# Development of a Hydrofacies Framework for Dual-Domain Transport Modeling*

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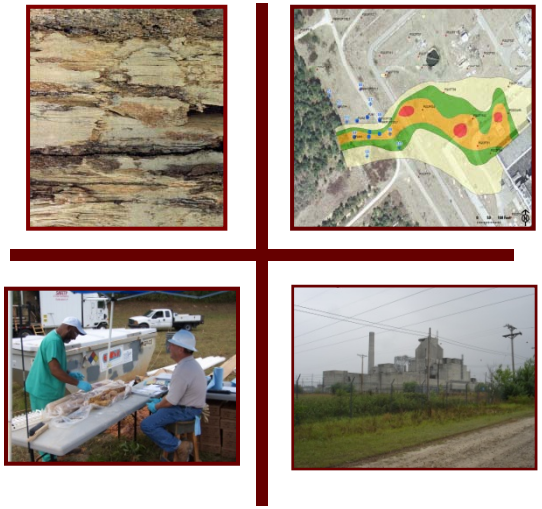
## Abstract

Initial field characterization data will be presented for an Office of Science Department of Energy research project. The final objective of the study is improved dual-domain transport modeling predictions. Data collected to date has delineated facies through multi-scale field characterization data (cone penetration testing (CPT), rotosonic coring, gamma logs, water and soil headspace analysis, electromagnetic borehole flowmeter (EBF), slug tests, injection tests, and water level data). Surface and shallow geophysical techniques will be integrated with the overall facies framework for transport modeling. The study area is located in the upper Atlantic coastal plain of South Carolina consisting of interbedded and heterogeneous fluvial, deltaic, and shallow-marine sediments. The area also has a trichloroethylene (TCE) plume, with concentrations ranging from less than 100 μg/L to greater than 20,000 μg/L. Geophysical and hydrogeologic borehole-scale data were collected and analyzed from three new wells, piezometer installation and CPT. Three clay-rich horizons and three sand-rich horizons along with a very poorly sorted pebble-rich zone were defined. Hydrofacies were assigned using core-descriptions, sieve data, and EBF data. Water and soil headspace analysis provided contaminant concentrations. Lower concentrations of TCE were observed in the high and low permeability (K) facies while higher concentrations appear in the moderate K facies and fringes of low K intervals. The data support a hydrofacies framework for transport modeling and suggest the plume center of mass has since passed the study area. Additional characterization data will be collected to refine the integrated hydrogeophysical model for the dual-domain TCE transport model based on the findings to date.

# Development of a Hydrofacies Framework for Dual-Domain Transport Modeling



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Savannah River National Laboratory, Aiken, SC

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- USC-Columbia
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- Lawrence Berkeley National Laboratory
  - Susan Hubbard, Mike Kowalsky
- Savannah National Laboratory
  - Greg Flach, Margaret Millings, Mary Harris




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# DOE-Office of Science Research Project

## "Integrated Hydrogeophysical & Hydrogeologic Driven Parameter Upscaling for Dual-Domain Transport Modeling"

- Improved prediction of contaminant transport can be achieved using a dual-domain transport approach driven by integration of hydrogeophysical & hydrogeological parameter estimation & upscaling.

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# Research objectives

- Develop facies-based multi-scale field characterization approach
  - Integrate formation / facies / permeability data with geophysics
- Dual-domain modeling approach
  - Numerical experimentation to define optimal dual-domain parameters in terms of reasonably-available site characterization data
- Overall
  - Test integrated approach (data integration & dual-domain modeling) for plume behavior at field site

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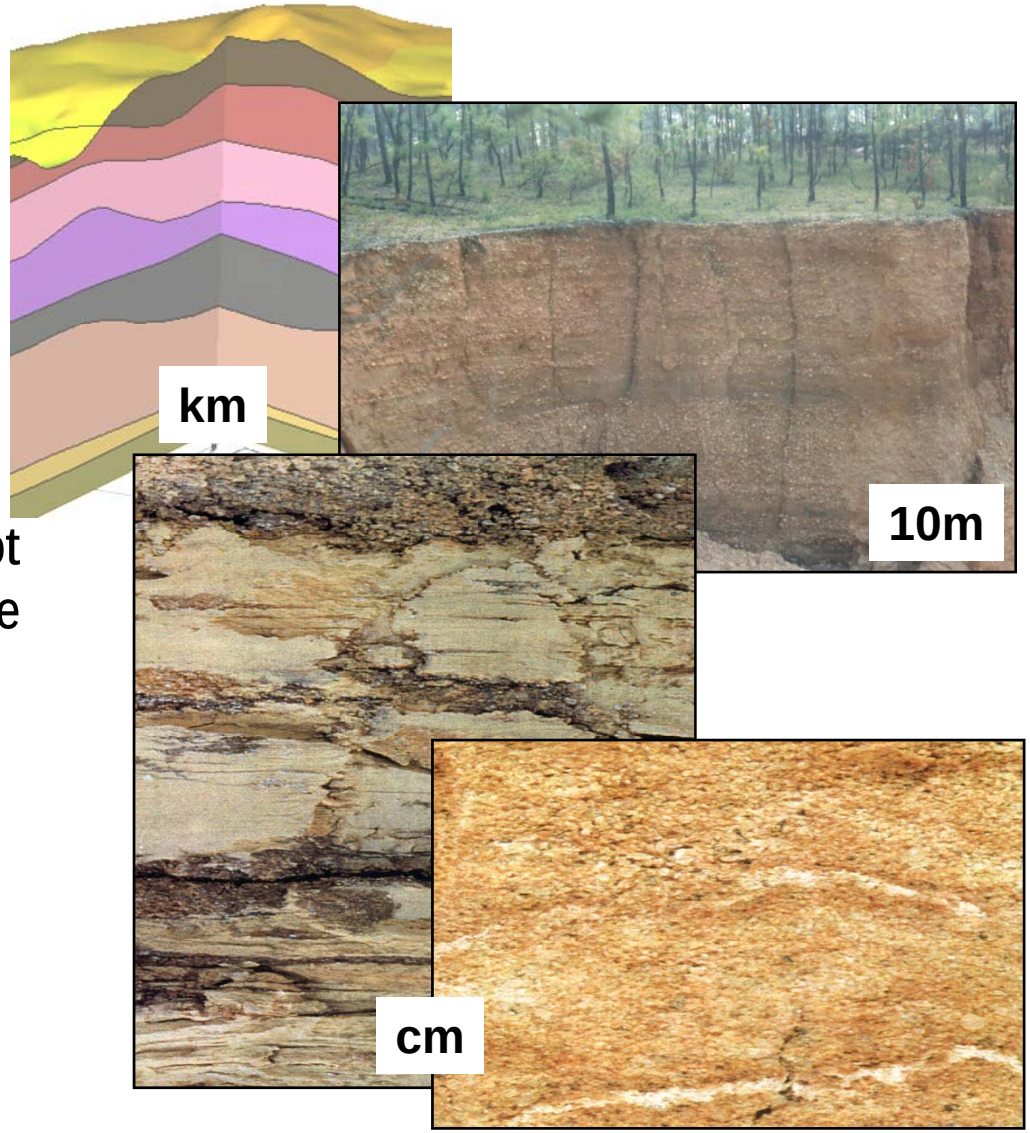
# Challenge of Field Scale Prediction

- Physical heterogeneity across many scales
- Conventional approaches characterize only a fraction of heterogeneity affecting field-scale transport
- Conventional modeling approaches with sparse data sets typically do not successfully predict long-term plume behavior for remediation strategy guidance
- Residual contamination in lower permeability zones is a particular concern

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# Progress to date

- Site development & plume characterization
- Development of numerical simulation framework
- Development of a multi-scale hydrogeophysical characterization framework
- Field characterization using borehole datasets
- Field crosshole geophysical imaging
- Field surface geophysical imaging
- Aquifer testing (slug & BFM)

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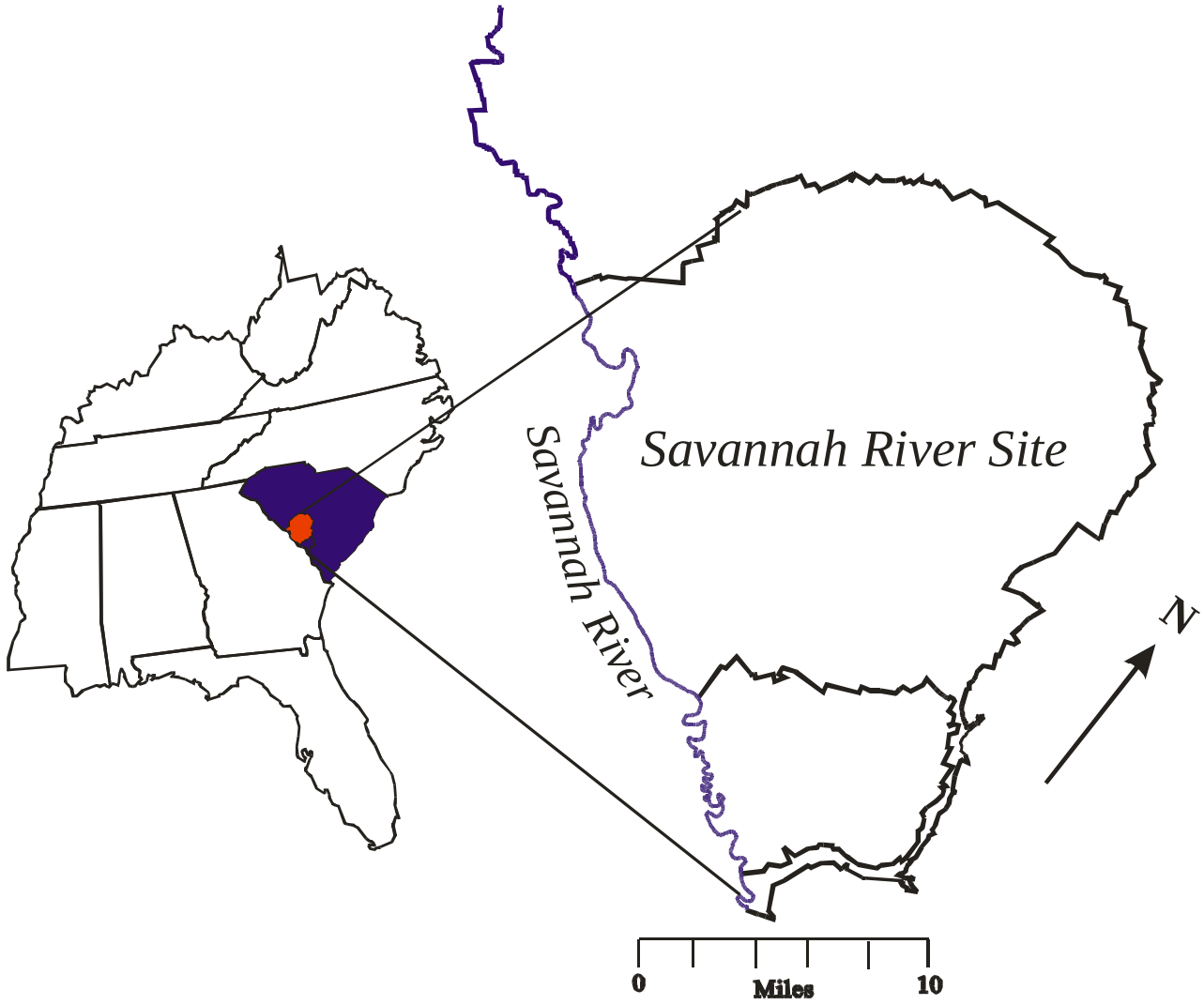


