Integrated Hydrogeophysical and Hydrogeologic Driven Parameter Upscaling for Dual-Domain Transport Modeling

UNIVERSITY OF SOUTH CAROLINA

John Shafer, Mike Waddell, Camelia Knapp

Berkeley Lab

Susan Hubbard, Mike Kowalsky

SRNL

Greg Flach, Mary Harris

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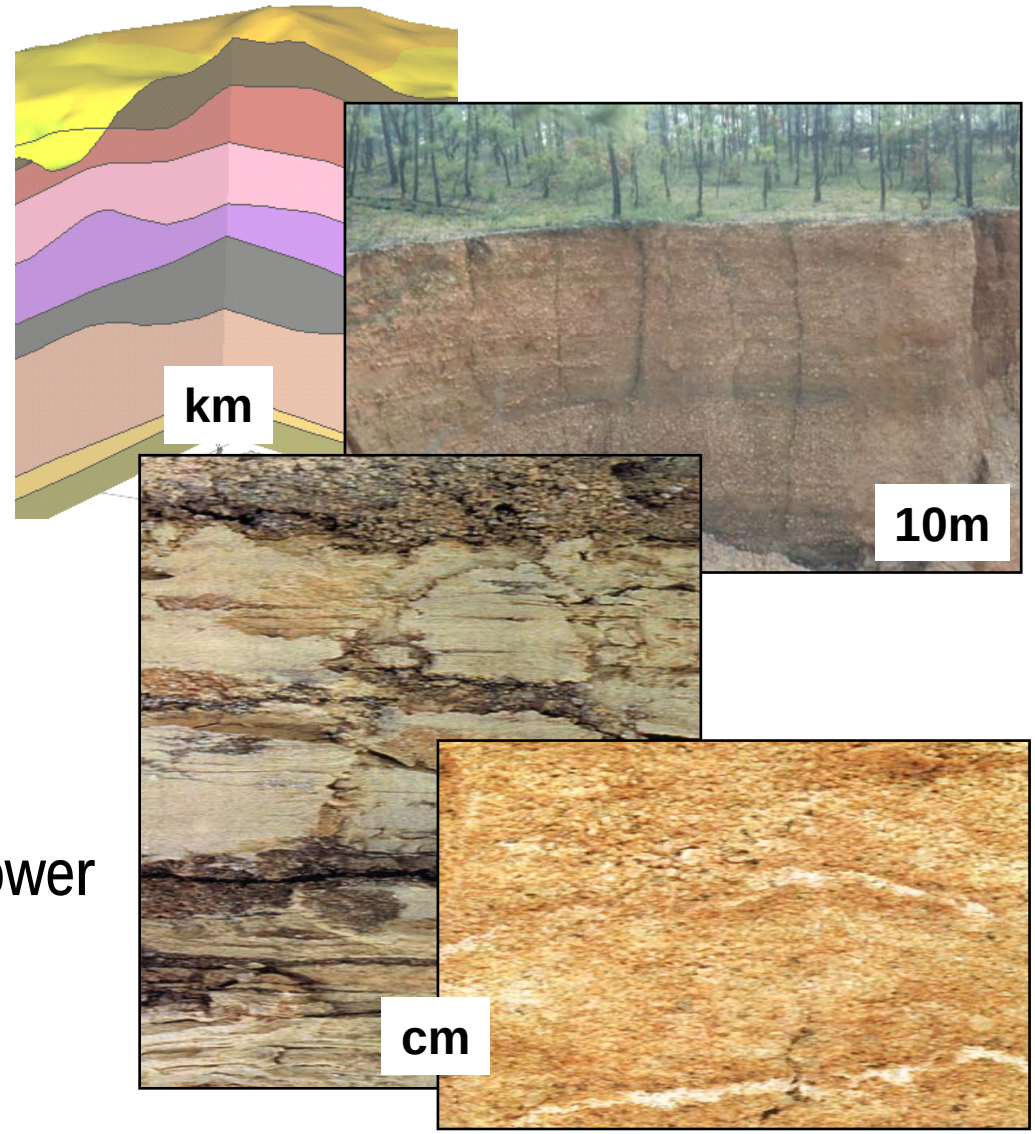
Research Objectives

- Develop a suite of multi-scale geophysical characterization and data integration techniques for estimating hydrogeological parameters at field-relevant spatial scales
- Relate dual-domain transport parameters to field-scale characterization data in a general manner
- Couple these complementary goals to achieve significantly improved transport predictions at field-scale

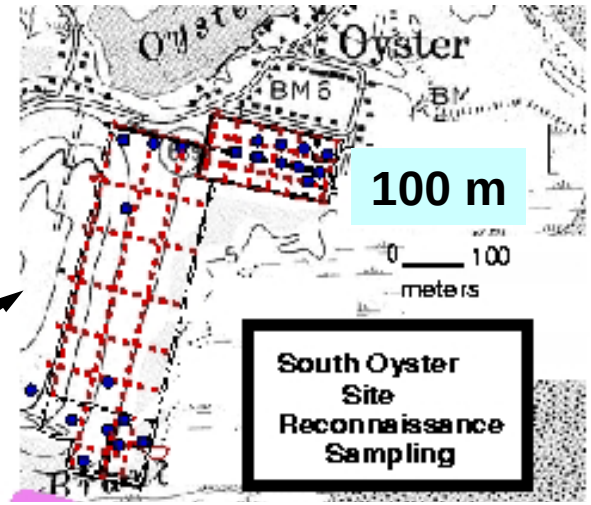
Challenge of Field Scale Prediction

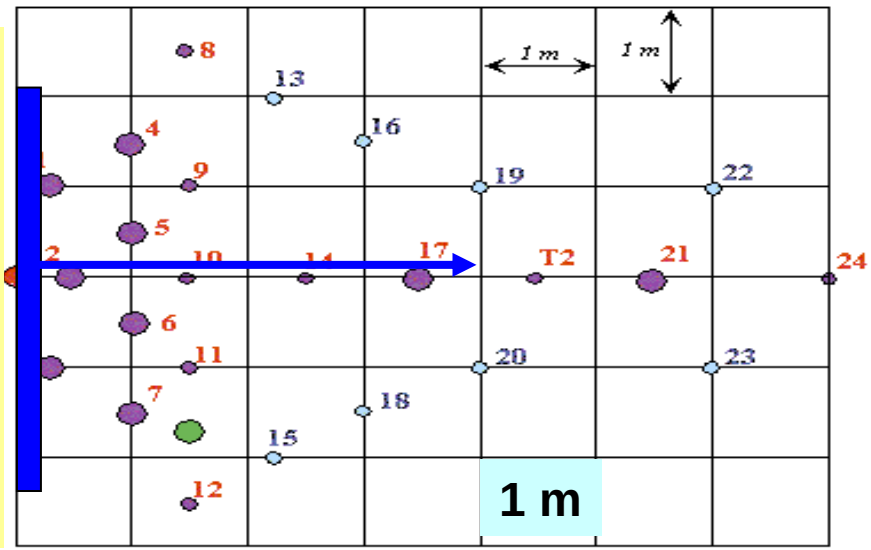
- Physical heterogeneity across many scales
- Conventional approaches characterize only a fraction of heterogeneity affecting field-scale transport
- Modeling predictions are limited by sparse data and computing capabilities
- Residual contamination in lower permeability zones is a particular concern



Hydrogeophysics

- Hydrogeophysics offers potential for spatially dense 3D characterization
- Sequential, two-scale characterization example: DOE Bacterial Transport Site, Oyster VA





