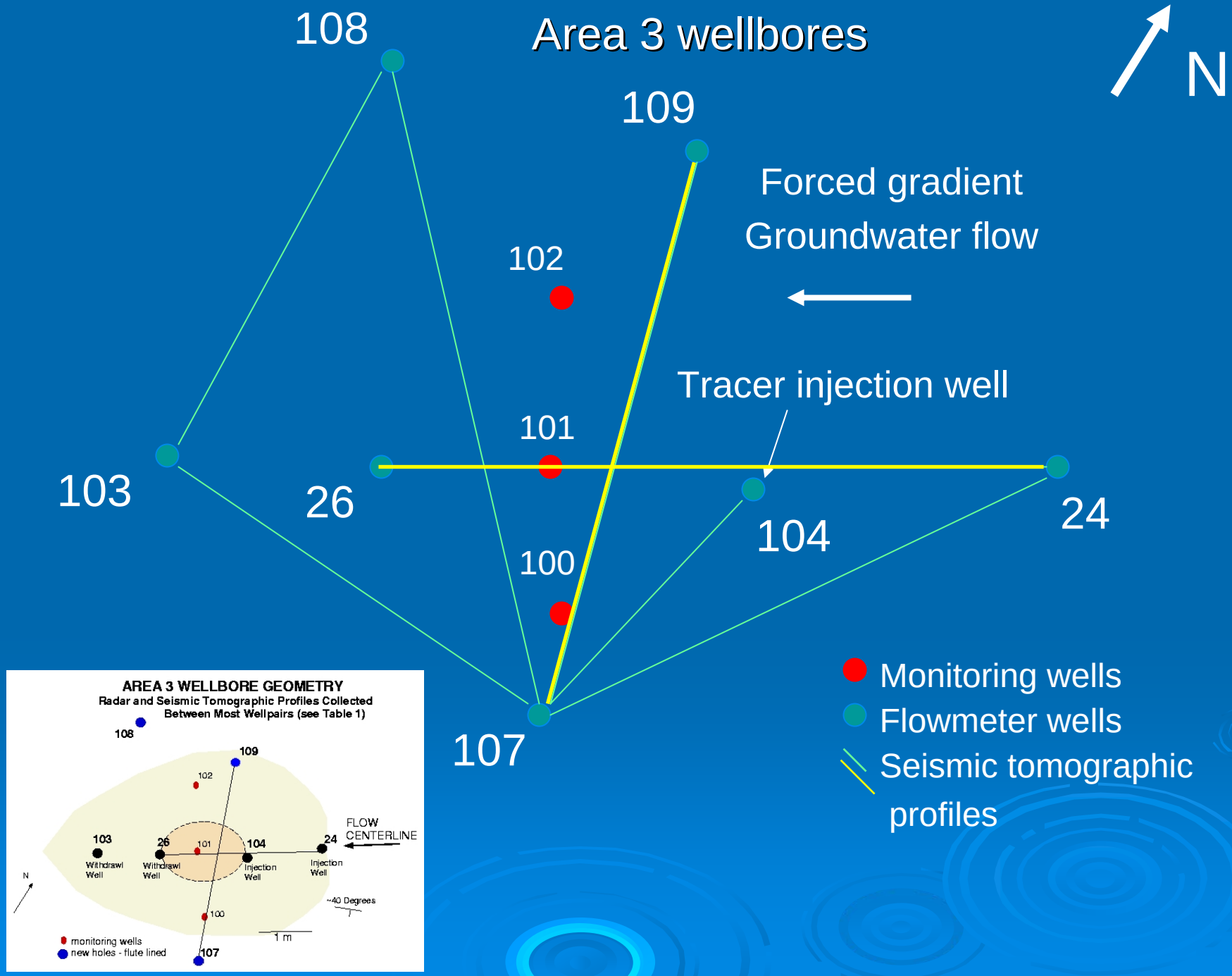




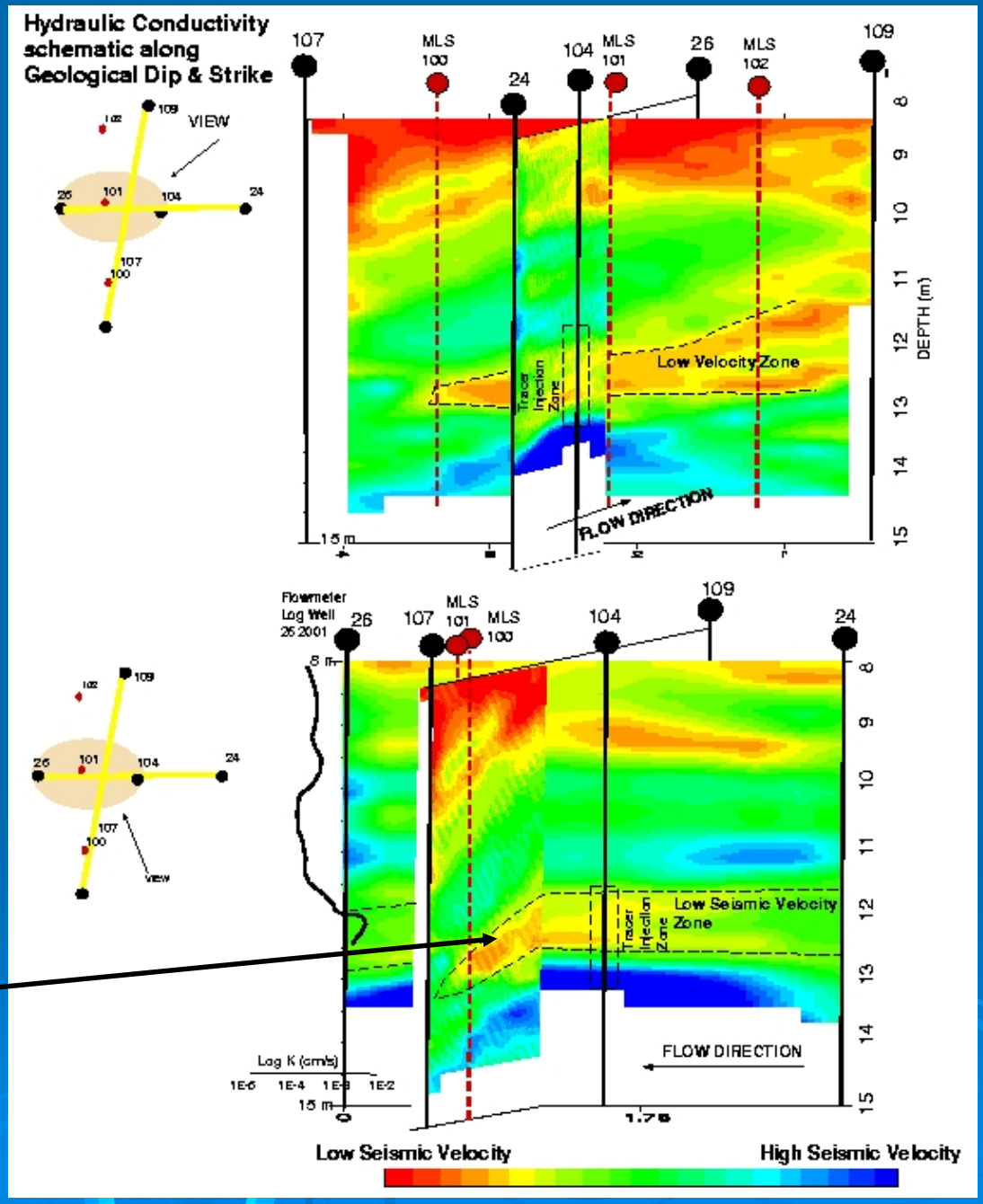


S-3 Ponds Cap
Surface Seismic & Electrical
(Bill Doll et al., *SAGEEP*, 2002 and David Watson et al., *Spectrum*, 2002).

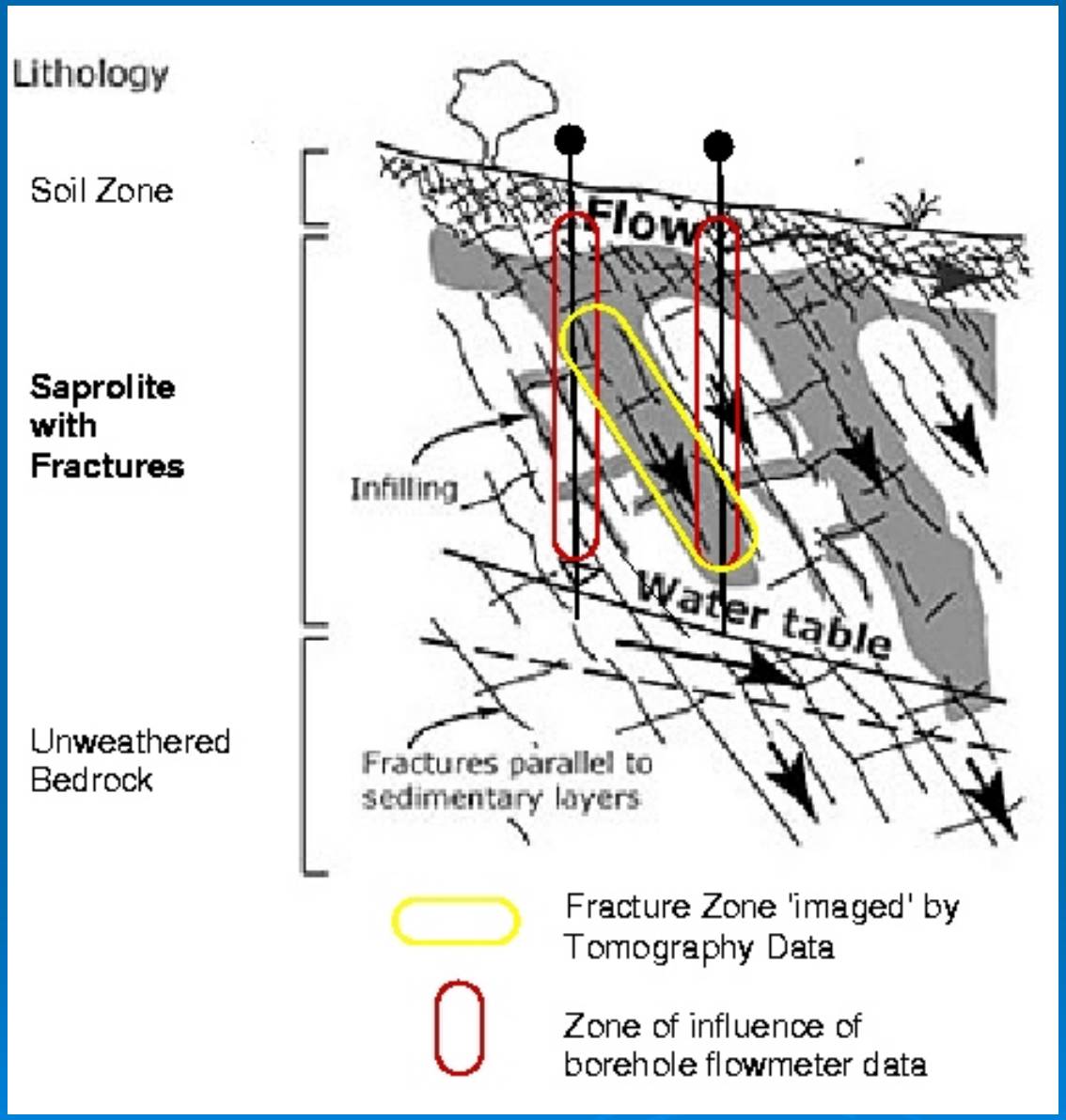
Area 3 wellbores



Seismic Velocity Signatures of Stimulation Zone in Geological Strike and Dip Directions



Geometry of low velocity zone (zone of lower stiffness) is spatially variably



Saprolite system conceptual model from McKay et al (Univ. of Tennessee)

Problems:

- Borehole and
- crosshole datasets have different measurement support scales;

- Values of seismic velocity are directionally dependent (anisotropy);

- The scale problem is exacerbated in fractured systems.

