Characterization at DOE Sites using Geophysical Data

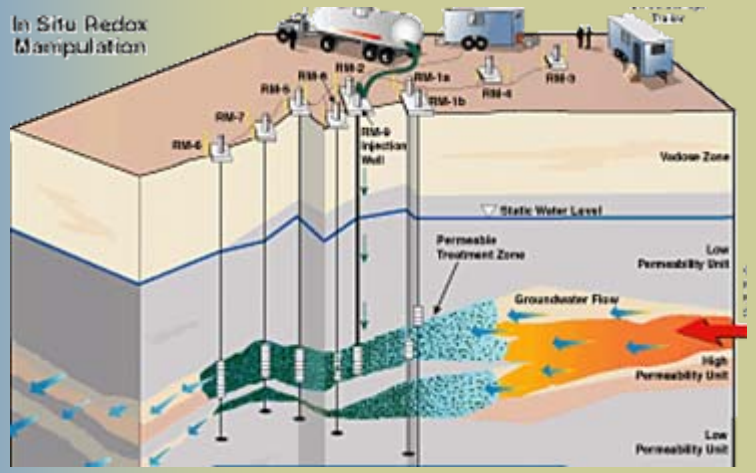
1. Common DOE Characterization Approaches and Needs
2. Comparison with Petroleum Approaches

Susan Hubbard
LBNL

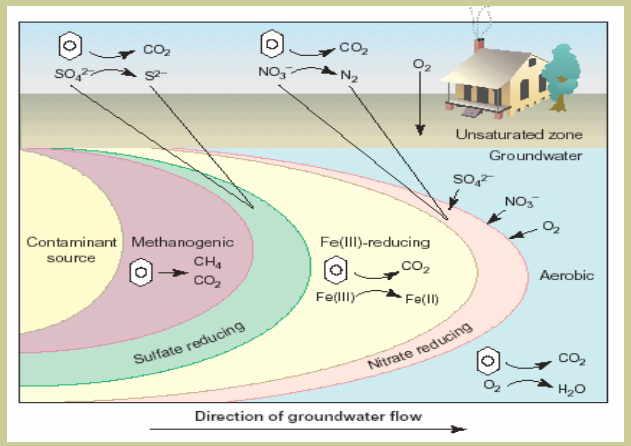
Importance of Heterogeneity to Remediation

- The efficacy of in-situ remediation depends in part on the ability to
  - Understand the initial distribution of contaminants;
  - Design treatments that bring amendments into contact with the distributed contaminants;
  - Sustain the hydrogeochemical conditions favorable for the chosen treatment.
- These factors are **largely governed by heterogeneity**!

Hydrogeological Heterogeneity



Geochemical Heterogeneity



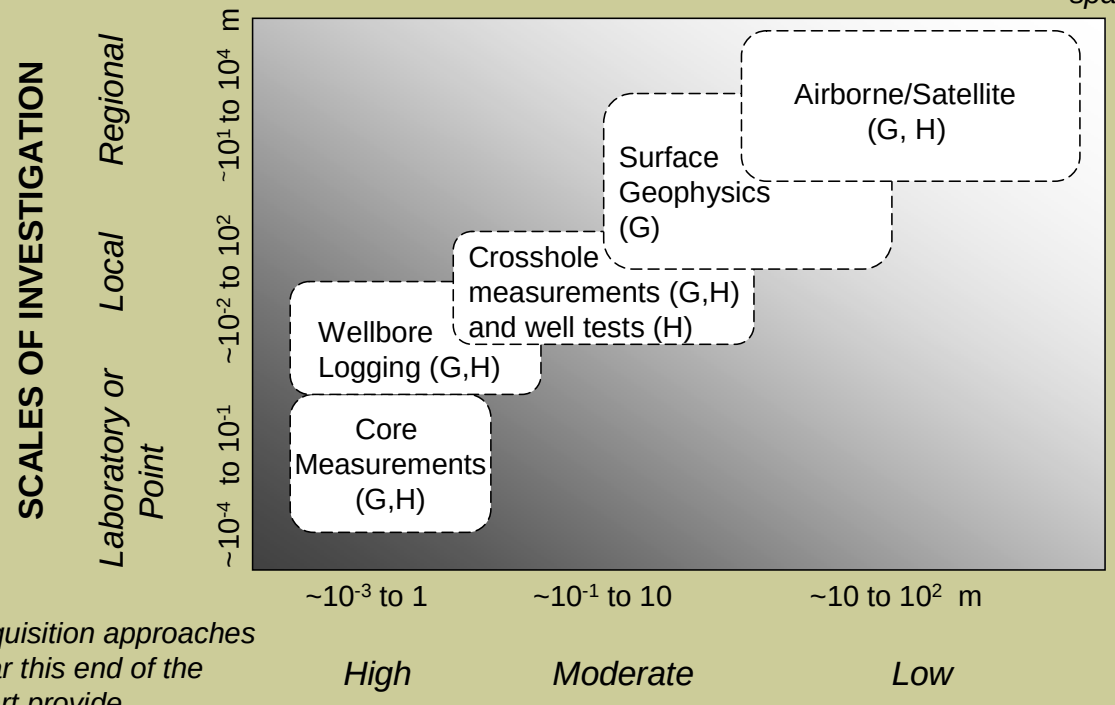
Lovley, 2001

Common Characterization Objectives and Approaches

- Lithologic zonation
- Hydrofacies
- Hydraulic conductivity & porosity
- Fast path delineation
- Fracture zonation
- Sediment and Aqueous Geochemistry

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

Scales and Resolution of Geophysical (G) and Hydrological (H) Characterization Approaches



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

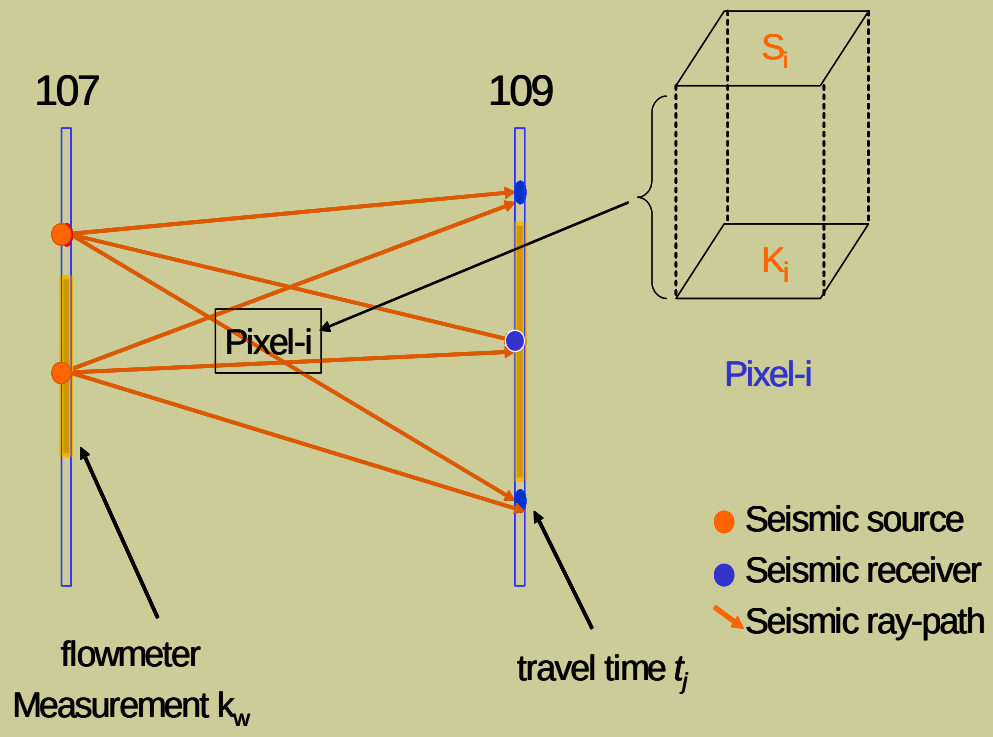
Subsurface Characterization using Geophysical Data

Advantages:

1. Minimally invasive
2. Greater spatial extents than conventional measurements
3. Measurements not as effected by borehole disturbances

Disadvantages:

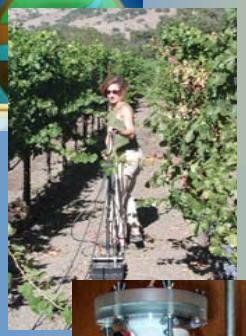
1. Additional costs & expertise
2. Indirect
3. Volume averaged
4. Nonuniqueness