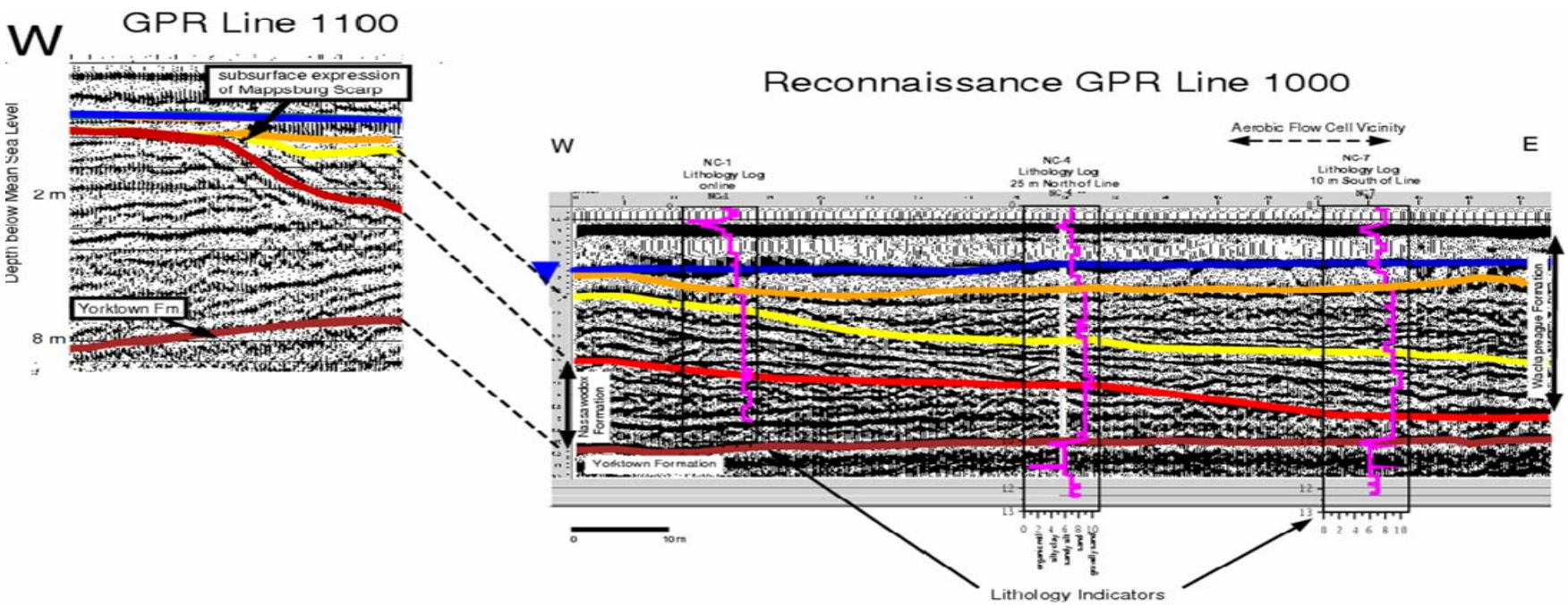
- <u>Research needs:</u>

  Integrated, multi-scale, approaches

  Sensitivity of geophysical attributes to hydrofacies properties

DOE Bacterial Transport Site

Step 1 - Surface GPR and CPT data were used to define lithofacies architecture <u>across 100's of meters</u>, and to choose study site location (Hubbard et al. 2001)

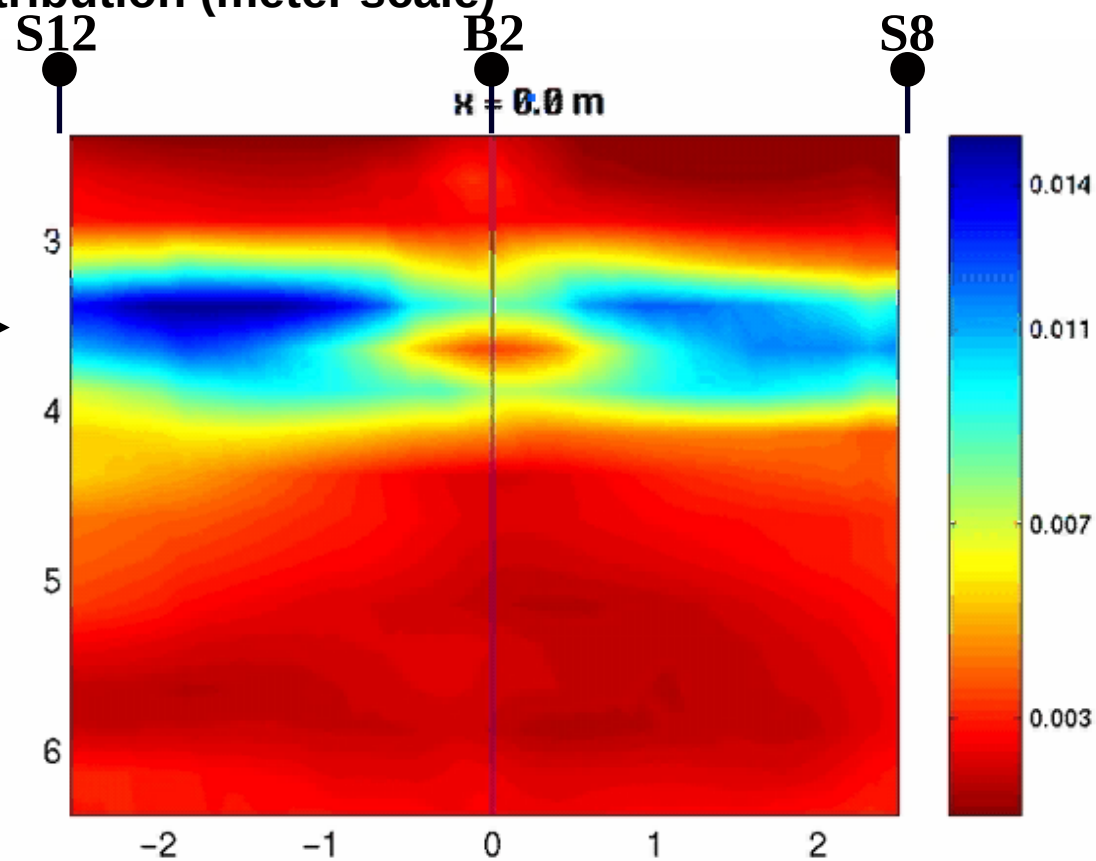


DOE Bacterial Transport Site

Step 2 - Flowmeter and tomographic data used at local scale to estimate 3D Hydraulic conductivity distribution (meter scale)

Higher
K Zone
Gets Thicker
and Deeper

Stepping from up to down gradient along planes perpendicular to injection centerline



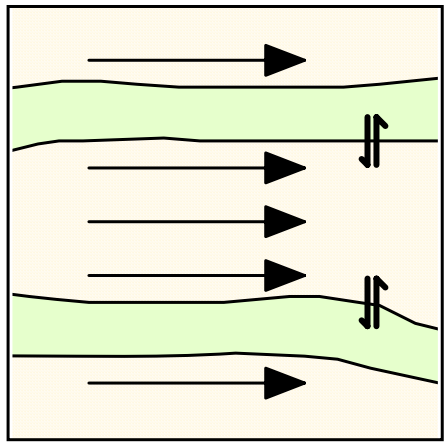
Research opportunity. . .

- Local-scale K estimation only (limited by tomographic imaging distances)
- Does not take advantage of facies concept or regional architecture

Unresolved Heterogeneity

- Even with better characterization, unresolved heterogeneity will remain, especially at smaller scales
- Dual-domain formulation appears to be an efficient and effective technique for capturing sub-grid scale heterogeneity
- Research need is reliable method for defining optimal parameter values based on site data
- Field-scale transport in sedimentary systems is new application of concept