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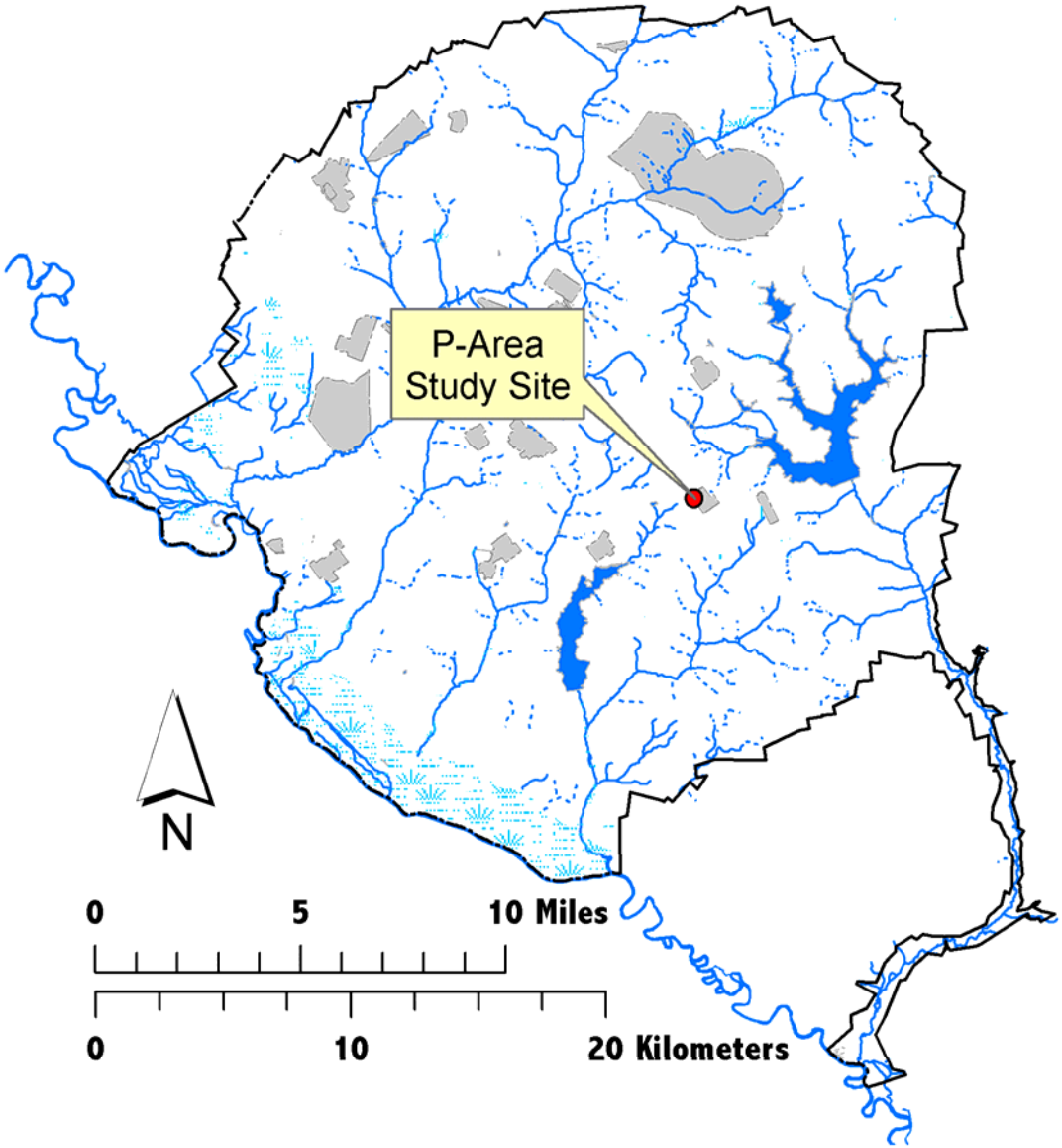


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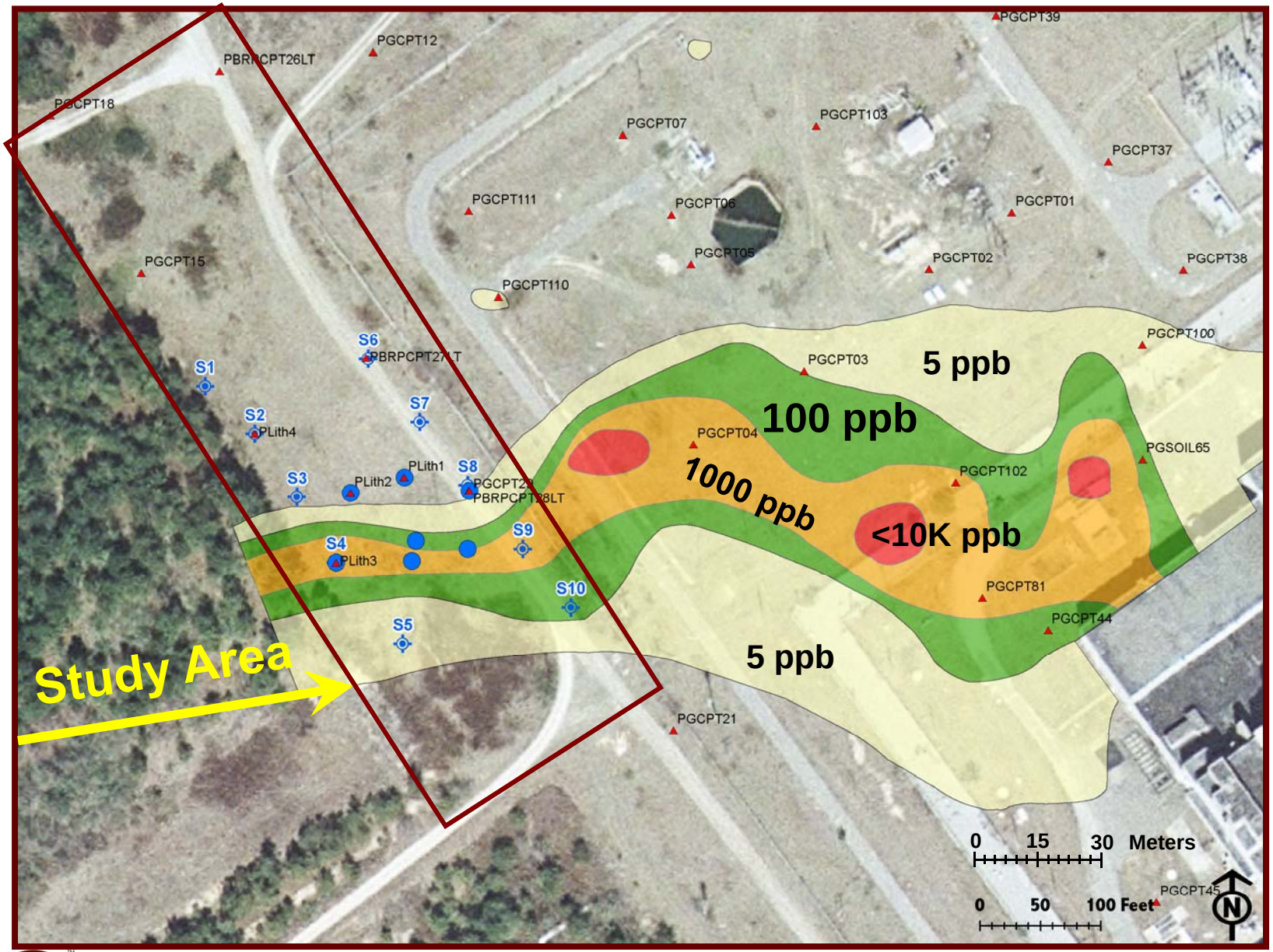
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PGCPT15
PGCPT05
PGCPT02
PGCPT38
PGCPT110
PGCPT100
S6
PBRPCPT27LT
PGCPT03
5 ppb
S1
100 ppb
S7
S2
PLith4
PGCPT04
PGSOIL65
1000 ppb
PLith1
S8
PGCPT102
S3
PLith2
PGCPT28
PBRPCPT28LT
<10K ppb
S9
S4
PLith3
PGCPT81
S10
PGCPT44
S5
5 ppb
Study Area
PGCPT21
0 15 30 Meters
PGCPT45
0 50 100 Feet
N

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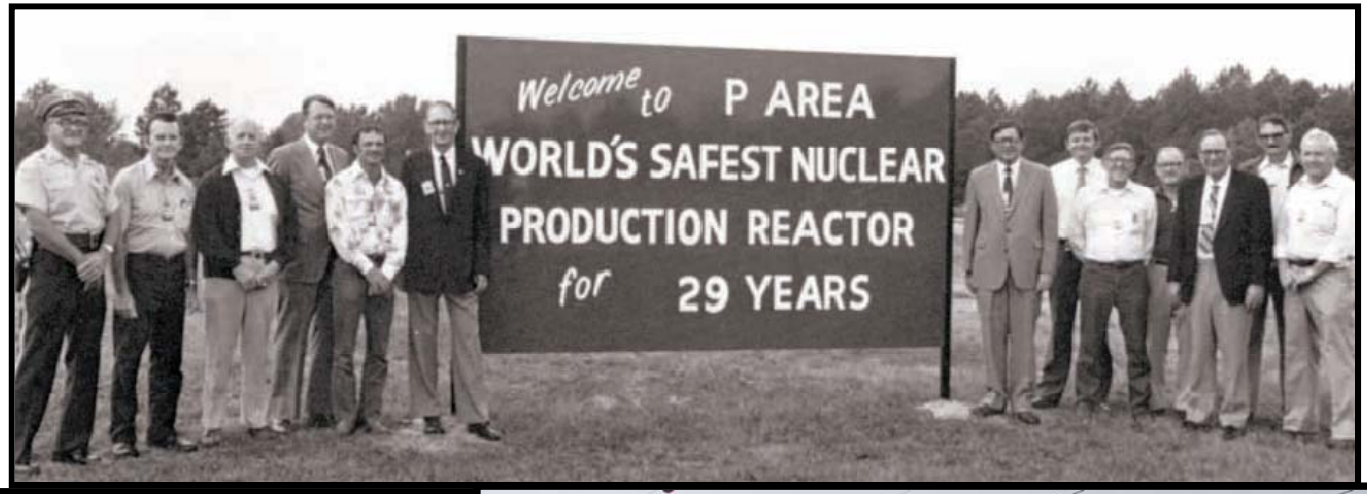
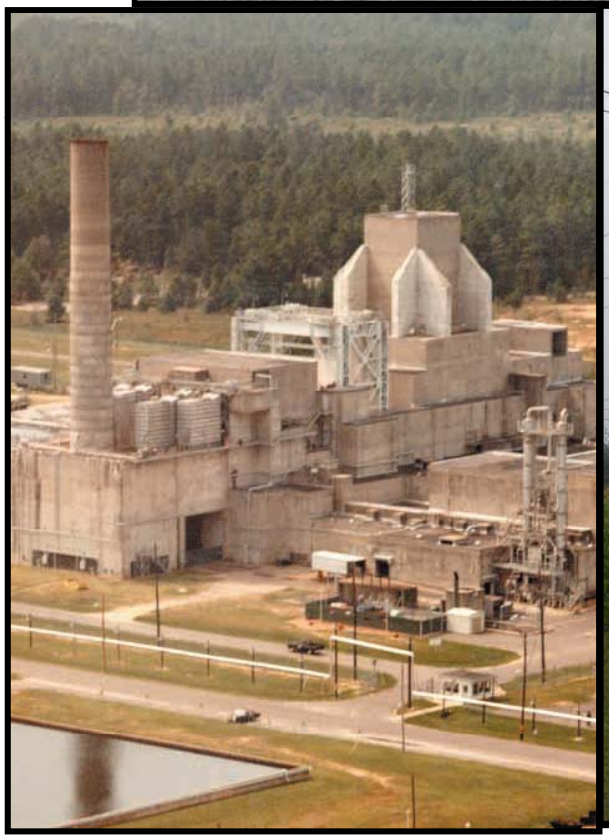