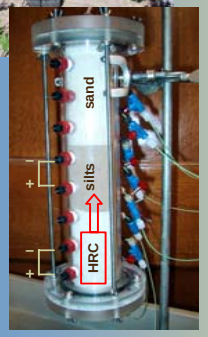


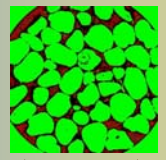
Requirements……

Exploration of Geophysical Approaches through Lab and Field Investigations

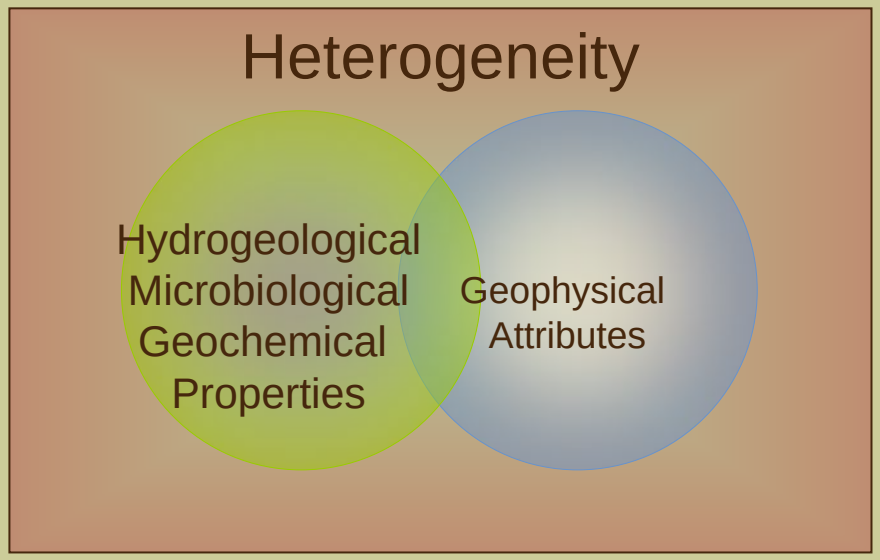
Key Components

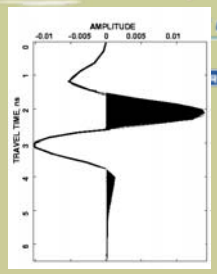


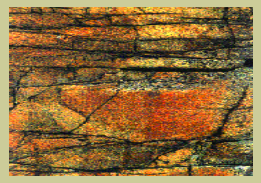




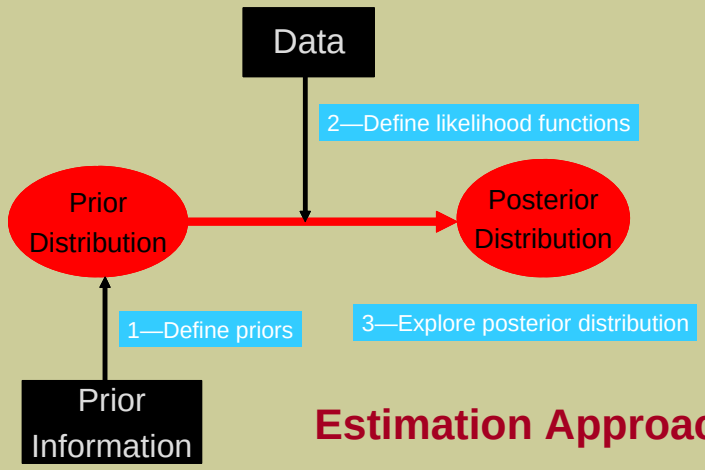
1 mm







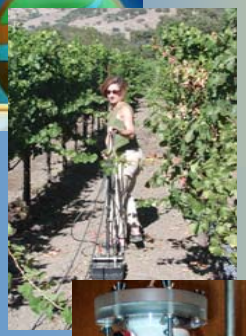
Petrophysics

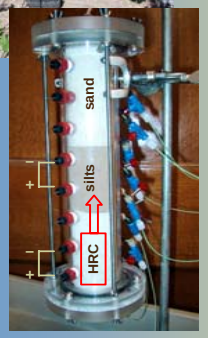


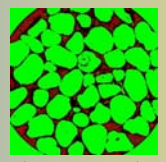
Estimation Approaches

Exploration of Geophysical Approaches through Lab and Field Investigations

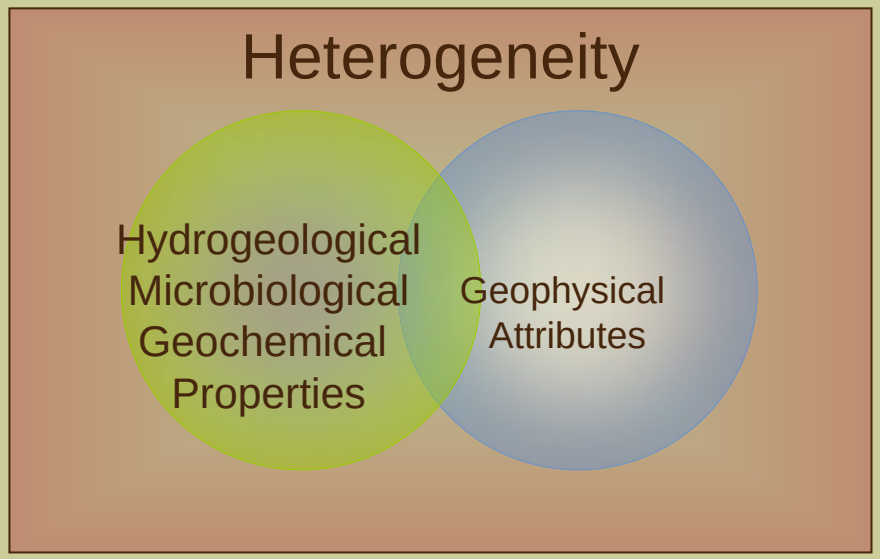
Key Components

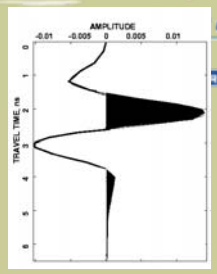


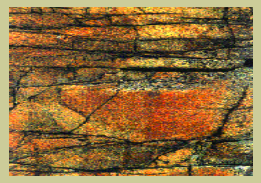




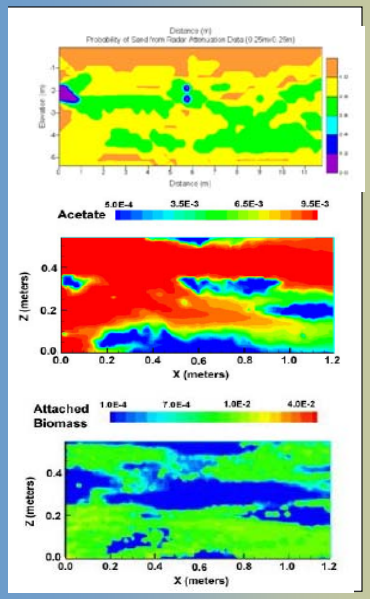
1 mm



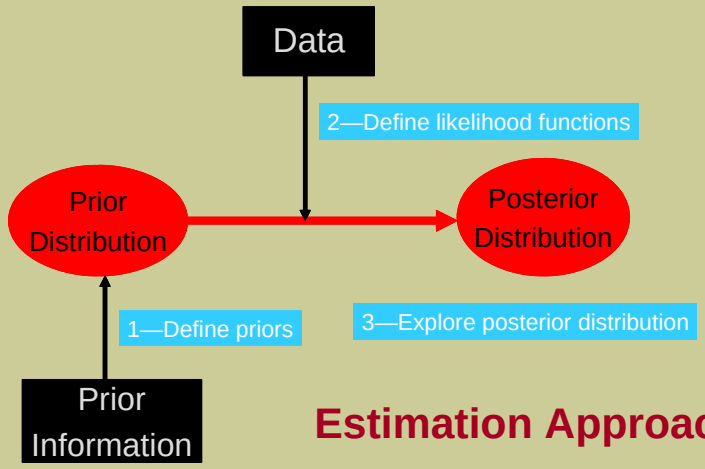




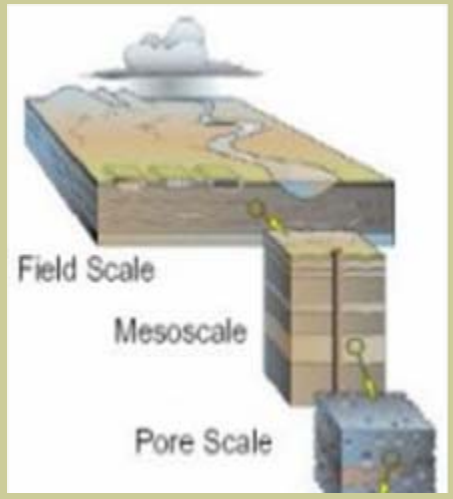