- Poor direct relationship between borehole K and seismic v at wellbore location.

- This renders estimation of ‘continuous’ values of hydraulic conductivity difficult

Approach: Joint Inversion of seismic travel time data with K indicator values (from flowmeter logs) using Monte Carlo Markov Chain (MCMC) method

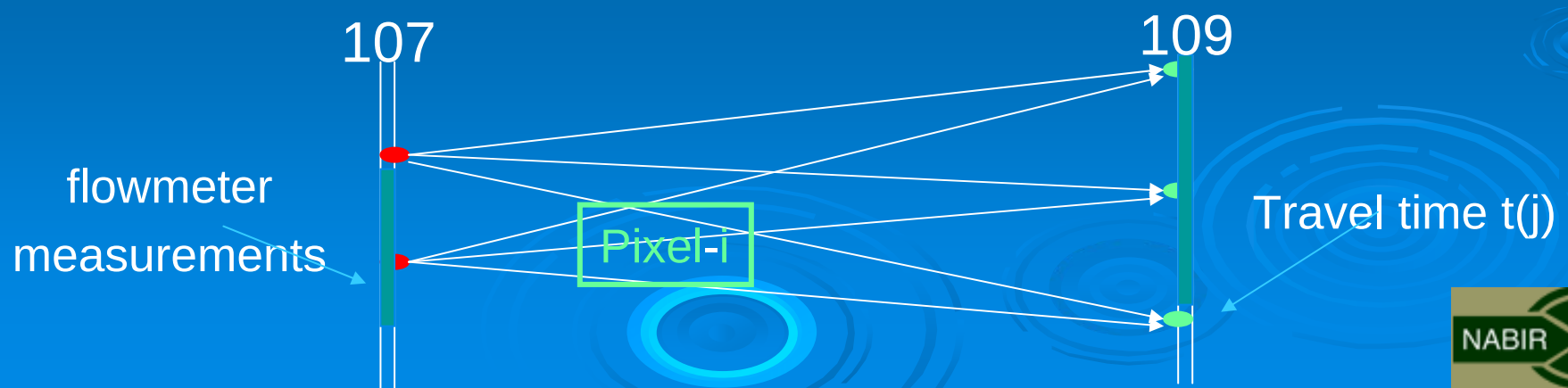
Step-1: Define Posterior Distribution

- likelihood functions for data
- develop posterior pdfs

Step-2: Draw Samples From pdf

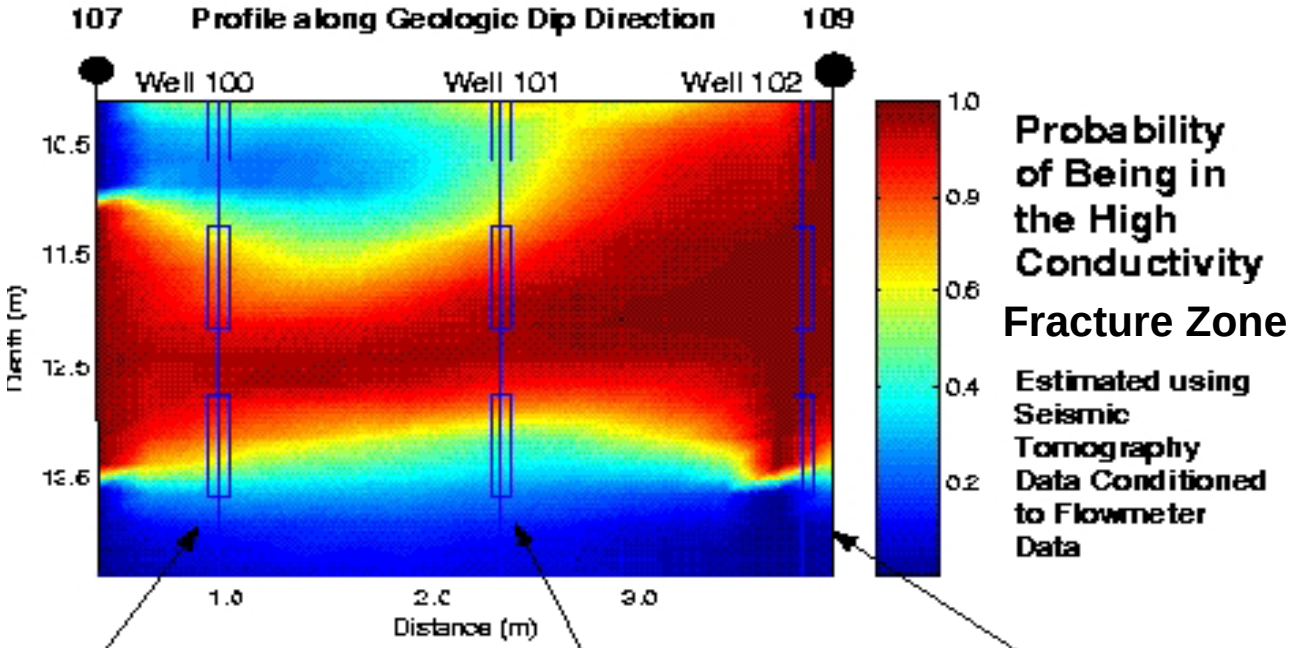
Step-3: Infer

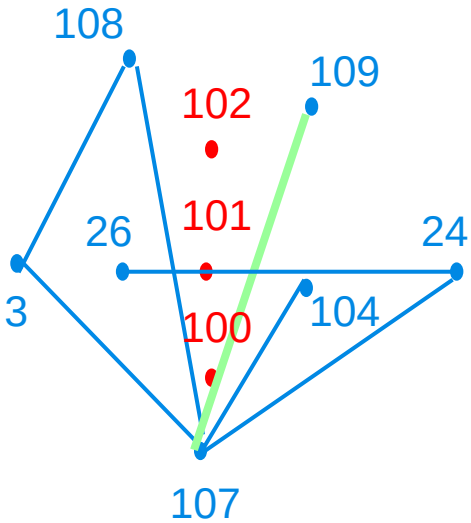
- Mean
- Variance,
- Quantiles
- Probability function