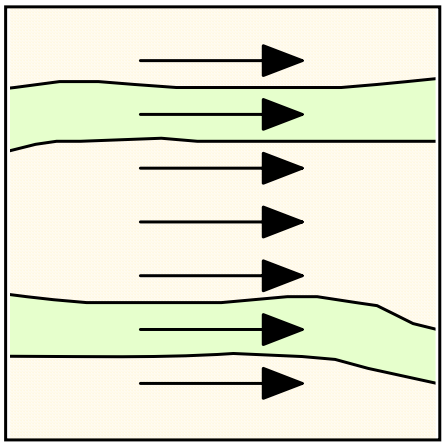
Dual-media mass transfer



allow mass transfer between mobile and immobile water

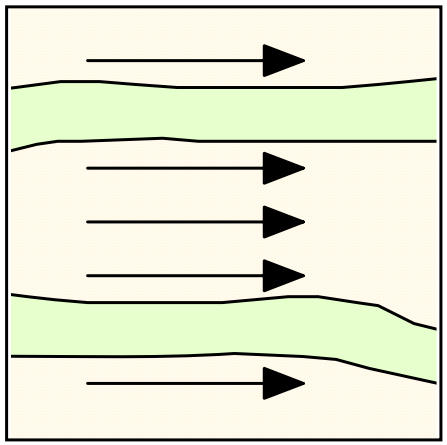
Dual-Domain Concept

ADE using total porosity



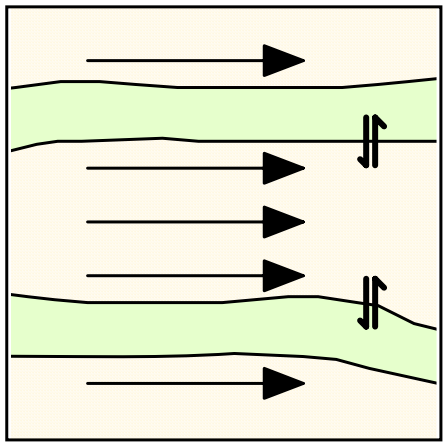
uniform velocity field within model grid block

ADE using effective porosity



lower permeability sediment assumed to contain immobile water

Dual-media mass transfer



allow mass transfer between mobile and immobile water

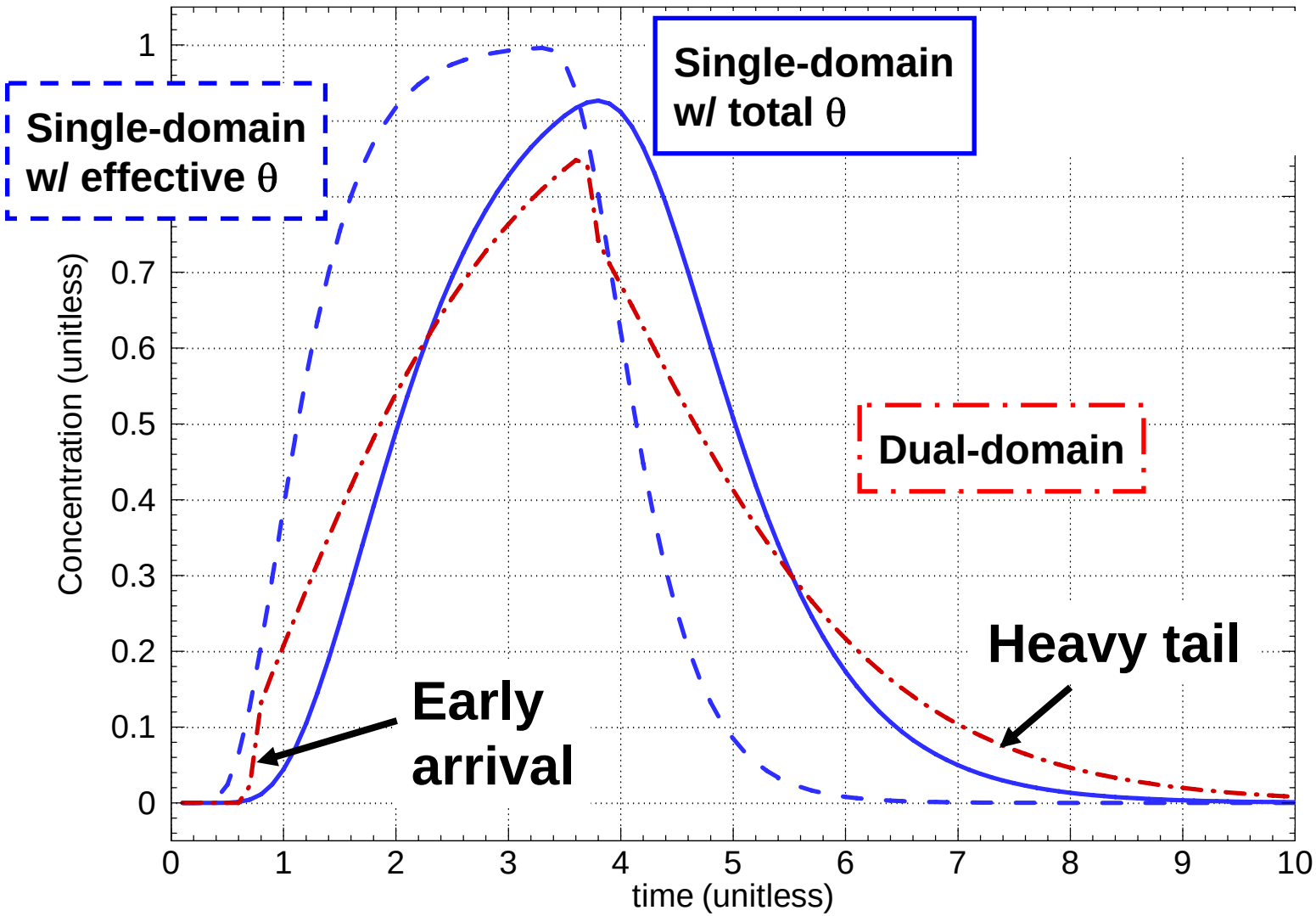
mobile+immobile balance:

$$\theta_m \frac{\partial C_m}{\partial t} + \theta_{im} \frac{\partial C_{im}}{\partial t} = \theta_m D \frac{\partial^2 C_m}{\partial x^2} - \theta_m v_m \frac{\partial C_m}{\partial x}$$

immobile balance:

$$\theta_{im} \frac{\partial C_{im}}{\partial t} = \zeta \left(C_m - C_{im} \right)$$