Petrophysics



Modeling



Estimation Approaches

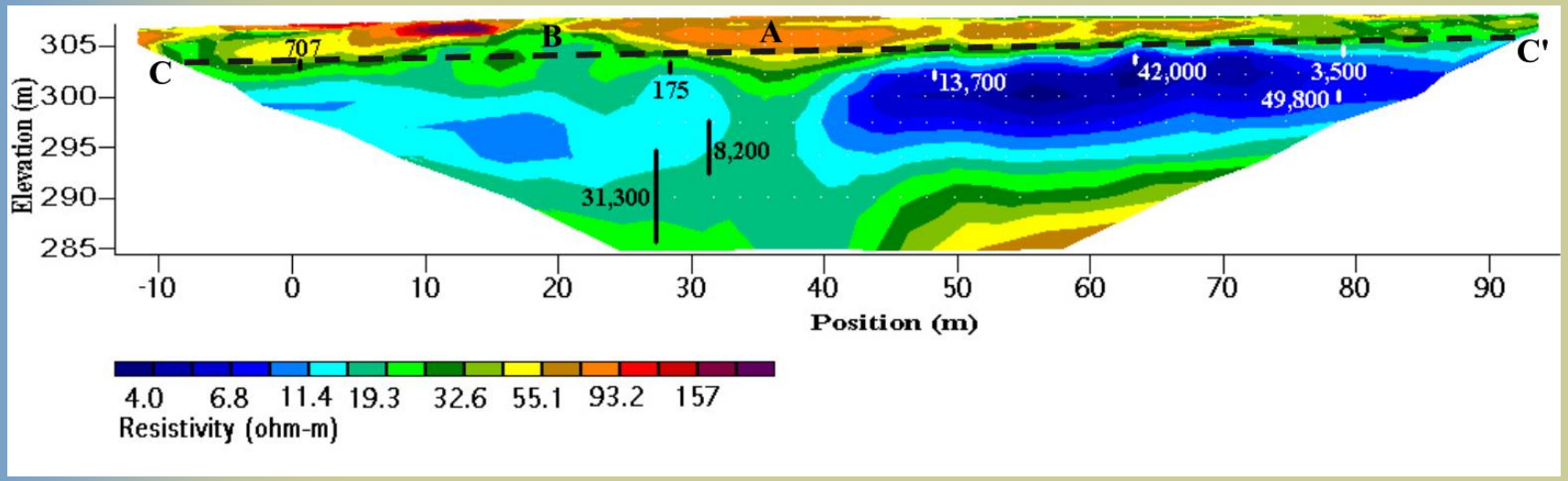


Scaling Issues

Some Examples of Characterization and Monitoring at DOE Sites

Use of Surface Geophysics at the FRC

(Dave Watson)



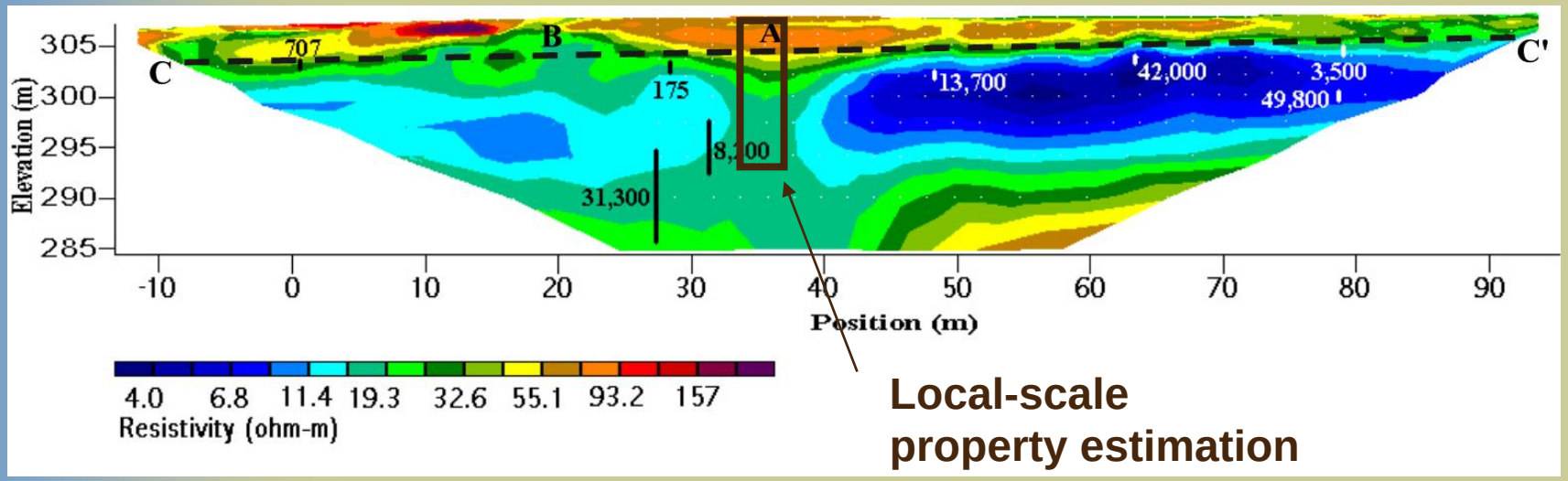
Used to:

- Guide borehole sampling locations
- Extrapolate borehole measurements
- Develop site-scale conceptual model

Surface Geophysics can be a Cost Effective Reconnaissance Tool !

Use of Surface Geophysics at the FRC

(Dave Watson)



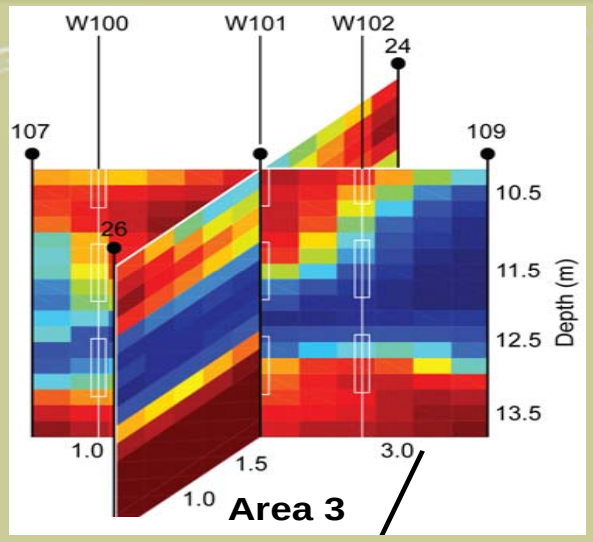
Local-scale property estimation

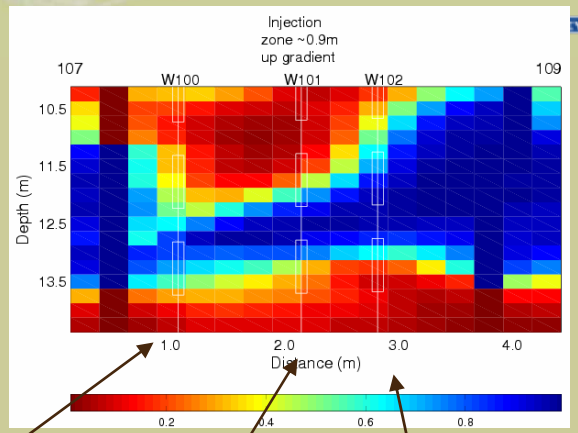
Used to:

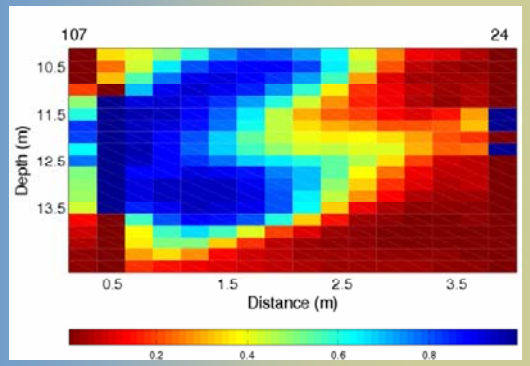
- Guide borehole sampling locations
- Extrapolate borehole measurements
- Develop site-scale conceptual model

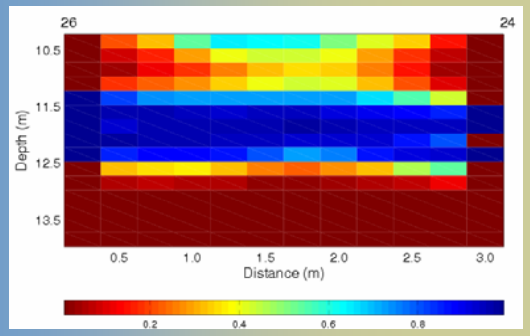
Surface Geophysics can be a Cost Effective Reconnaissance Tool !