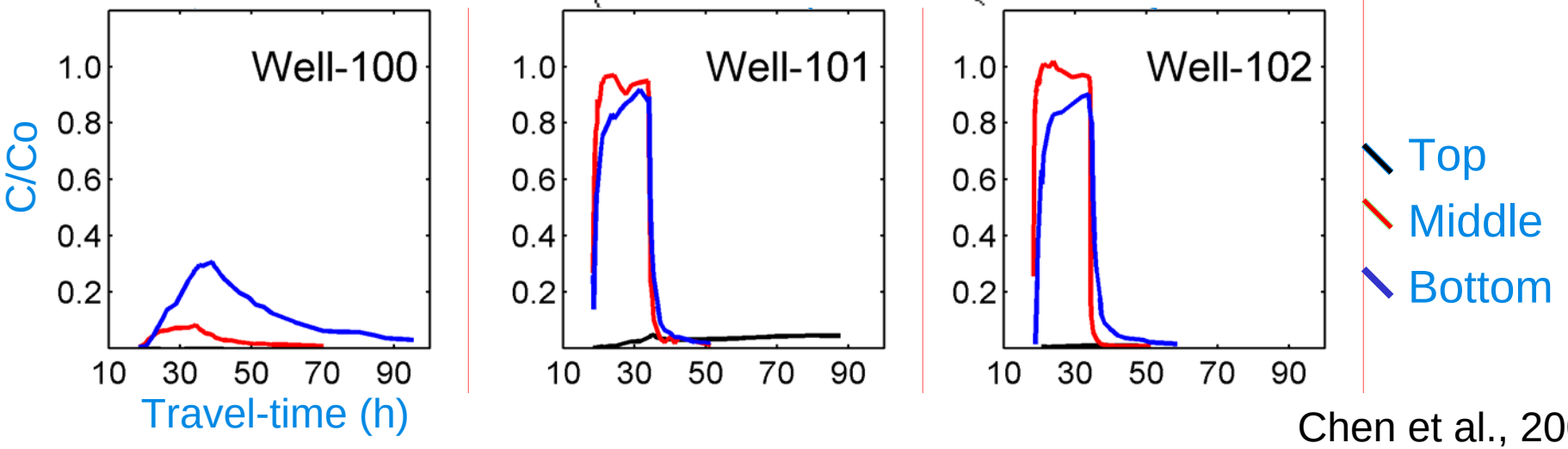


Comparison of with Tracer Experiment results

(Tracer Data from Phil Jardine, Tonia Mehlhorn and David Watson, ORNL)





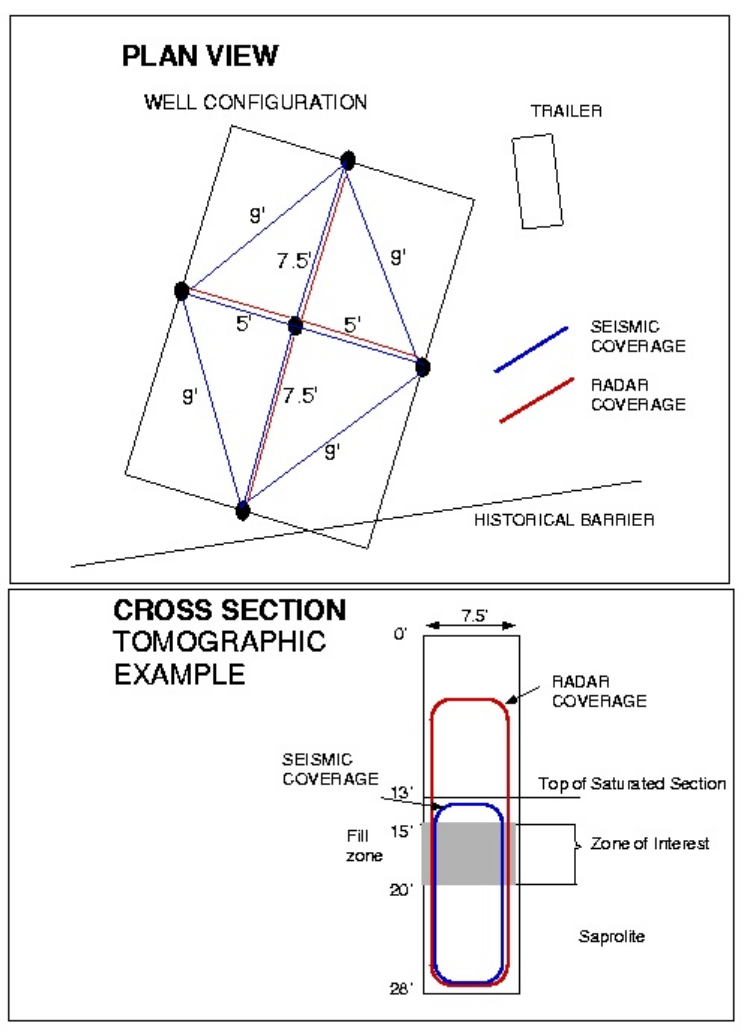


Chen et al., 2003

Summary: FRC Characterization

- Completed FRC Area 3:
  - Developed a new joint inversion approach for simultaneously fusing well and seismic travel time data
  - Estimated fracture zonation at Area 3.
- Planned at Area 2 (w/Scheibe et al.)
  - 2004: Radar/Seismic tomographic acquisition and data quality check
  - 2005: If data quality is sufficient, estimate hydrogeological properties to provide constraints to flow and transport models.

