

Geophysical Investigations at the Old Rifle IFC Site

Kenneth H. Williams, Susan S. Hubbard, Jillian F. Banfield,
Andreas Kemna, Lucie N'Guessan, and Philip E. Long

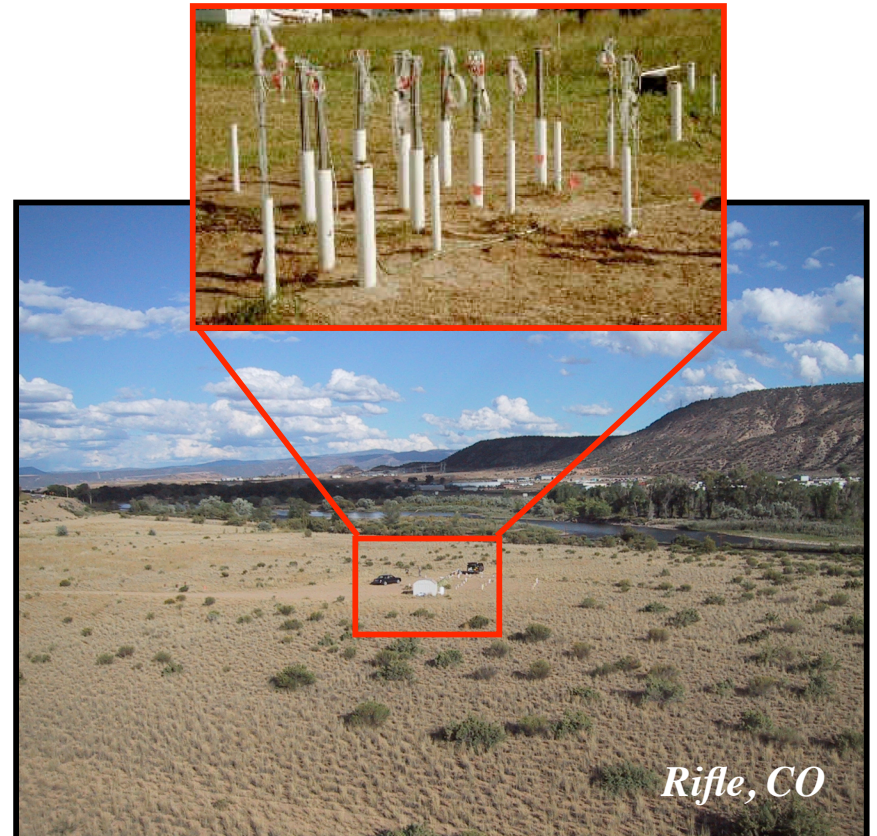
Objective

Demonstrate the utility of geophysical methods for characterizing structure¹ and monitoring processes² **over field-relevant scales**

Hypothesis²: Microbial processes induce **physical property changes** that can be detected using time-lapse geophysical methods

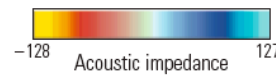
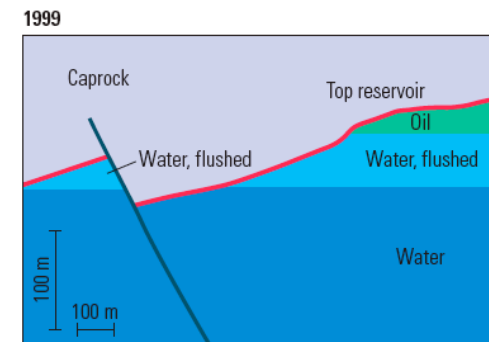
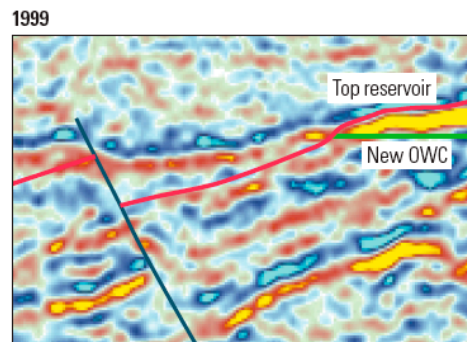
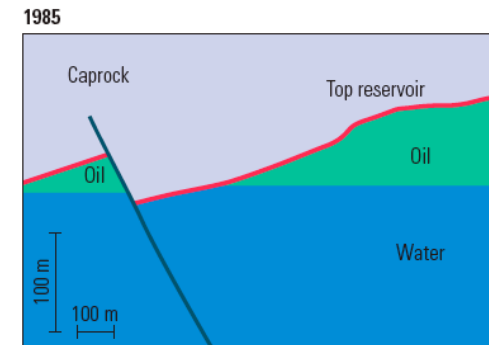
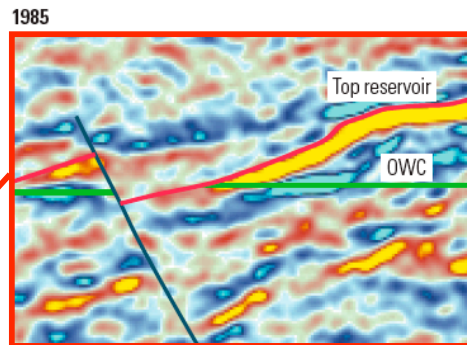
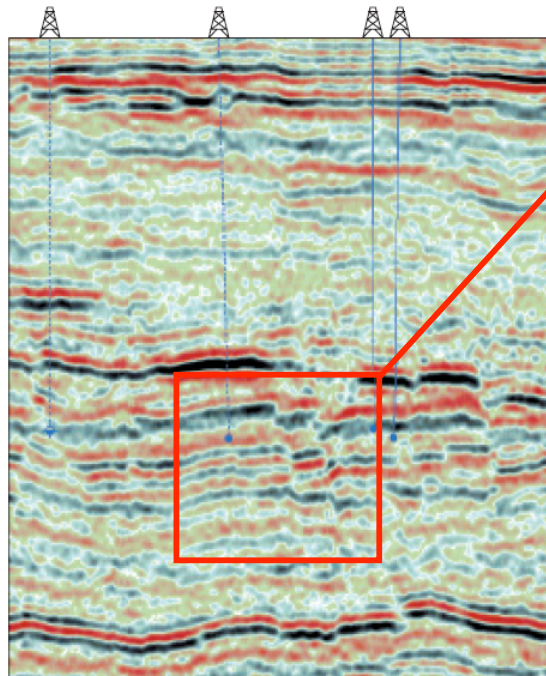
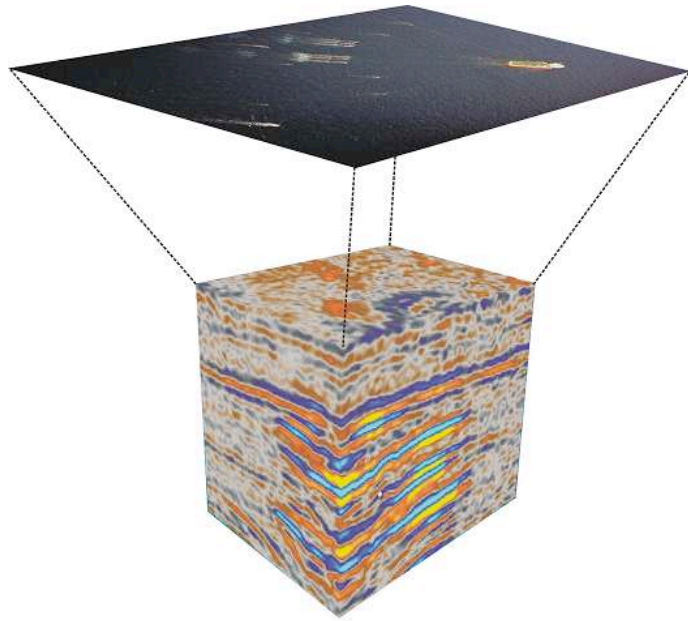
Challenges:

- Unfavorable lithology
- Competing metabolic processes
- Non-unique signatures



Why Use Geophysics?

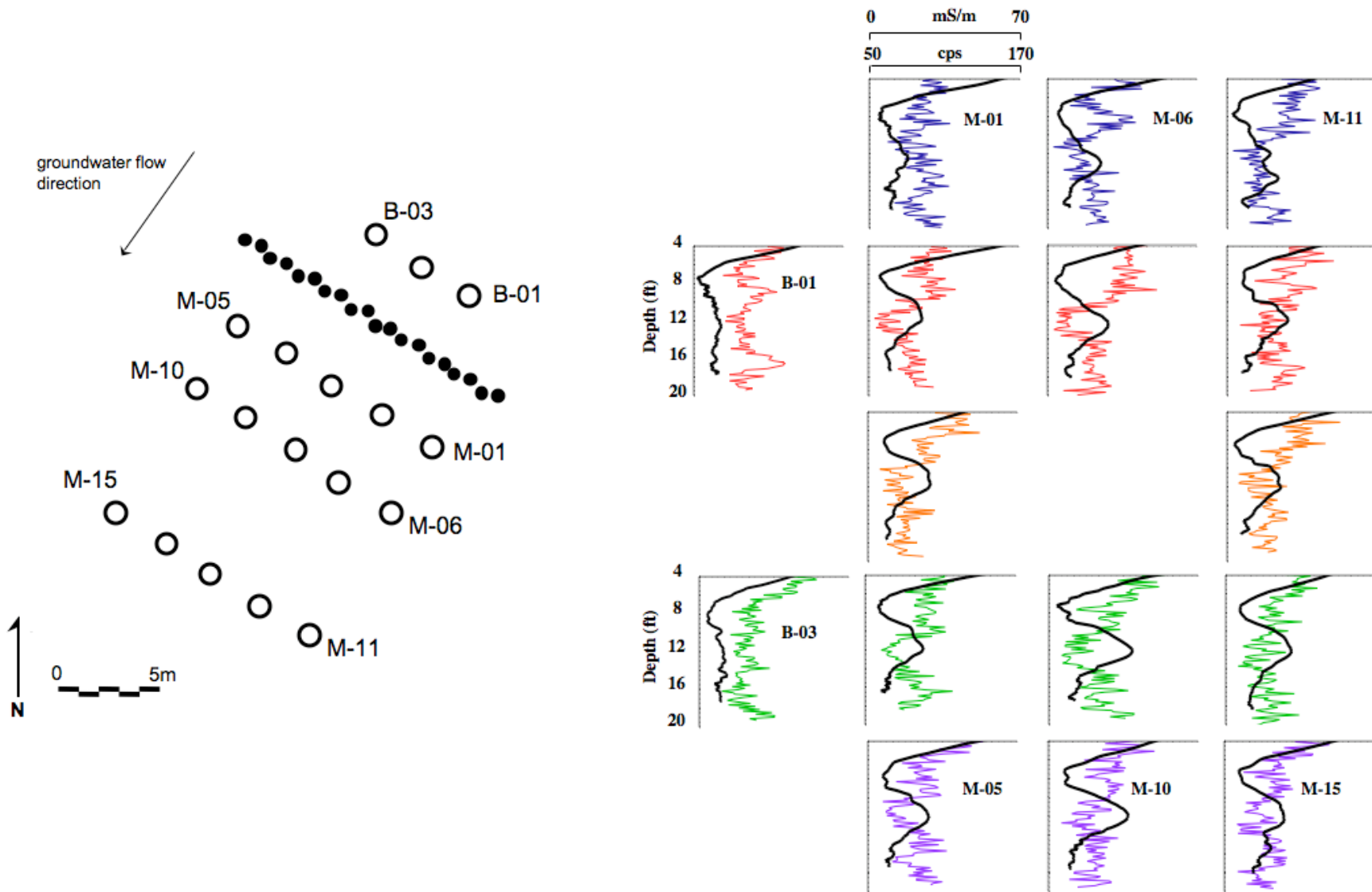
- The same reason the oil industry does...
 - Define structure
 - Highlight production changes



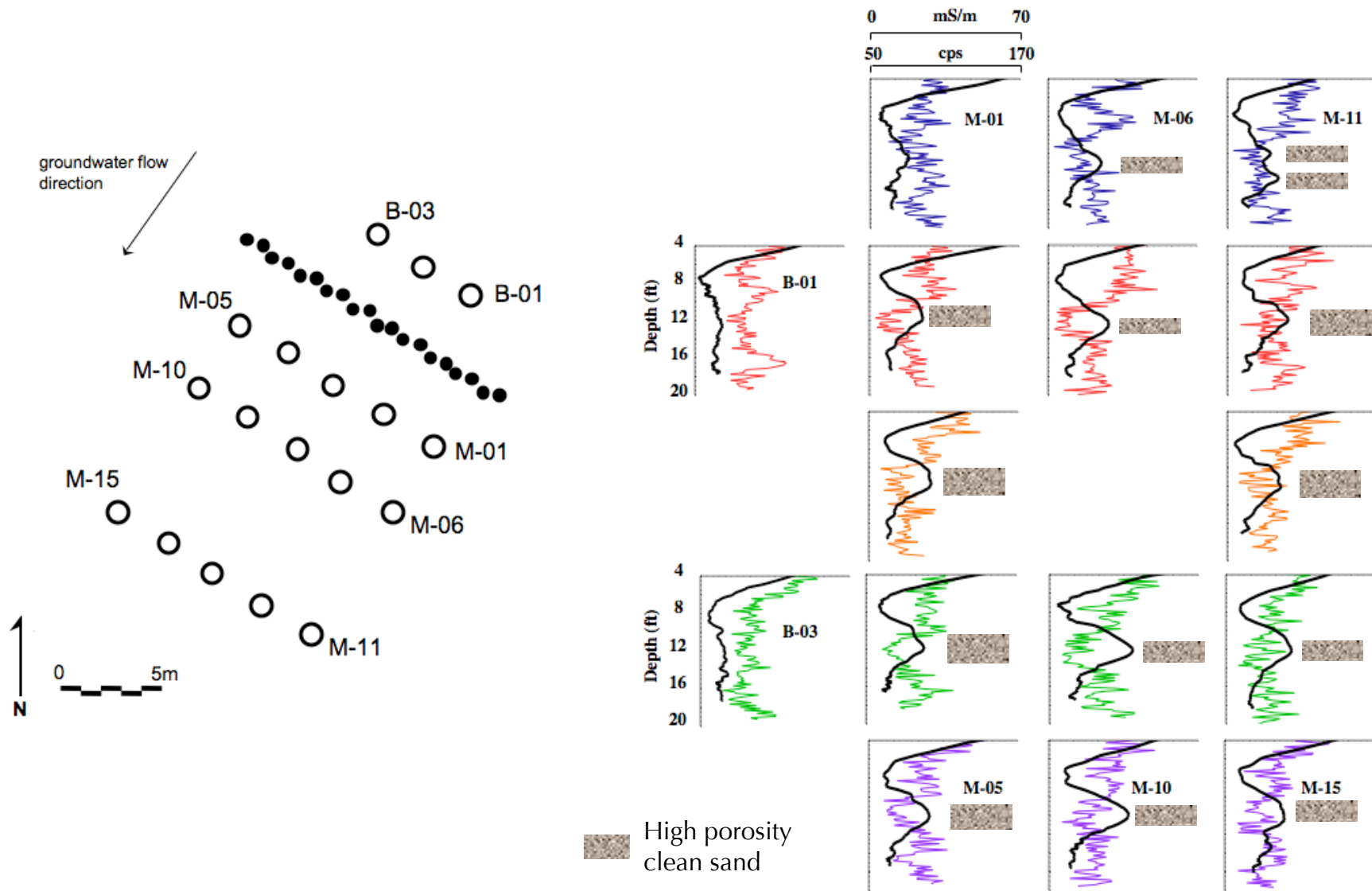
Characterization...



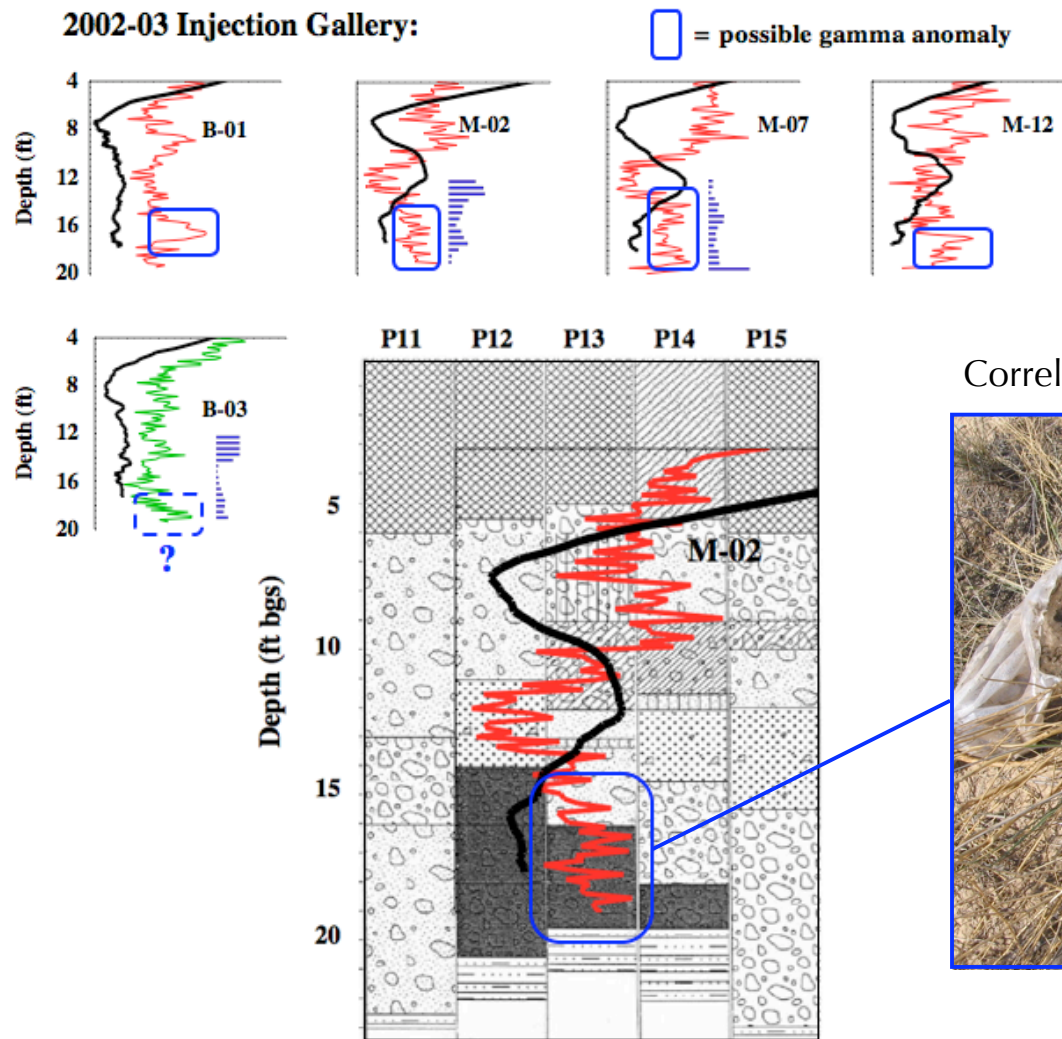
Assessing Vertical Heterogeneity: *Borehole logging*