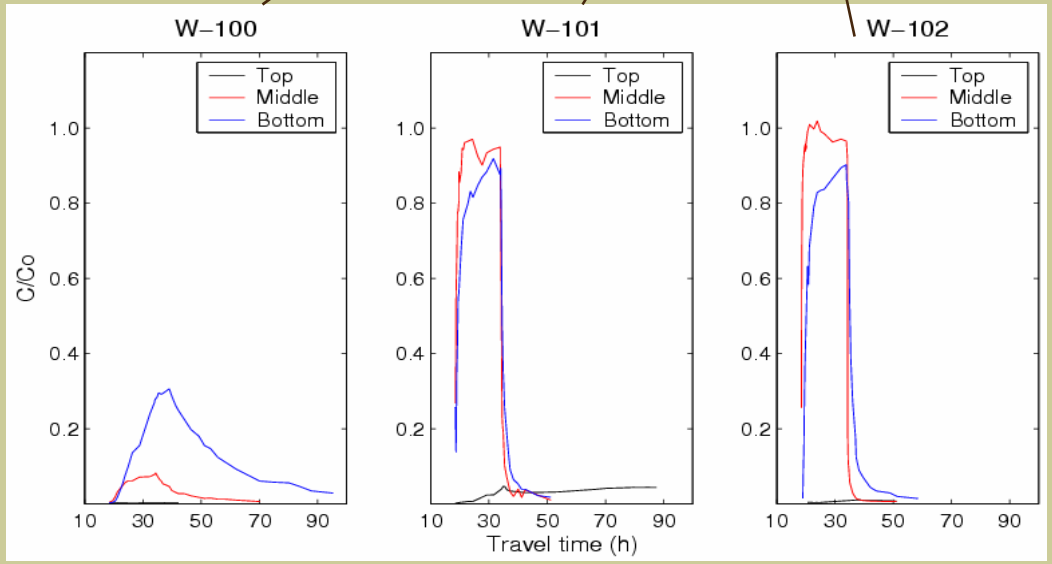
Fracture Zonation Estimation using Tomographic Seismic Methods











Fracture geometry estimated using geophysical data explains spatial variation of tracer breakthrough and U bioreduction

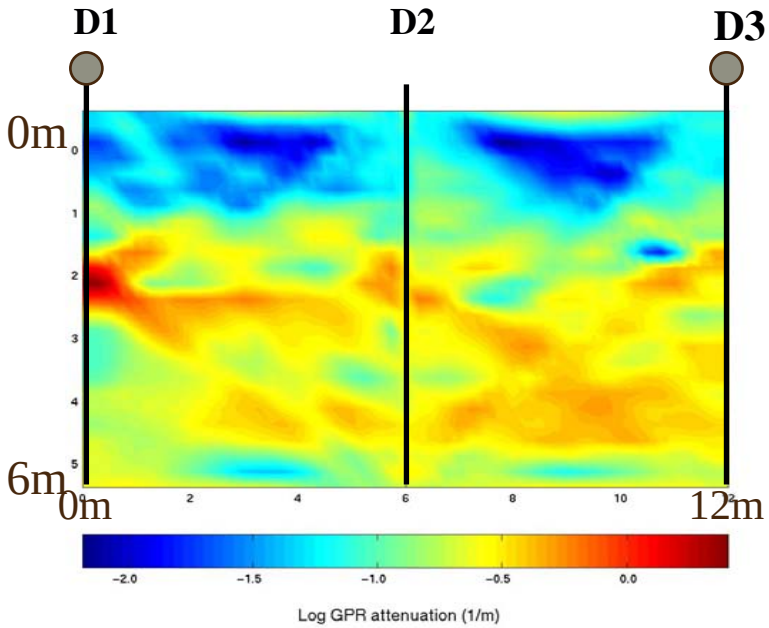
Breakthrough data: from Tonia Mehlhorn and Phil Jardine

Chen et al., Estimation of Fracture Zonation using Geophysical data, WRR, 2005

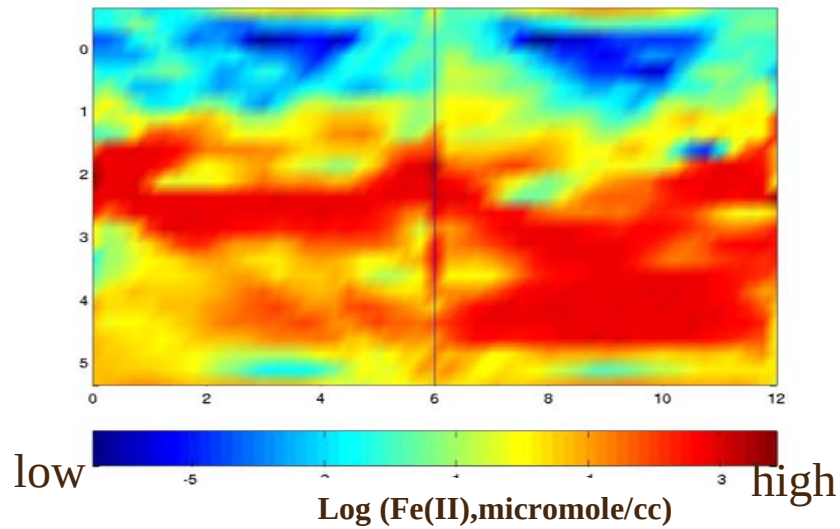
Geochemical-Lithological Parameter Estimation using Radar Tomographic Data