Welcome to P AREA
WORLD'S SAFEST NUCLEAR
PRODUCTION REACTOR
for 29 YEARS



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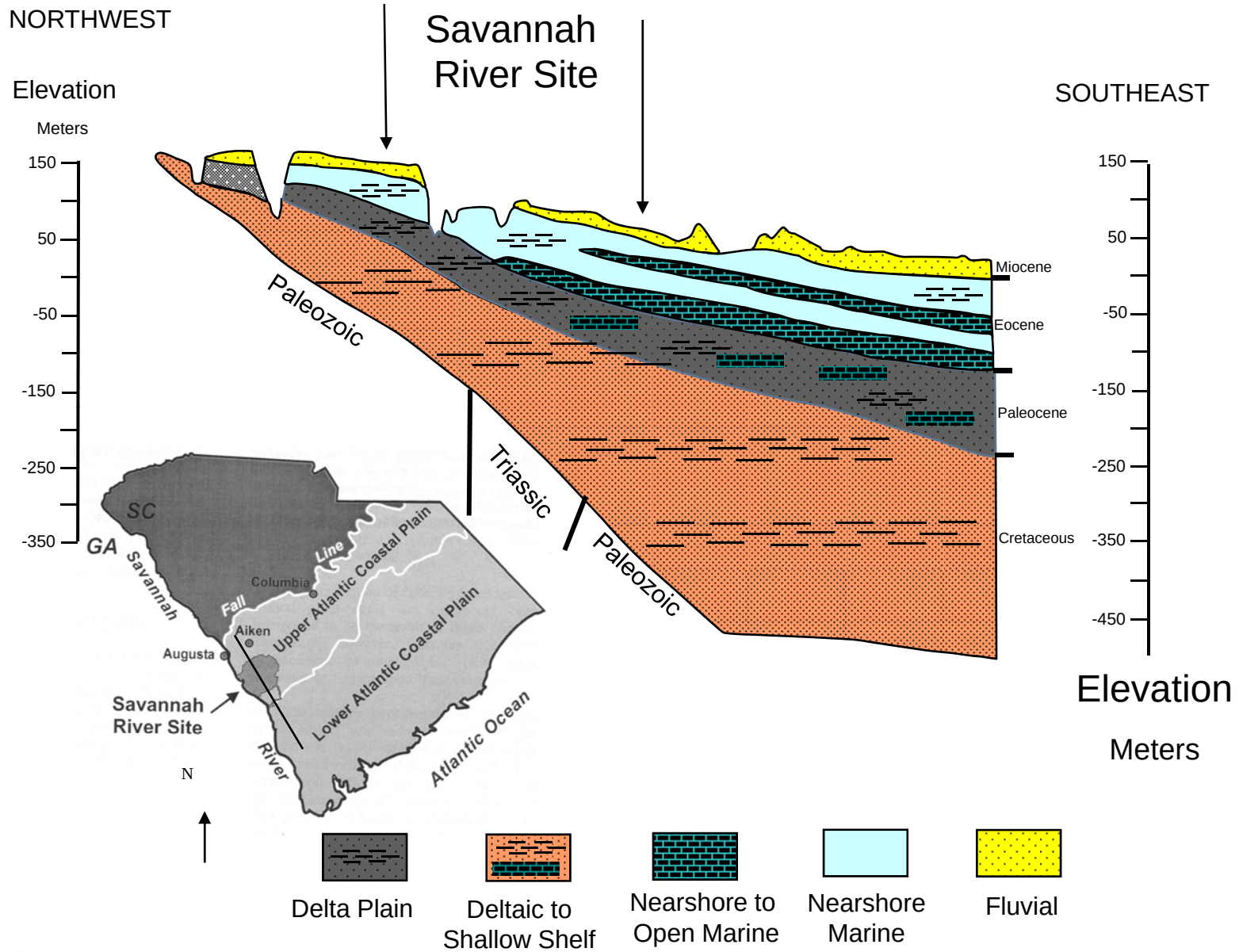
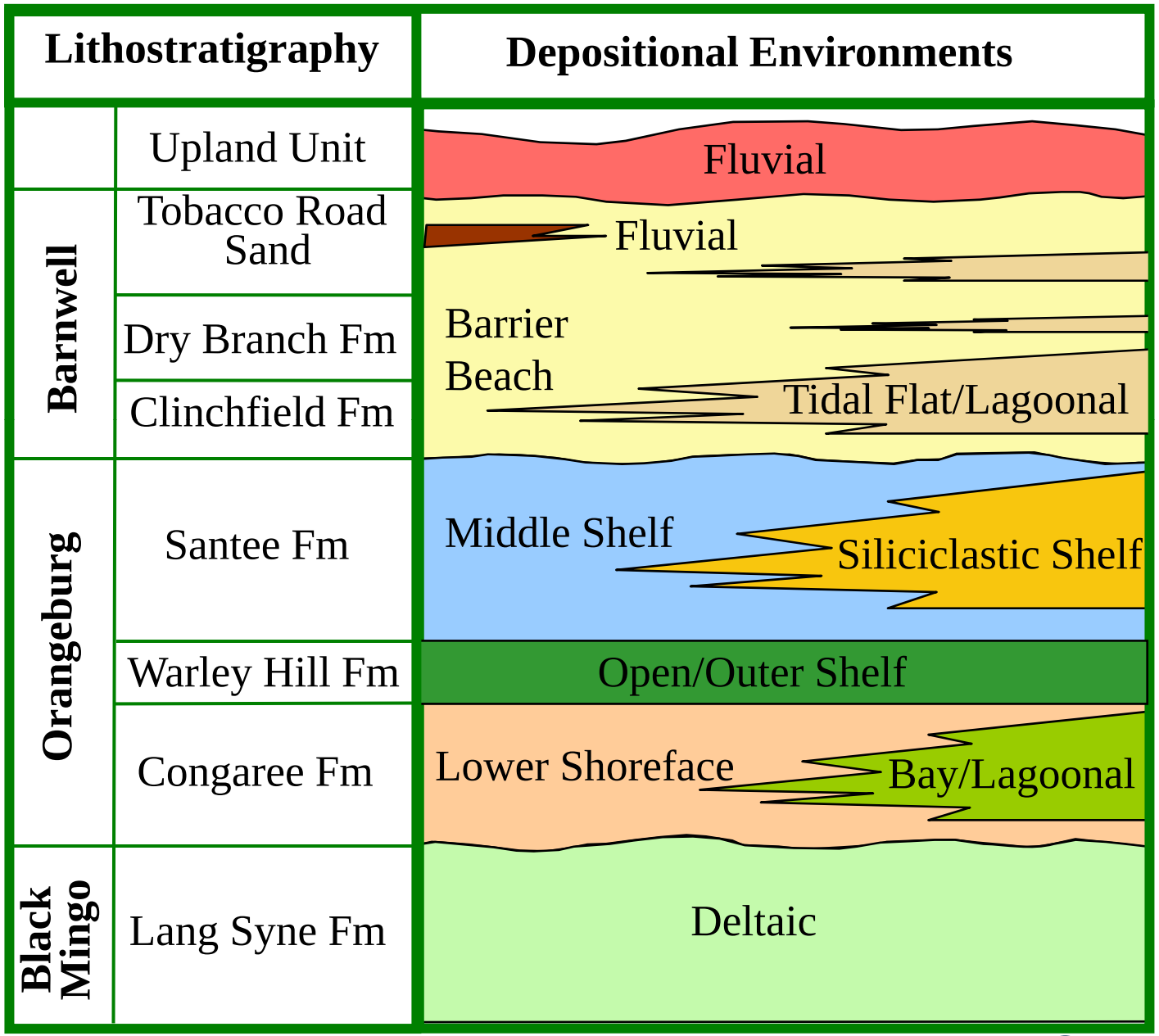



Generalized Depositional Environments


Lithostratigraphy
Depositional Environments
Upland Unit
Barnwell
Tobacco Road Sand
Dry Branch Fm
Clinchfield Fm
Orangeburg
Santee Fm
Warley Hill Fm
Congaree Fm
Black Mingo
Lang Syne Fm
Fluvial
Fluvial
Barrier Beach
Tidal Flat/Lagoonal
Middle Shelf
Siliciclastic Shelf
Open/Outer Shelf
Lower Shoreface
Bay/Lagoonal
Deltaic

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# Multi-scale field characterization data

- Cone Penetration testing (CPT)
- Rotosonic coring
- Gamma logs
- Water & soil headspace analysis
- Electromagnetic borehole flowmeter (EBF)
- Slug tests
- Injections tests
- Water level data
- Surface & shallow geophysical

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# Rotosonic Coring, Sampling & Well Installation

- 10 cm (4 in) Casing installed in 13 cm (5 in) borehole without a filter pack (goal of natural formation collapse around the screen)
- Continuous soil headspace sampling for VOC's on all boreholes


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# CPT Characterization

- Lithologic Data
  - Tip, sleeve, pore pressure
- Water samples
  - TCE
- Installed Piezometers

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# Slug Testing

- USC graduate student, Duke Brantley, with the packer assembly designed specifically for testing these wells.