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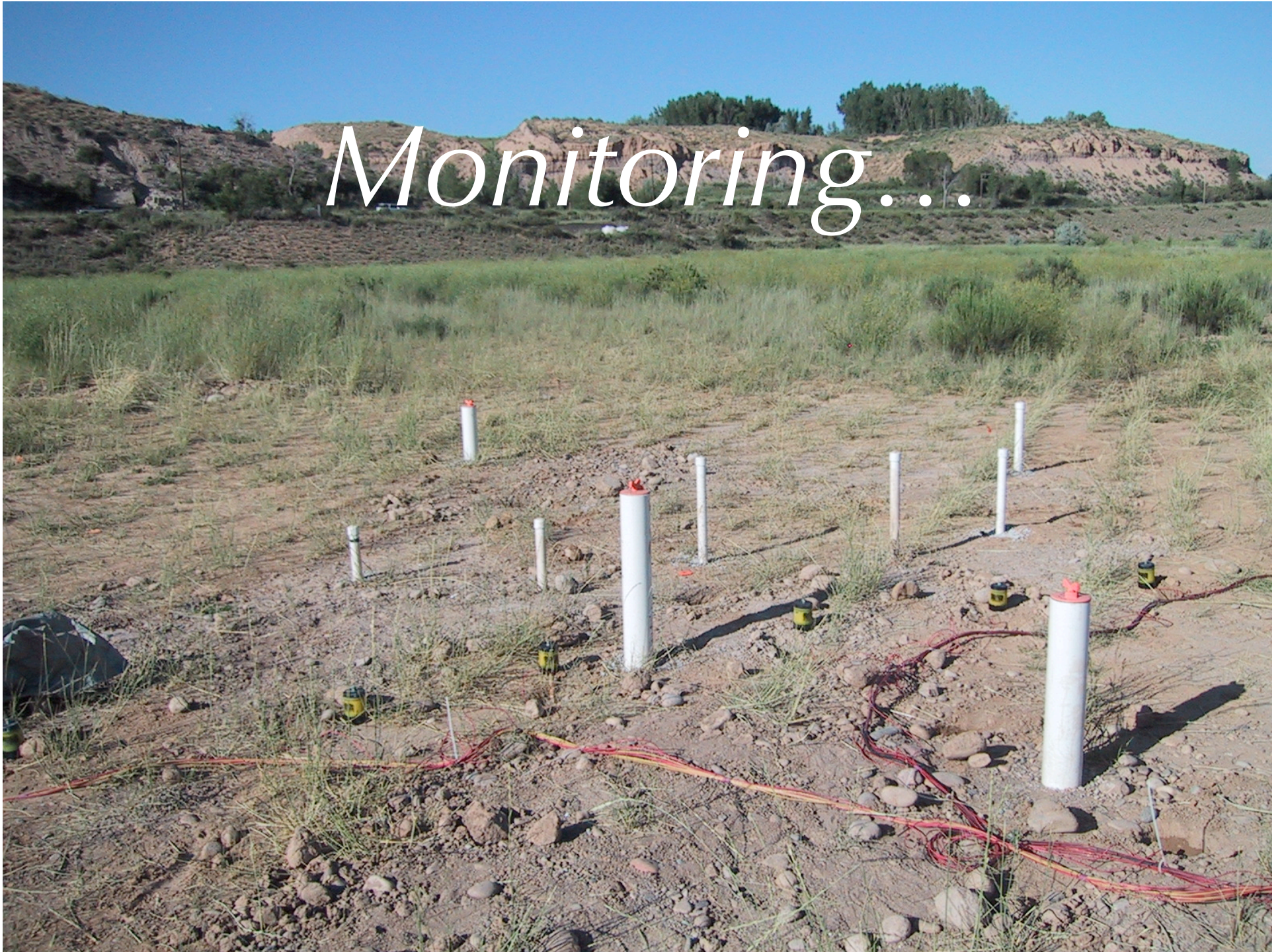


Correlate response with recovered materials

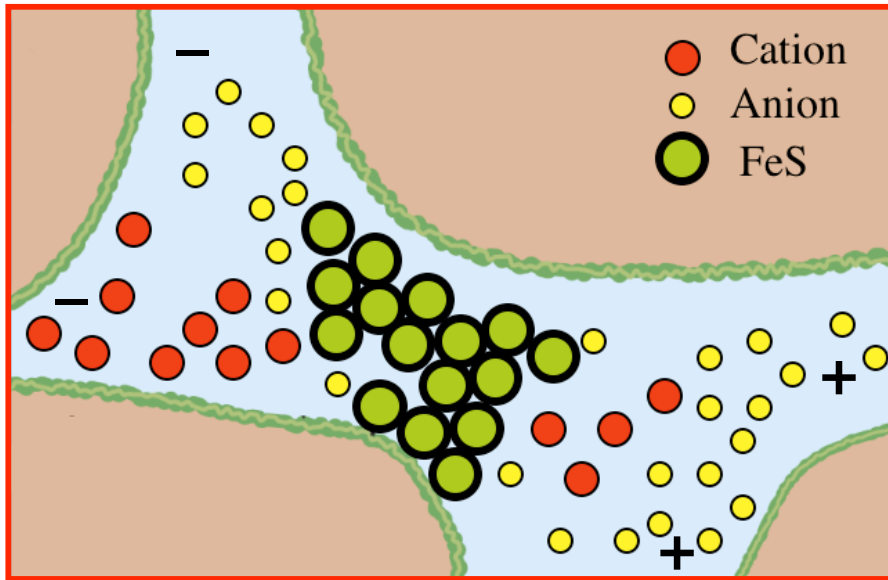


Modified from Vrionis *et al.*, 2005

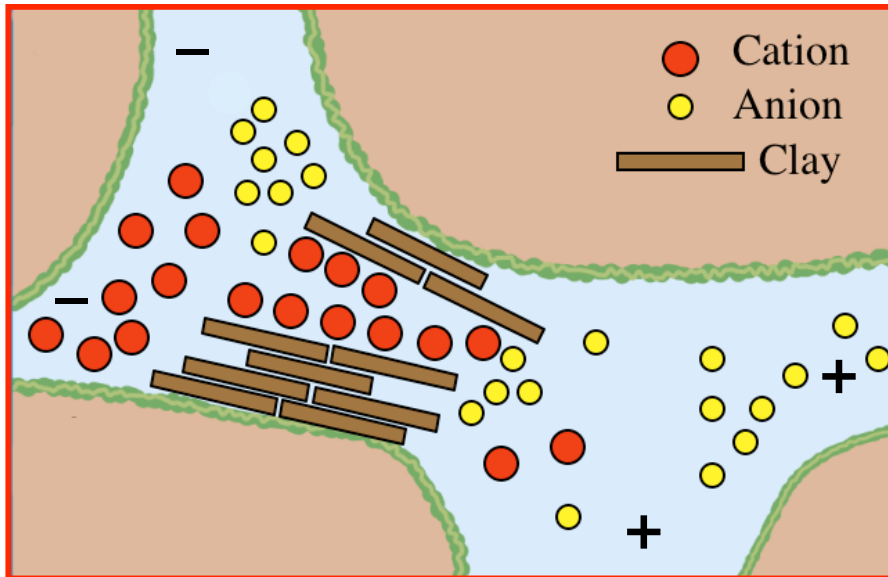
Monitoring...



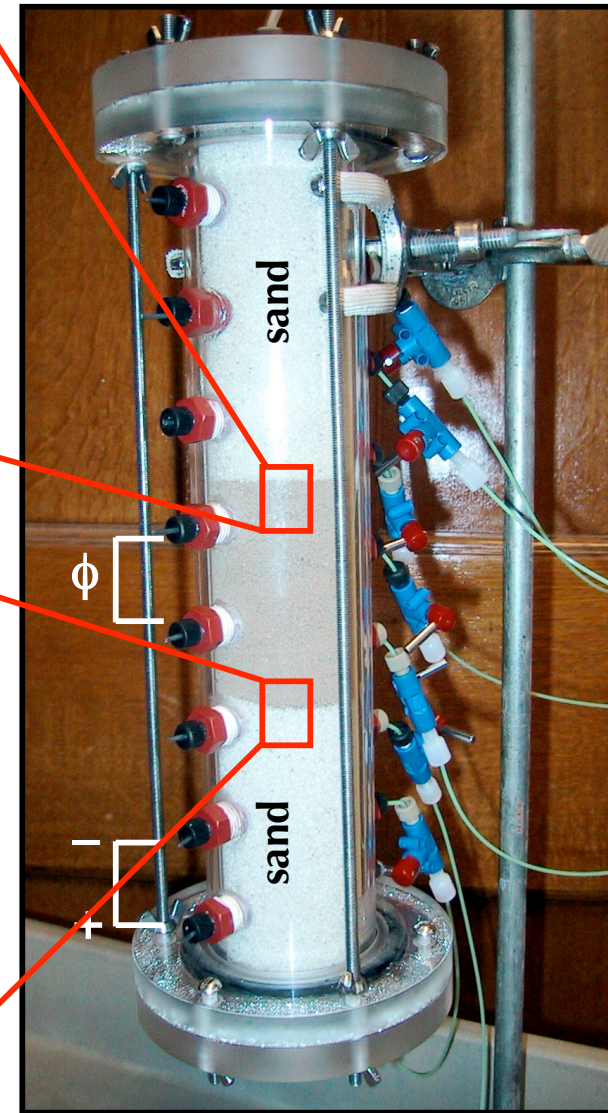
Sulfides: electro-active + surface charge



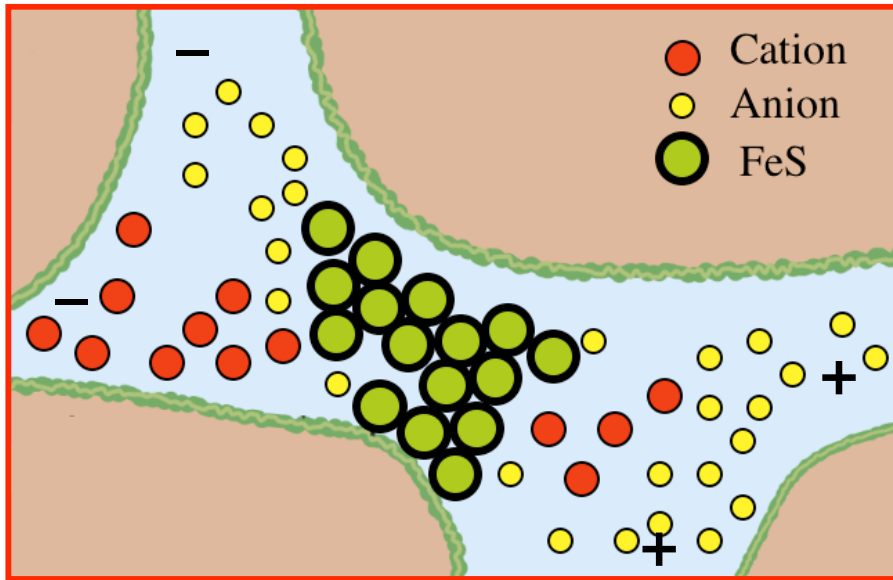
Clays: EDL ions impede electrolytic flow



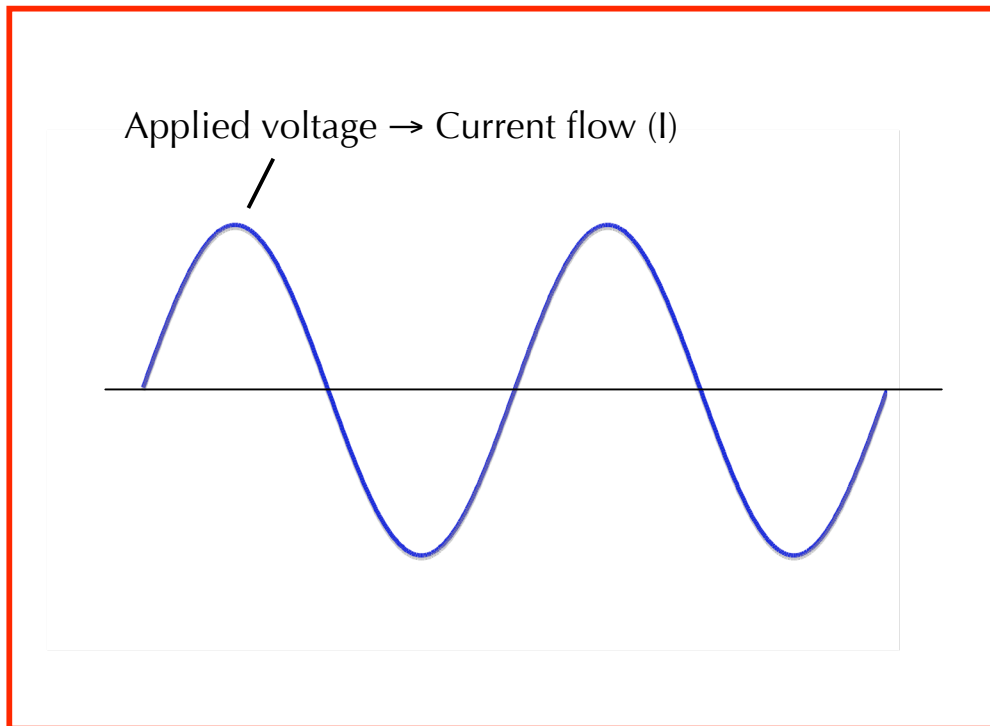
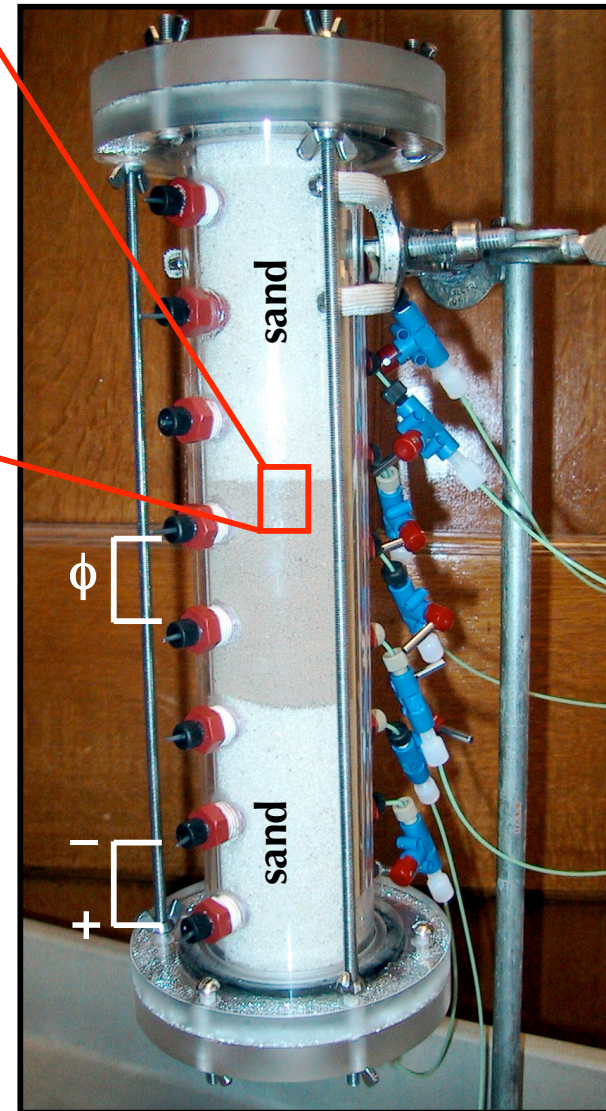
Complex Resistivity (CR)