AREA 2 Geophysical Geometry

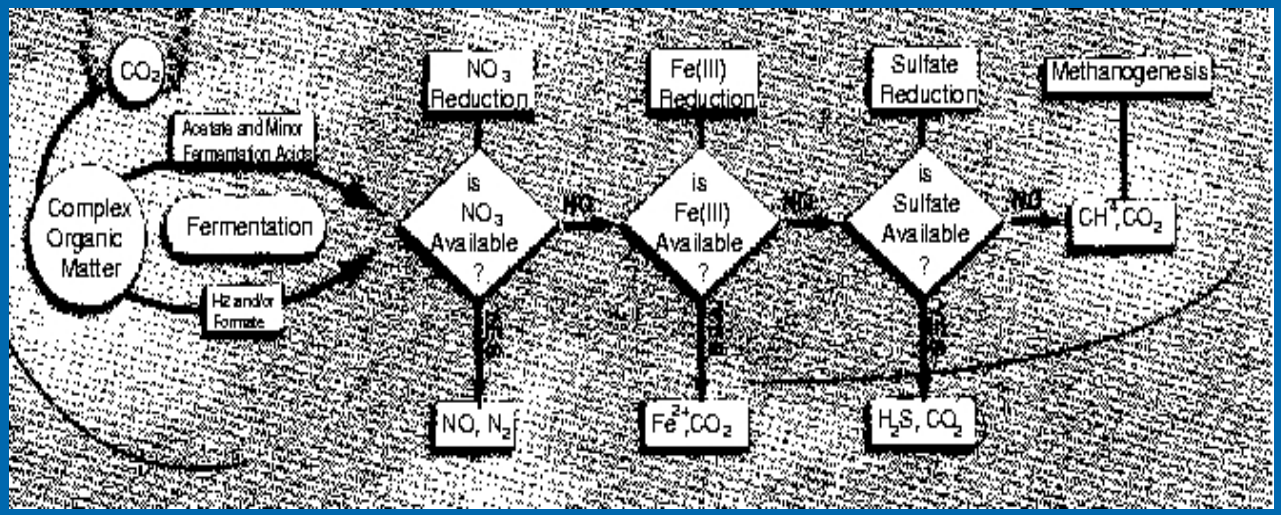


Geophysical Monitoring of Biostimulation

- Background
- Column-Scale Work
- Experiments in progress with J. Istok at Areas 1 and 2

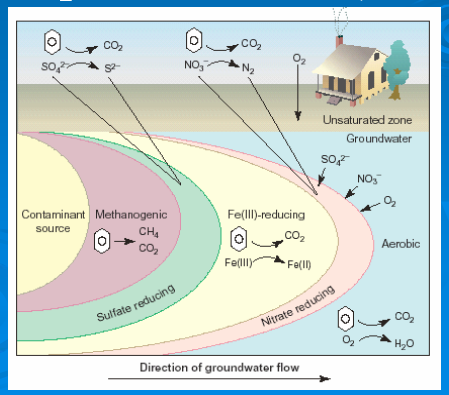
Background:
Geophysical Monitoring of Bacterial-Induced Phenomena

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



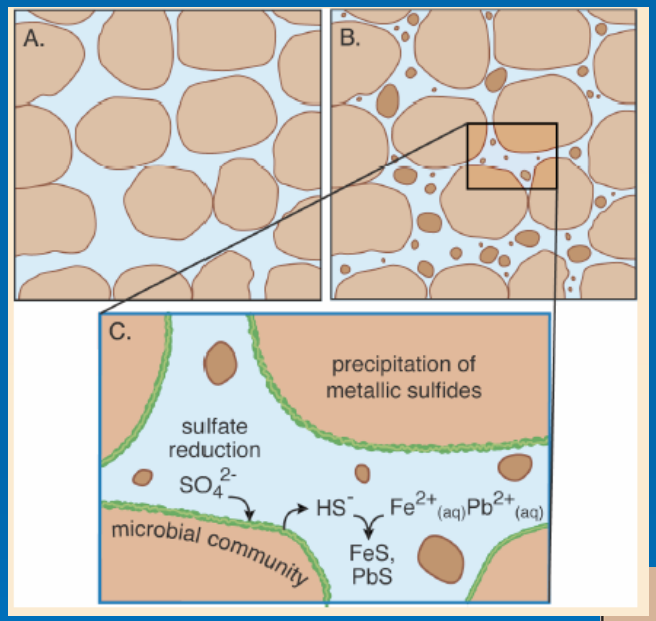
Chapelle, 2000

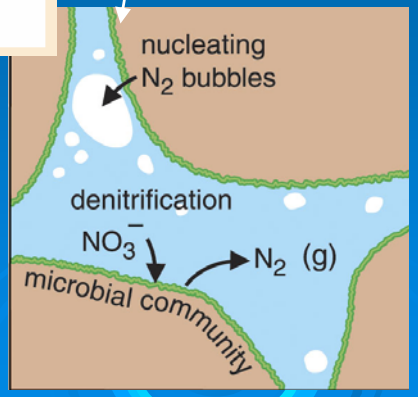
- Spatiotemporal variations extremely difficult to understand using wellbore data!
- Investigate utility of geophysical methods (seismic, radar, complex electrical) for providing information about system transformations over space and time:
  - *Gas Generation*,
  - *Biofilm development*
  - *Precipitation*