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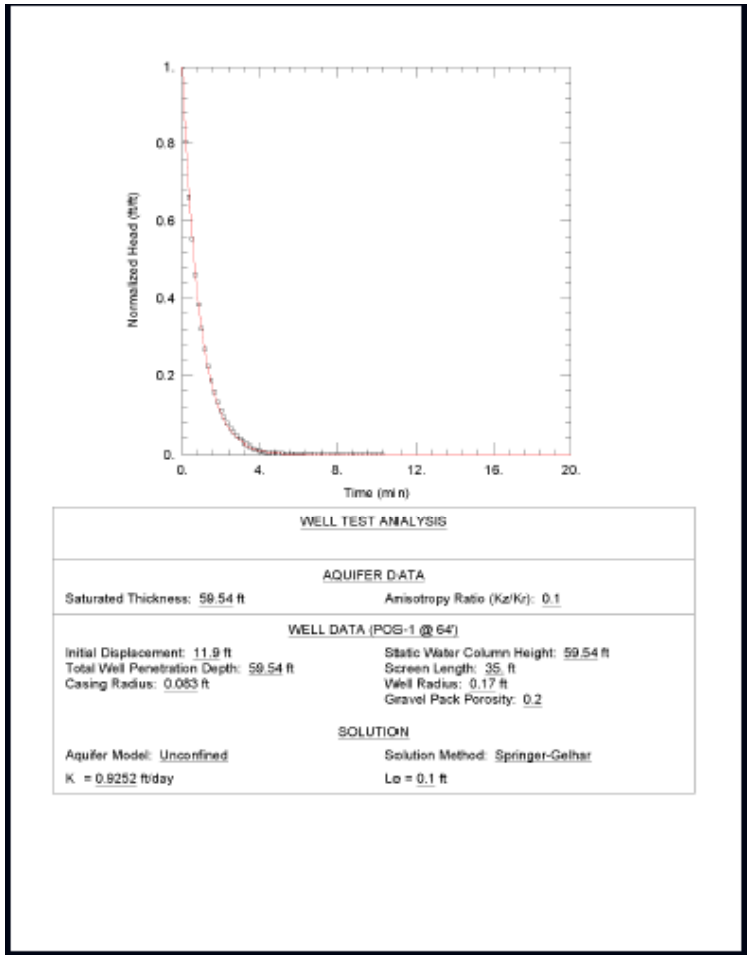
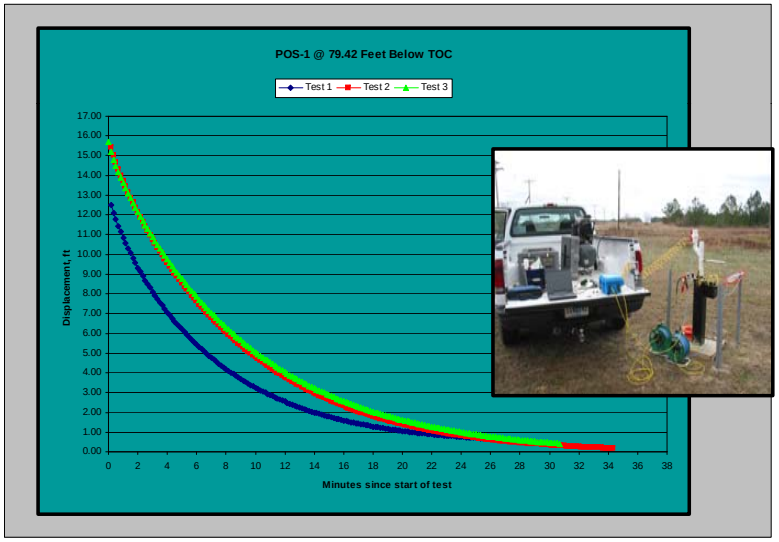
# Slug Test Response

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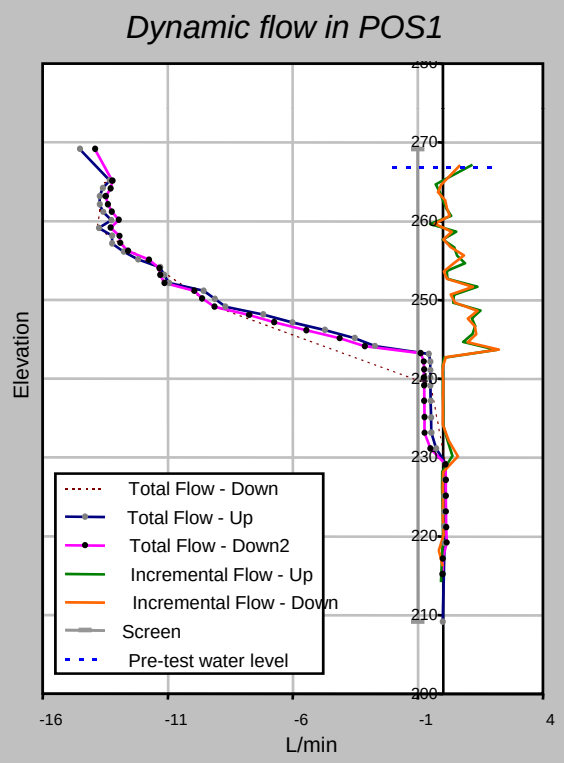
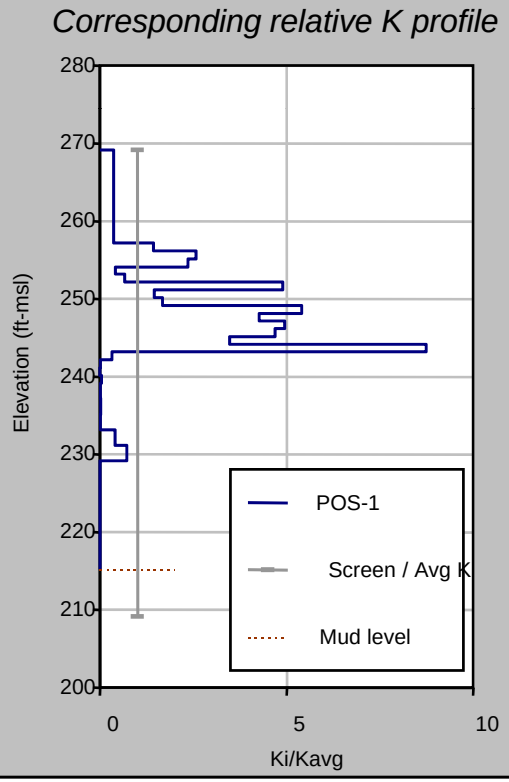
# Borehole Flow Meter

- During an injection test, the borehole flow meter measures the flow leaving the well screen on a foot-by-foot basis. Horizontal conductivity is proportional to the relative flow profile.

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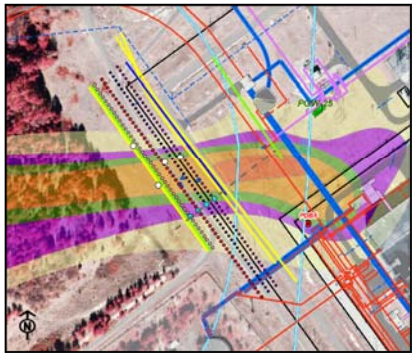
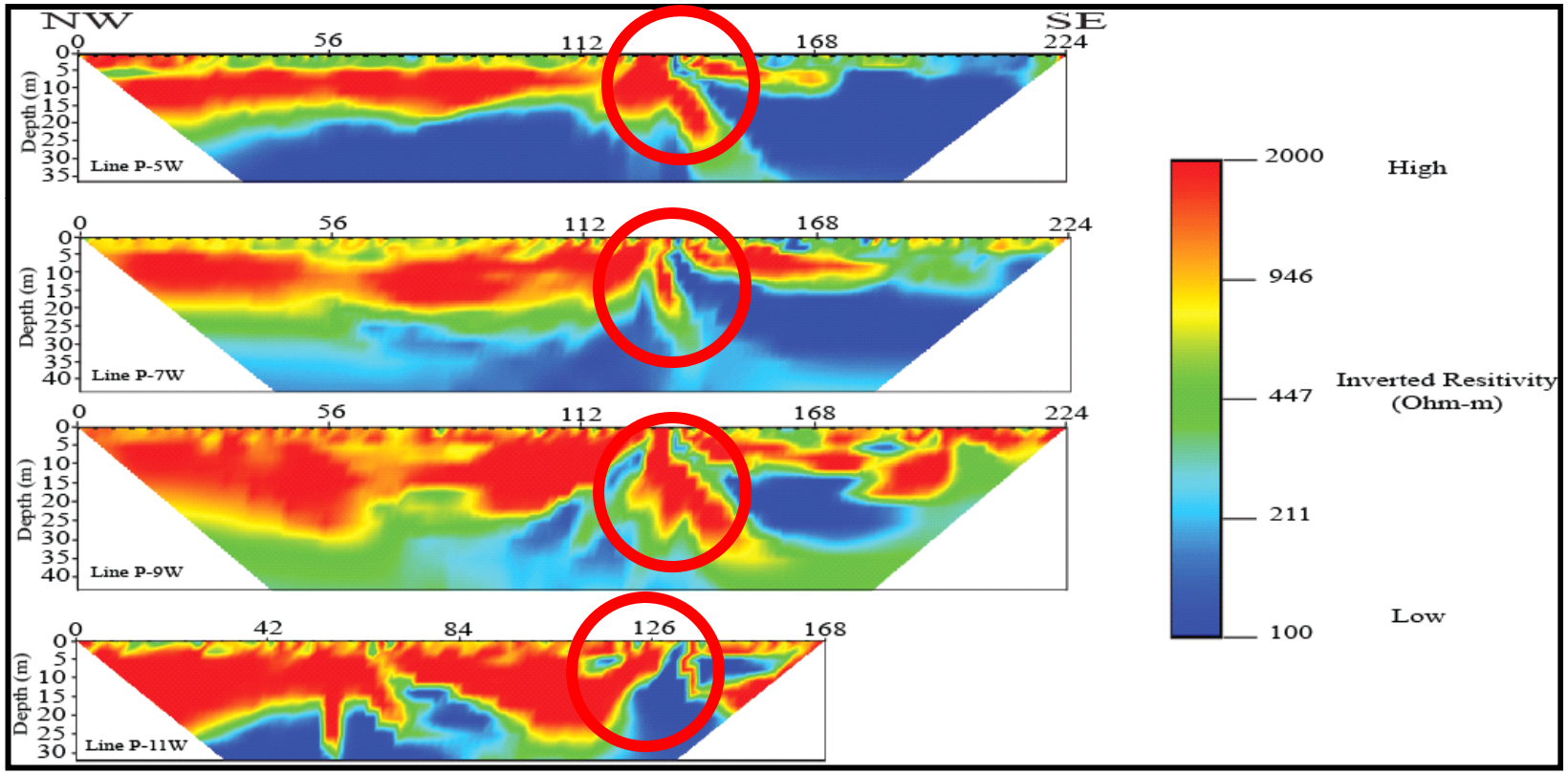
# Electrical Resistivity Tomography