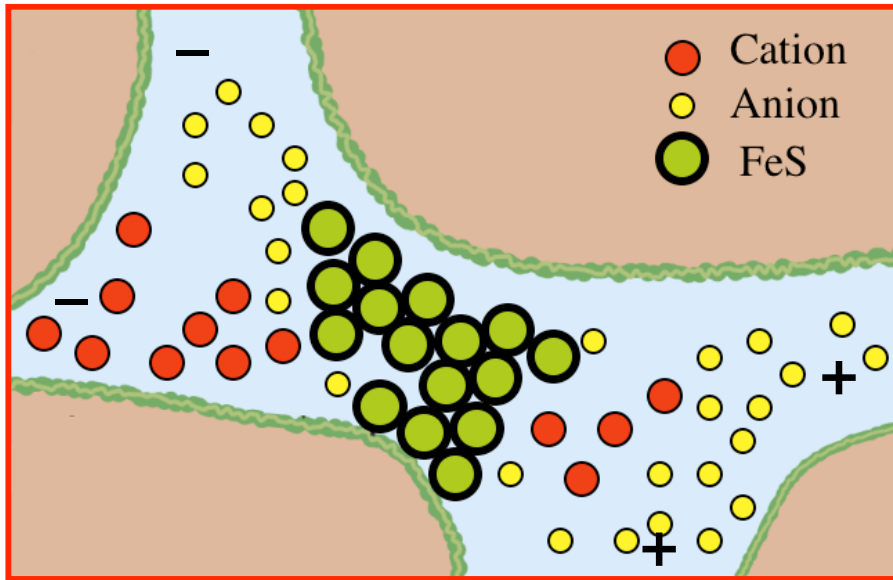
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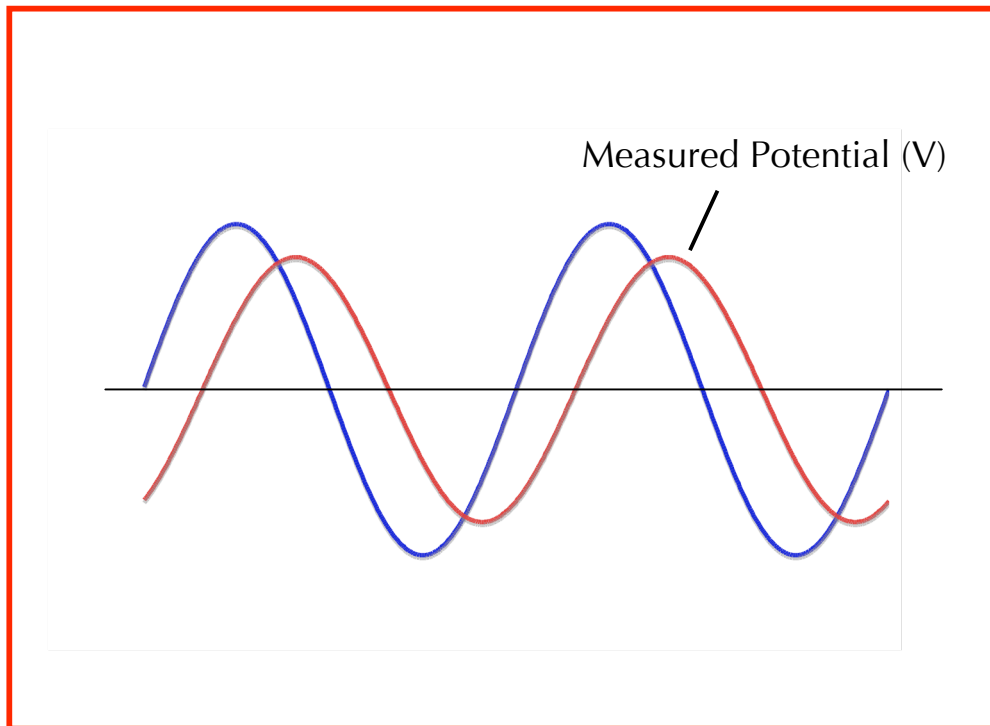
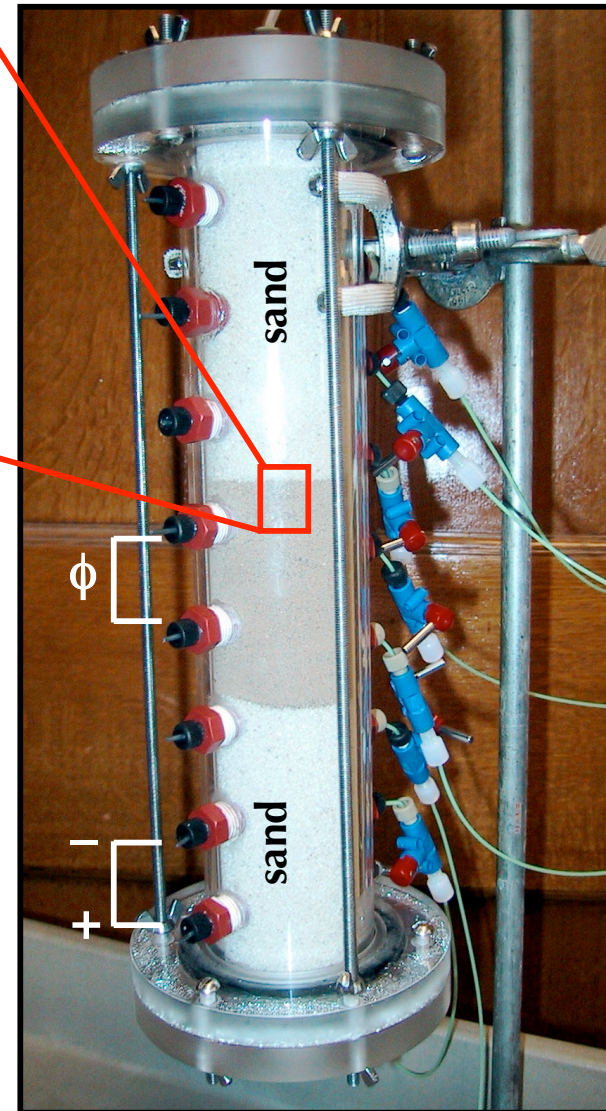
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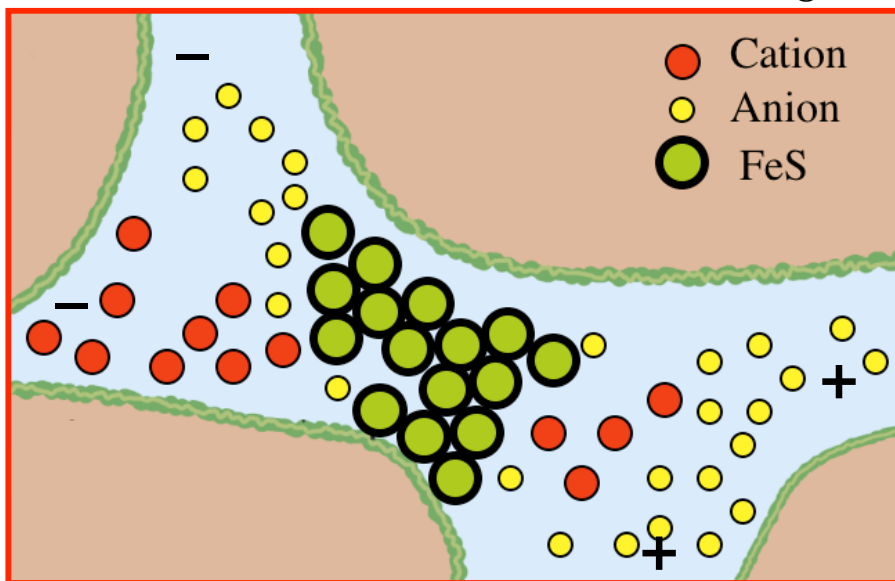
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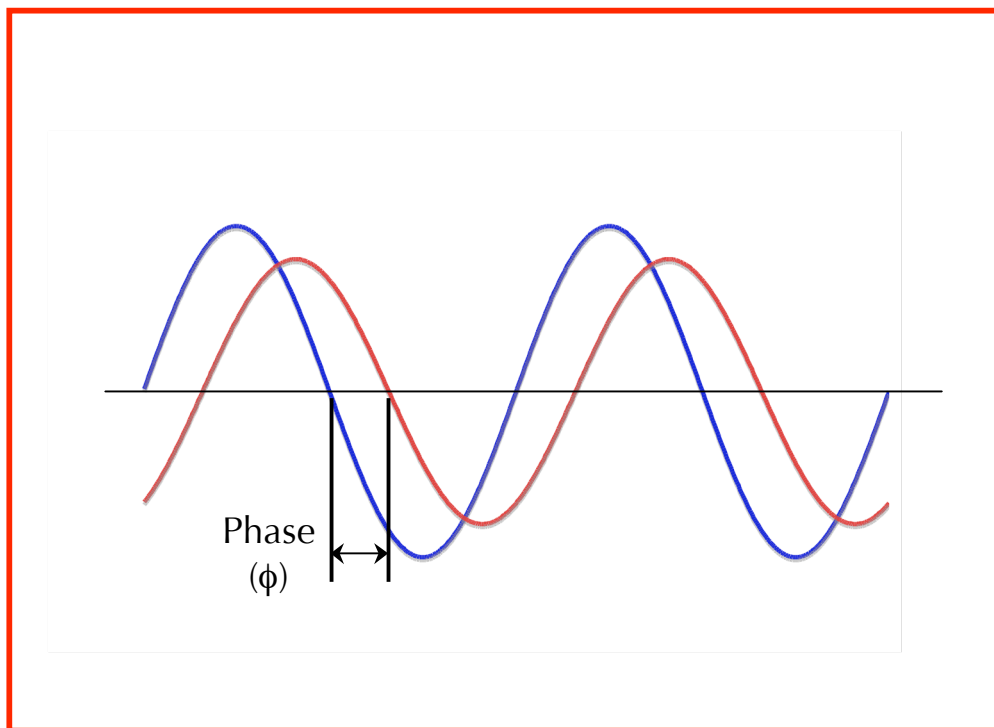
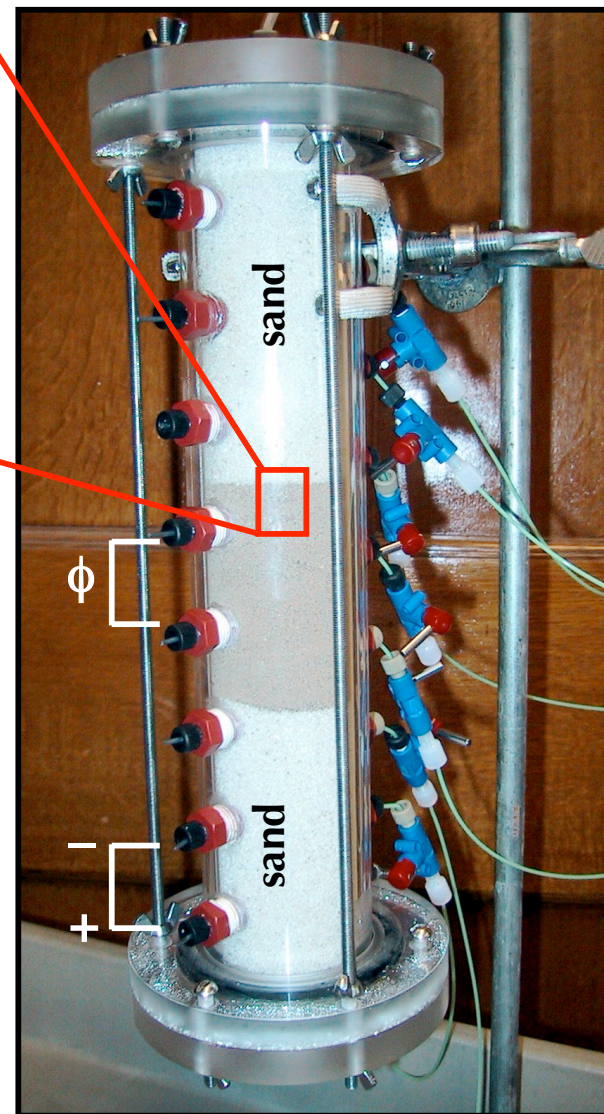
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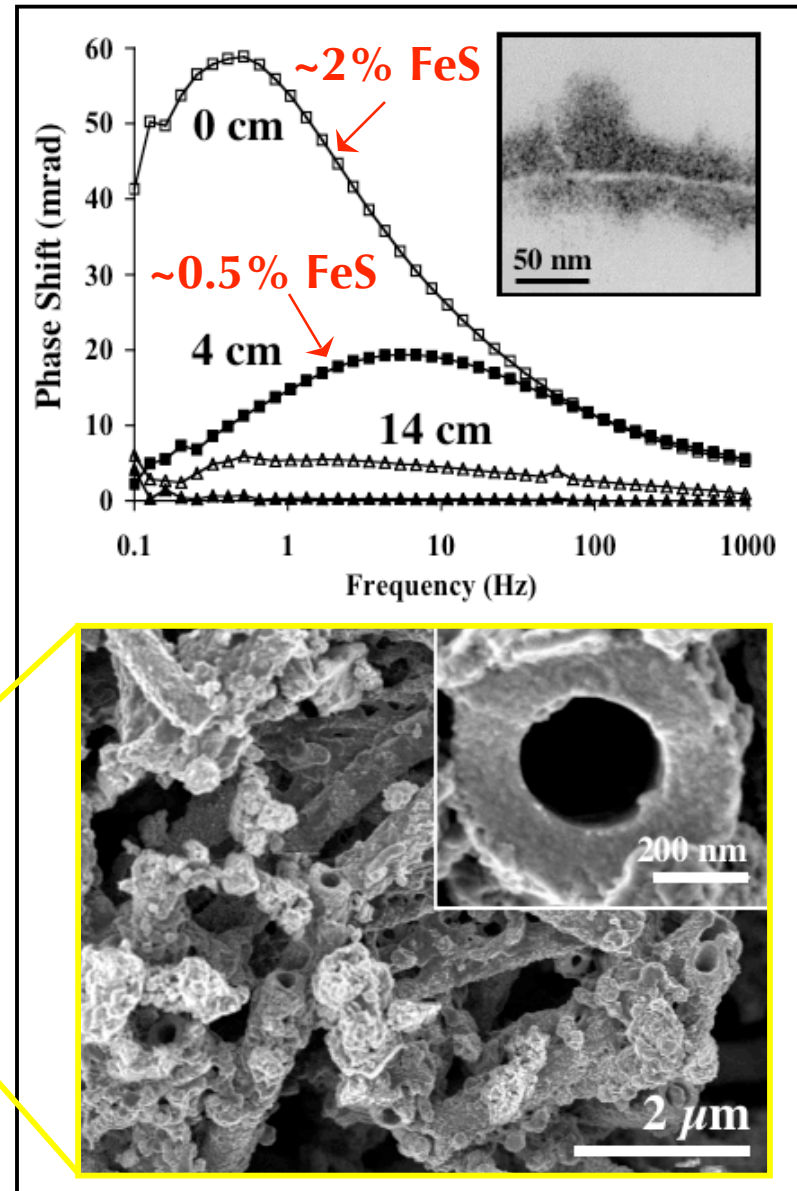
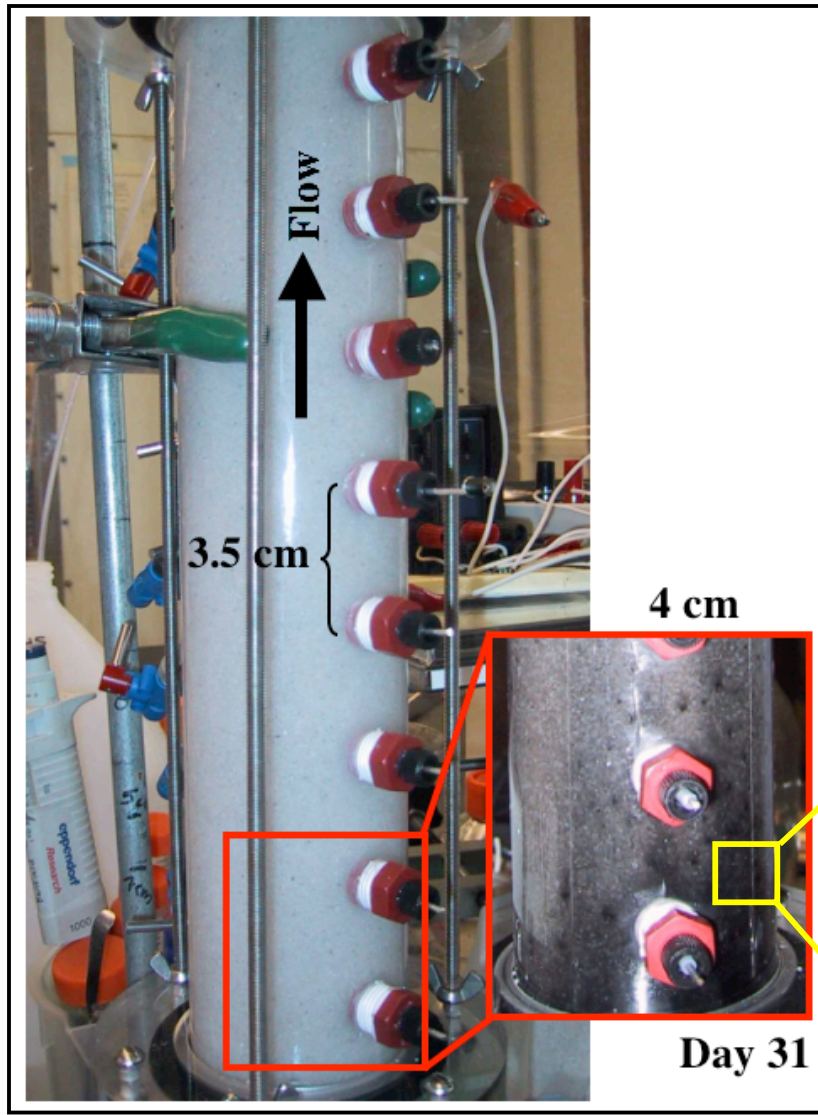
Sulfides: electro-active + surface charge



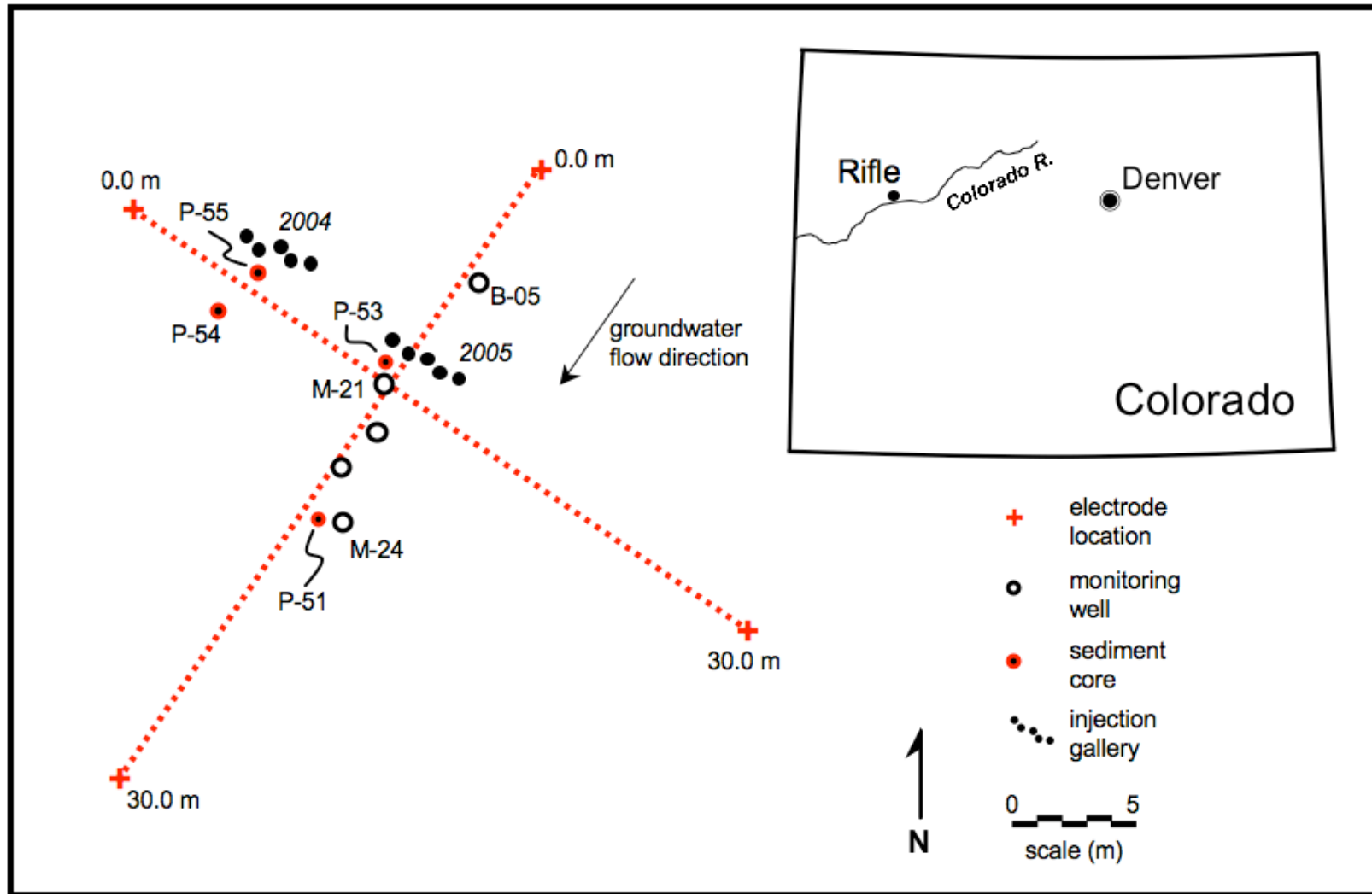
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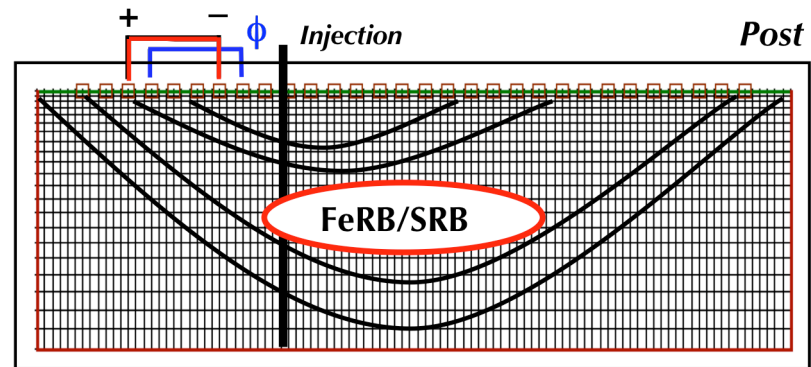
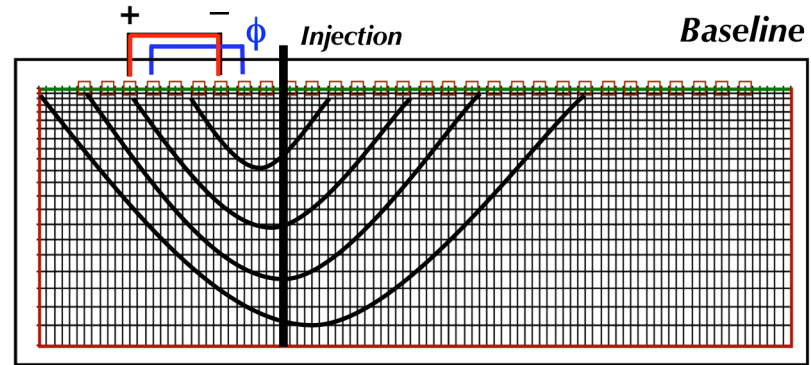
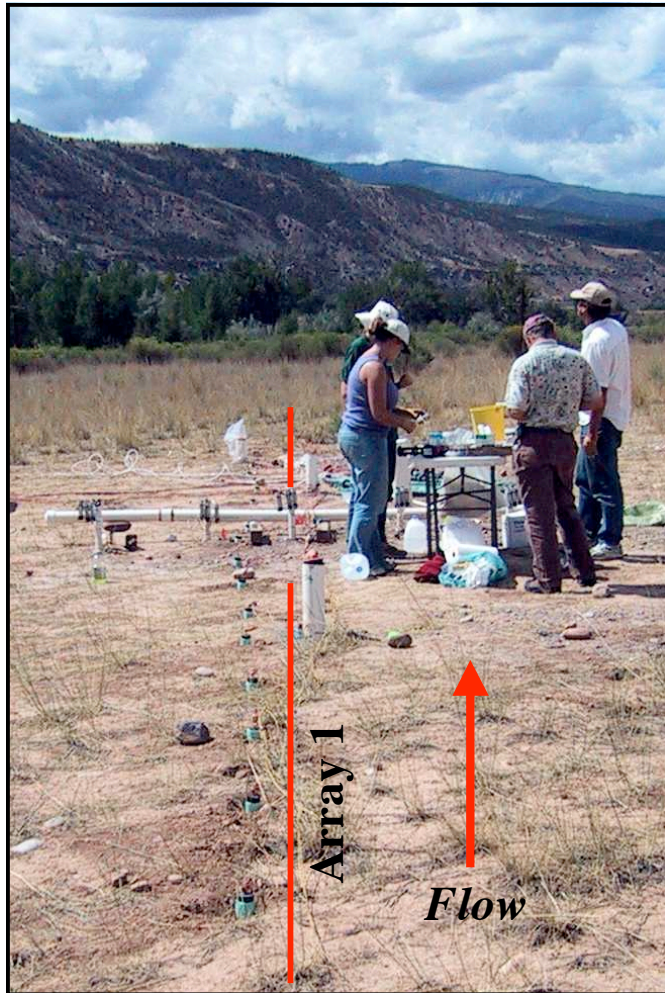
Impact of FeS Precipitation on CR Signals