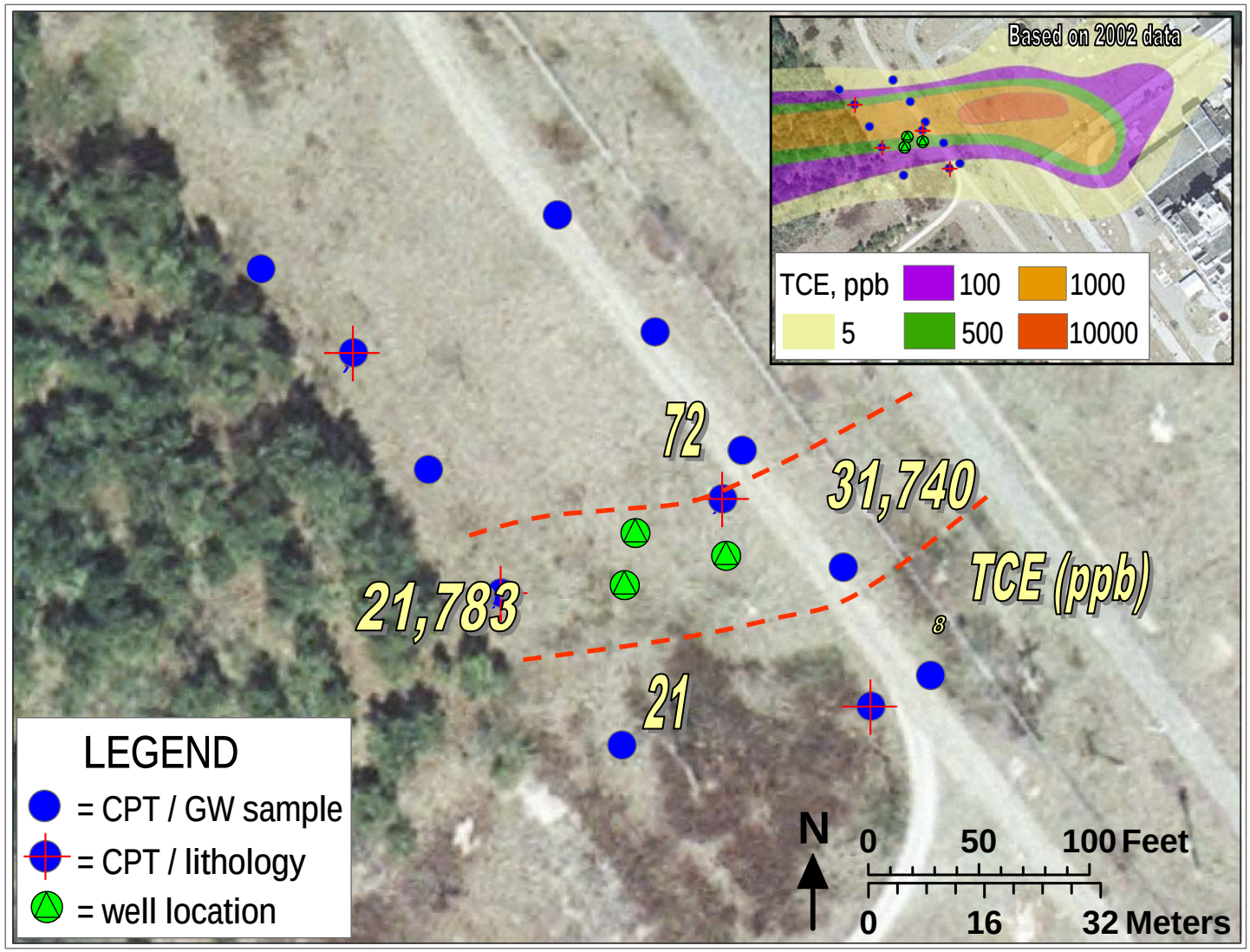
Example Breakthrough Curves



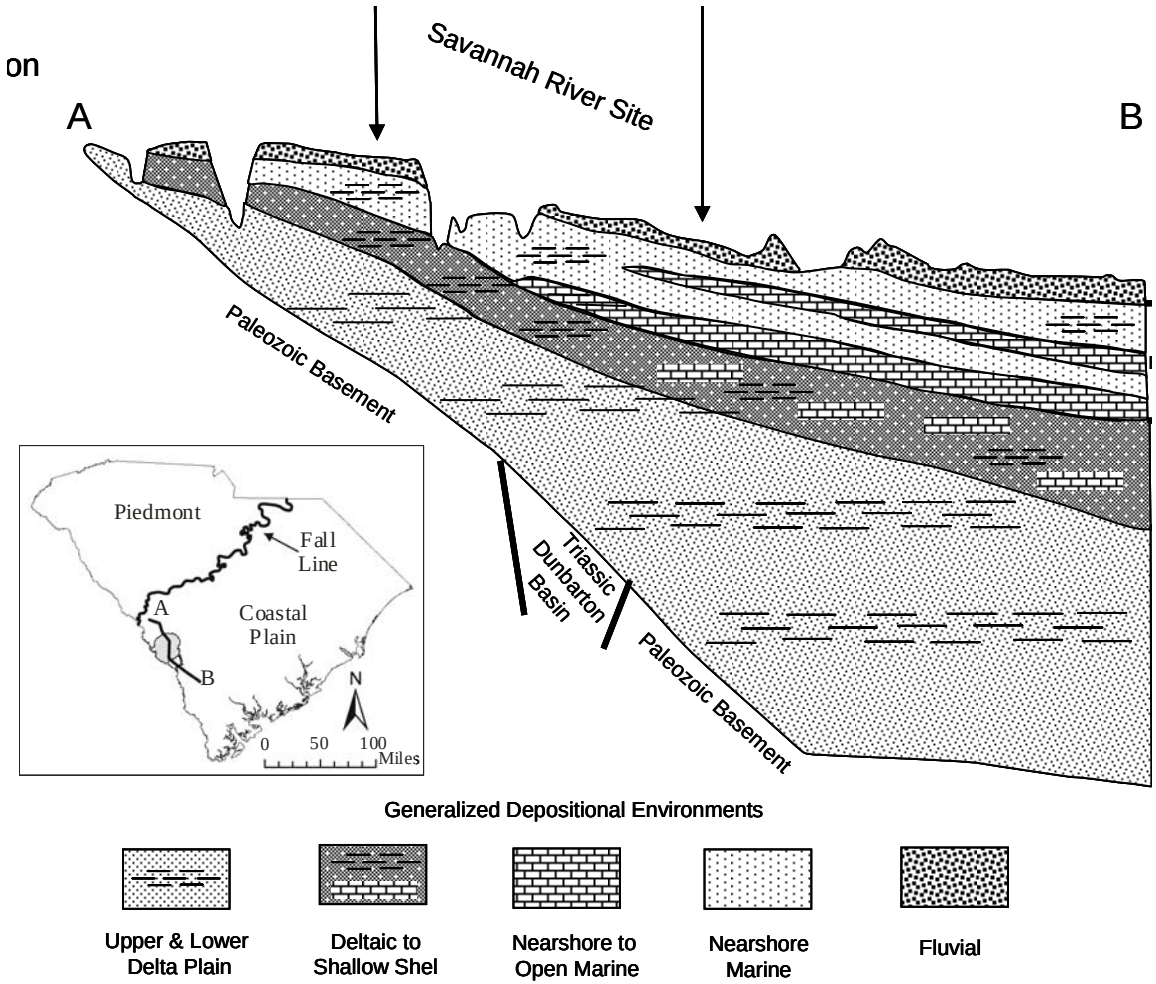
Research Approach

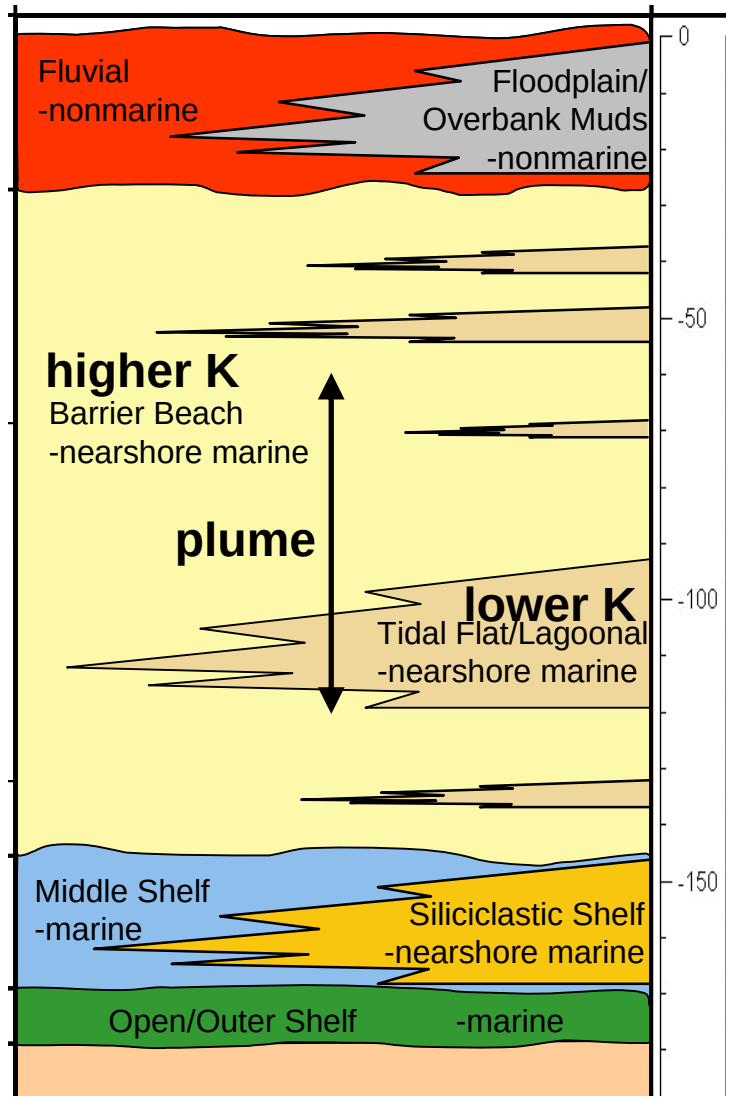
- Hydrogeophysics
  - Joint, multi-scale, characterization approach
  - Integrate formation / facies / permeability data with geophysics
  - Characterization will be guided by data quality, site-specific relationships, and modeling insights
- Dual-domain
  - Numerical experimentation to define optimal dual-domain parameters in terms of reasonably-available site characterization data
- Overall
  - Test integrated approach for TCE plume at field site