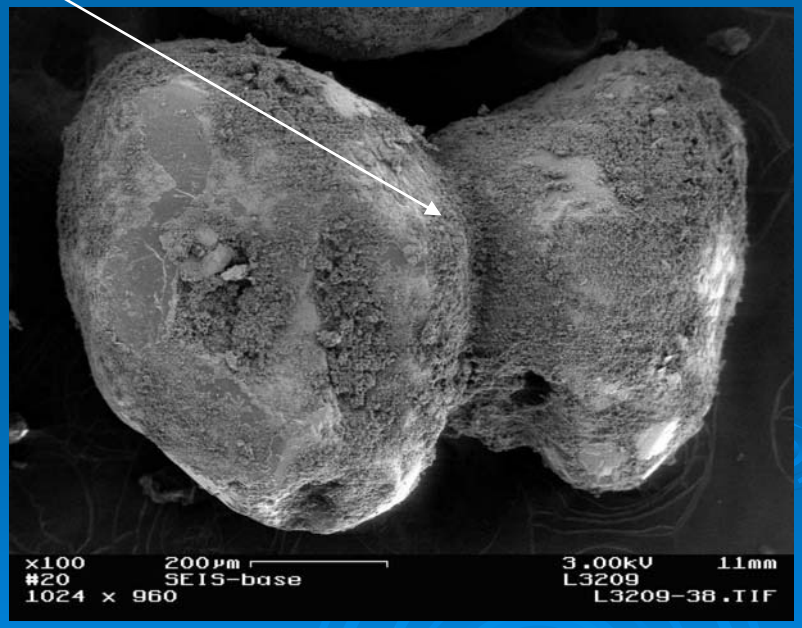


•Geophysical measurements sense VOLUME AVERAGED changes in systems during perturbations.

•Products may block pore throats and reduce K





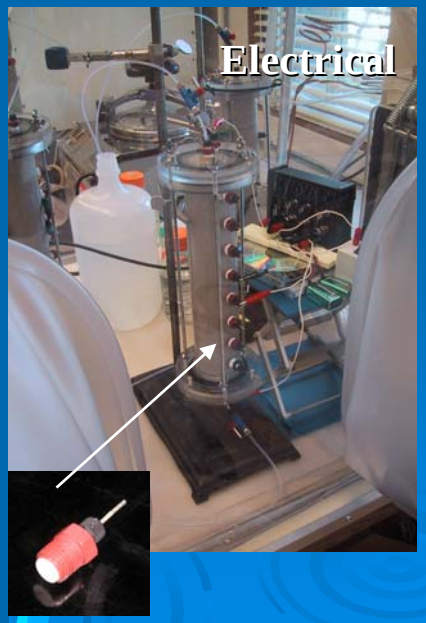


Zn/Fe-sulfide crusts on quartz grains

Lab-Scale Investigations under Controlled Conditions. Collect coincident Biogeochemical-Hydrological-Geophysical Measurements during Stimulation

- Acoustic Method:
  - Cross-column acoustic pulses (10^5-10^6Hz)
  - Velocity and amplitude information
- Electromagnetic (TDR) Method
  - Time Domain Reflectometry (1-3GHz)
  - Velocity and amplitude information
- Complex Resistivity (10^{-1}-10^3Hz)

  in collaboration with Lee Slater, Rutgers
  - Non-polarizing (i.e. low-noise) Ag/AgCl potential electrodes
  - Gold current electrodes
- Biogeochemical
  - Fluid chemistry (anions, cations, organic acids, pH)
  - Biomass sampling (quantitative AODC, PLFA)
  - Nanoparticle sampling and analysis (XRD, SEM, TEM)
  - Electron microscopy of microbe-sediment associations

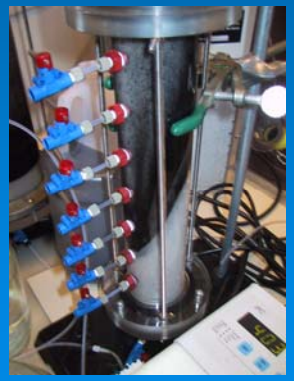


EMSP
Environmental Management Science Program

Summary of Results
(Visit Poster!)

Spatiotemporal changes in geophysical responses coincident with biogeochemical variations:

- Significant Radar and Seismic responses to gas generated during denitrification;
- Significant IP and seismic amplitude responses associated with the formation of insoluble metal sulfides during biostimulation.