'Field-Scale' CR Monitoring at Old Rifle, CO

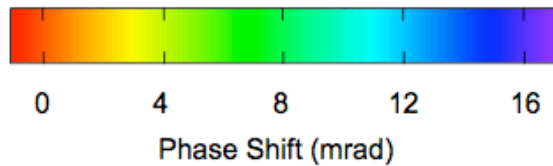
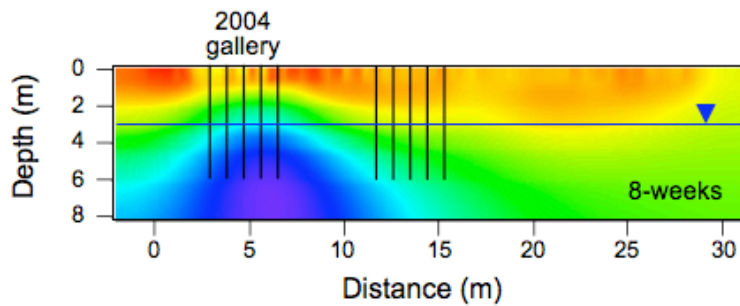
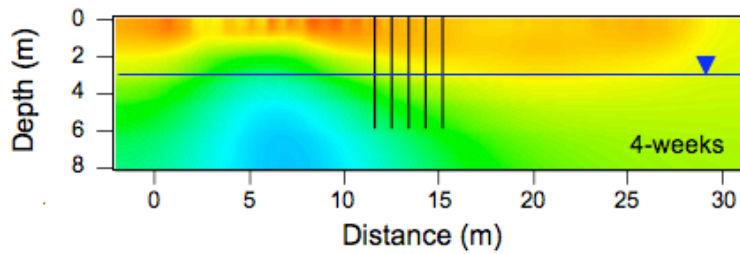
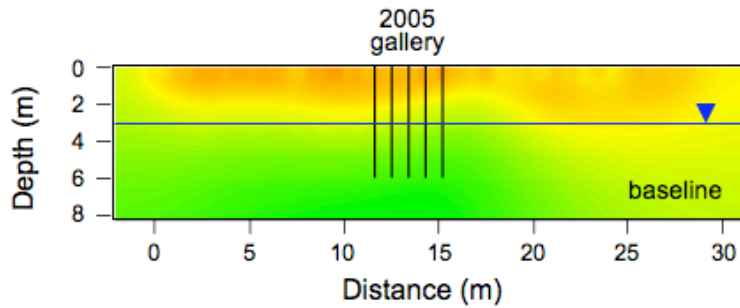


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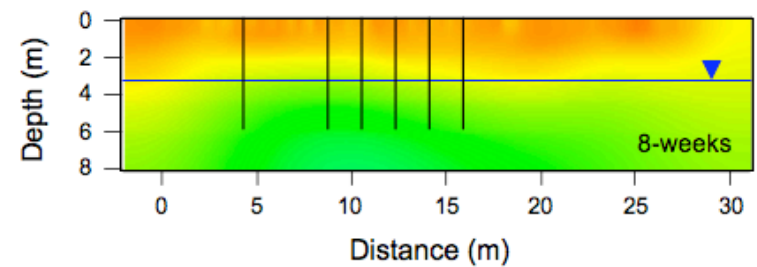
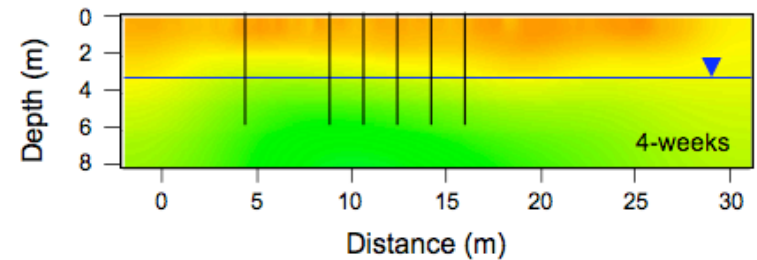
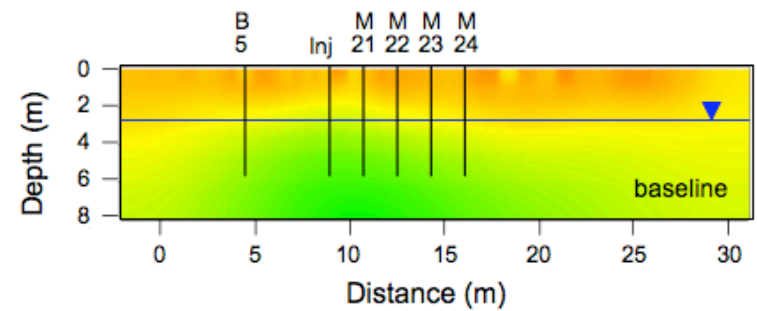


Surface CR Results: *Identical Phase Scale*

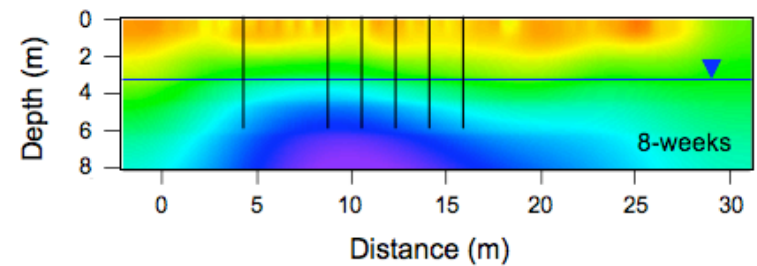
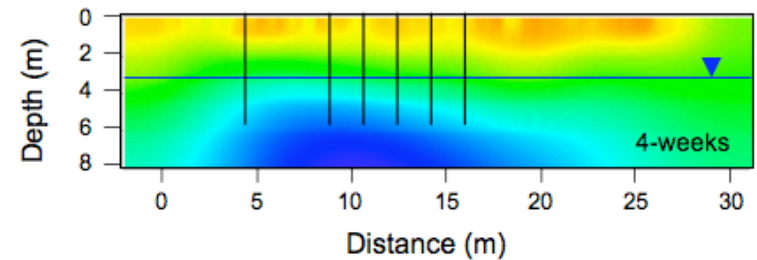
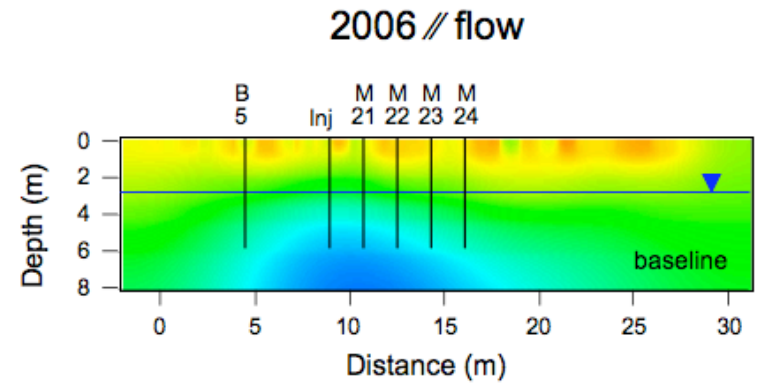
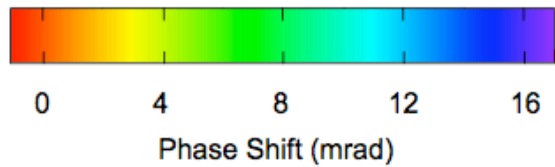
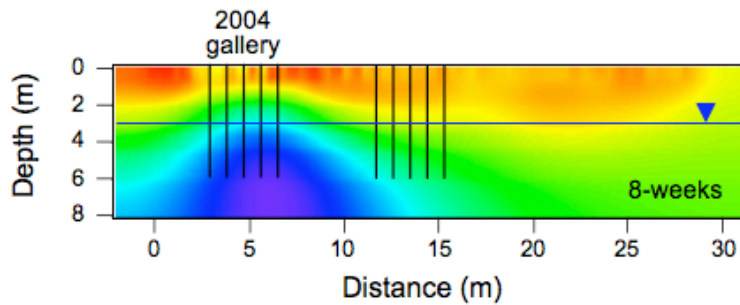
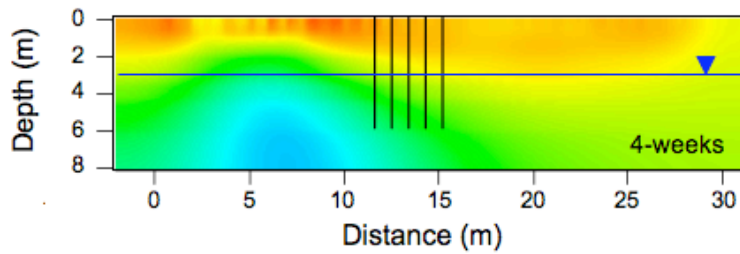
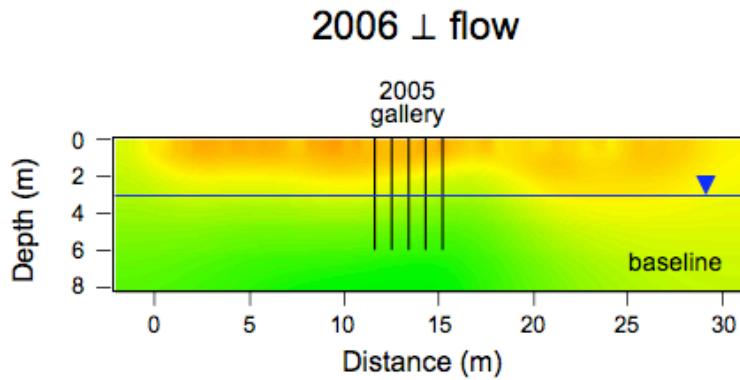
2006 \perp flow



2006 // flow

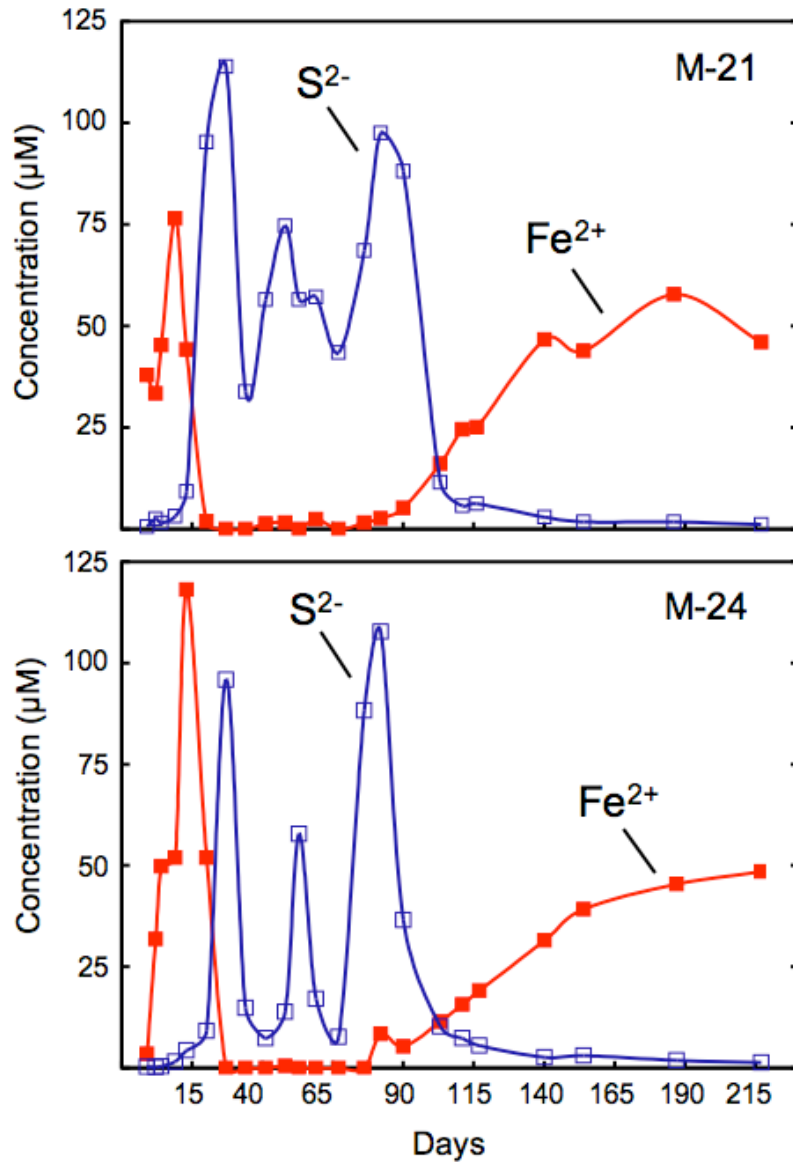


Surface CR Results: *Expanded Phase Scale*

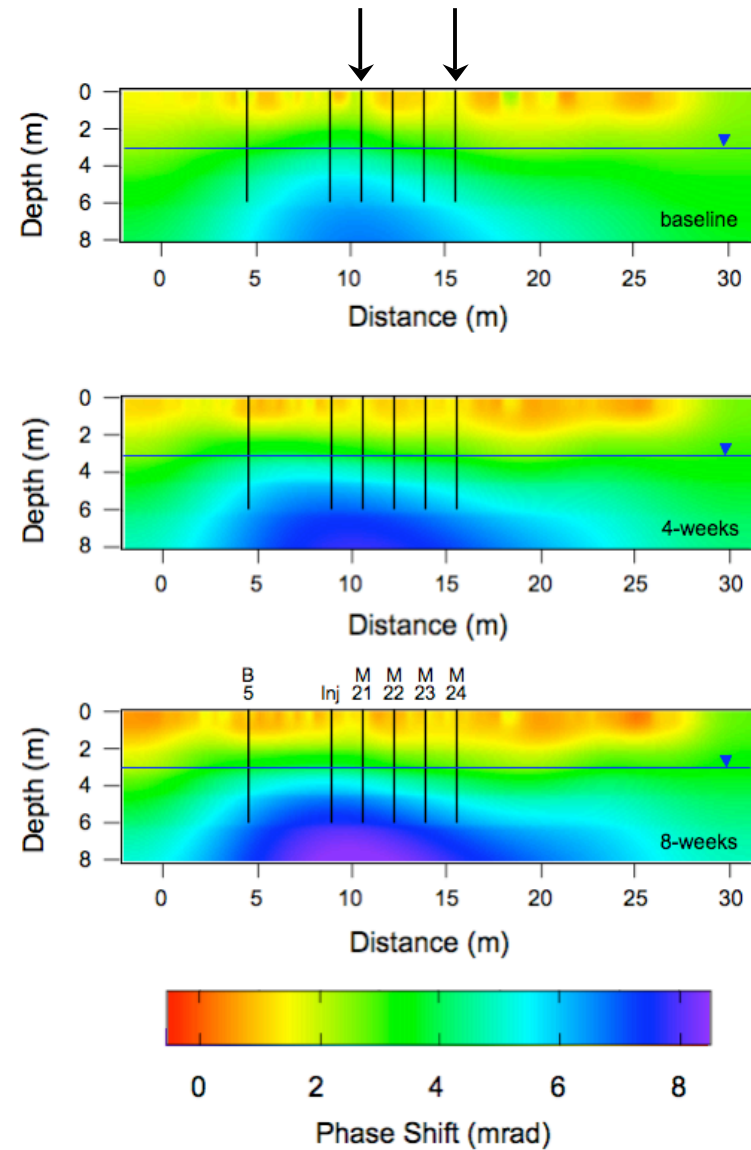


Constraining CR Results: *Geochemistry*

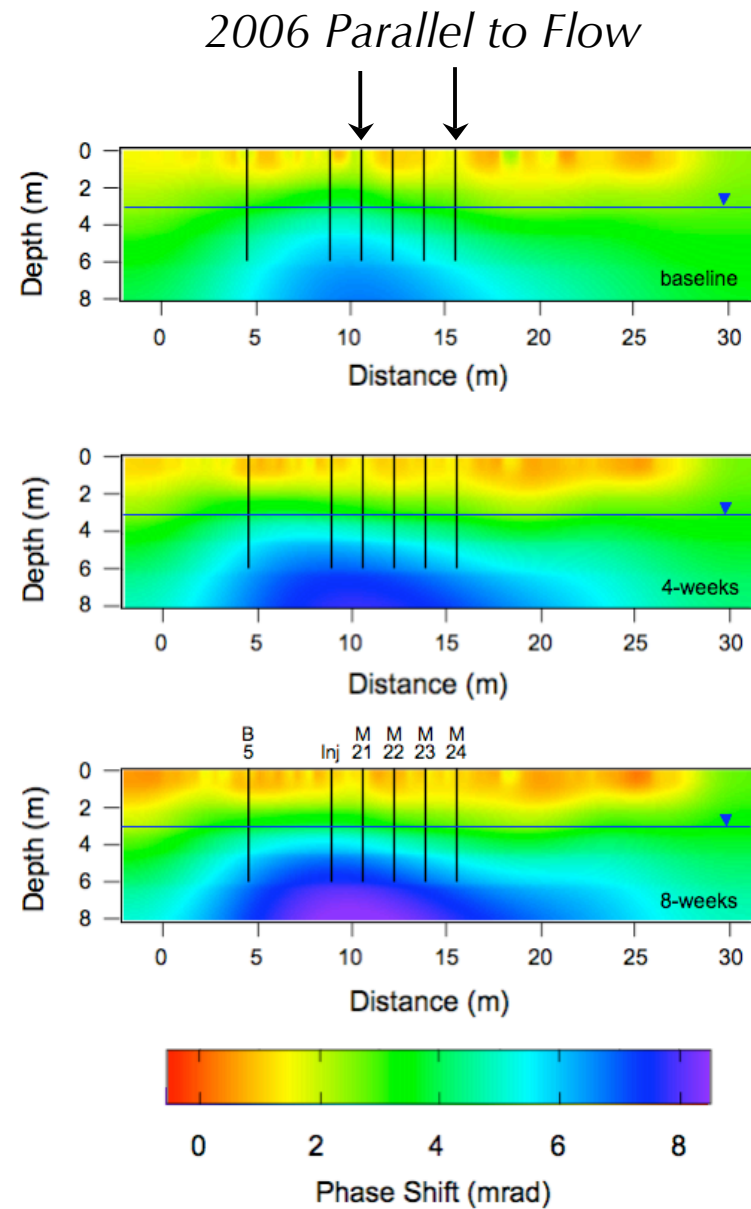
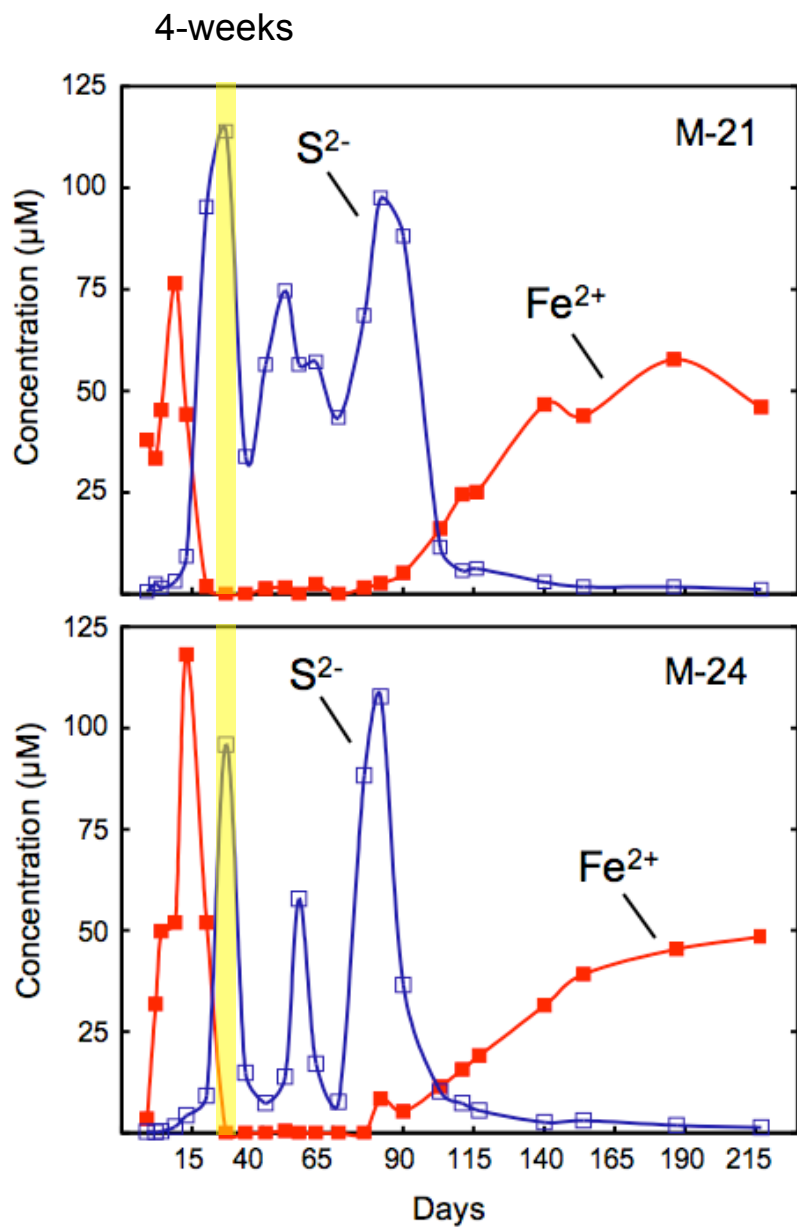
Fe²⁺ and HS⁻ vs. Time



