Demonstrating A Geophysics Strategy for Minimally Invasive Remediation Performance Assessment

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Outline

- Basic Theory and Operation
  - Deployment, measurements, processing
- Application Sampler
  - Characterization imaging
  - Time-lapse imaging
  - Real Time Imaging
- Managing Expectations, Limitations and Pitfalls
  - Consequences of Limited Resolution
  - Tools and Approaches for Reducing Risk
- Case Study
  - Brandywine M.D. Defense Reutilization Marketing Office

Electrical Imaging Step 1: Deploy Data Collection Hardware

Step 1: Electrode arrays are installed in the field and connected to a data collection system.

Step 2: Collect Tomographic Data

Current Injection and Potential Field

Step 2:

- Current is inject between a pair of electrodes
- Voltage is measured across another pair
- Many such measurements are collected to form a tomographic data set.

Step 3: Convert measurements to images via tomographic inversion

Step 3:

- Data sets are inverted to recover “images” of electrical properties
- Static images show absolute properties
- Time-lapse images show changes over time
- Conductive and capacitive properties

What can electrical properties tell us about the subsurface?

A geophysical property dependent on many subsurface properties....
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The Detection Problem: Finding a plume

Electrical Resistivity Anomaly (plume)

Electrical Resistivity Cross section

Electrical Resistivity Tomogram

→ Plume is masked by geologic heterogeneity

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Time Lapse Difference Imaging

Electrical Resistivity

AFTER

BEFORE

Difference Tomogram

→ Plume is revealed by subtracting out pre-injection background, removing unrelated spatial contrasts; i.e., we removed the haystack

Implementation Example 1: Imaging Vadose Zone Contamination (Hanford)

High conductivity zones correspond to elevated saturation and high nitrate concentrations from past waste infiltration.

2006/2007 Surface ER Survey

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Data courtesy HydroGeophysics, Inc.

Example 2: Time-lapse monitoring of stage-driven river water intrusion

Fluid conductivity (e.g., specific conductance) contrast between river water and groundwater enables river water to be imaged as it infiltrates into the aquifer during high stage.

Example 3: Real-Time monitoring of amendment delivery via surface infiltration

Plan view of 300 Area Treatment Site

Photo at A facing A'

- ~10 m thick uranium contaminated vadose zone
- saturated zone hydraulically connected to Columbia River
- phosphate amendment binds uranium to sediments
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Example 3: Results

Solute velocity and arrival time analysis

Developing Realistic Expectations

Pros:
- Minimally invasive
- Relatively low cost
- Can cover a large area
- ‘Sees’ in between wells
- Good at the “when and where”

Cons:
- Indirect – correlation or interpretation requires
- Limited resolution
- Not good at the “what”

Note: There is NO such thing as geophysical X-ray vision! No silver bullets!

Consequences of Limited Resolution

Example 3: Real Time Web Delivery

New image every 12 minutes

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Beware of Misuse/Overselling

- Blatant overselling of capabilities by service providers is common
- Tools and approaches are available to test feasibility and reduce risk

Managing expectations and reducing risk through pre-modelling feasibility assessment

Example: Pre-modelling a DNAPL Spill

Case Study: Brandywine M.D. DRMO

ER 200717 Project Summary

Primary Objective: Demonstrate the capability to autonomously image 3D bio-amendment distribution with time.

ER 200717 Imaging Results

Summary
- Successfully imaged the 3D emplacement and migration of amendment.
- Observed secondary increase in conductivity within the treatment zone after about 1 year.
- Validated the cause of the secondary increase to be bio-induced solid-phase transformation (likely FeS precipitation).
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Post Remediation Assessment Objectives

1. Identify the long-term geophysical footprint of active bioremediation at a VOC contaminated site.
2. Determine the significance of the geophysical footprint with respect to solid phase mineral transformations and/or biofilms induced by the treatment process.
3. Demonstrate the use of 1 and 2 above to map gradients in the geophysical footprints of biostimulation along a transect crossing the boundary of the treatment area at an active remediation site, and interpret those gradients in terms of long-term biogeochemical impacts.

Crosshole Imaging/Fluid Sampling Arrays

- Eight vertical arrays installed via direct push
  - Each array includes 24 electrodes and 3 fluid sampling ports
  - Enables 3D crosshole imaging directly in the ER0717 injection zone
  - Enables 2D crosshole imaging inside and outside of the treatment area.
  - Enables depth-discrete pore fluid sampling inside and outside of treatment zone

Core Sampling/Logging Holes

- Four continuous core boreholes completed with PVC
  - Enables direct lab measurement of electrical geophysical properties with depth, inside and outside of treatment zone
  - Enables assessment of microbial communities and biogeochemical solid phase product inside and outside of treatment zone.
  - Enables 1D geophysical logging profiles.
  - Critical to relate field-scale images to long-term biogeochemical impacts

Surface Imaging Arrays

- Surface ERT Arrays
  - Enables evaluation of larger scale, lower resolution, less expensive surface based imaging for impact assessment.
  - Enables inspection of the treated-to-untreated transition zone.

Borehole Imaging Results

- High phase (polarization) in the treated zone relative to untreated
- Highest polarization and conductivity occur in the vicinity of the injection well (profile xi-2)

Project Status

- Long-term geophysics footprint of bioremediated site exists and is identified
- Origin of geophysical signature in terms of solid phase mineral transformations and/or biofilms (in progress)
- Interpretation of images in terms of long-term biogeochemical impacts
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**Summary**

- Remediation performance assessment using geophysical imaging is advancing
  - Reduced monitoring costs, autonomous, continuous in space and time, minimally invasive, good at the “when and where”
- Important to understand limitations, avoid overselling
  - Feasibility and expectations through pre-modelling
- Quantitative interpretation requires coupling with laboratory analysis → site specific relationships between geophysical and geochemical parameters → mapping geochemical property estimates

**Supplementary Slides**

**Engineered Vadose Zone Desiccation**

- Dry nitrogen injection system
- Instrument panels
- Extraction blower
- Pre-desiccation ERT Image

**Autonomous 3D Monitoring of Vadose Zone Desiccation**

- Time-lapse 3D imaging of engineered vadose zone desiccation

**Real Time Imaging of Flow in Fractured Rock**

- south to north view
- west to east view

**Real-time Imaging**

- Challenges
  - Wireless communications
  - Secure supercomputer access
  - Coordination between supercomputer and field system
  - How do we set the inversion parameters before we see the data?

**Remarkable Slides**

**Engineered Vadose Zone Desiccation**

- BC-Cribs Desiccation TT Field Site
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