Field Study Site



Geologic Setting





FY06 Field Work

K pdf1

K pdf2

K pdf3

Joint pdf

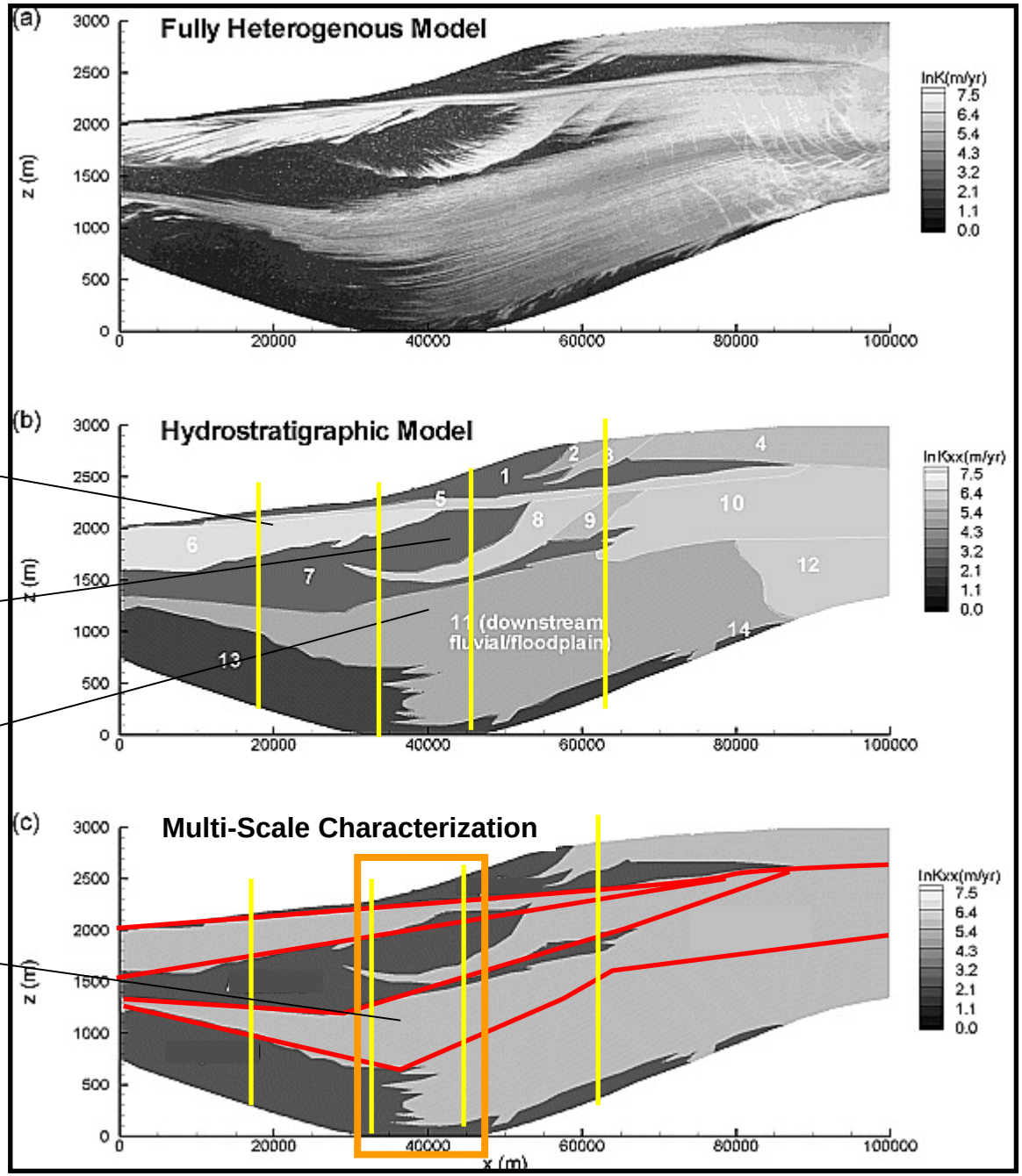


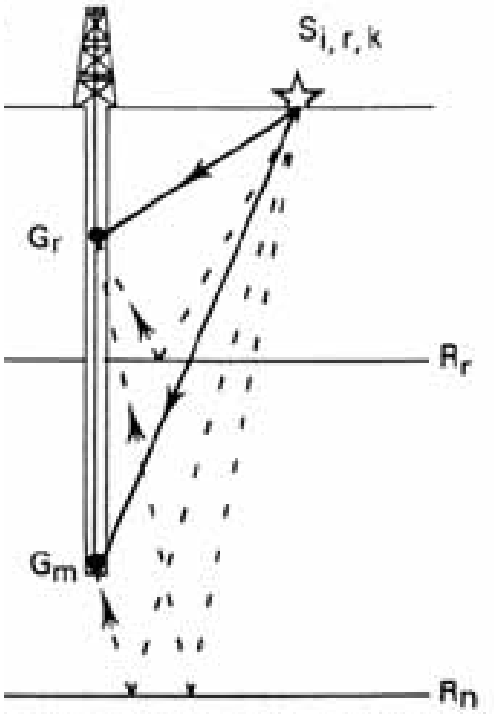
Figure modified from Zhang et al., 2006

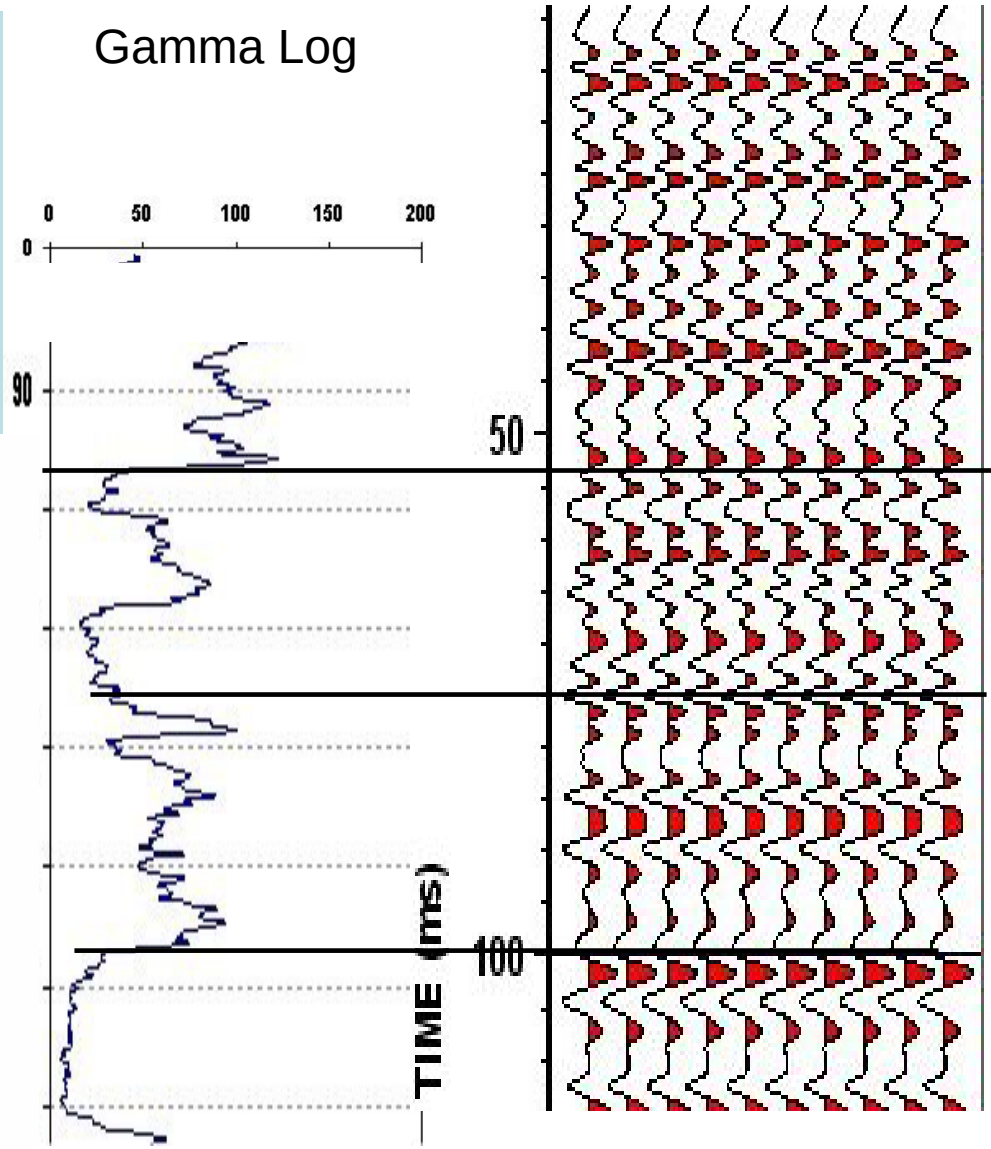
Flowmeter
CPT
Core Analysis

Borehole data
Surface and Tomographic Geophysical Data
Conditioned to Borehole Data