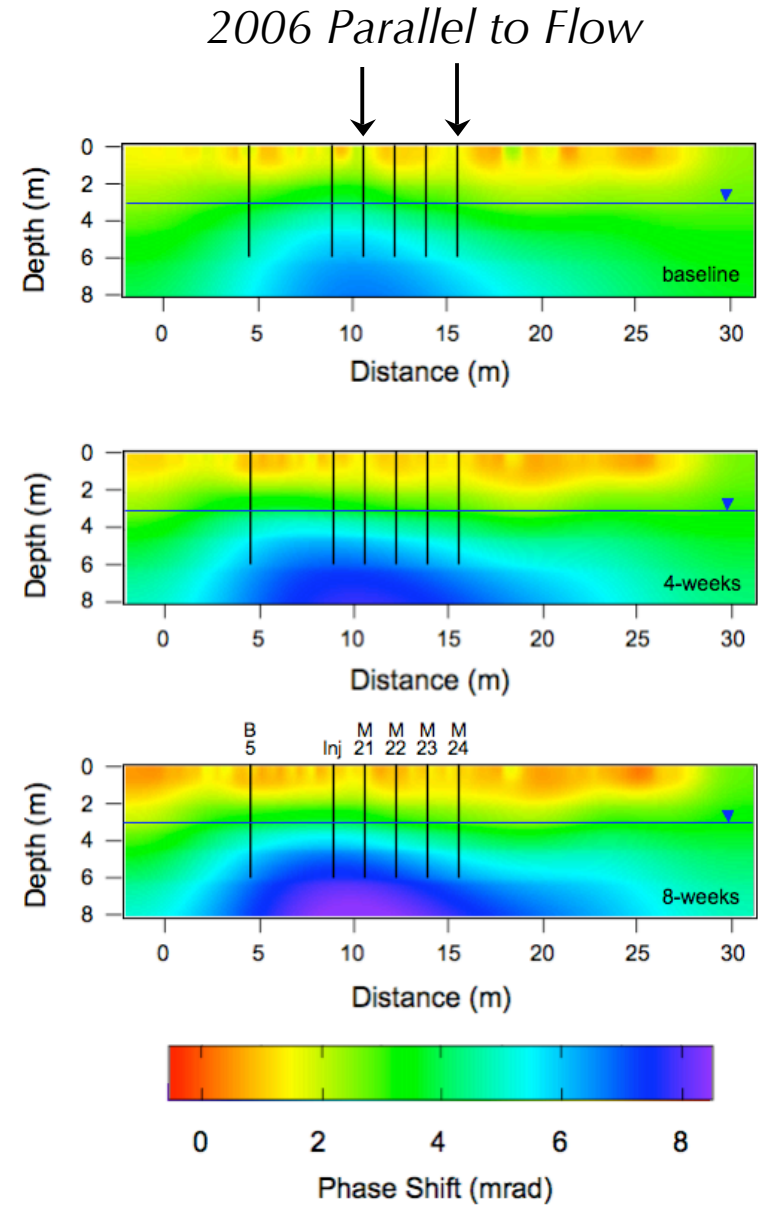
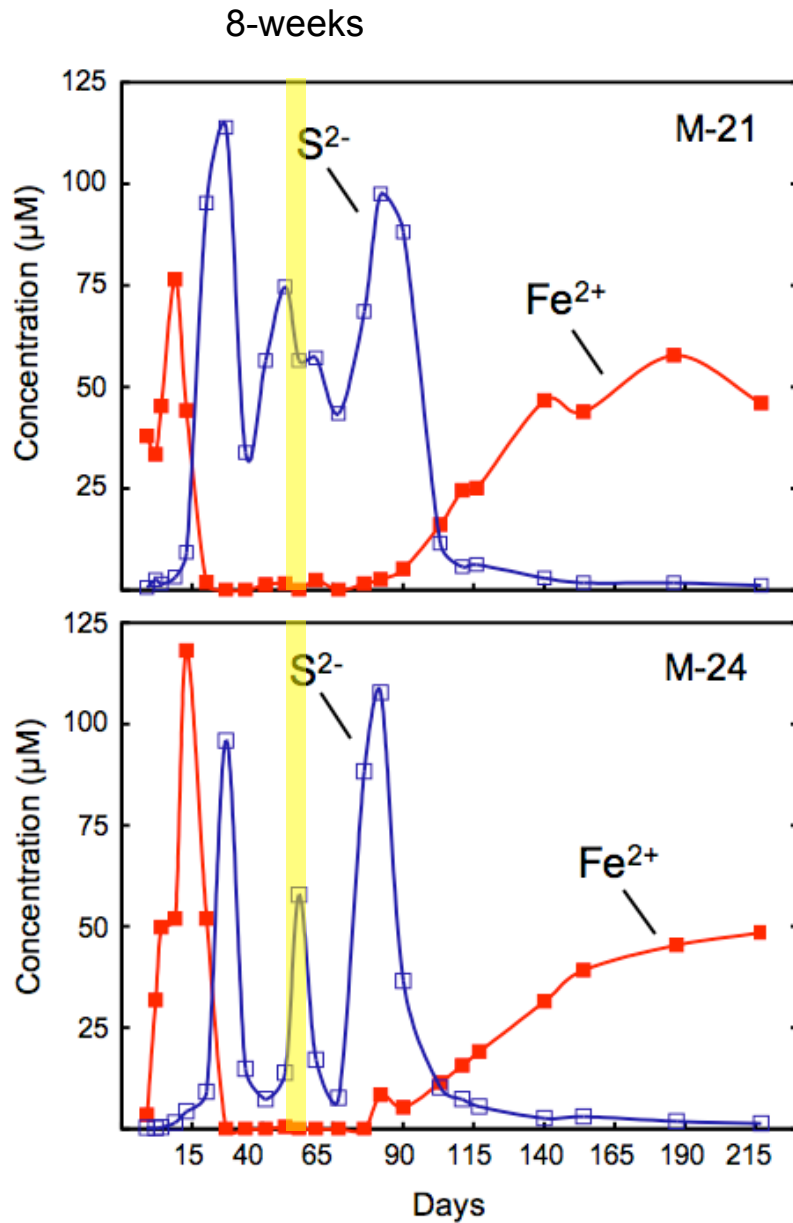
2006 Parallel to Flow



Constraining CR Results: *Geochemistry*

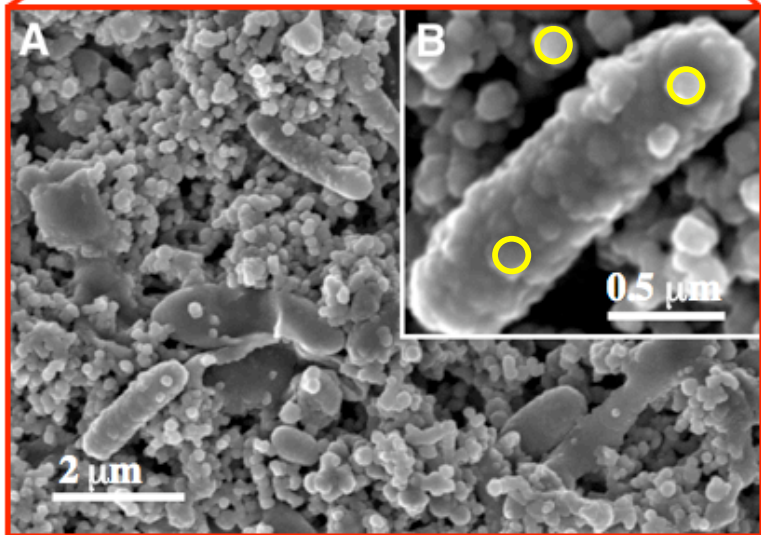
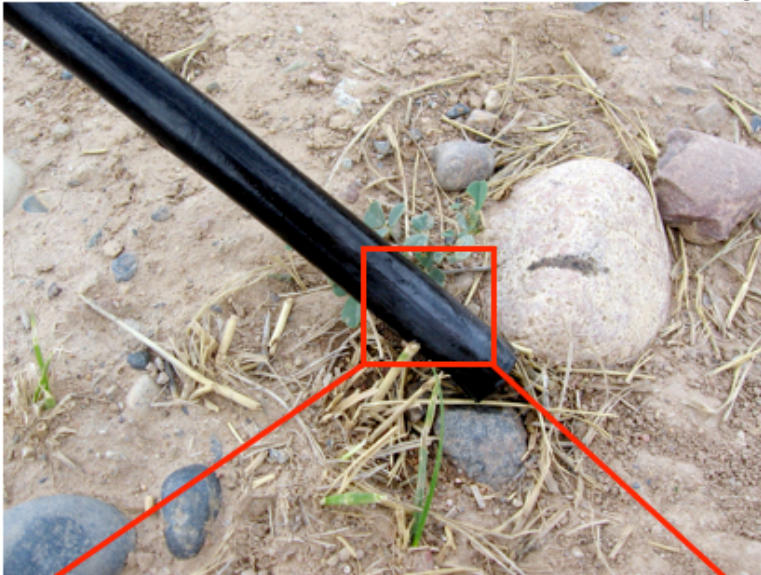