Chen, Hubbard, Murray, Rodin, and Majer, ***WRR, 2005***

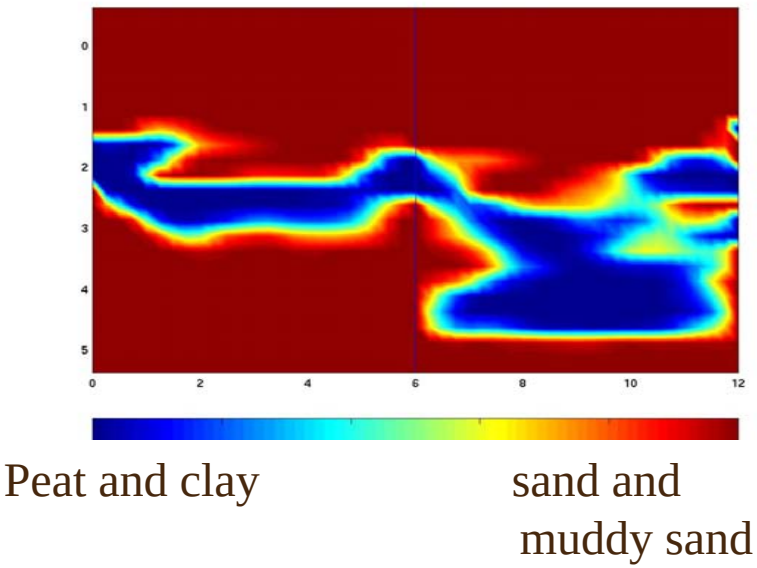
Radar Attenuation



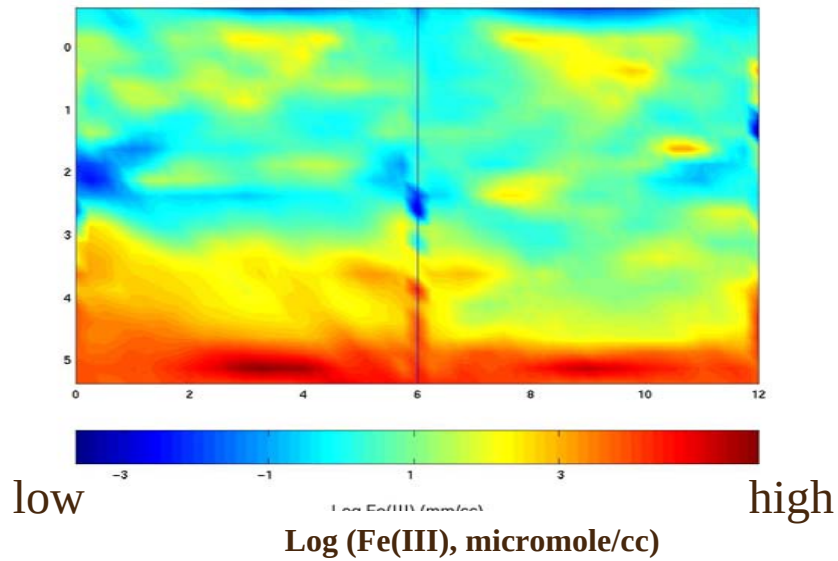
Estimated Fe2



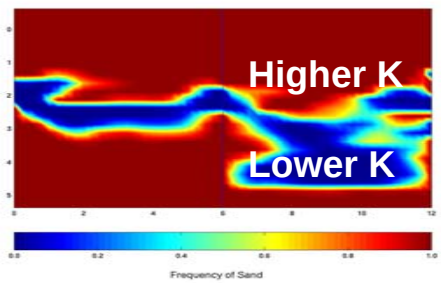
Estimated Lithology



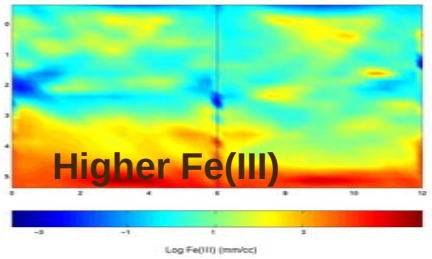
Estimated Fe3



Use of Geophysics for Parameterizing Numerical Flow and Transport Models - MOVIE

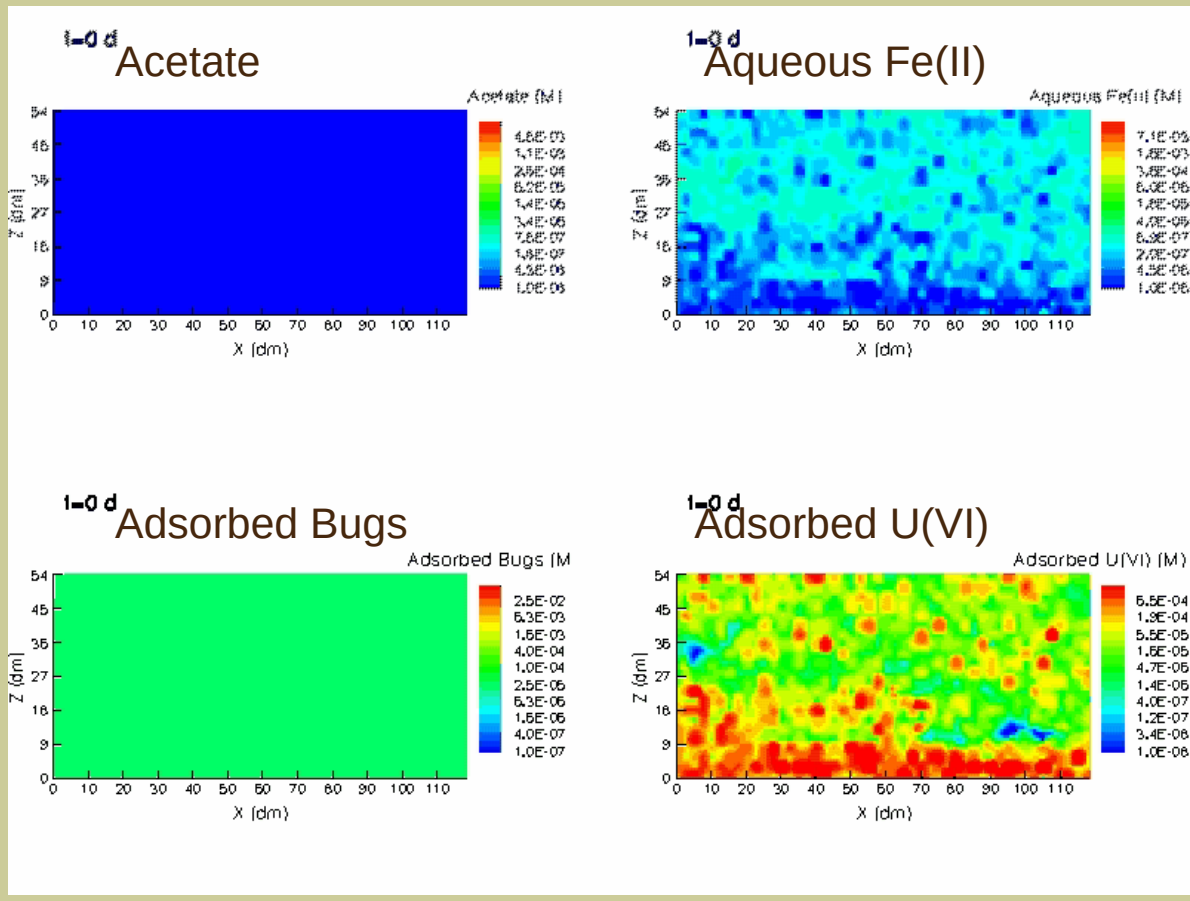


Lithology → K



Fe(III)

Correlated physical and geochemical heterogeneity obtained using tomographic estimates (Chen et al., 2005)

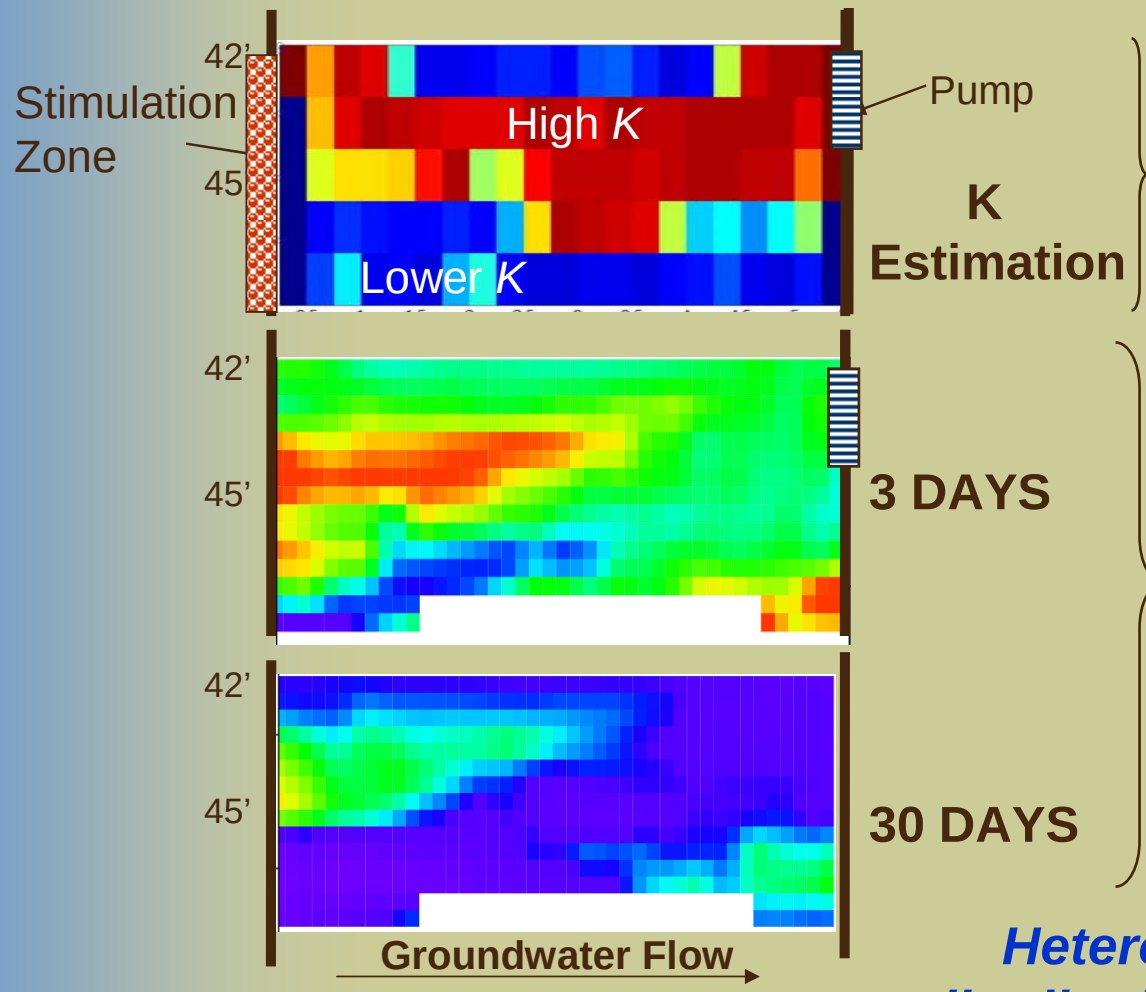


- Simulation of U(VI) loading over 22 years;
- 2D Simulation of biostimulation via acetate injection in presence of FeRB for 200 days (Scheibe et al., 2006)