FY06 Field Characterization: Vertical Seismic Profile (VSP)

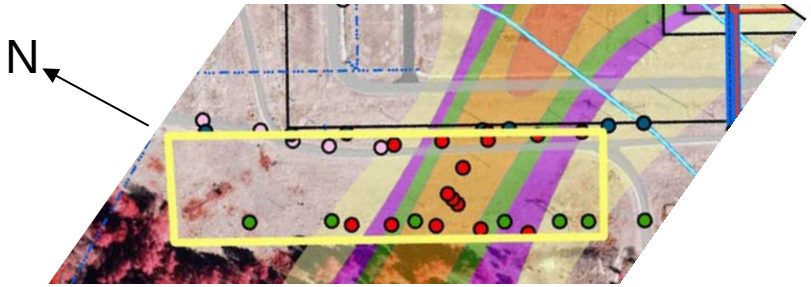
- **Good data quality**
- **Distinctive signatures of key horizons**
- **Used to design 2.5D campaign**



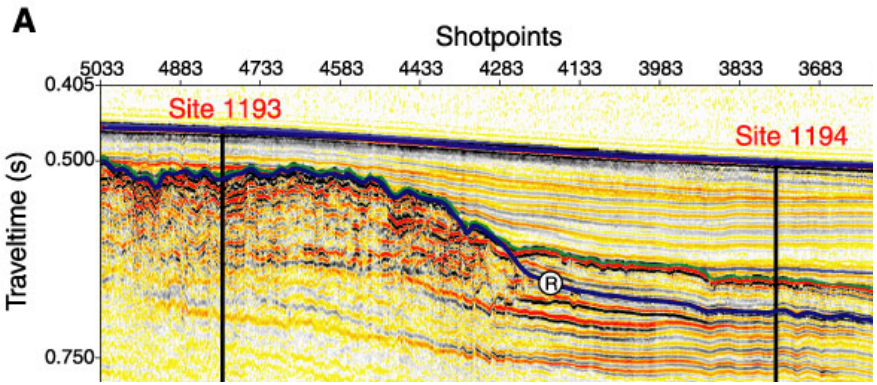


Mike Waddell
USC

2.5D Surface Seismic Campaign Slated for January 2007



- By tying reflection signatures to log/core data, surface seismic will be used to map key boundaries at study site
- Acoustic inversion may yield information about property changes within units.



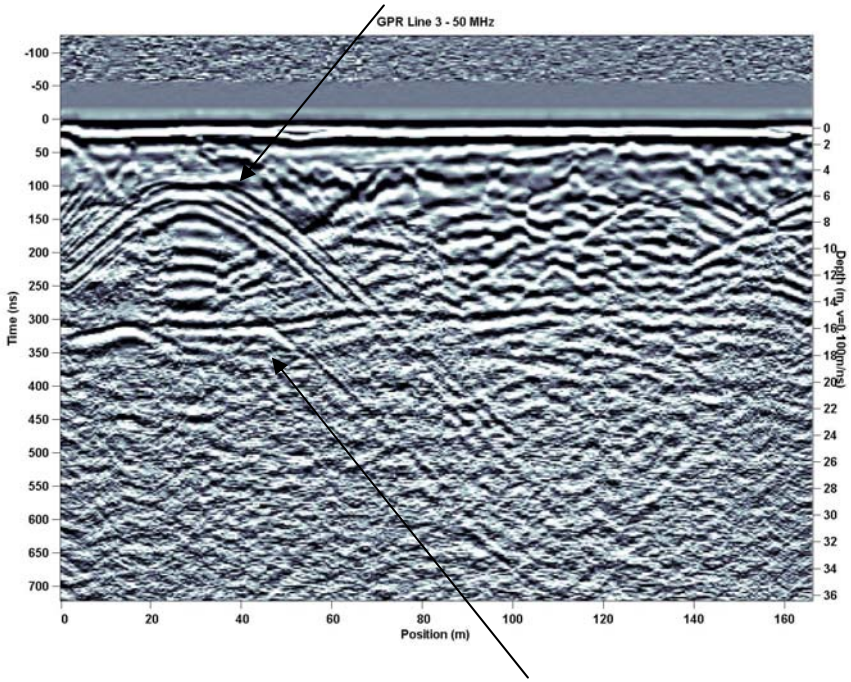
sedimentary example

Type of survey	P wave 2.5 D Swath
Survey Dimensions	~175 X 50 meters
Station interval	1 meter
Source	Hammer, 4.5 kg
Source interval	1 meter on half stations
Repetitions/SP	6
Record Length	500 milliseconds
Recording instrument	Geometrics RX 24 bit A/D resolution
Number of channels	120
Sample interval	0.5 millisecond
Data redundancy	30 Fold
Geophones	Geospace 40 Hz vertical 3/ station bunched
Receiver line spacing	1 meter
Source line spacing	1 meter
Total receiver and source lines	50
Estimated number of shots	8700

FY06 Field Characterization: Surface GPR Test to Ascertain Data Quality

- Surface Ground Penetrating Radar (GPR)
  - 4 (50-200 m long) 50 MHz profiles
  - 4 (50-200 m long) 100 MHz profiles
  - 1 (100 m long) 200 MHz profile
  - Common mid-point GPR surveys (50, 100 MHz)
- Vertical Radar Profiles (at PGW 17B)
  - Multi-offset, 50 MHz
  - Multi-offset, 100 MHz

Cultural noise



Deepest reflectors ~15m

Tests indicated that GPR unlikely to successfully image below water table

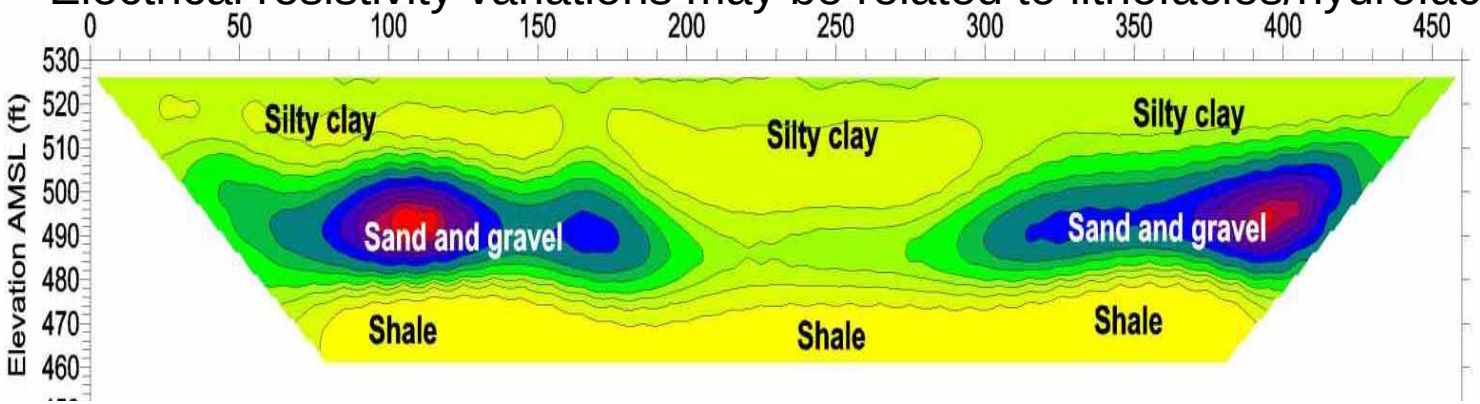
FY07 Field Campaign: Surface Electrical Survey