Constraining CR Results: *Geochemistry*

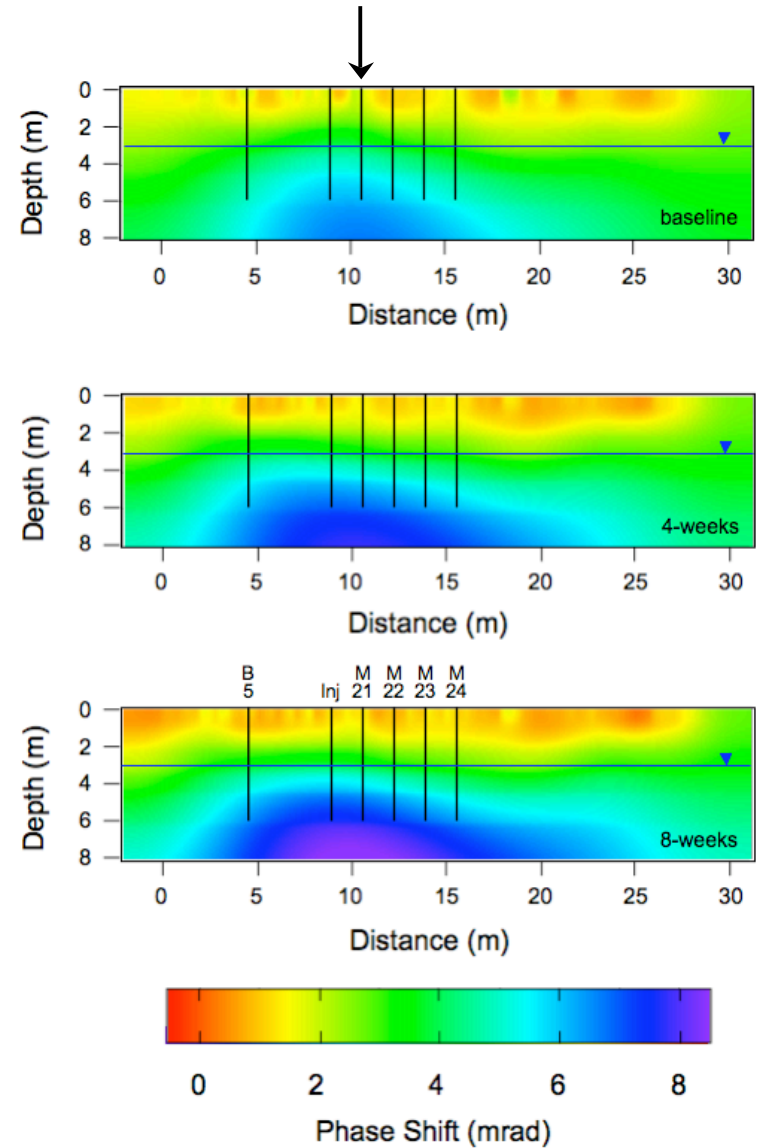


Constraining CR Results: *Geomicrobiology*

M-21: FeS-encrusted tubing

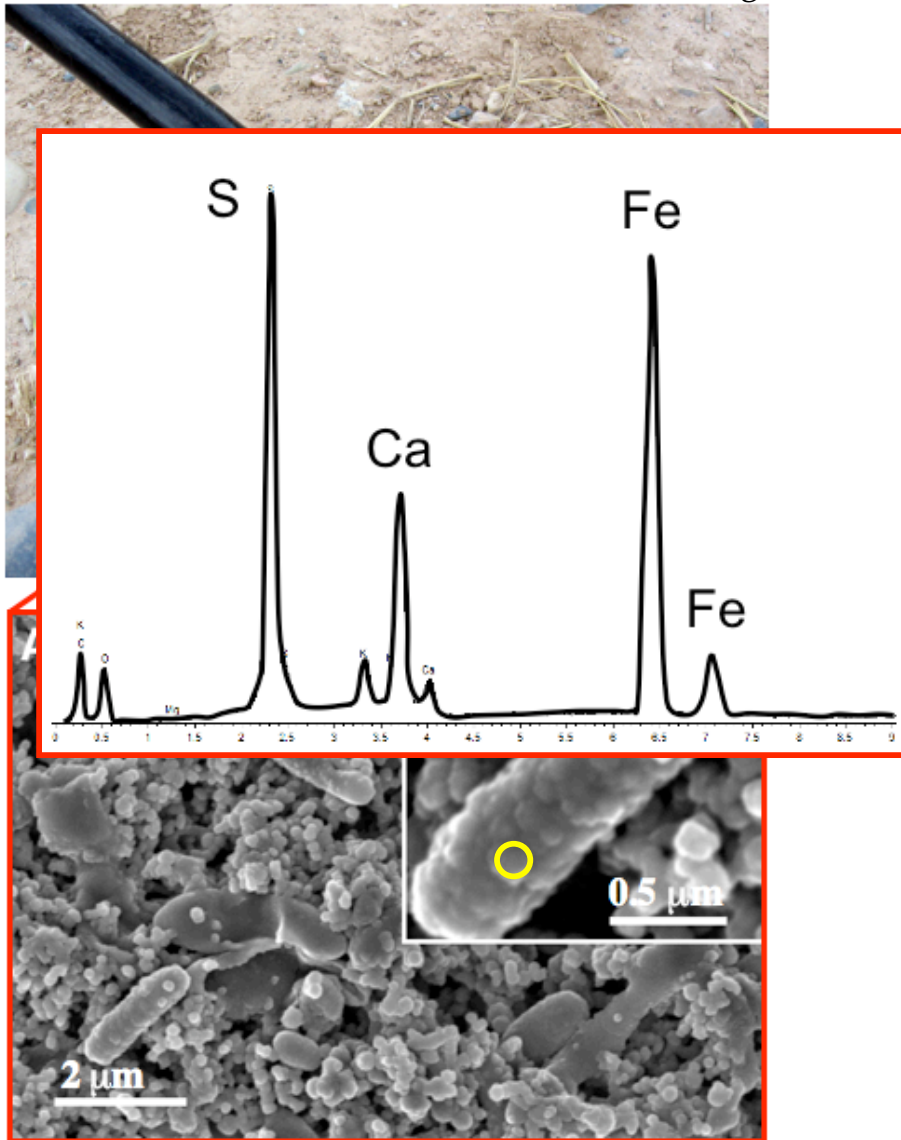


2006 Parallel to Flow

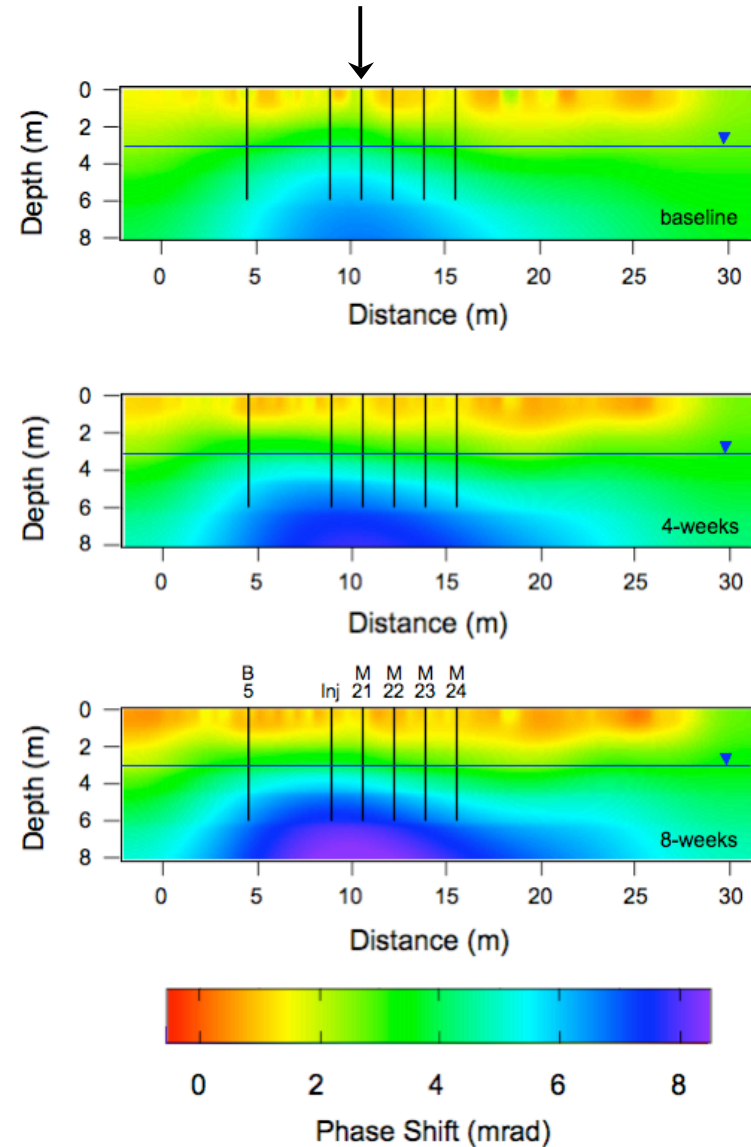


Constraining CR Results: *Geomicrobiology*

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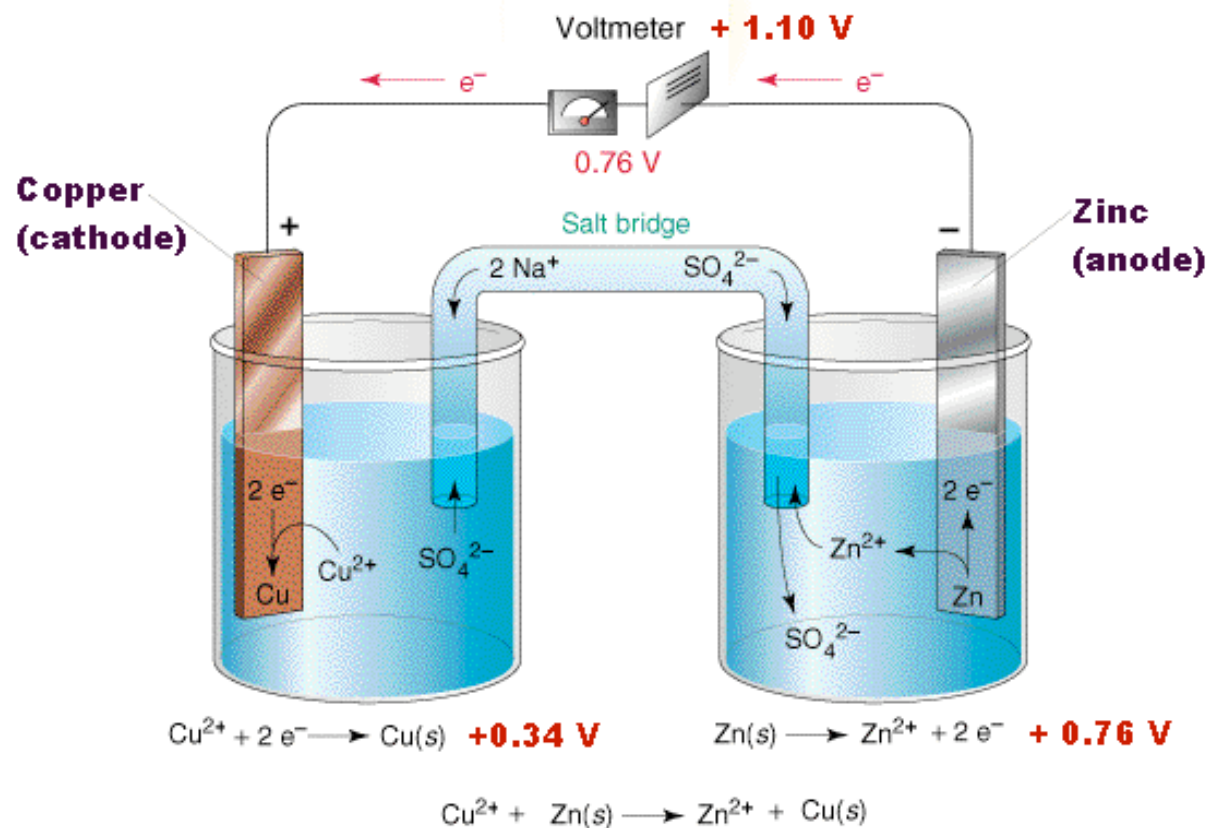


2006 Parallel to Flow

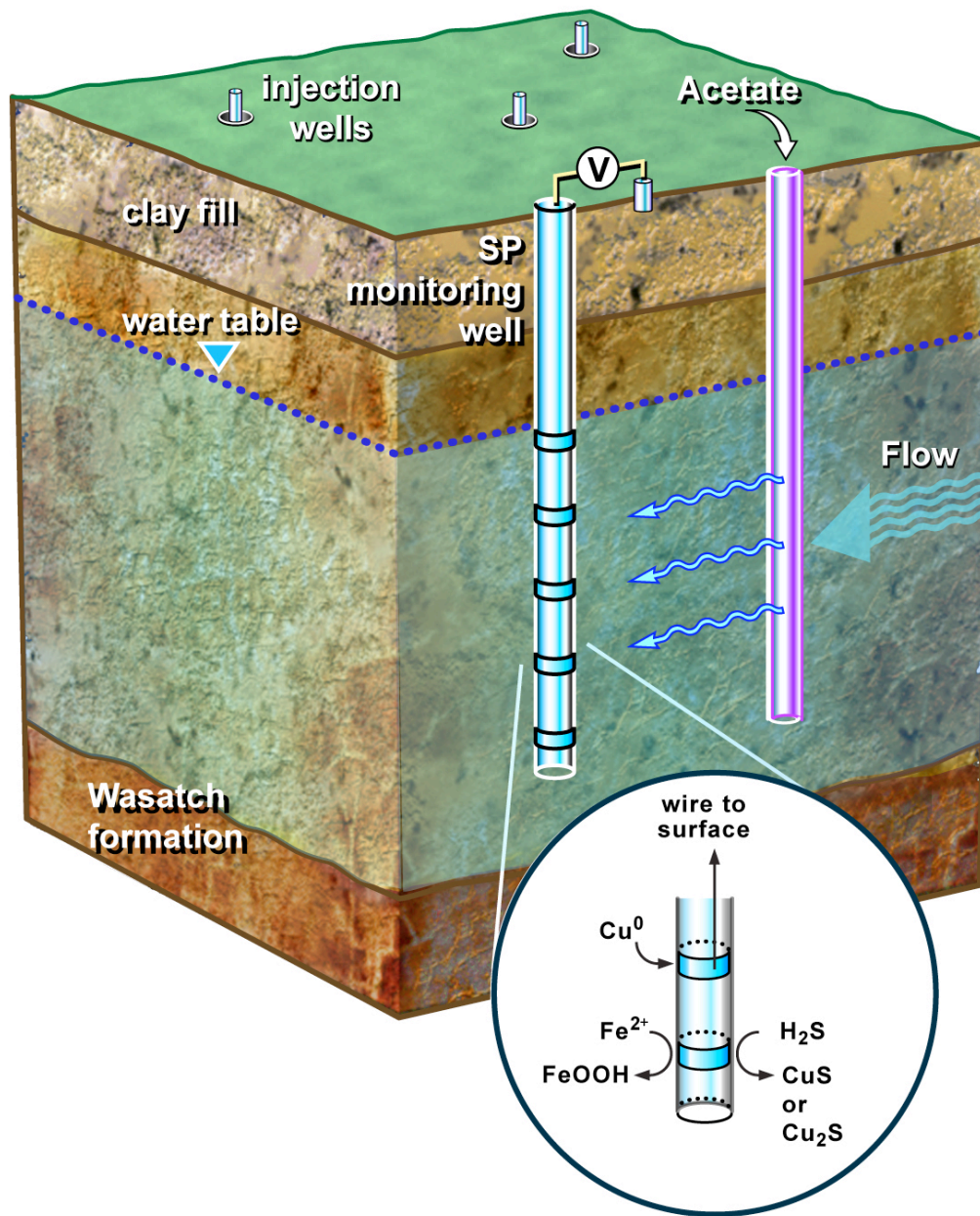


Self-Potential Monitoring

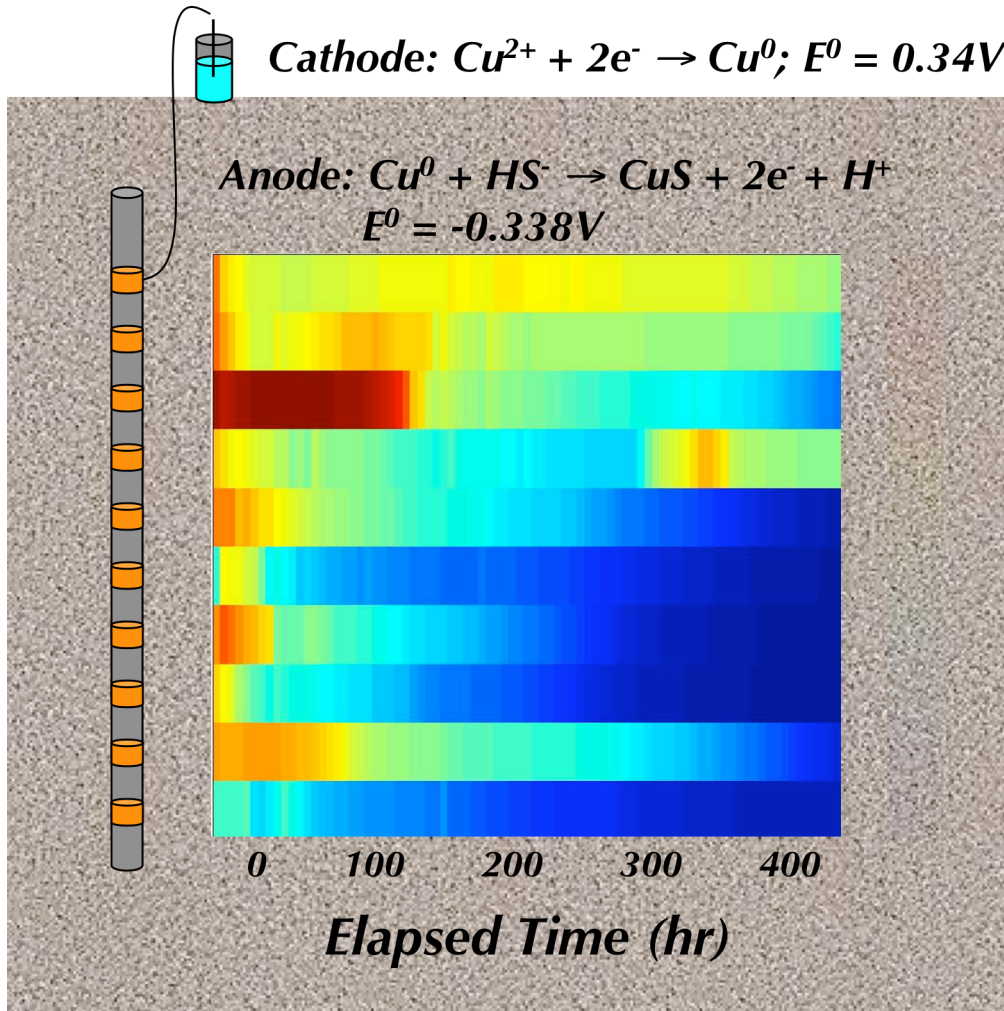
Self-Potential (SP): The generation of voltage potentials within earth materials, which can be measured between electrodes located at the surface or within boreholes.



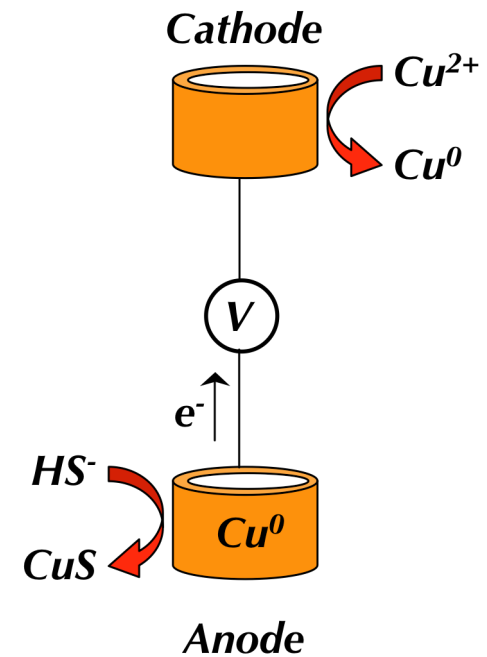
Borehole SP Monitoring: *Conceptual Model*



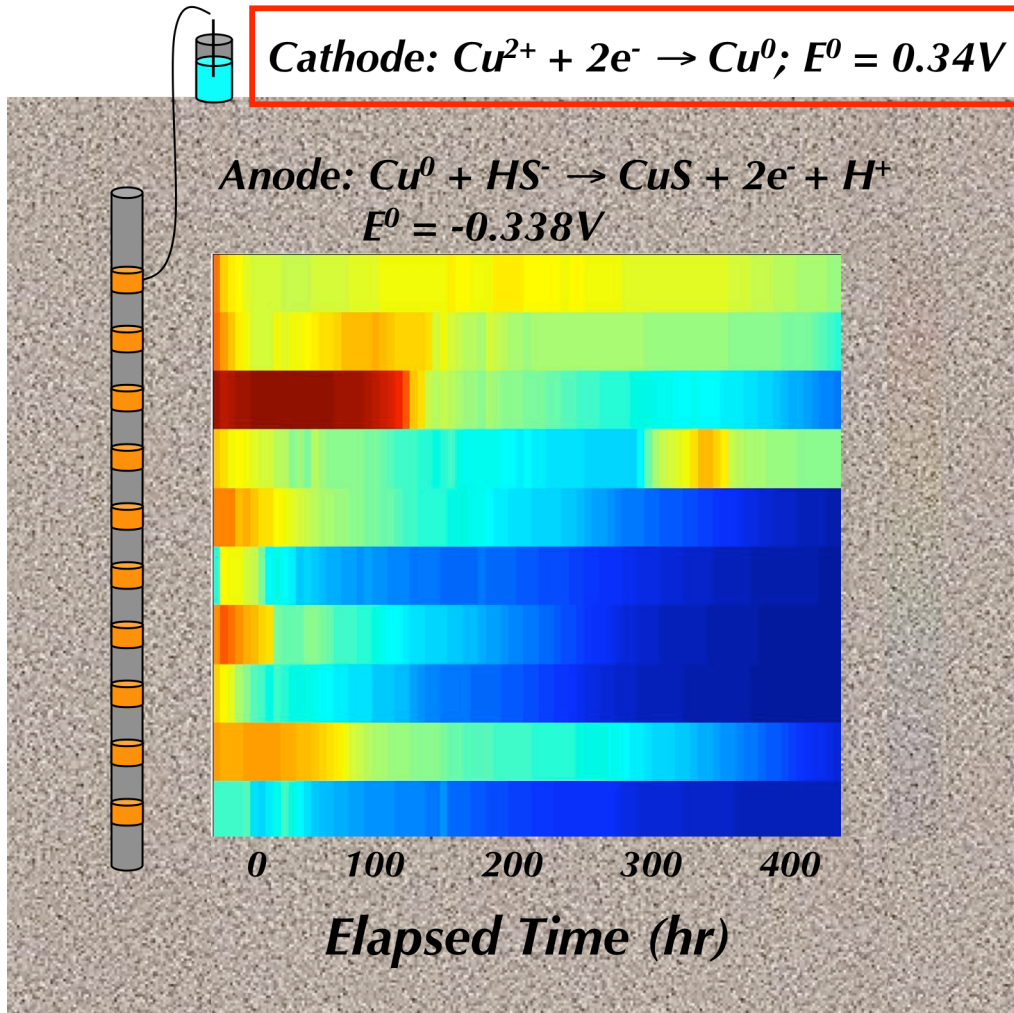
Borehole SP Monitoring: *Conceptual Model*



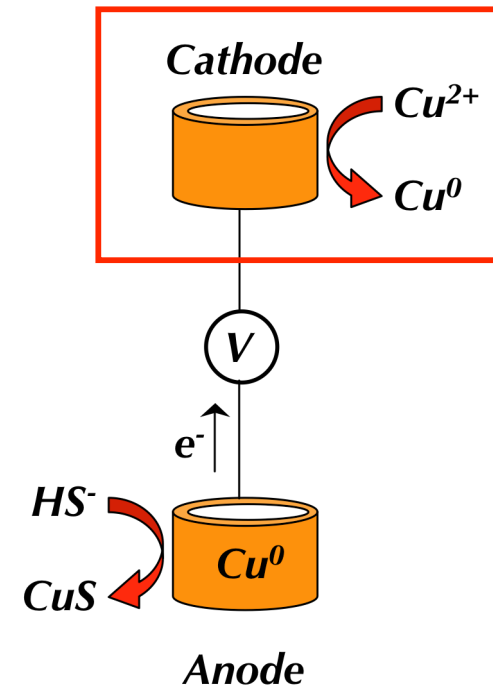
Galvanic Model:



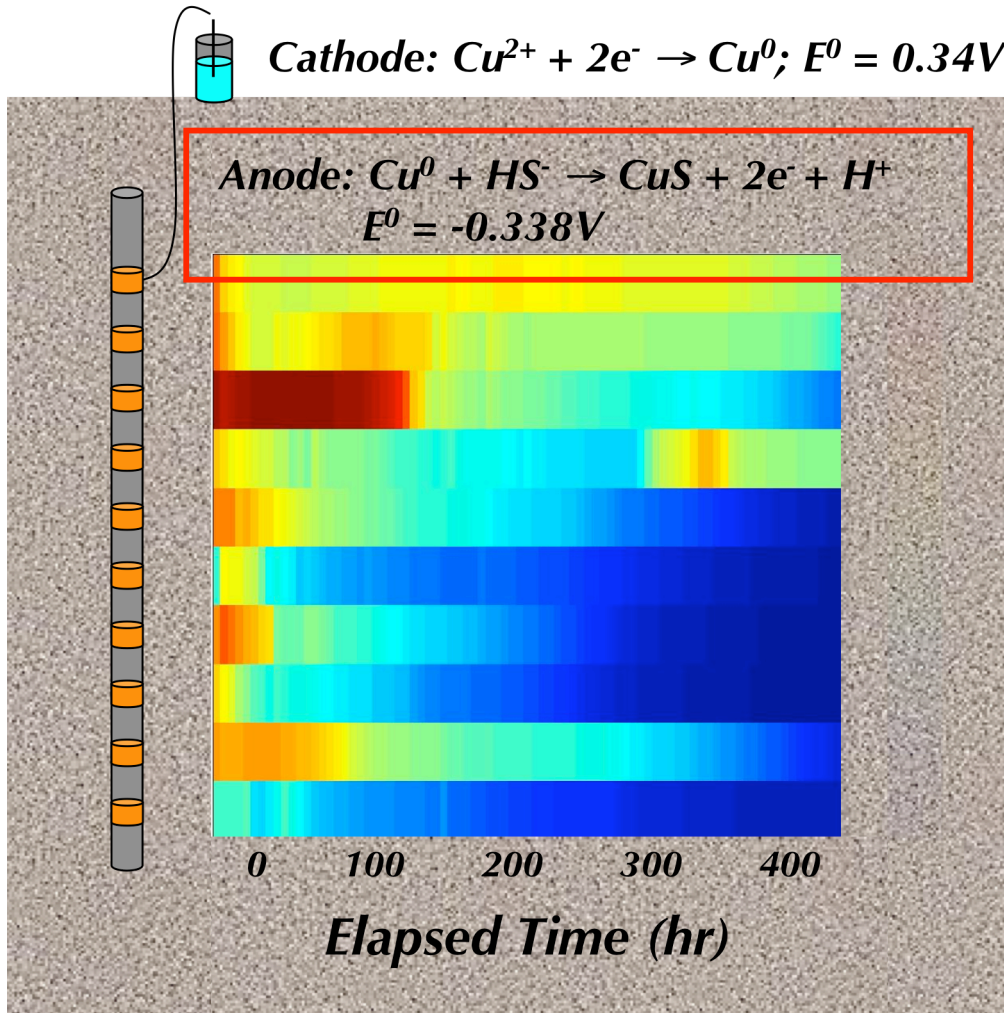
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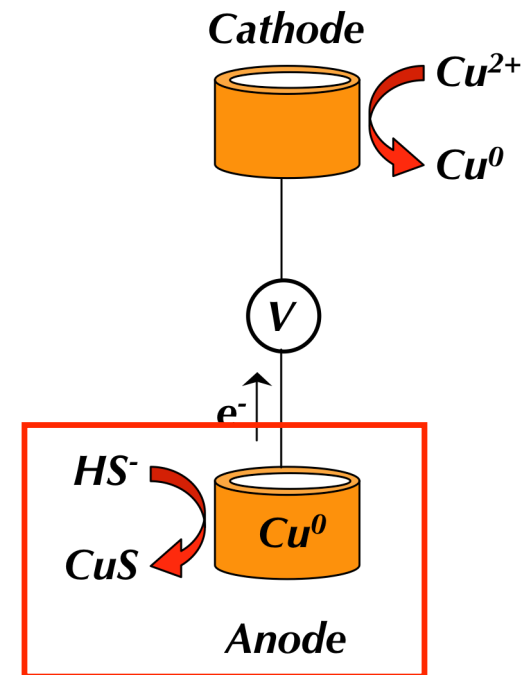
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Borehole SP Monitoring: *Conceptual Model*