Role of heterogeneity on contaminant distribution and remedial processes

Use of Geophysics for Guiding and Monitoring Remediation

Hanford 100H Site (Hazen)



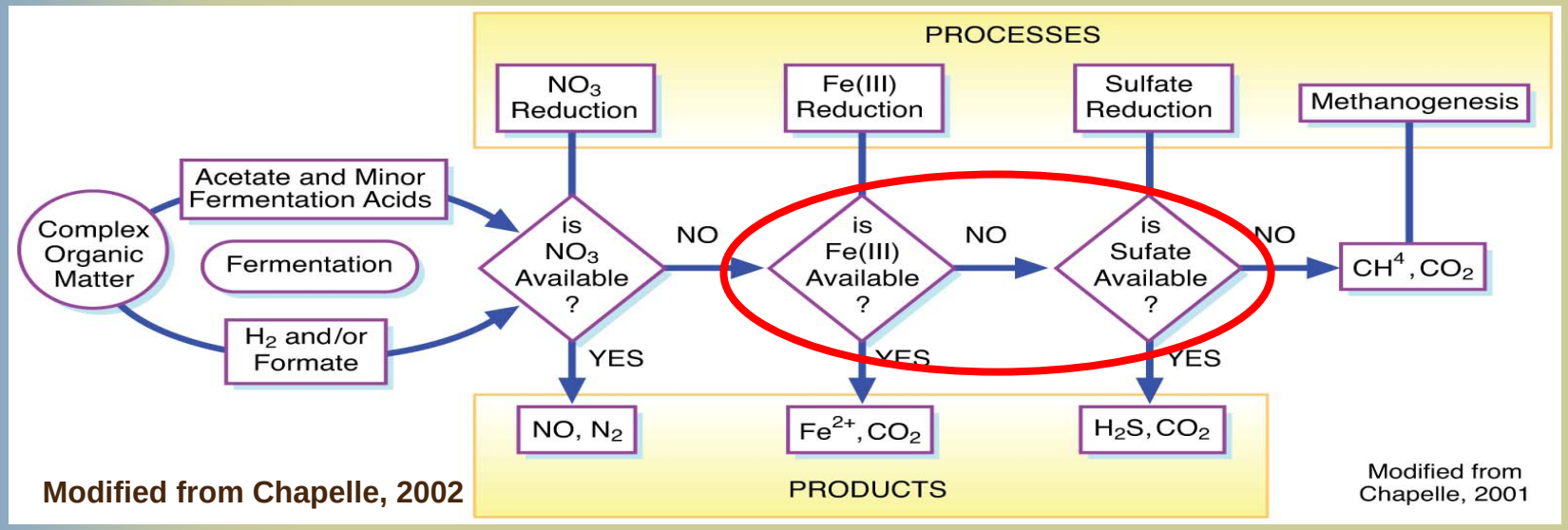
Characterization performed using tomographic and wellbore flowmeter data

Monitoring of post-stimulation amendment distribution and transformations

Heterogeneity influences distribution of Amendment and System Transformations

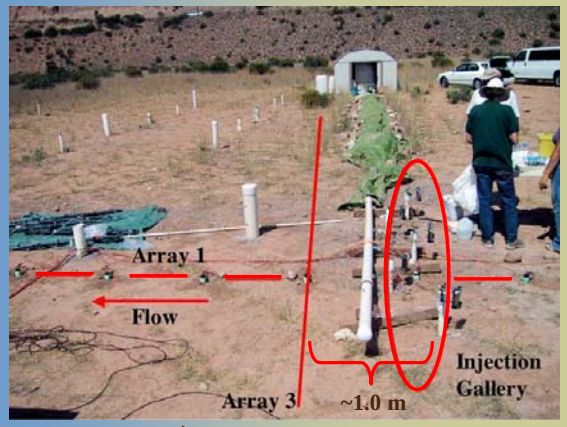
Use of Geophysical Data for Monitoring Geochemical Conditions needed for Sustained Remediation (Rifle, CO Site)

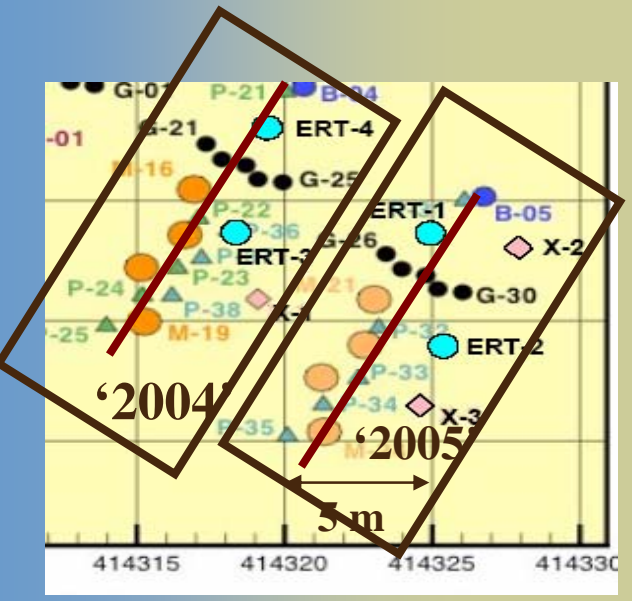
- Acetate addition for facilitating **microbial reduction of U(VI) to U(IV)**;
- Field results illustrate the **importance of maintaining** poised redox conditions (Phil Long)



Modified from Chapelle, 2002

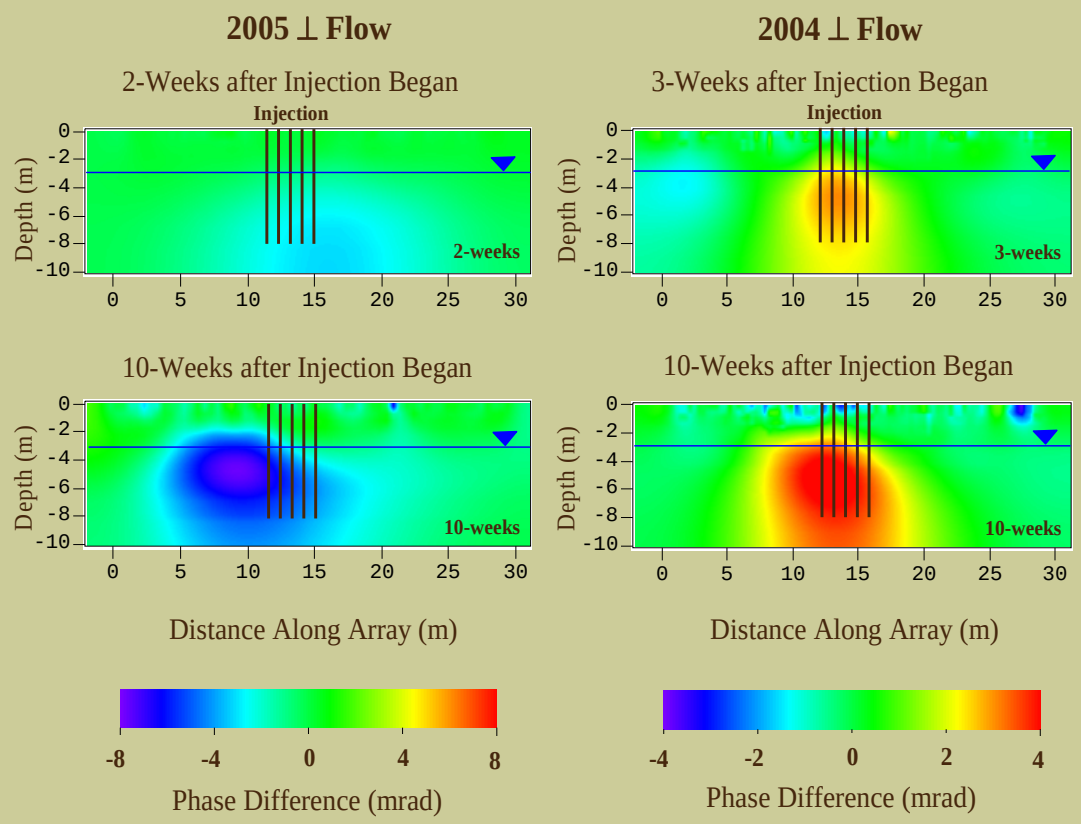
Use of Geophysical Signatures for indicating Fe vs. Sulfate Reducing Conditions