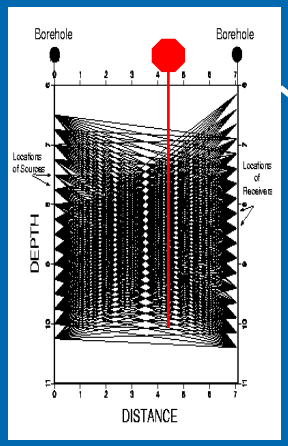


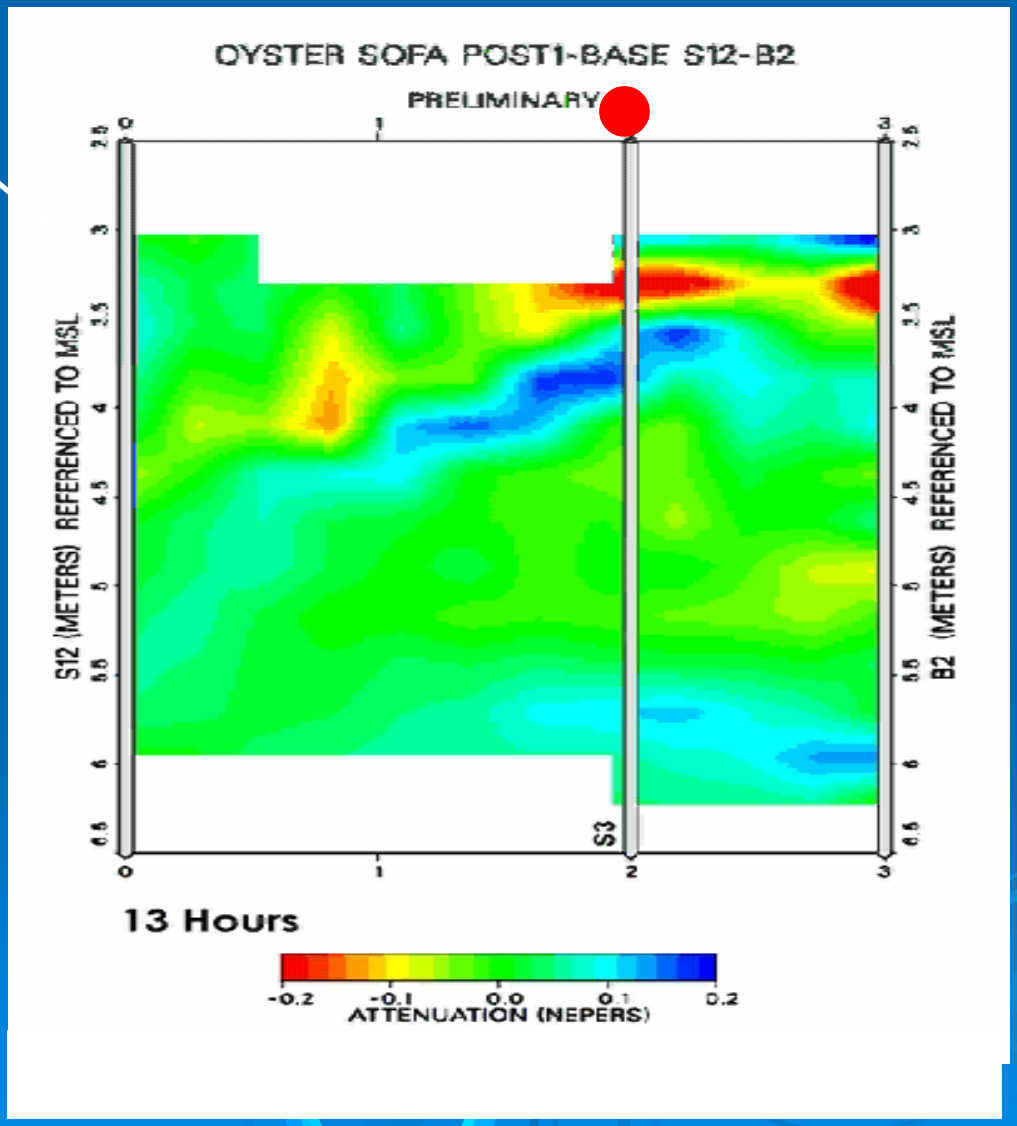
Geophysical Method	Geophysical Attribute	Gas Evolution	Precipitation Formation	Biofilm Formation
Radar	**Velocity**	*Large Increase*	*Not Signficant*	*In progress*
	Amplitude	*Increase*	*Not Significant*	
Seismic	**Velocity**	*Small Decrease*	*Small Increase*	
	Amplitude	*Large Decrease*	*Large Decrease*	
Electrical	**Conductivity**		*Small Response*	
	Phase		*Large Response*	

Williams et al., 2004; Ntarlagiannis et al., 2004

Time-Lapse Seismic Tomography Imaging of Gas Production: Piggy-back Trial at the Oyster Nabir Site

Lactate Injection Well





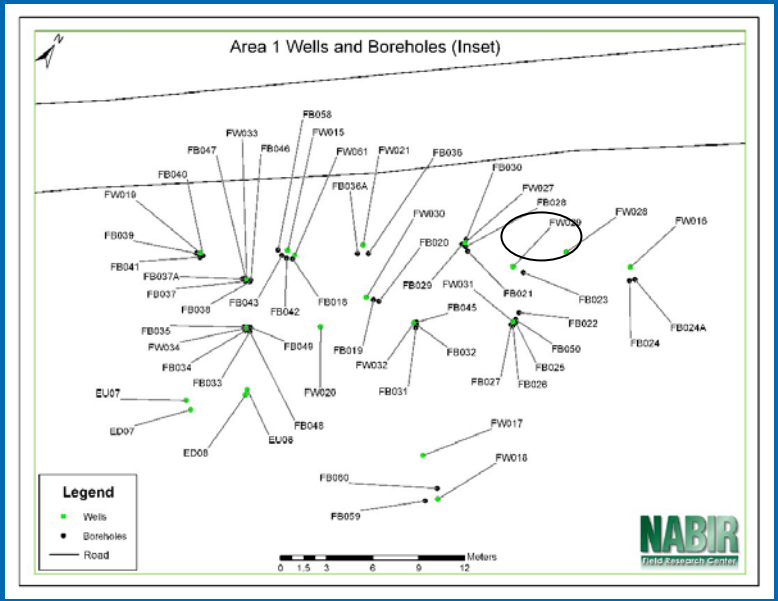
Biostimulation Experiment.
Nitrate Initial Concentration <12 mg/L (avg. 7mg/L)

Mailloux et al., 2002

Variations in seismic amplitude appeared to correlate with N2 production near the wellbore AT THE FIELD SCALE…

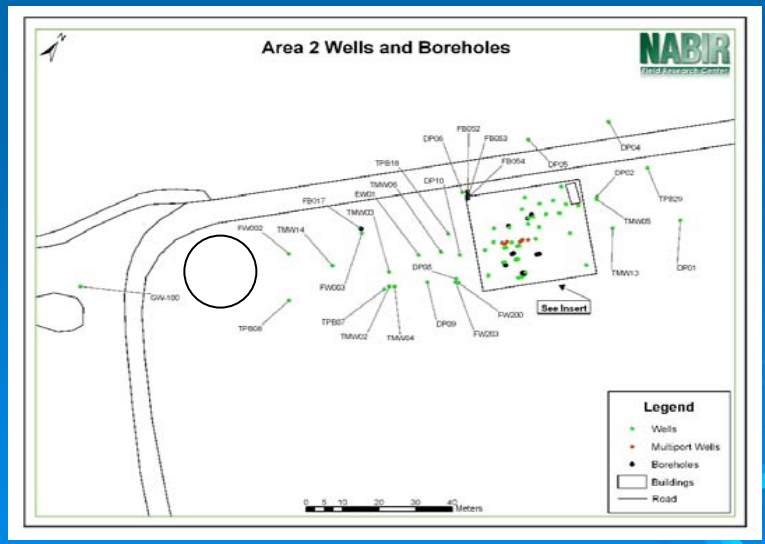
Calibrated Tests Needed!