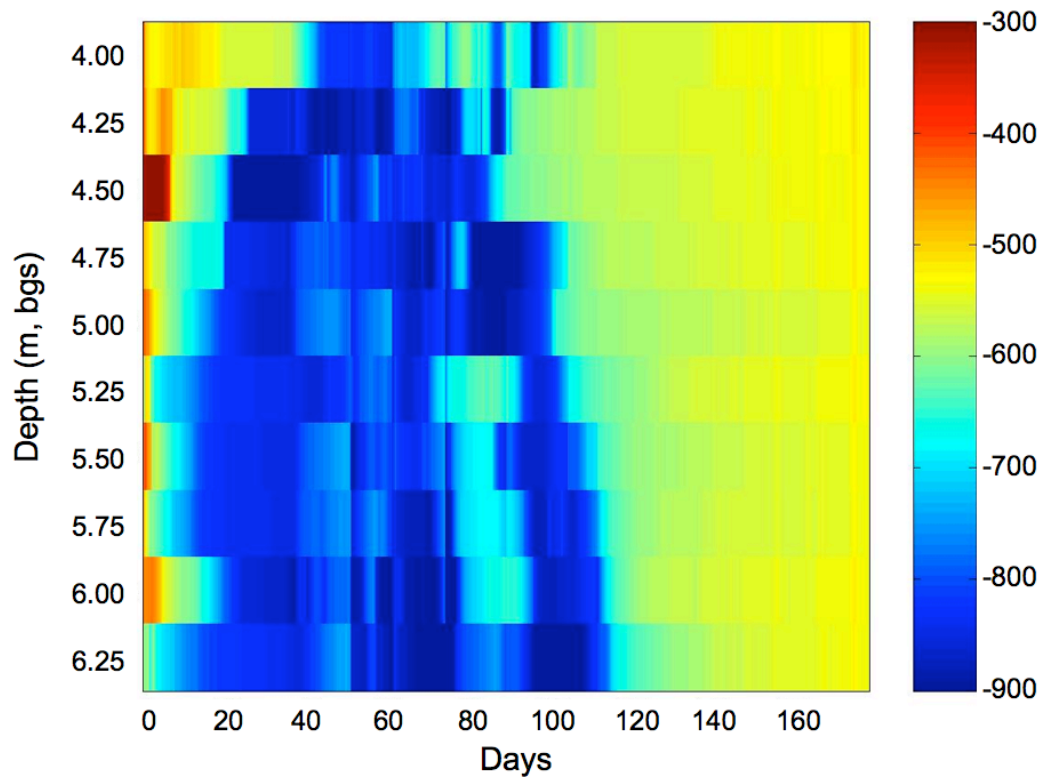


Galvanic Model:



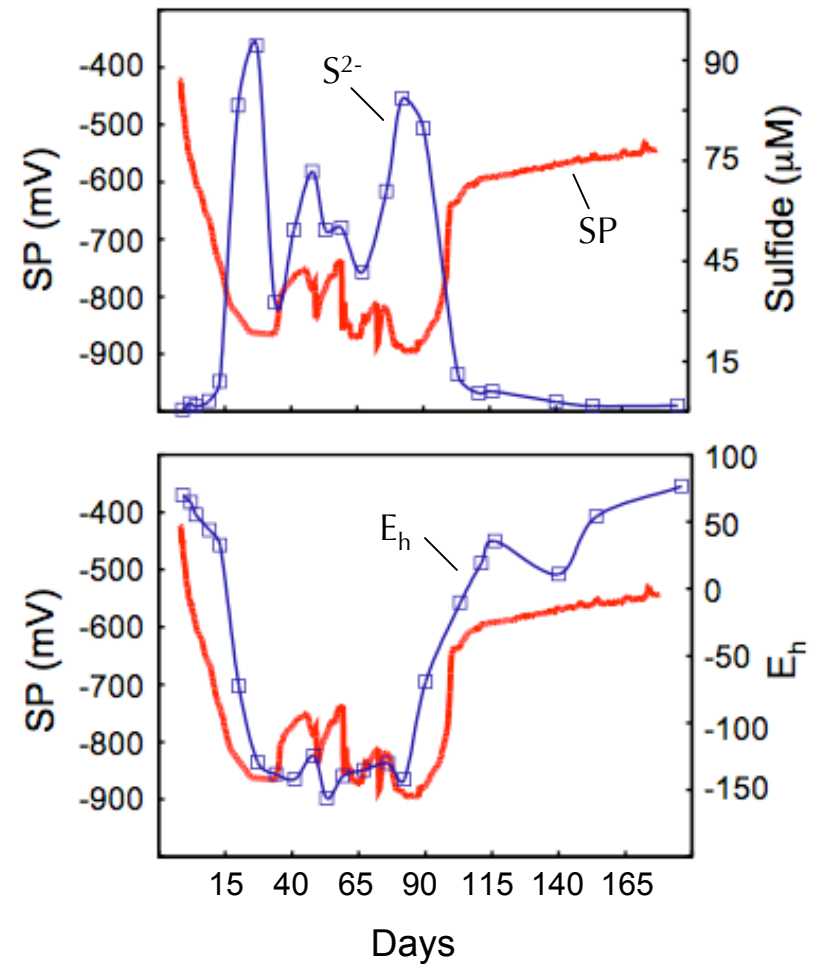
Borehole SP Monitoring: *Field Data*

~2.5m downgradient



SRB dominant...

Discrete electrode (5.0-m bgs)

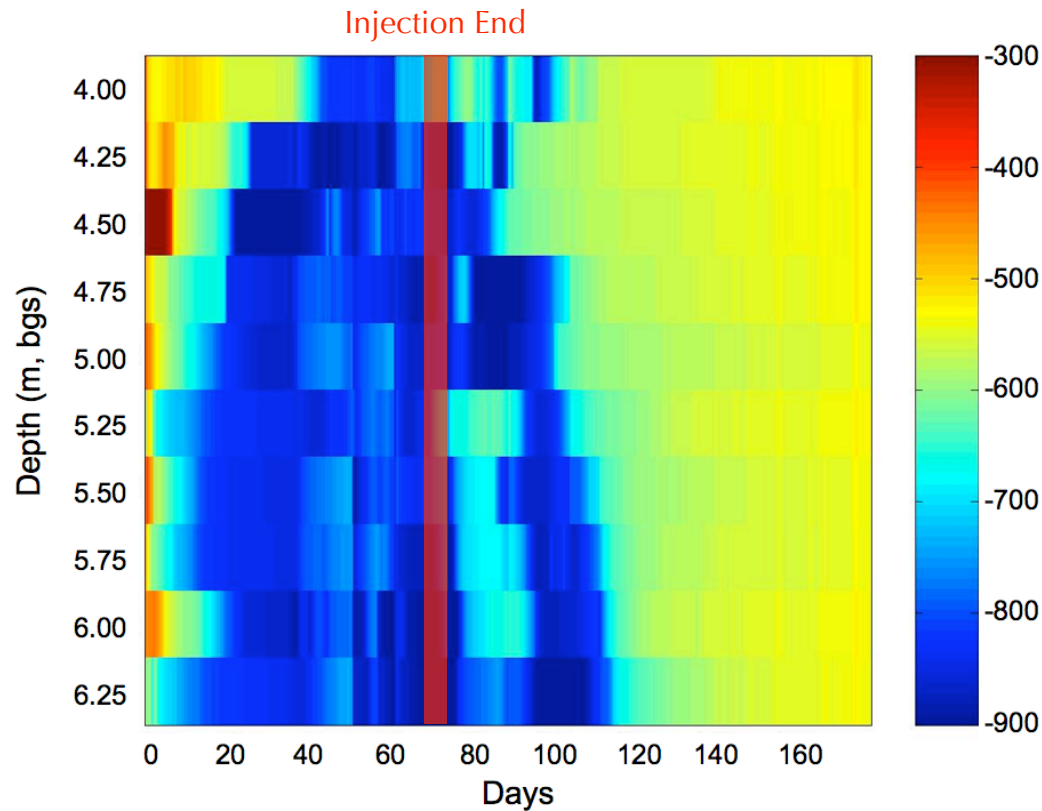


SP Benefits:

- *Rapid logging interval (here, 6-hr)*
- *High spatial resolution (25-cm)*
- *Good correlation: $[\text{HS}^-]$, E_h*

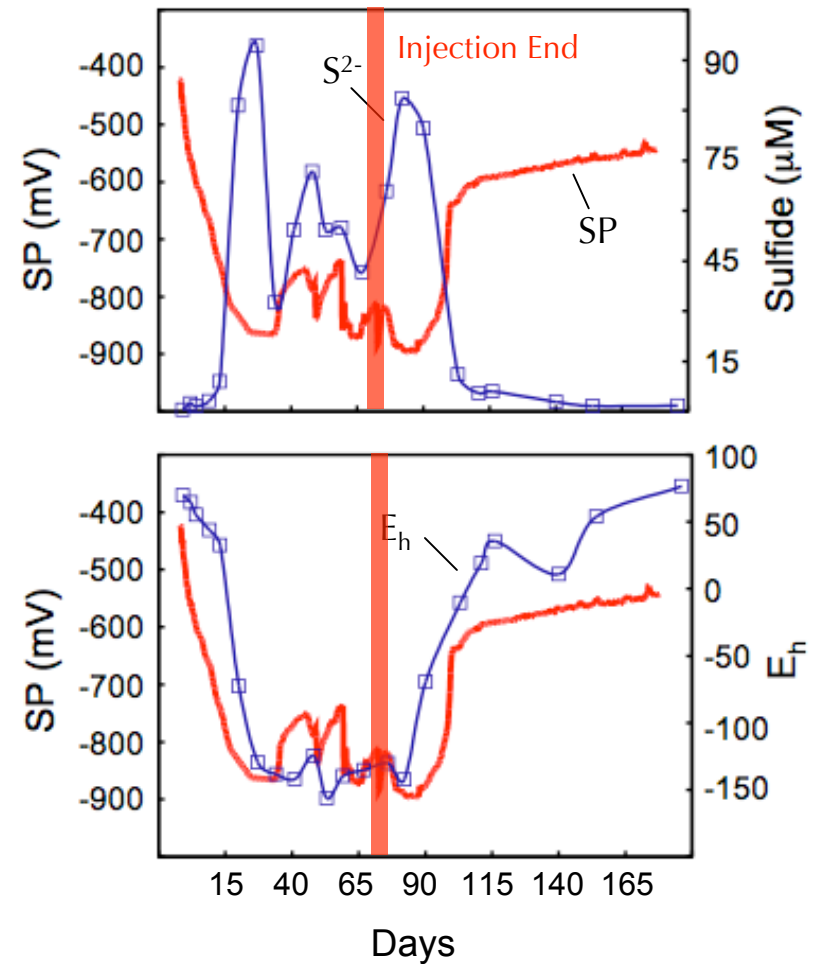
Borehole SP Monitoring: *Field Data*

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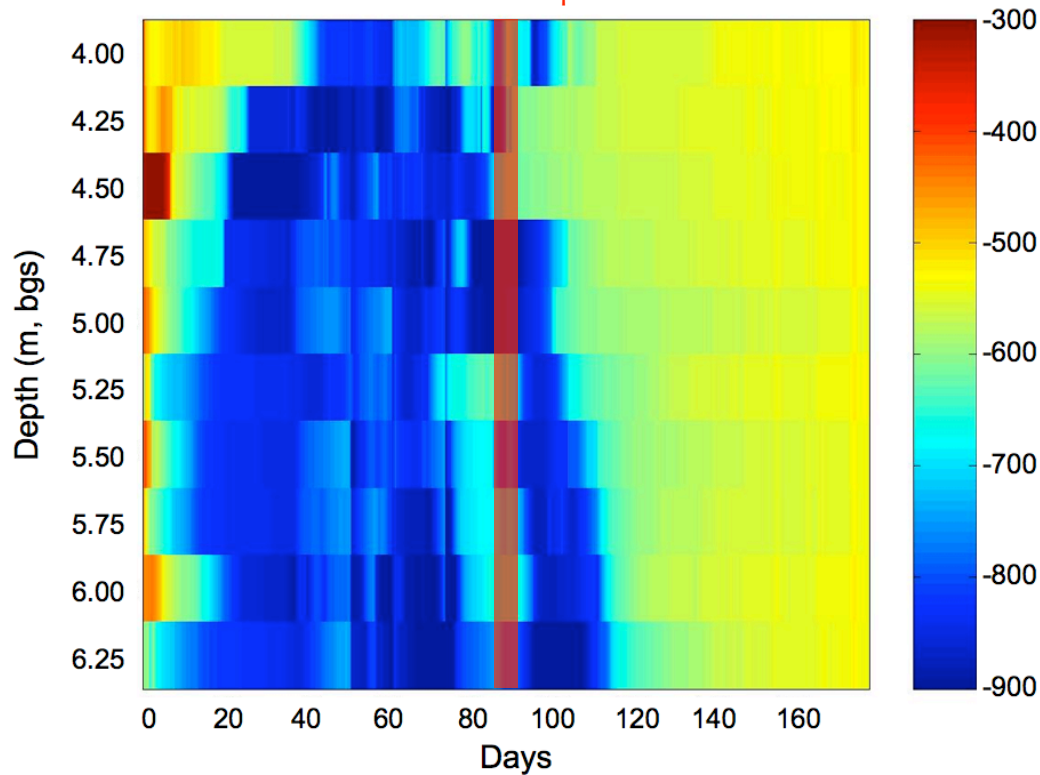
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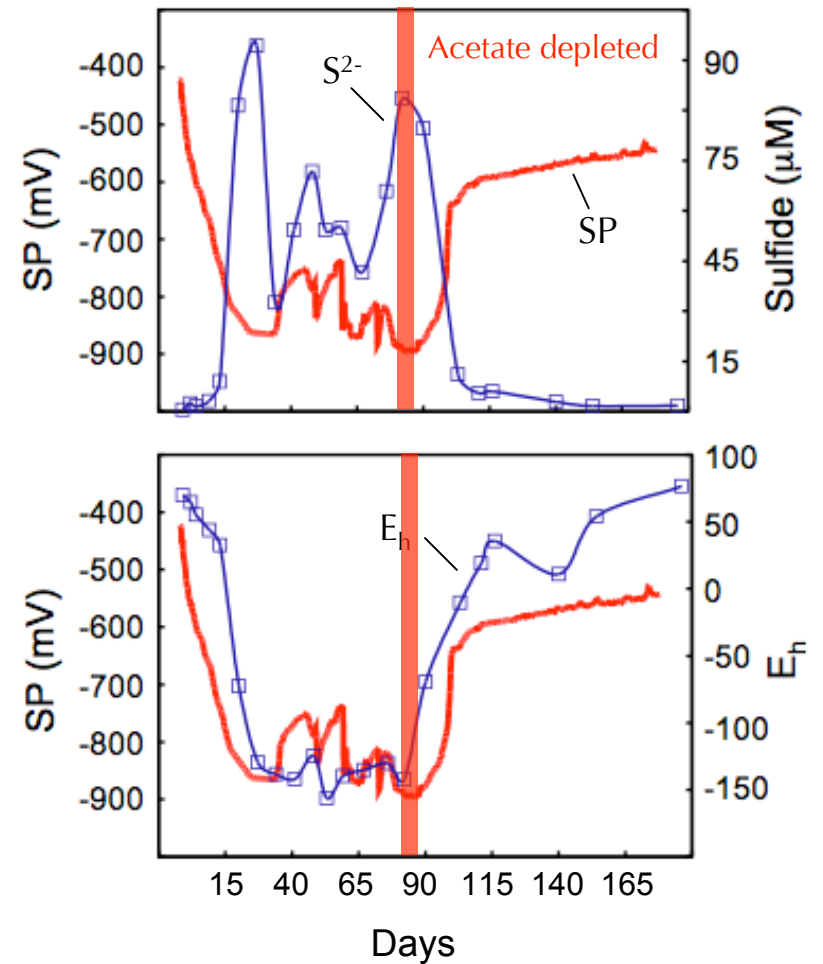
~2.5m downgradient

Acetate depleted



SRB dominant...

Discrete electrode (5.0-m bgs)

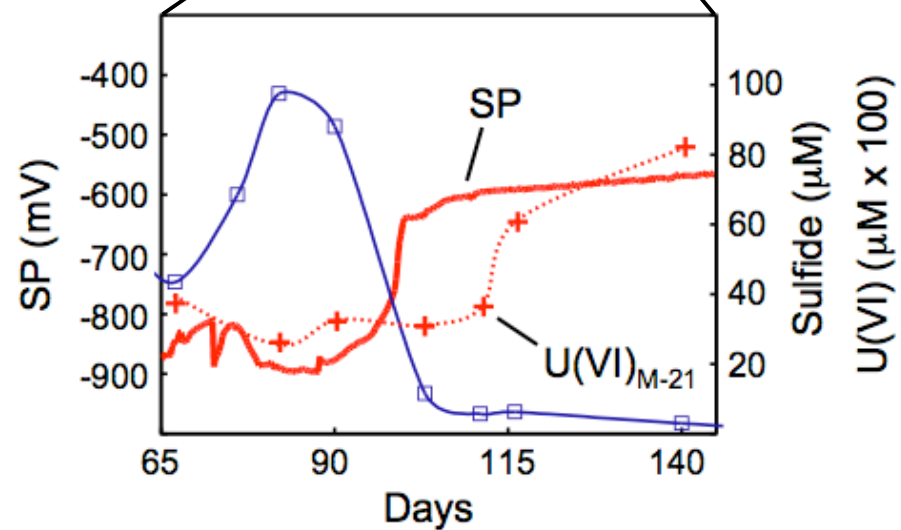
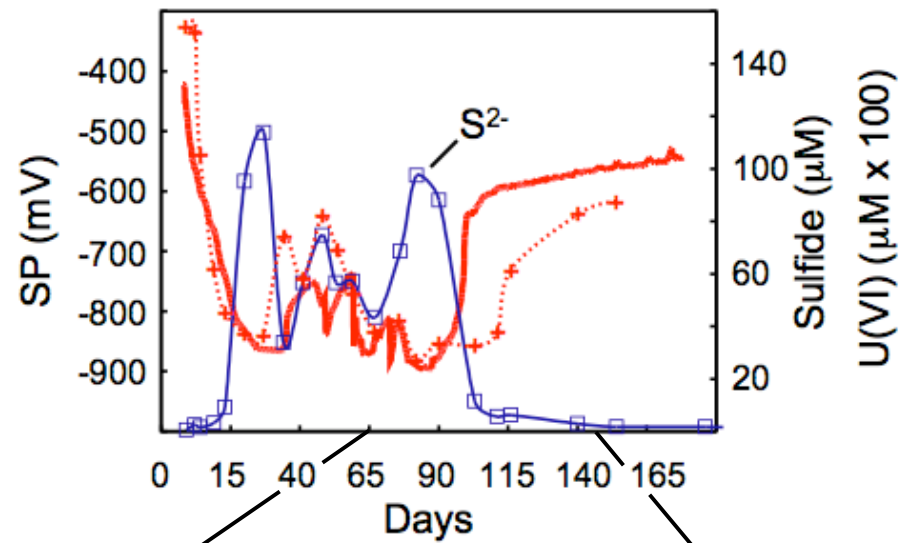


SP Benefits:

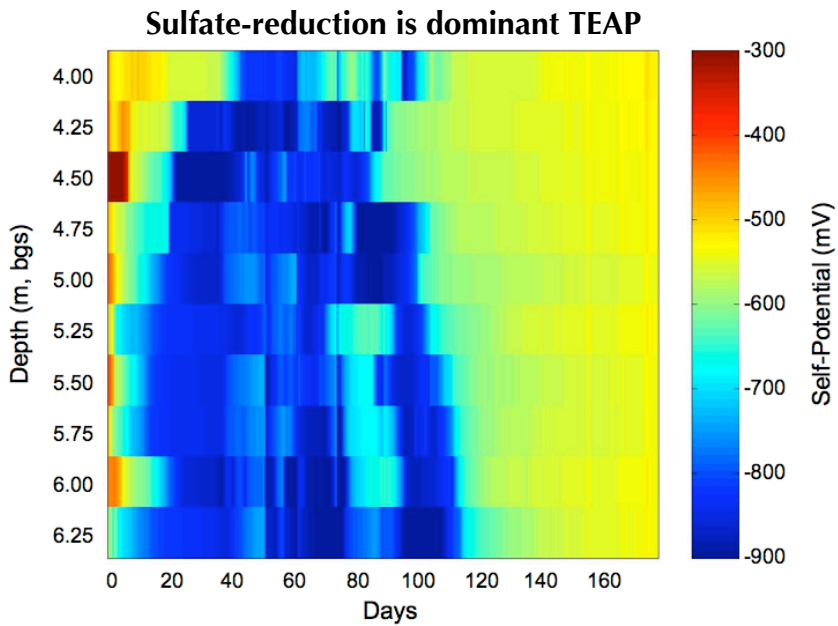
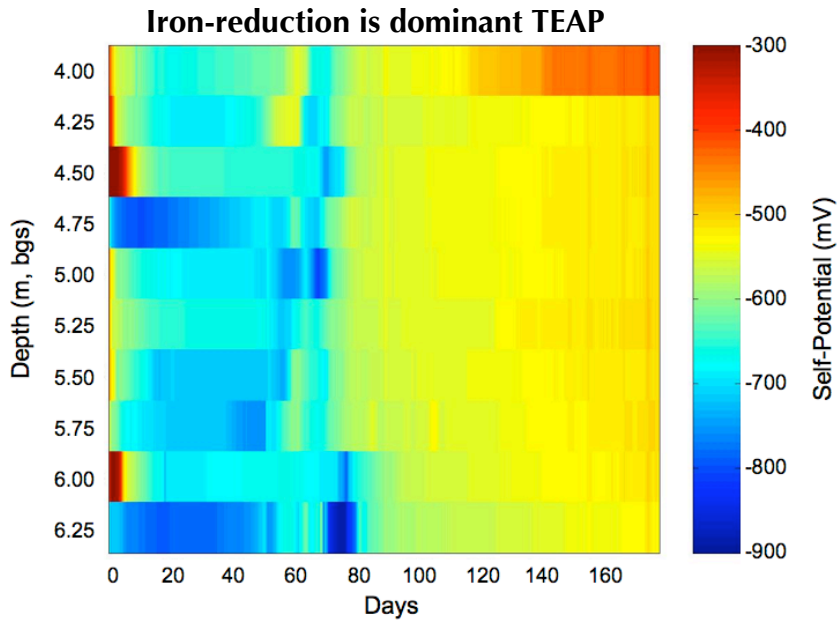
- *Rapid logging interval (here, 6-hr)*
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Borehole SP Monitoring: *Field Data*

Relevance to uranium removal...