**ERT Results – Wenner Array analysis**

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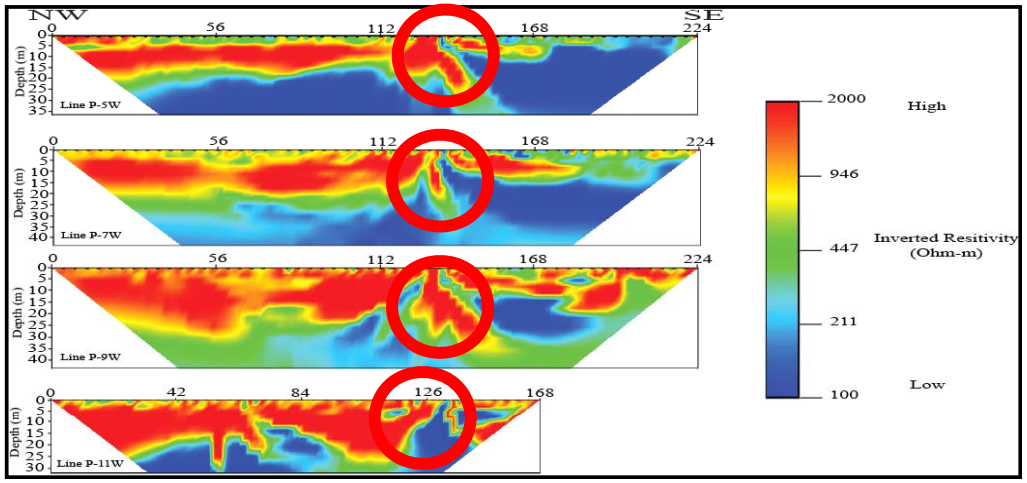
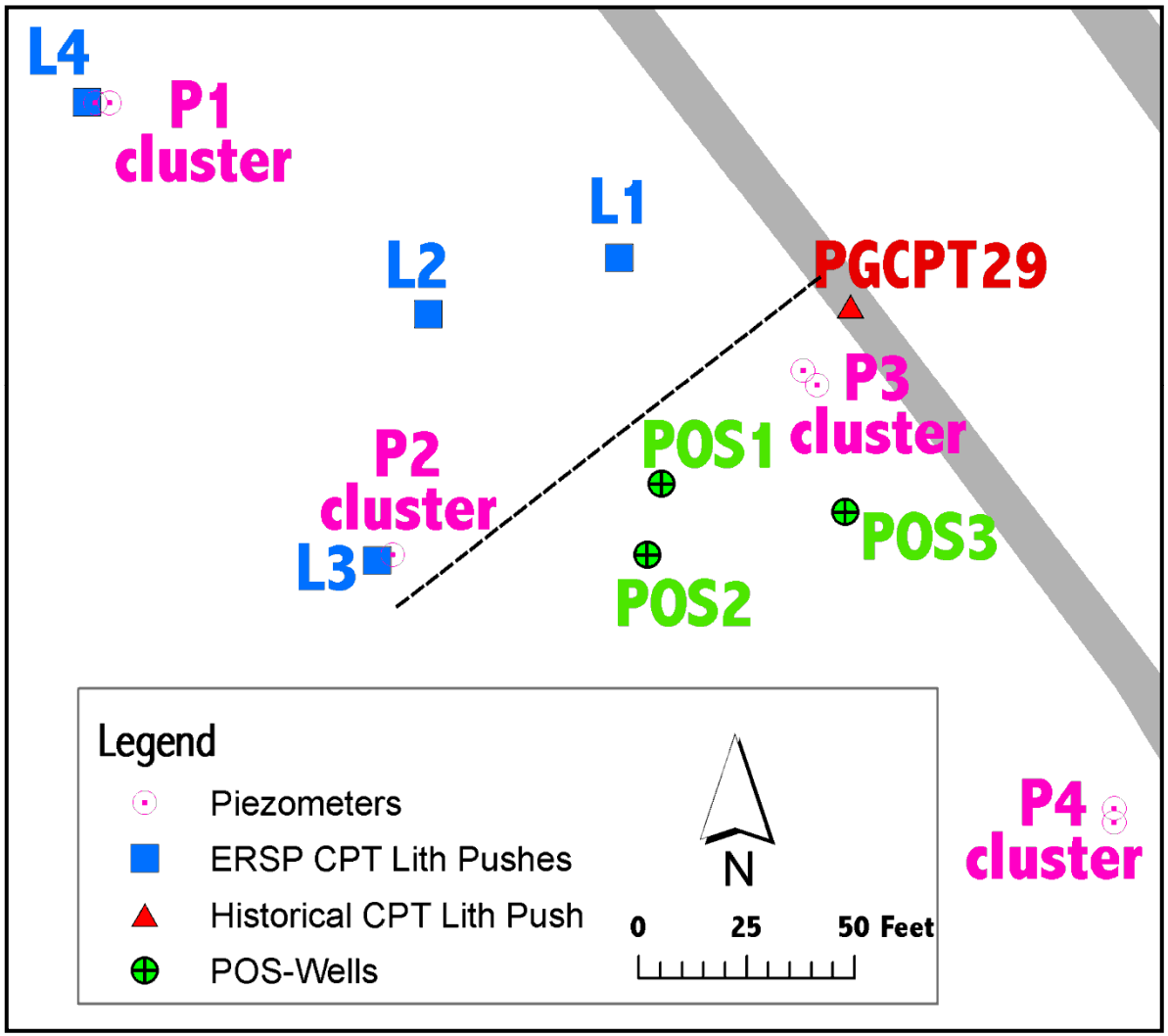
# Surface Investigation Results

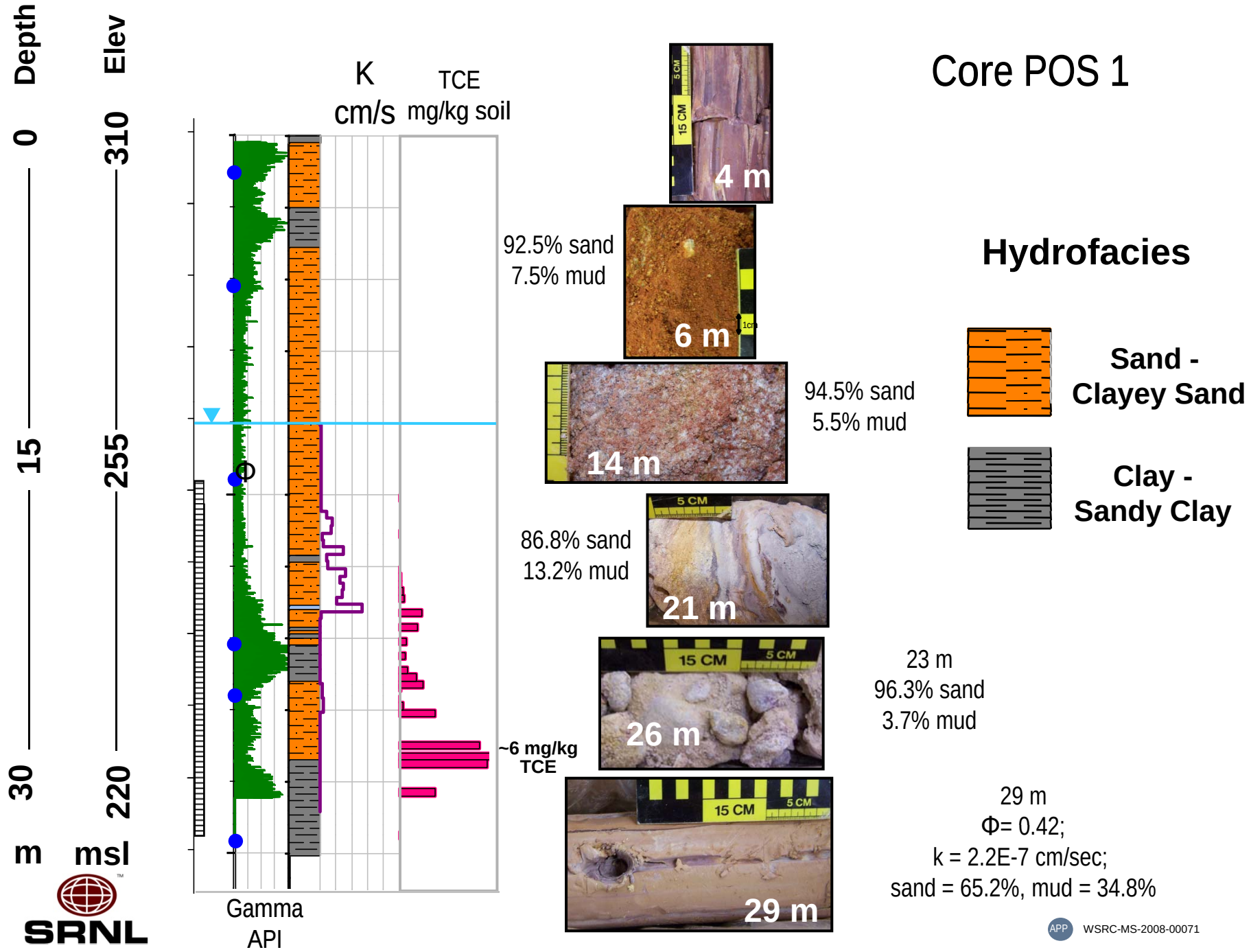
- GPR results good ~15m through vadose zone
- Surface ERT good penetration ~35 m with quality lateral stratigraphic/structural definition
- Good correlation with CPT resistivity data
- VSP's indicate good quality surface seismic data will be obtained.




L4
P1
cluster
L1
L2
PGCPT29
P3
cluster
POS1
P2
cluster
L3
POS3
POS2
P4
cluster
Legend
Piezometers
ERSP CPT Lith Pushes
Historical CPT Lith Push
POS-Wells
N
0
25
50 Feet