- Surface electrical data expected to yield information that is complementary to surface seismic
- Initial testing will be performed with a Terrameter (simple 4-electrode system) in November
- If data quality acceptable, surface Electrical Resistivity Tomography 2.5D survey will be collected to coincide with the 2.5D seismic

Acquisition parameters will be determined during testing stage. Possible parameters:

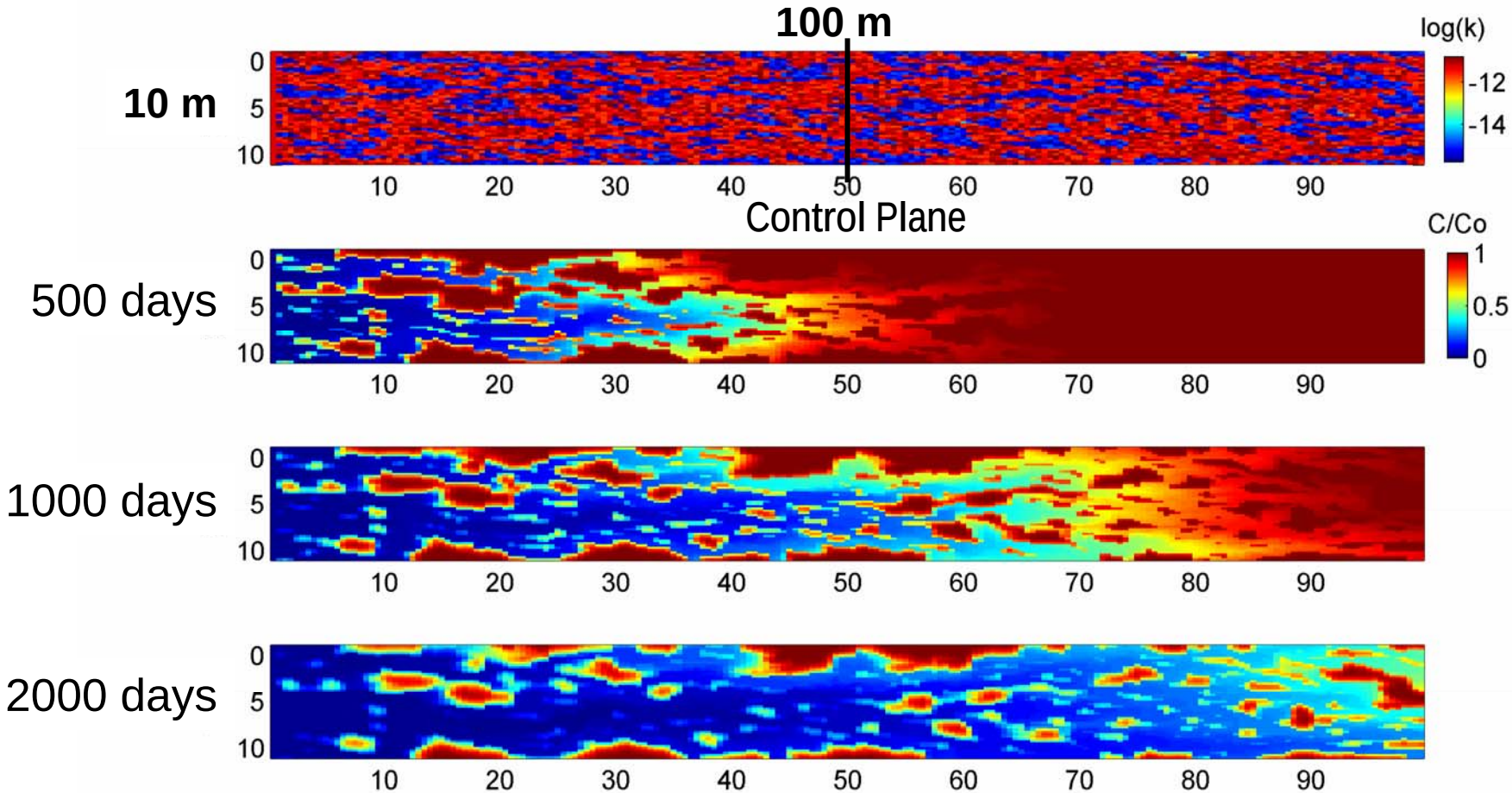
System	SuperSting R8/IP multi-channel resistivity imaging system by Advanced Geosciences
Electrode configuration	Dipole-dipole (~40m), wenner (>50m penetration)
Channels	56
Electrode spacing	6m

Electrical resistivity variations may be related to lithofacies/hydrofacies



sedimentary example

High-Resolution Reference Model

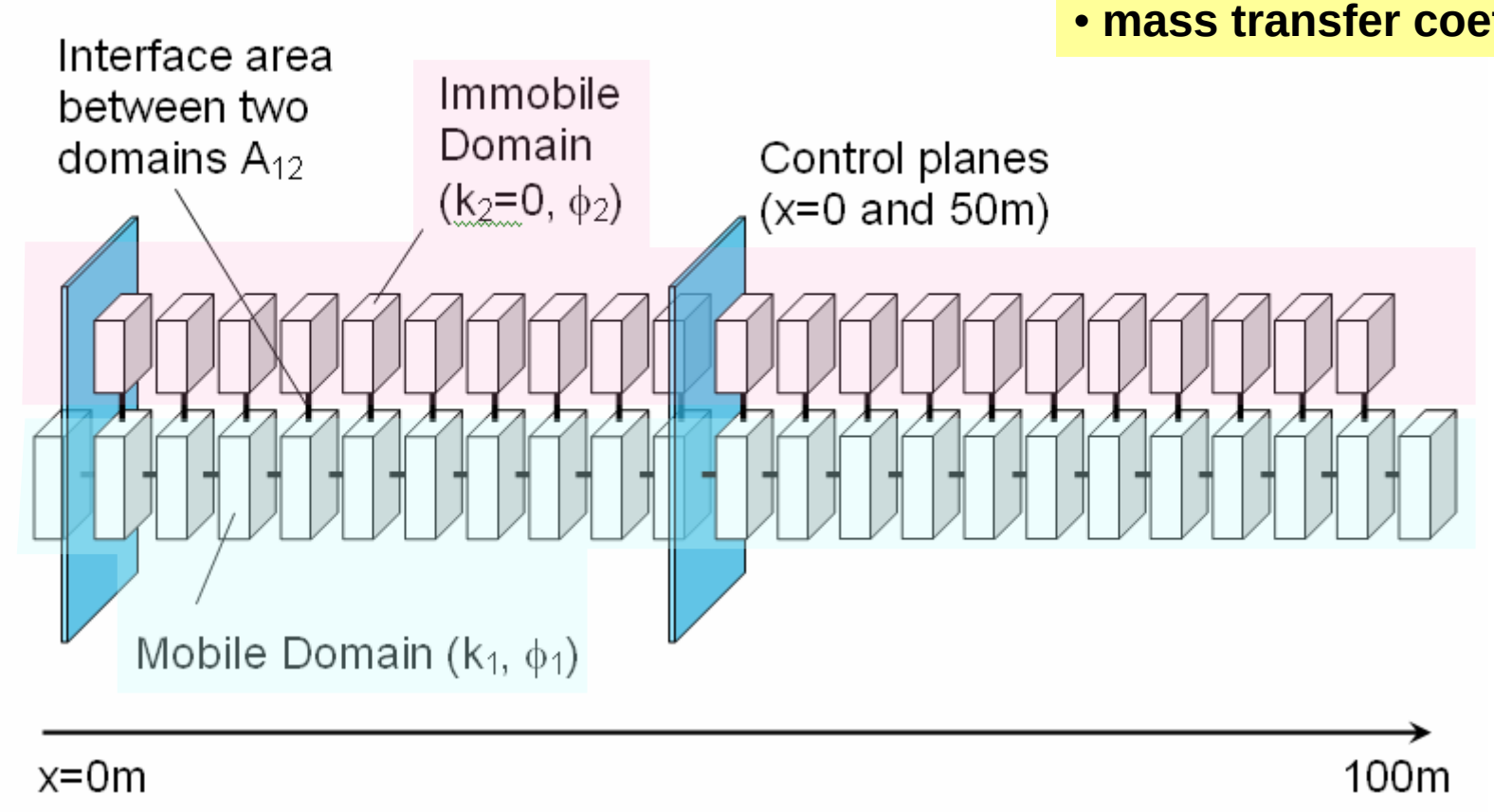


$\langle \log(k1) \rangle = -11.3$, $\langle \log(k2) \rangle = -15.3$, $\sigma_{k1} = \sigma_{k2} = 0.29$, $V1/(V1+V2) = 0.7$
Spherical semivariograms: range = 0.5 m, anisotropy = 5, angle = 5°