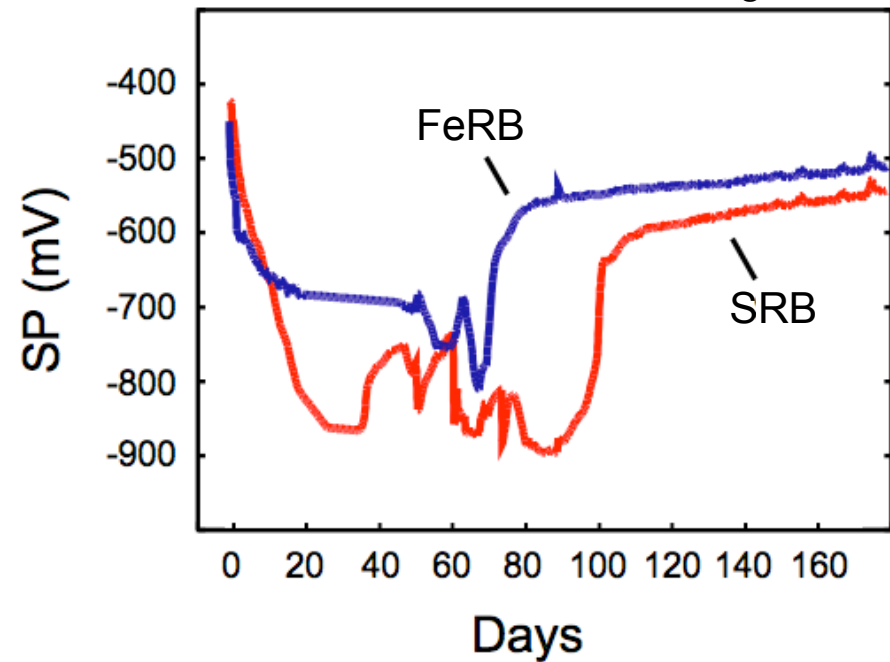


Borehole SP Monitoring: *Field Data*



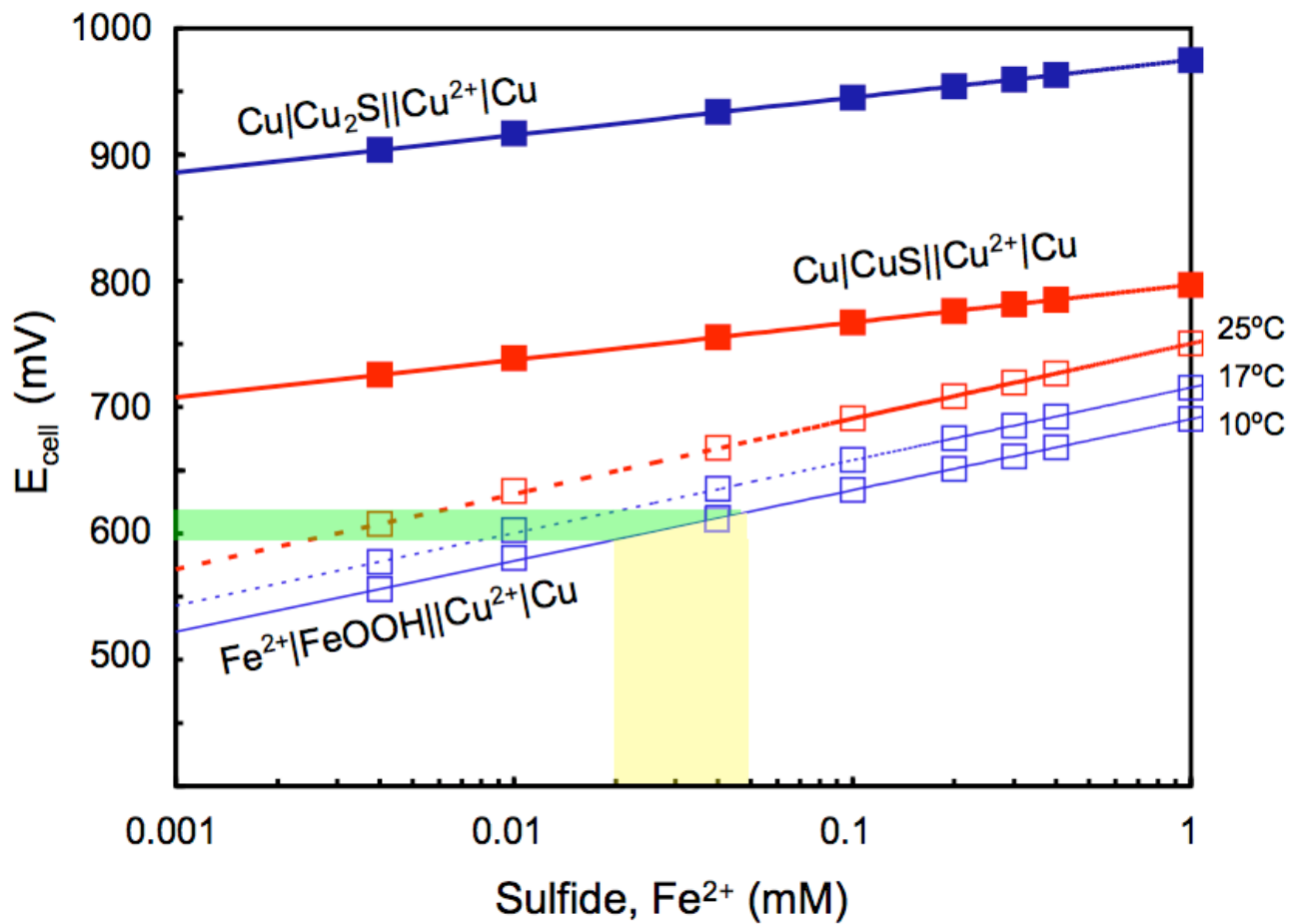
Impact of location and TEAP-dependent geochemistry...

Discrete electrodes (both 5.0-m bgs)



Borehole SP Monitoring: *Field Data*

Impact of location and TEAP-dependent geochemistry...



Conclusions

“Geophysical methods represent a key component of characterization and monitoring activities at the DOE IFC sites”

Old Rifle Site:

CR and SP methods are valuable tools for monitoring subsurface changes accompanying bioremediation

CR → **Mineralogy** (*FeS precipitation*)

SP → **Geochemistry** (*HS⁻ and Fe²⁺ gradients*)

Acknowledgments



Field sampling and analysis:

Jenny Druhan, Tom Resch, Evan Arntzen (*all PNNL*)

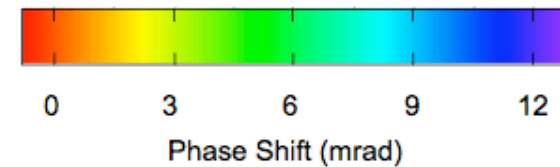
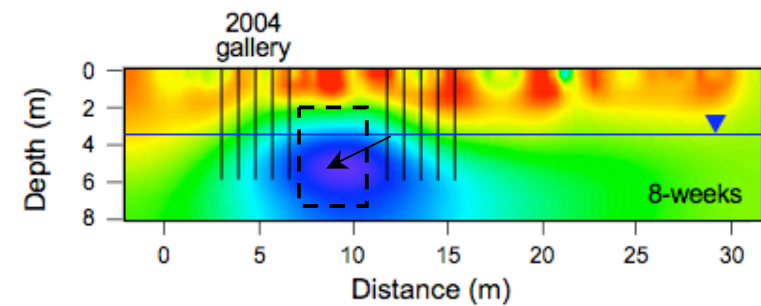
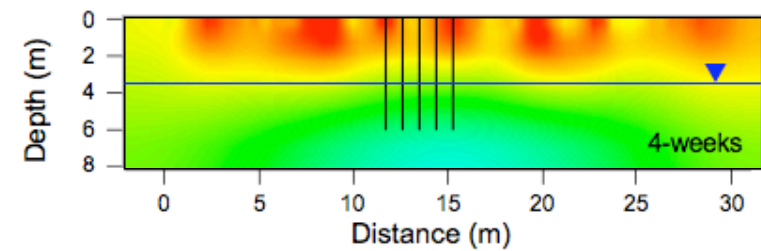
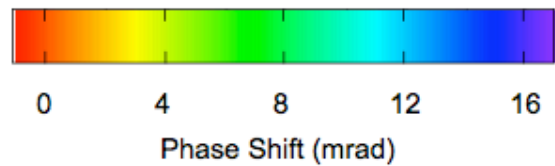
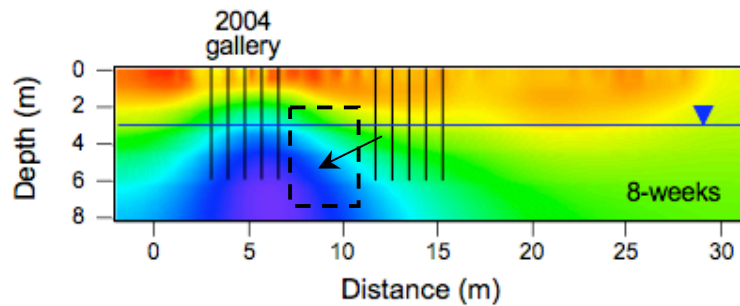
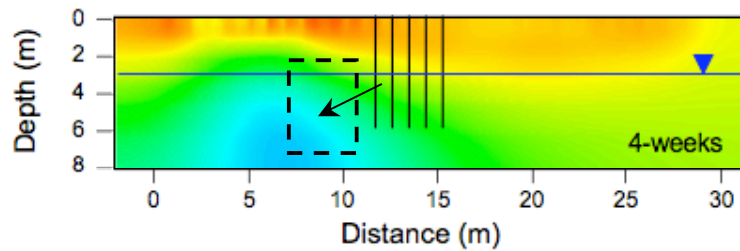
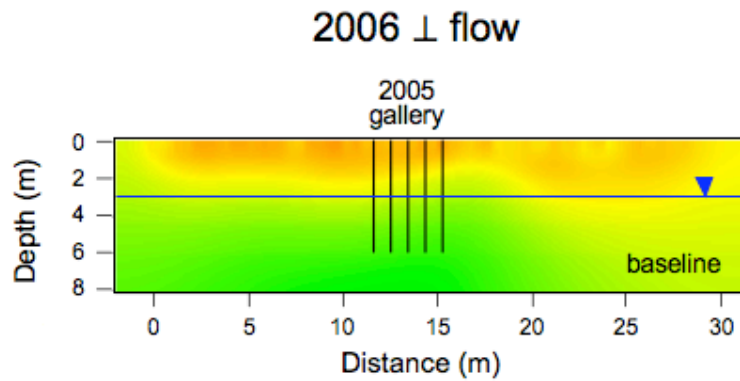
Electron Microscopy:

Alice Dohnalkova and Bruce Arey (*EMSL; PNNL*)

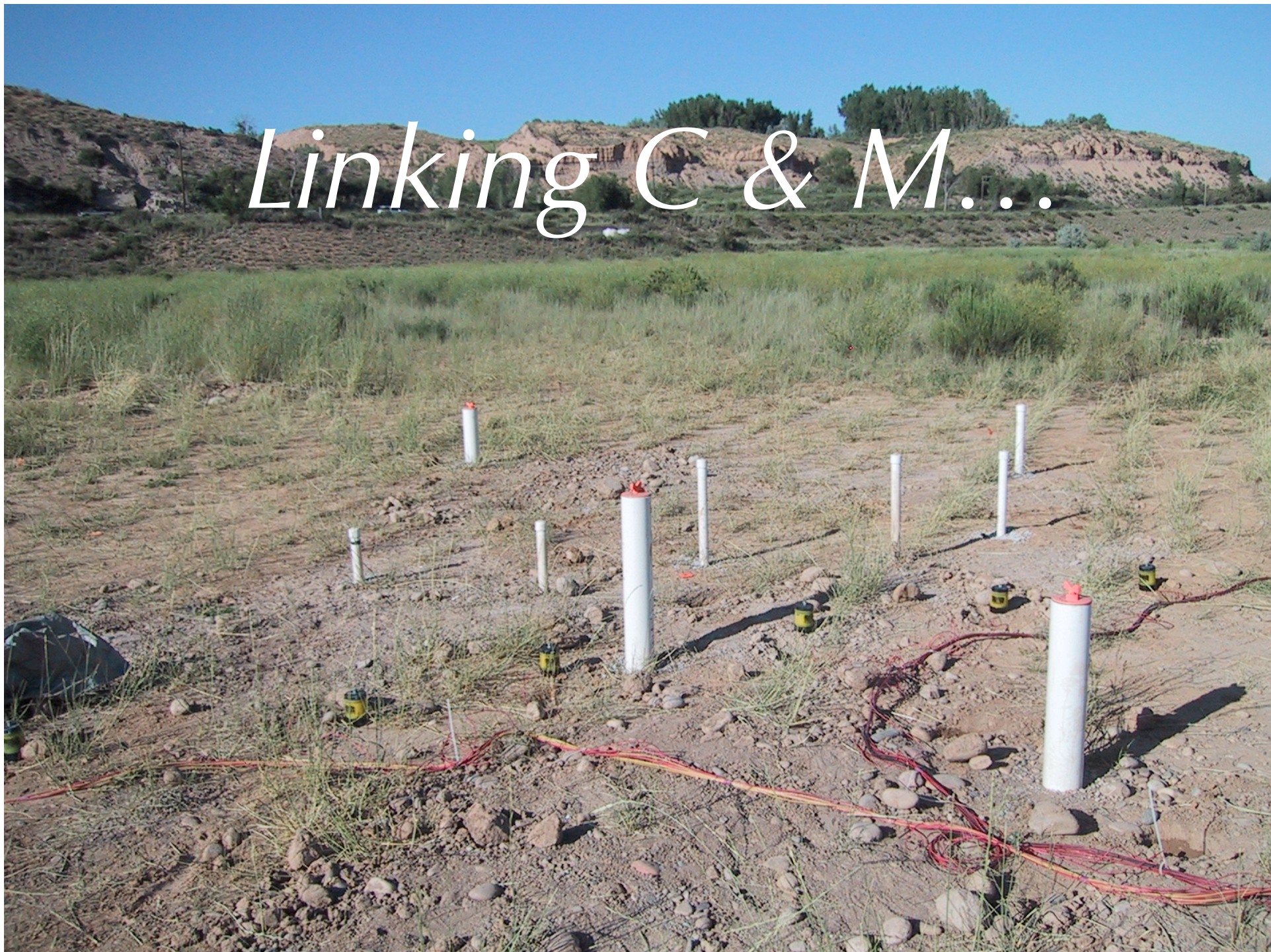
Funding:

DOE's EMSP and ERSP Program (*Susan Hubbard and Jill Banfield, co-PI's*)

Linking Characterization and Monitoring: *Heterogeneity*

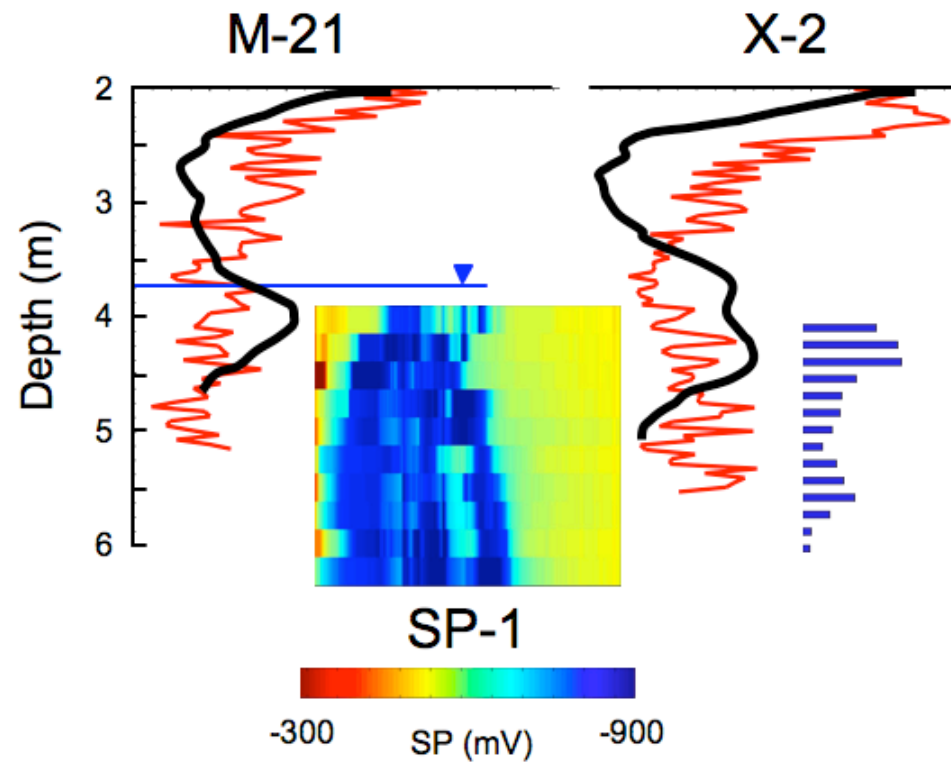


Linking C & M...



Linking Characterization and Monitoring: *Heterogeneity*

Impact of heterogeneity on temporal geophysical response...



Linking Characterization and Monitoring: *Heterogeneity*

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