2005 Gallery: Fe reduction

2004 Gallery: Sulfate Reduction



Decreased Phase Difference

Increased Phase Difference

Field signatures consistent with laboratory studies

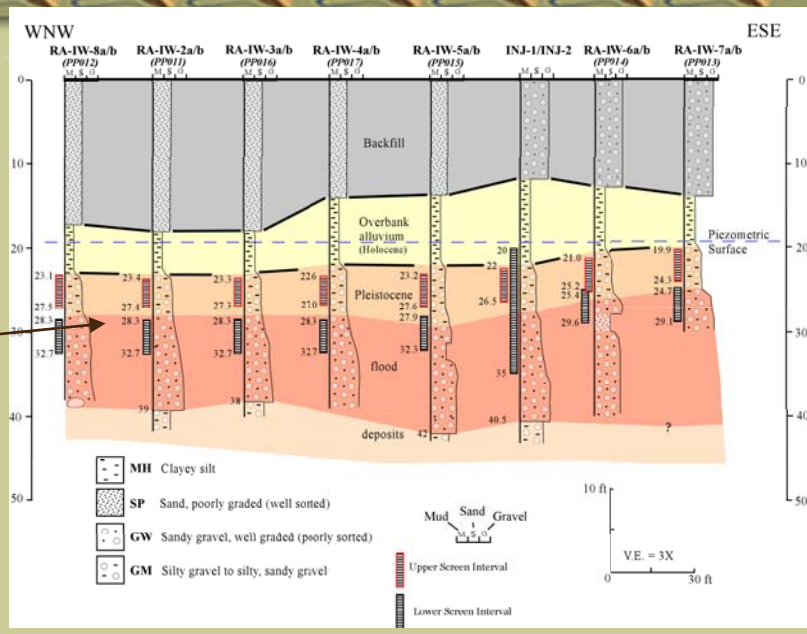
Typical DOE Geophysical Characterization Attributes

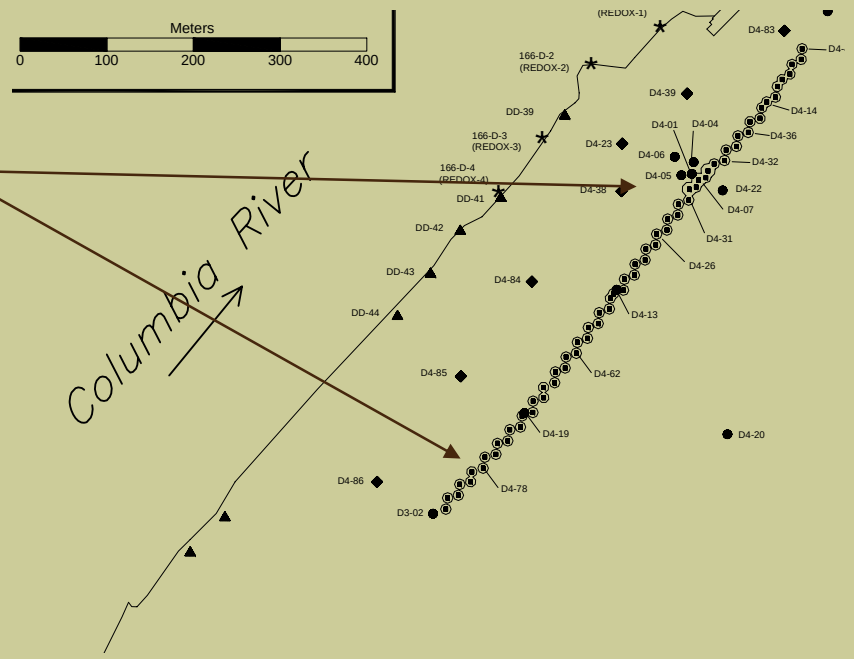
- Integration at local scale performed in conjunction with some research projects;
- Integration across larger field-scales seldom performed (except as ‘two step’ procedure)
- Specific characterization goals based on project objectives;
- Need to characterize biogeochemical heterogeneity as well as hydrogeological heterogeneity;
- Limited budgets;
- Not routinely performed or incorporated as first step in planning……

In Situ Redox Manipulation PRBs to reduce Cr(VI) – A Comparison

- Frontier Hard Chrome Superfund Site, Vancouver, WA.
  - Characterization and modeling used to guide ISRM design.
  - Successful, performed within budget.

- ISRM Hanford 100D Barrier 1999-2003 ($10 Million)
  - Little pre-injection characterization;
  - Estimated longevity of barrier based on bench tests >20 years;
  - Cr breakthroughs detected within few years;
  - Failure attributed to heterogeneity;
  - Several characterization and 'mending' projects are in progress or planned.





Pre-Treatment Characterization and monitoring can reduce closure and LTS costs!!!

Images from V. Vermeul, PNNL

CRITICAL QUESTIONS

What properties/features must be characterized to capture the behavior of a system under particular environmental conditions, treatments, and length/time scales?

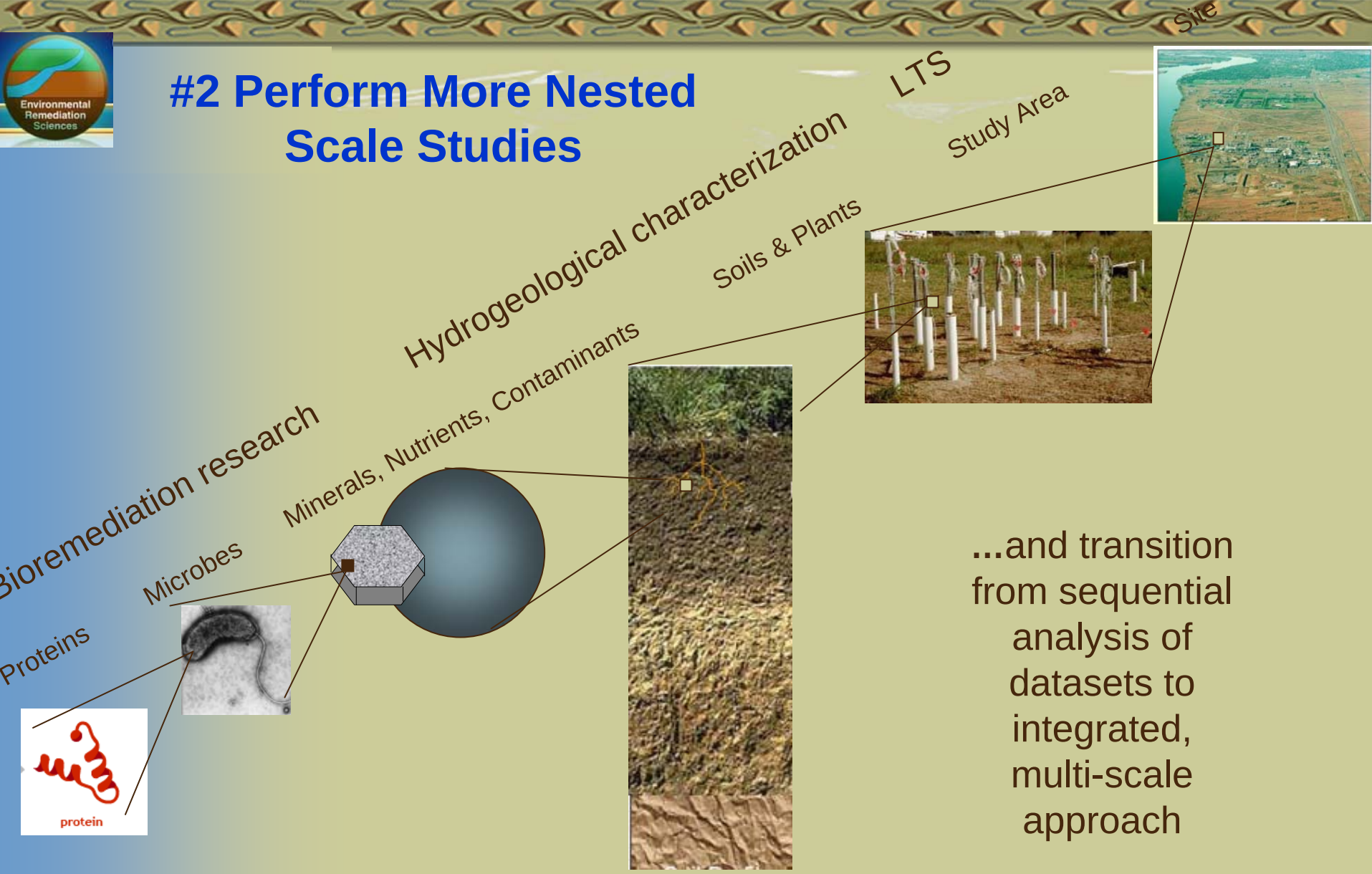
Which method (or combinations of methods) yield the desired accuracy, cost-efficiency, resolution, and spatial extent given for the problem?