FRC Field-Scale Push-Pull Monitoring. Remotely monitor: (1) zone of influence and (2) reaction products as a function of Hydrogeological Heterogeneity



Area 1 'Opportunity' at Istok et al. MSL Experiment.

- Conditions: High Nitrates and Al, higher conc. of dissolved metals in water, primarily in saprolite;
- Expected products: gasses, ppts, biomass, K reduction;
- Collected baseline data, started ethanol injection end Sept/ beg. October 2004

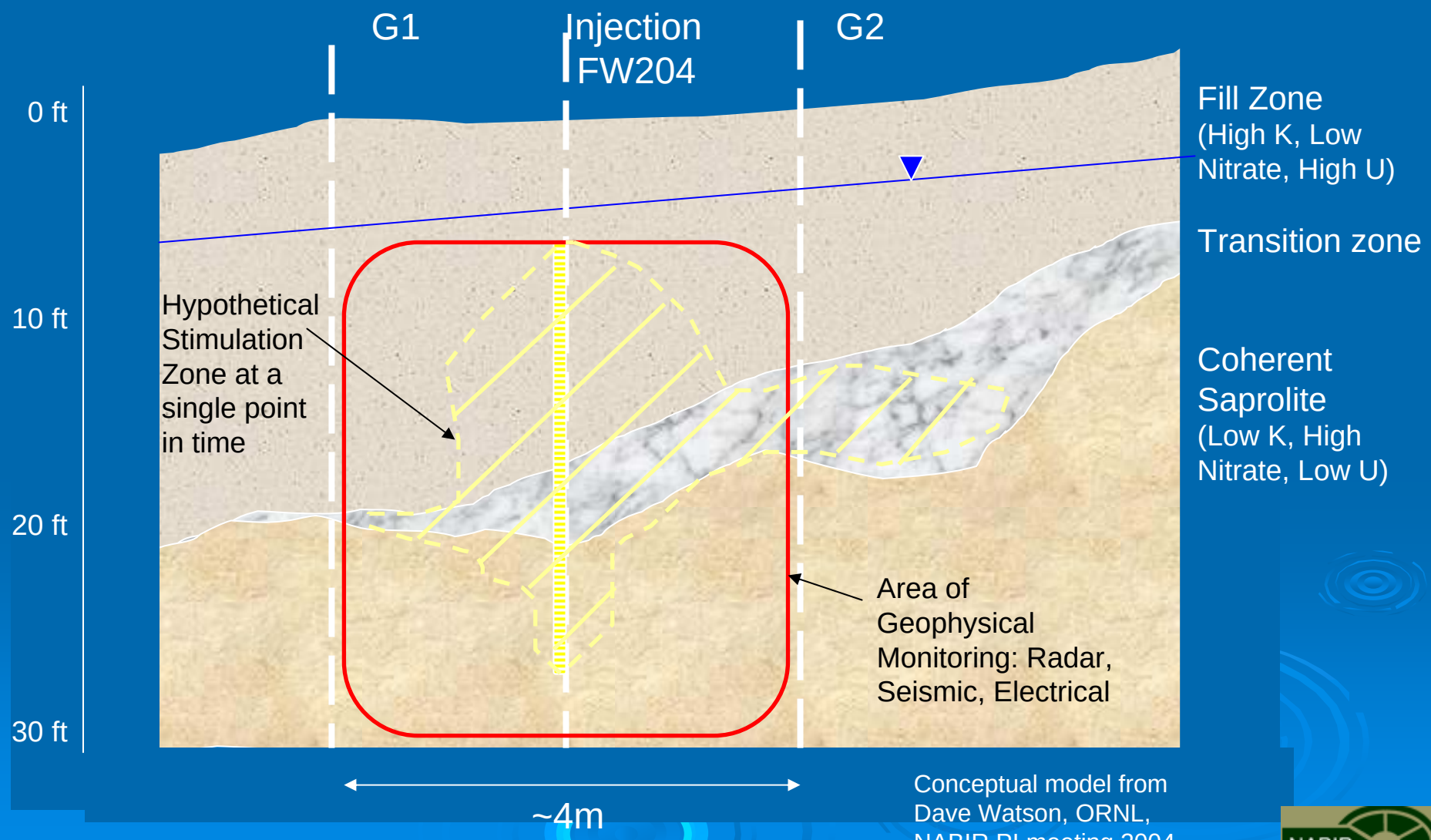


Area 2 Planned Stimulation w/ Istok et al.

- Conditions: Lower nitrates and Al, possibly higher Sulfates lower conc. of dissolved metals in groundwater;
- Expected products: ppts
- Design to traverse both fill and saprolite zone –collected baseline data in Sept. 2004

Schematic Field Scale Imaging of Push Pull Tests to Monitor:

* Zone of Influence of Injectate
* Preferential reactions as function of natural heterogeneity



Conceptual model from Dave Watson, ORNL, NABIR PI meeting 2004

SUMMARY

General Theme – Use of geophysical tomographic methods for characterization contaminated subsurface regions and for monitoring bioremediation processes. Processes that are monitored include the spatial extent of the injectate, as well as the detection of generated gasses and precipitates.

NABIR project structure – Projects are small (~35k), and are performed in conjunction with other funded projects. Represent 'tests' rather than complete investigations.

Results to Date:

Developed a novel inversion method for joint use of seismic travel time data and flowmeter hydraulic conductivity indicator information using a MCMC method.

Applied the inversion technique to data collected at the Area 3 stimulation site to image spatially varying fracture zonation;

In Progress:

Repeat Characterization Effort for Scheibe et al. Site

Monitor Zone of Influence and Stimulation Products of Push Pull Tests.