Geophysical Investigations at the Old Rifle IFC Site

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Objective

Demonstrate the utility of geophysical methods for characterizing structure\(^1\) and monitoring processes\(^2\) over field-relevant scales

*Hypothesis*\(^2\): Microbial processes induce *physical property changes* that can be detected using time-lapse geophysical methods

*Challenges*:
- Unfavorable lithology
- Competing metabolic processes
- Non-unique signatures

Rifle, CO
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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Assessing Vertical Heterogeneity: *Borehole logging*

Correlate response with recovered materials.
Monitoring...
Sulfides: electro-active + surface charge

Complex Resistivity (CR)

Clays: EDL ions impede electrolytic flow
**Sulfides:** electro-active + surface charge

Complex Resistivity (CR)

Applied voltage $\rightarrow$ Current flow ($I$)
**Sulfides:** electro-active + surface charge

**Complex Resistivity (CR)**

- Cation
- Anion
- FeS

**Measured Potential (V)**
Sulfides: electro-active + surface charge

Complex Resistivity (CR)
Impact of FeS Precipitation on CR Signals

- ~2% FeS
- ~0.5% FeS
‘Field-Scale’ CR Monitoring at Old Rifle, CO
‘Field-Scale’ CR Monitoring at Old Rifle, CO
Surface CR Results: Identical Phase Scale
Surface CR Results: *Expanded Phase Scale*
Constraining CR Results: Geochemistry

$Fe^{2+}$ and $HS^-$ vs. Time

2006 Parallel to Flow
Constraining CR Results: Geochemistry

4-weeks

2006 Parallel to Flow
Constraining CR Results: Geochemistry
Constraining CR Results: Geomicrobiology

M-21: FeS-encrusted tubing

2006 Parallel to Flow
Constraining CR Results: Geomicrobiology

M-21: FeS-encrusted tubing

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
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Cathode: $\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu}^0; E^0 = 0.34V$

Anode: $\text{Cu}^0 + HS^- \rightarrow \text{CuS} + 2e^- + H^+$
$E^0 = -0.338V$

Galvanic Model:
Borehole SP Monitoring: Conceptual Model

Cathode: \( Cu^{2+} + 2e^- \rightarrow Cu^0; \ E^0 = 0.34V \)

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Galvanic Model:

\[\begin{array}{c}
\text{Cathode} \\
\downarrow \\
Cu^{2+} \\
\uparrow \\
\text{Anode} \\
\end{array}\]

\[\begin{array}{c}
\text{Cathode} \\
\downarrow \\
Cu^0 \\
\uparrow \\
\text{Anode} \\
\end{array}\]

\[\text{HS}^-, \ CuS \]

Elapsed Time (hr)
Borehole SP Monitoring: Conceptual Model

**Cathode:** \( \text{Cu}^{2+} + 2e^- \rightarrow \text{Cu}^0; \ E^0 = 0.34V \)

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**Galvanic Model:**

**Cathode**
- \( \text{Cu}^2+ \)
- \( \text{Cu}^0 \)

**Anode**
- \( HS^- \)
- \( CuS \)

**Elapsed Time (hr)**

0 100 200 300 400
Borehole SP Monitoring: *Field Data*

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

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**Discrete electrode (5.0-m bgs)**

- $S^2-$
- SP

SRB dominant...
Borehole SP Monitoring: Field Data

SP Benefits:
- Rapid logging interval (here, 6-hr)
- High spatial resolution (25-cm)
- Good correlation: [HS⁻], $E_H$

~2.5m downgradient

Discrete electrode (5.0-m bgs)

SRB dominant...
Borehole SP Monitoring: Field Data

SP Benefits:
- Rapid logging interval (here, 6-hr)
- High spatial resolution (25-cm)
- Good correlation: \([HS^-], E_H\)
Borehole SP Monitoring: *Field Data*

*Relevance to uranium removal...*
Borehole SP Monitoring: Field Data

Iron-reduction is dominant TEAP

Impact of location and TEAP-dependent geochemistry...

Discrete electrodes (both 5.0-m bgs)

Sulfate-reduction is dominant TEAP
Borehole SP Monitoring: *Field Data*

*Impact of location and TEAP-dependent geochemistry...*

![Graph showing the relationship between electrode potential (E_{cell}) and sulfide (Fe^{2+}) concentration.](image)
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 $\rightarrow$ **Mineralogy** (*FeS* precipitation)

SP $\rightarrow$ **Geochemistry** (*HS* and *Fe$^{2+}$* gradients)
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Linking Characterization and Monitoring: *Heterogeneity*
Linking C & M...
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*Impact of heterogeneity on temporal geophysical response...*
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