15 m

# Core POS 1


Depth
Elev
0
15
30
m
msl
310
255
220
K
cm/s
TCE
mg/kg soil
Gamma
API
4 m
6 m
14 m
21 m
26 m
29 m
92.5% sand
7.5% mud
94.5% sand
5.5% mud
86.8% sand
13.2% mud
~6 mg/kg
TCE
23 m
96.3% sand
3.7% mud
29 m
Φ= 0.42;
k = 2.2E-7 cm/sec;
sand = 65.2%, mud = 34.8%
Hydrofacies
Sand -
Clayey Sand
Clay -
Sandy Clay
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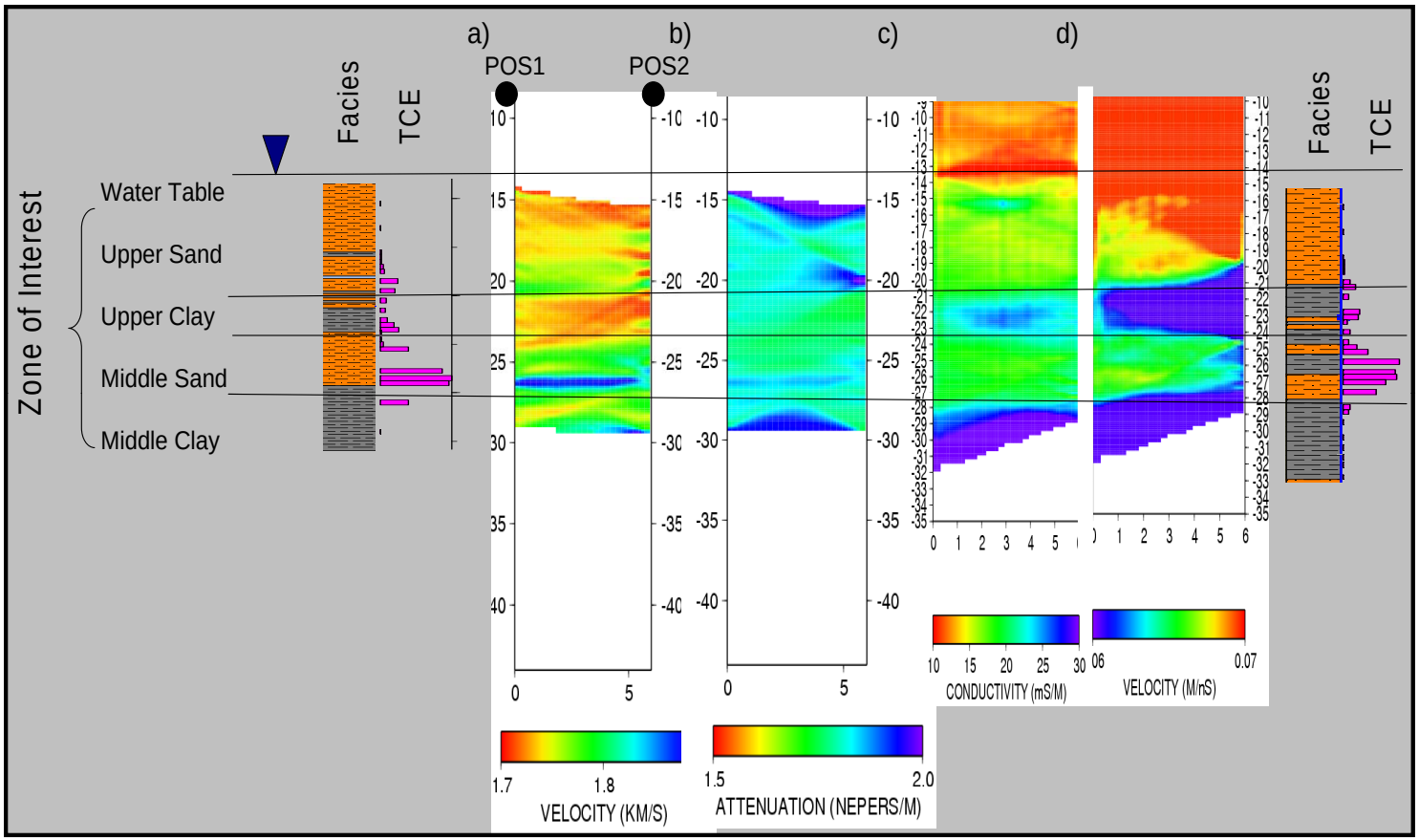
# Cross hole investigations




**Preliminary inversions of radar & seismic tomographic Datasets collected between wellbores POS1 & POS2**

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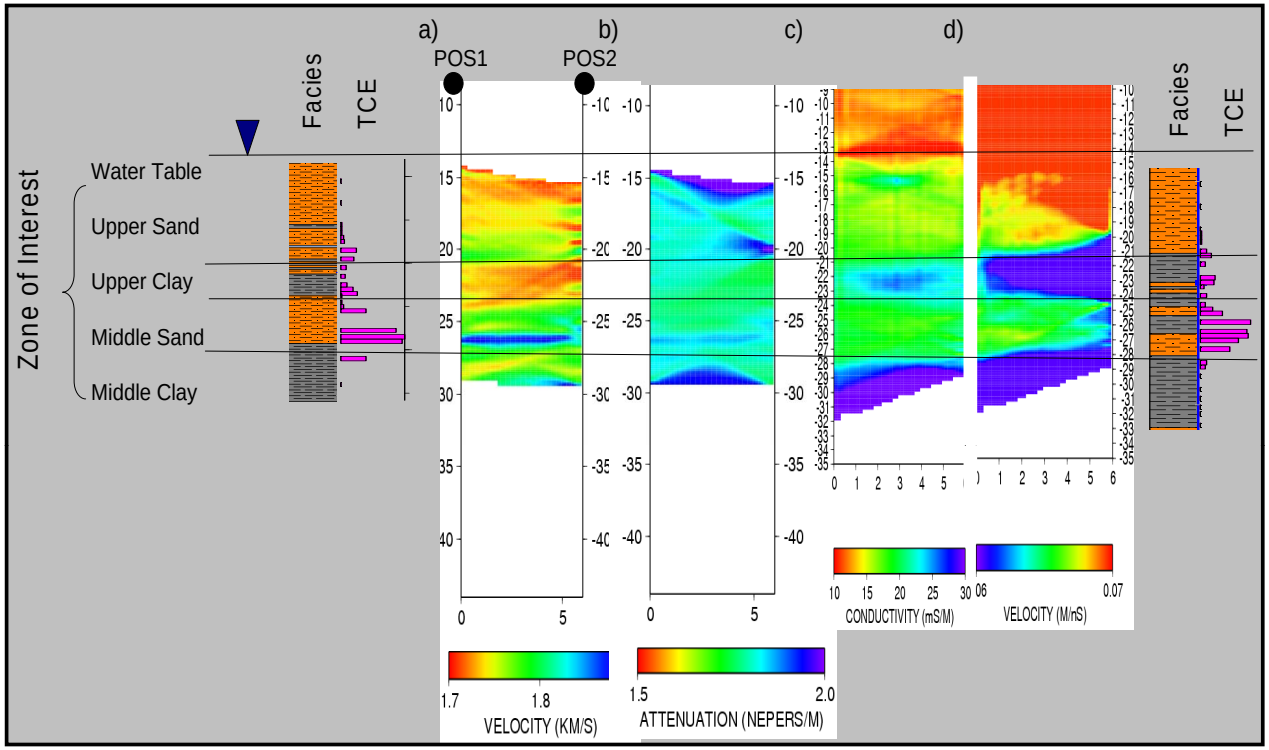
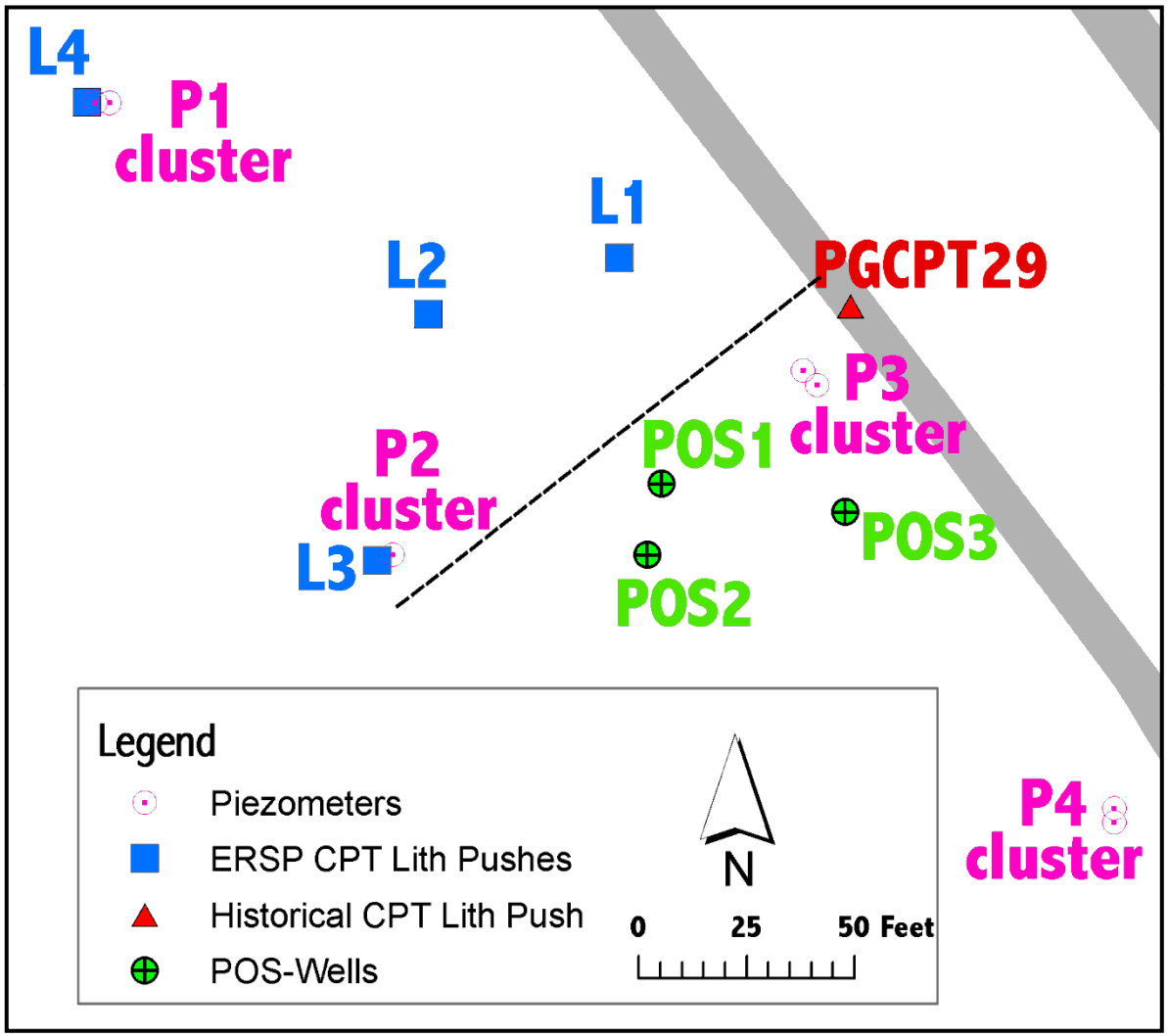
# Cross hole investigations




- Tomographic data should be useful for estimating the spatial distribution of the four unit/two facies contaminated zone of interest.