Dual-Domain Transport Model

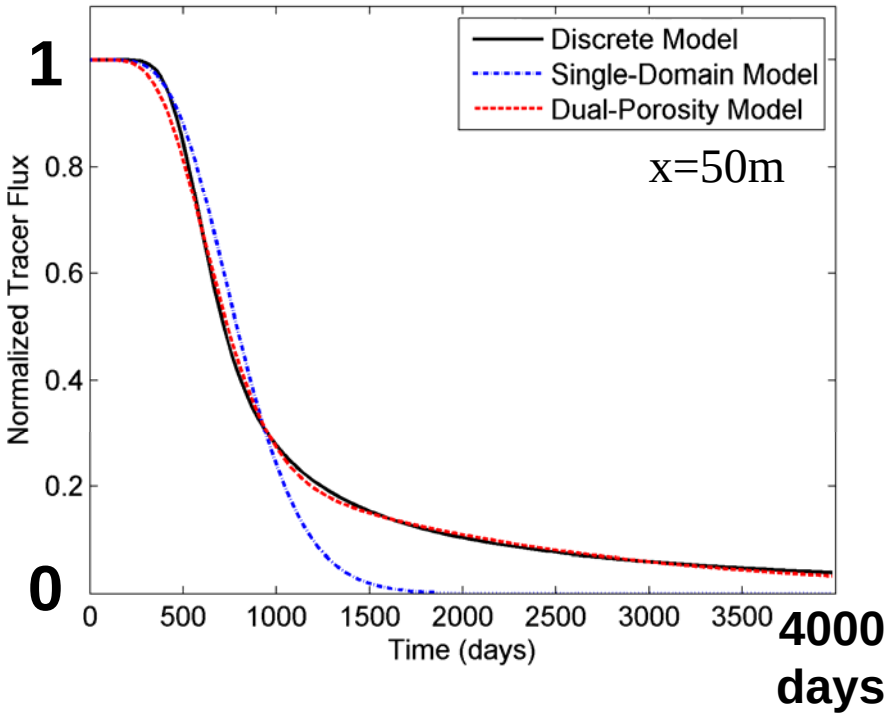
Numerical implementation using iTOUGH2

Parameters
- **mobile porosity**
- **immobile porosity**
- **mass transfer coeff.**

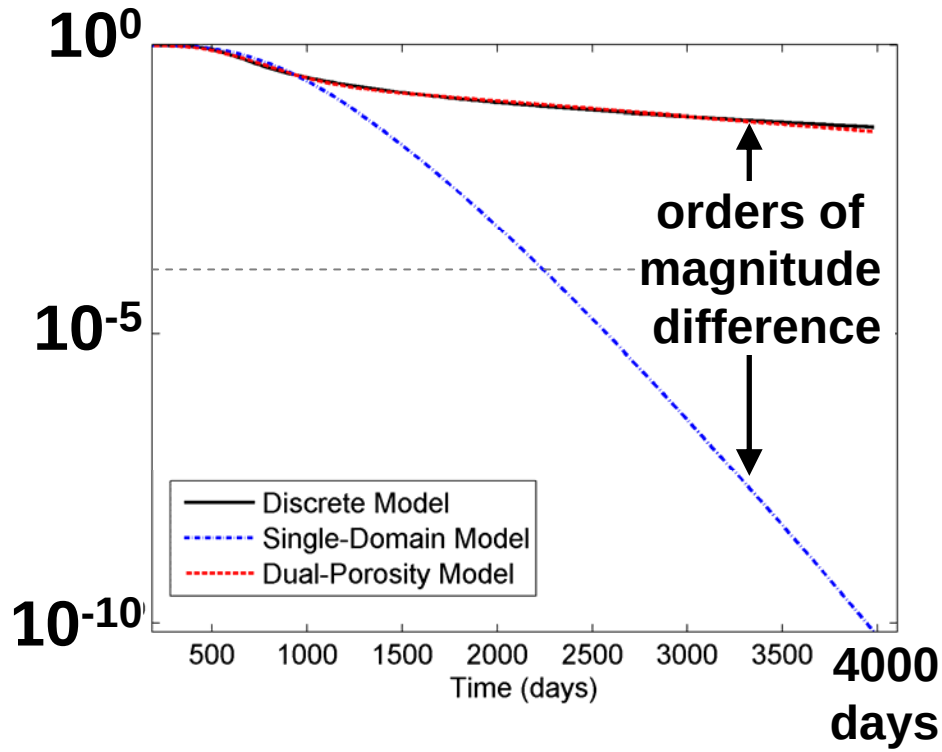


Breakthrough Comparison

linear scale



log scale



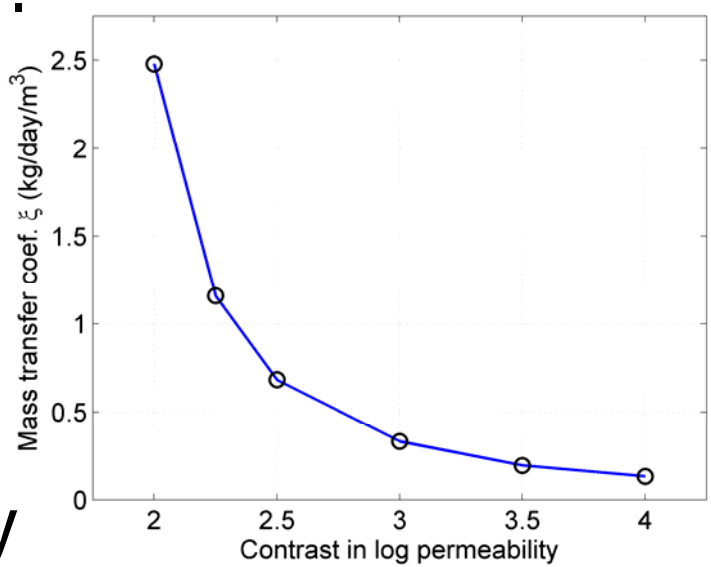
Single-Domain Parameters
$\log(k)=-11.72$, $\phi=0.39$

Dual-Porosity Parameters
$\log(k_1)=-11.72$, $\phi_1=0.34$, $\phi_2=0.42$, $A_{12}=0.0052$

Parametric Study

Dual-domain parameters related to . . .

- Facies proportion
- Permeability contrast / variability
- Spatial and temporal scales
- Spatial correlation and anisotropy
- Orientation of head gradient to strata



. . . but how?

Project Timeline

- FY06
  - Phase I field characterization
    - CPT plume delineation
    - surface GPR, surface seismic
  - Developed modeling framework (iTOUGH2)
- FY07
  - Phase II field characterization
    - Complete geophysical survey
    - Integrate geophysical / hydrogeological / plume data
    - Produce 3D map of permeability
  - Conduct numerical dual-domain study using synthetic data
- FY08
  - Predict plume behavior using 3D permeability map and optimal dual-domain parameters

Summary

- Phase I characterization, model framework development, and sensitivity studies in progress
- Early results suggest
  - Plume distribution (CPT)
  - Surface seismic quality is good
  - Surface GPR signal penetration not sufficient at P-Area
  - Coarse resolution dual-domain transport can reproduce high-resolution field-scale behavior, if optimal parameter settings are used
- Anticipated deliverables
  - Multi-scale geophysical characterization and data integration techniques for estimating hydrogeological parameters at field-relevant spatial scales
  - Dual-domain transport parameters related to field-scale characterization data in a general manner