How can we address these questions?

#1 Perform More 'Routine' Characterization!

- Include characterization in initial planning/budget steps;
- Improve communication between disciplines;
- Drill sufficient and 'deep enough' boreholes; collect enough coincident direct and indirect measurements to enable calibration/validation;
- Improve routine data integration;
- Iterate between characterization and modeling.

#2 Perform More Nested Scale Studies



...and transition from sequential analysis of datasets to integrated, multi-scale approach

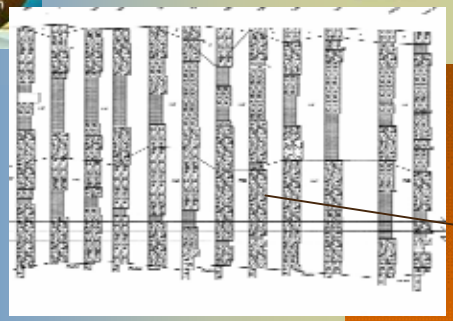
10^{-6} 10^{-4} 1 10 10^{3+}

Relative Characteristic Length Scales (m)

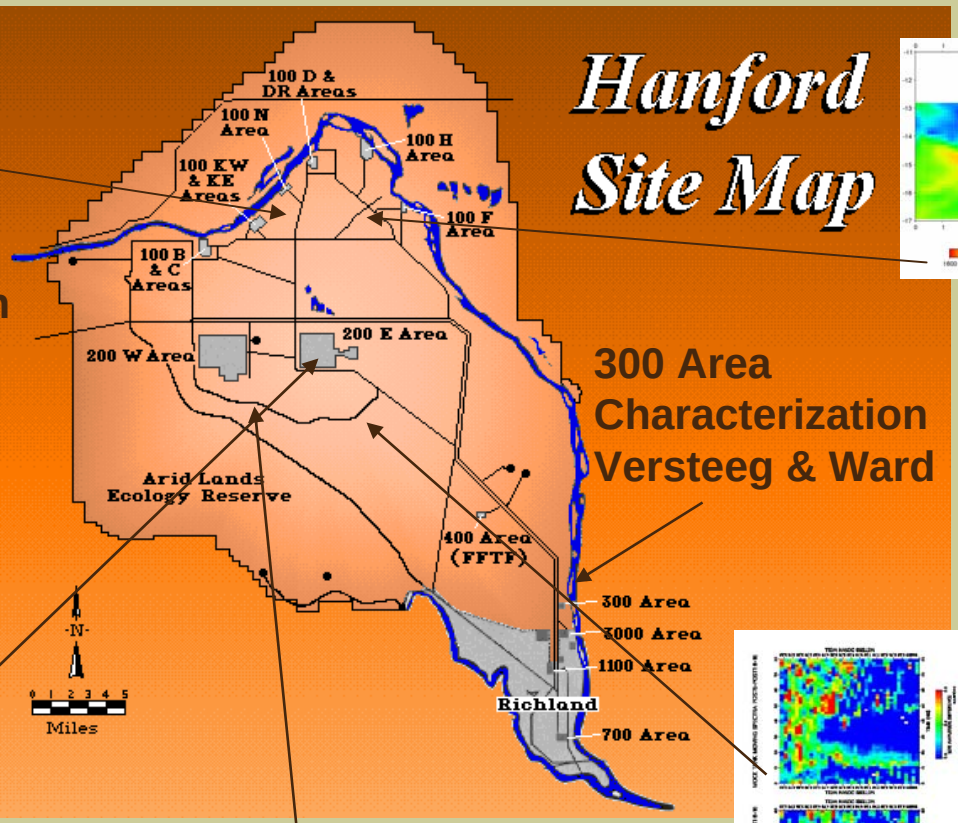
#3 Improve our ability to remotely characterize and Monitor Biogeochemical properties

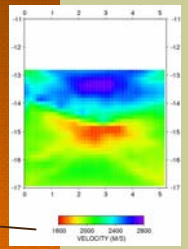
- Some work in progress but we are at an early stage;
- Included in ERSD strategic plan:
  - *'high resolution geophysical methods for measuring biogeochemical and hydrological responses to in situ manipulations of the subsurface',*
  - *'innovative methods for rapid assessment of changes in microbial community composition and metabolic potential',*
  - *'integrated experimental approaches to describe coupling of biological, chemical and hydrological processes at field-relevant spatial scales*

#4 Perform Synthesis Across Sites and Develop Databases!



Barriers Characterization
100D
Szecsody et al., 2005

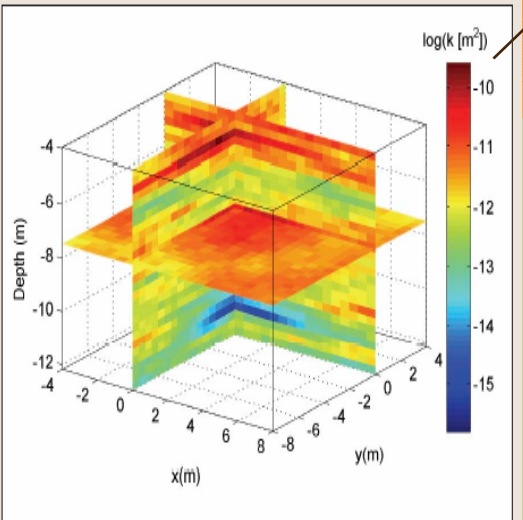




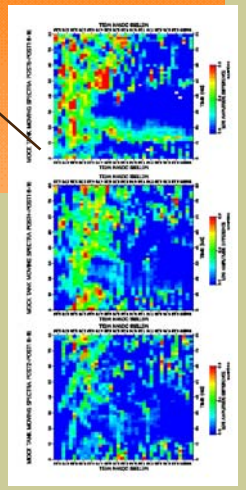
Characterization & monitoring
100H
Hubbard et al. 2006

300 Area
Characterization
Versteeg & Ward

K Estimation
Sisson&Lu
Kowalsky et al., 2006



Plume Delineation
T-Tank Farms
hydroGEOPHYSICS



Leak Detection
Mock Tank
Majer et al. 2004

Consensus from 2005 Field-Scale Break Out Session: What are the greatest challenges/gaps for DOE field-scale research?

MEASUREMENTS

- Identification of critical **Macroscale properties** at the field scale, and understanding of **how they relate to lab scale** measurements and rates;
- How to optimally characterize **field-scale reaction rates**;
- How to best **measure extremes**: flow conditions, level of contamination, aging?

PROCESSES and SCALE

- **Fundamental relations** among variables that are relevant to field scale processes;
- Effective **integration** of information base, process models, characterization data, predictive models and validation across scales;

FUNDING to permit **comprehensive, integrated, and longer term field investigations.**

Summary

- Geophysical methods can be useful for **remediation research and stewardship**:
  - Guiding the site choice and experimental design;
  - Parameterizing numerical models;
  - Monitoring remediation treatments;
  - Interpreting experimental results;
  - Understanding role of heterogeneity on treatment.

- Sufficient budgets and research advances are needed to facilitate routine, multi-scale characterization;

- ERSP is currently a key sponsor of the development of characterization approaches for near surface systems;

- What can we learn from Petroleum Industry Characterization Approaches?