L4
P1
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L1
L2
PGCPT29
P3
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POS1
P2
cluster
L3
POS3
POS2
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cluster
Legend
Piezometers
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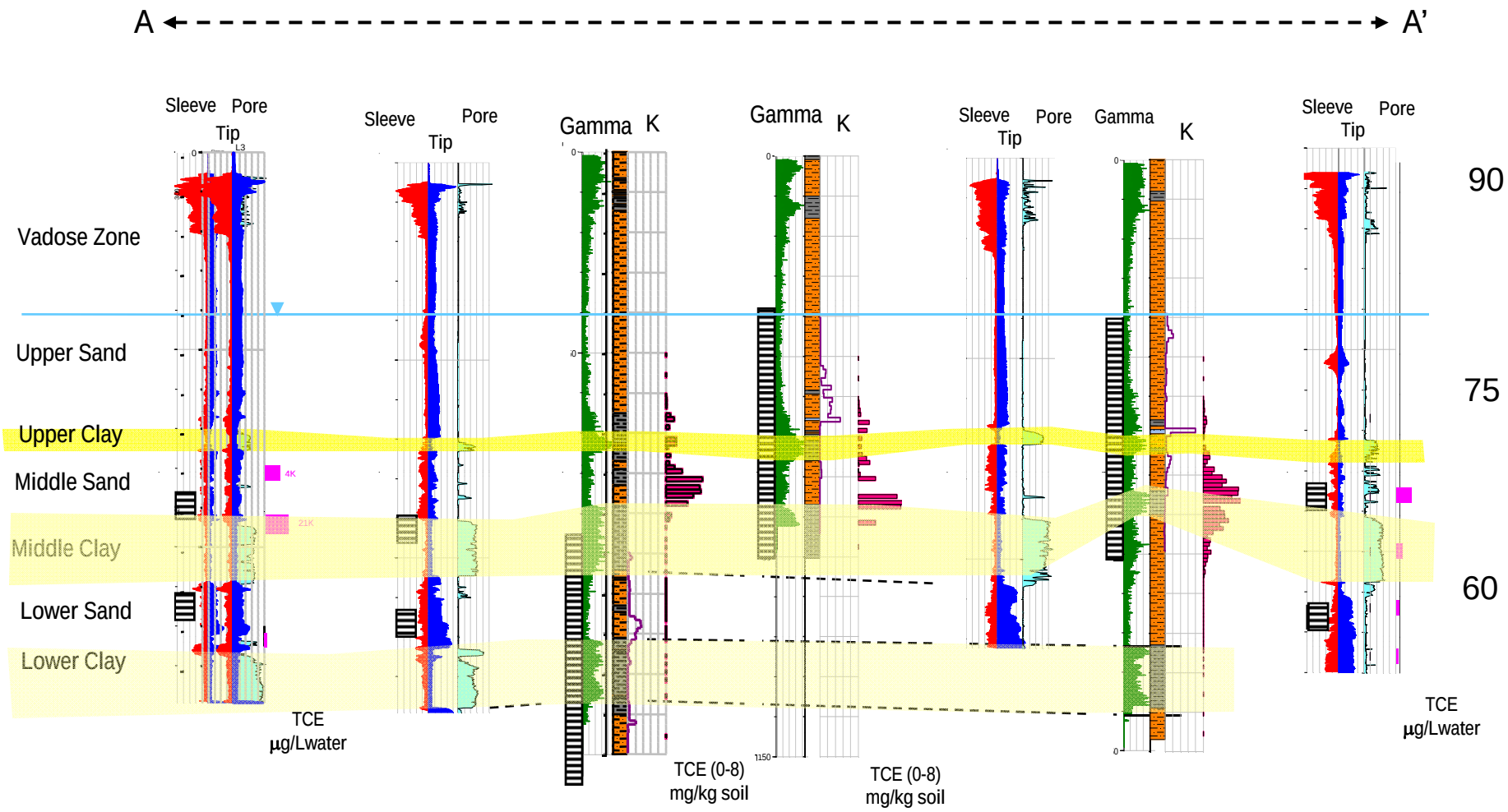
Historical CPT Lith Push
POS-Wells
N
0
25
50 Feet

15 m


A
A'
Sleeve
Pore
Tip
Gamma
K
Vadose Zone
Upper Sand
Upper Clay
Middle Sand
Middle Clay
Lower Sand
Lower Clay
90
75
60
TCE
µg/Lwater
TCE (0-8)
mg/kg soil
TCE (0-8)
mg/kg soil
TCE
µg/Lwater

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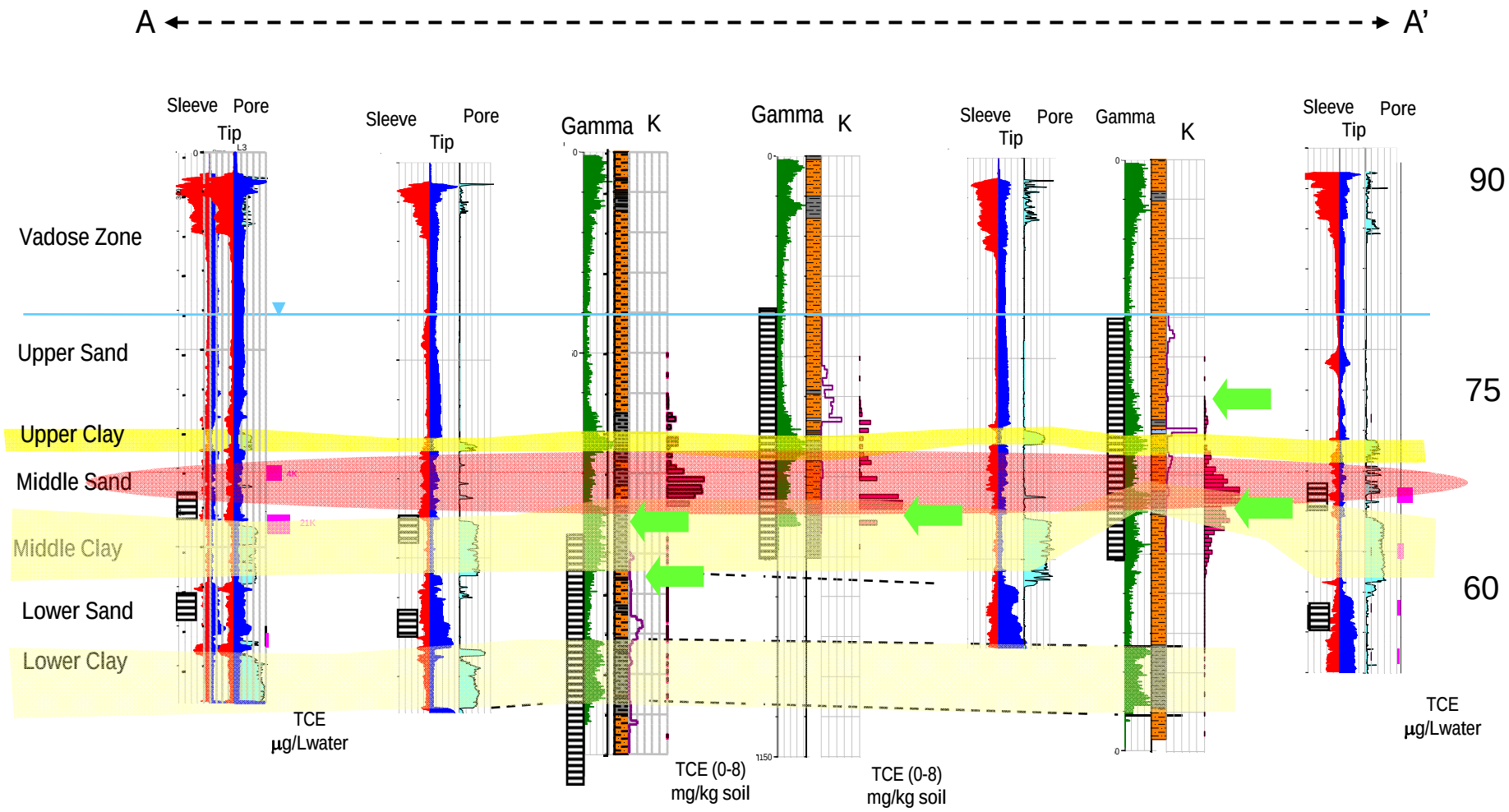


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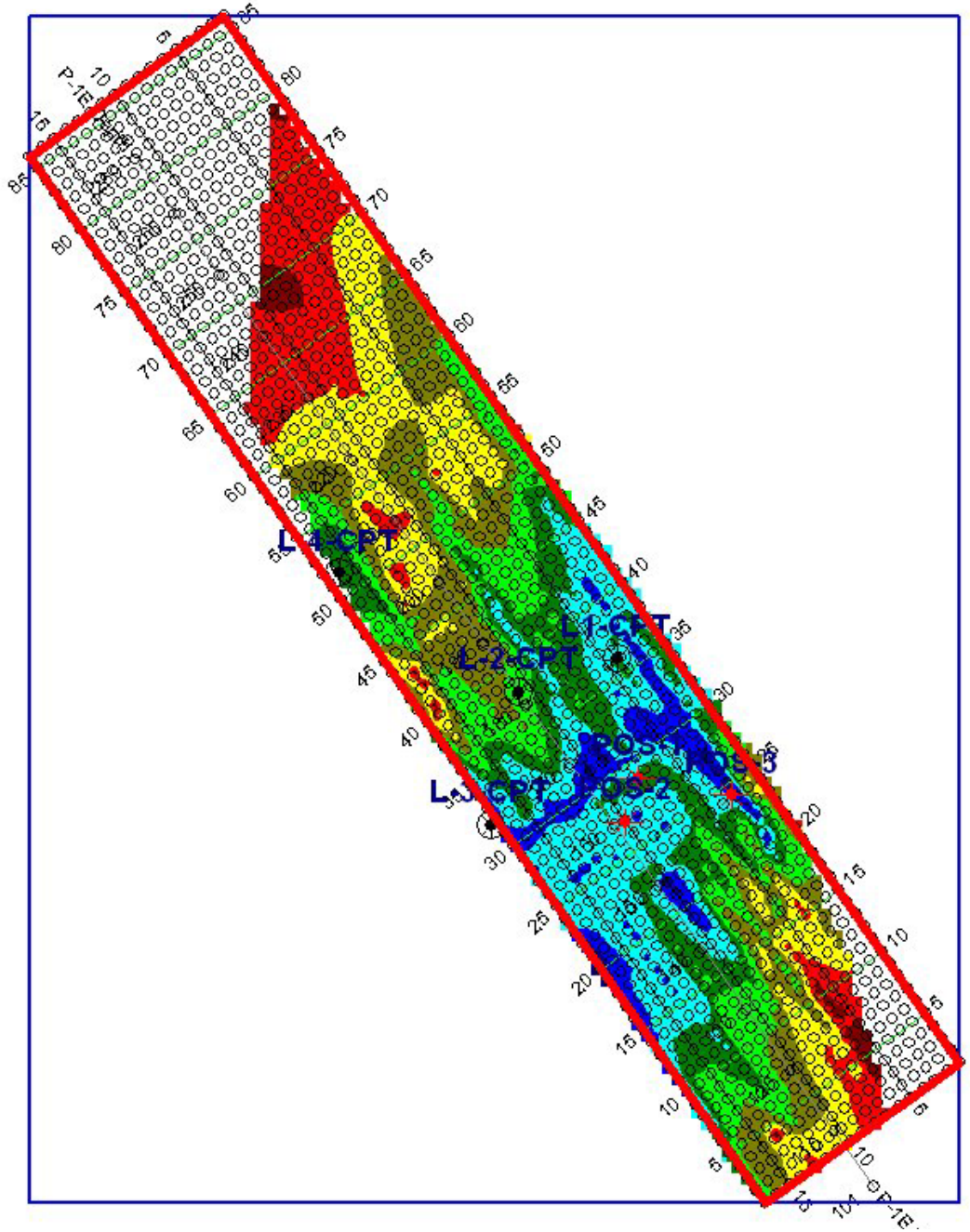
**Gravels**

# 3-D Seismic indicates a channel feature that appears to be controlling plume migration

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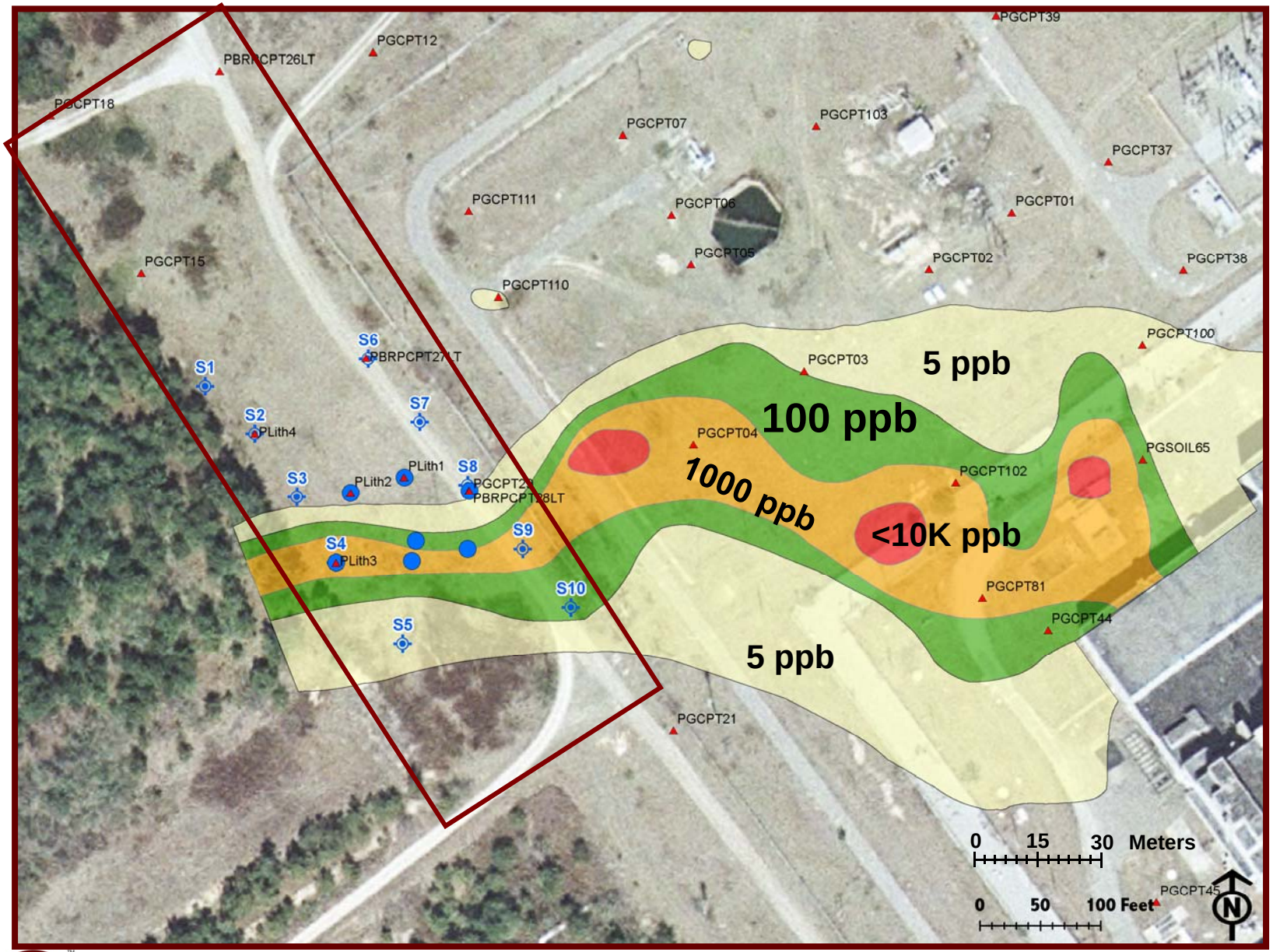
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PGCPT02
PGCPT38
PGCPT110
PGCPT100
S6
PBRPCPT27LT
PGCPT03
5 ppb
S1
100 ppb
S7
S2
PLith4
PGCPT04
PGSOIL65
1000 ppb
PLith1
S8
PGCPT102
S3
PLith2
PGCPT28
PBRPCPT28LT
<10K ppb
S9
S4
PLith3
PGCPT81
S10
PGCPT44
S5
5 ppb
PGCPT21
0 15 30 Meters
PGCPT45
0 50 100 Feet
N

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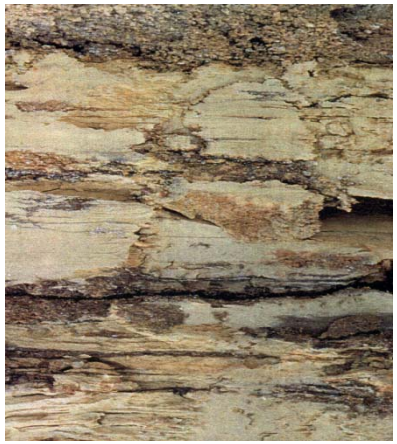
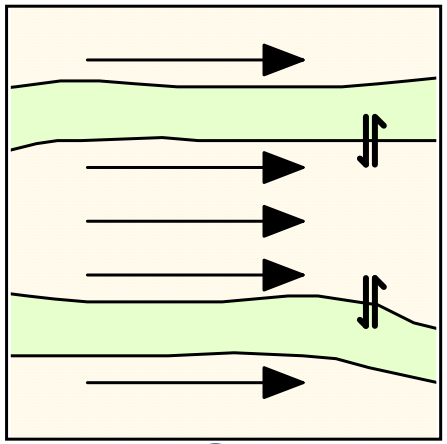
# Unresolved Heterogeneity – Modeling approach

- Even with better geophysical 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**



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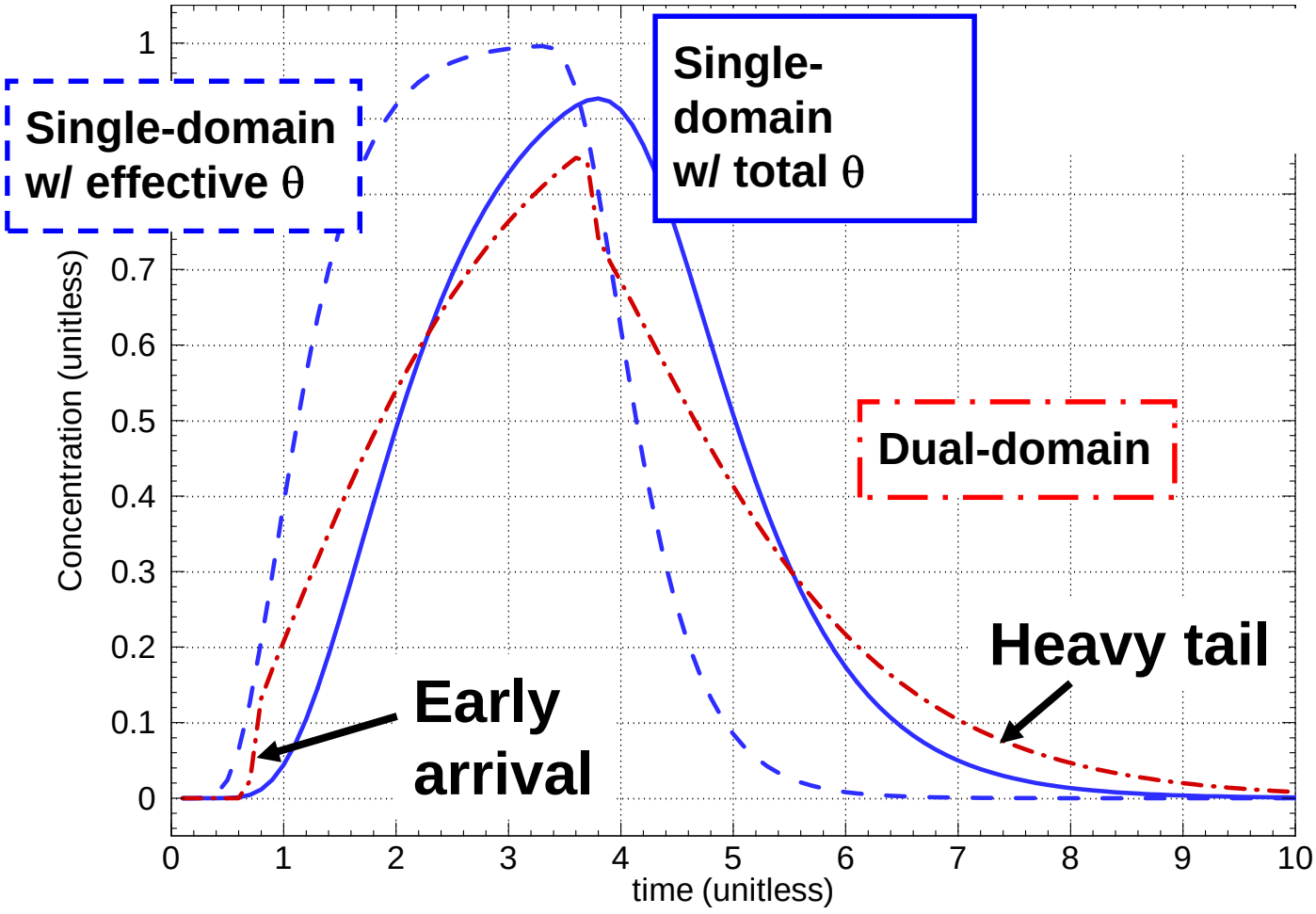
# Example Breakthrough Curves

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# Numerical Experimentation

- **Vary factors expected to influence best-fit parameters:**
  - **Permeability field**
    - facies proportion
    - K contrast
    - connectedness of high K
    - anisotropy
  - **Flow field**
    - orientation w.r.t. anisotropy
  - **Mass transfer time scales**
    - low K correlation length
    - Peclet number
    - contaminant exposure

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# Conclusions

- Incomplete sediment collapse was achieved over certain intervals in the wells, reducing vertical resolution of test results for the slug tests and BFM.
- Data supports a three porosity formulation and suggests the plume center of mass has since passed the study area.
- Geophysical data – ERT, crosshole investigations, and 3-D seismic are useful for both depositional environments and spatial distribution of the facies.

# Final Plans

- Data mining to explore relations between the hydrogeological-geophysical parameters measured using surface, crosshole, and borehole datasets
- Additional borehole and piezometers to refine characterization & validate modeling parameters
- Additional crosshole and surface geophysical surveys
- Prototype dual-domain TCE transport model will be completed along with initial multi-scale integration of geophysical & hydrogeological data with the facies delineation.
  - Test integrated approach for TCE plume at field site

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