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Predicting Remediation Technology Longevity using Spectral Induced Polarization

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2023 Global Summit on Environmental Remediation
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Outline

- permeable reactive barrier (PRB), this study: redox reactive PRBs:
  - measure injection extent (ERT, SIP)
  - performance over time (i.e., oxidation)
- spectral induced polarization (SIP) use in subsurface sediments
  - quantify temporary electron storage
  - frequency specific surface phase imaginary conductivity
- geochemical and SIP comparison of redox reactive surface phases
- geochemical and SIP comparison of four reductive technologies

Permeable Reactive Barrier (PRB)

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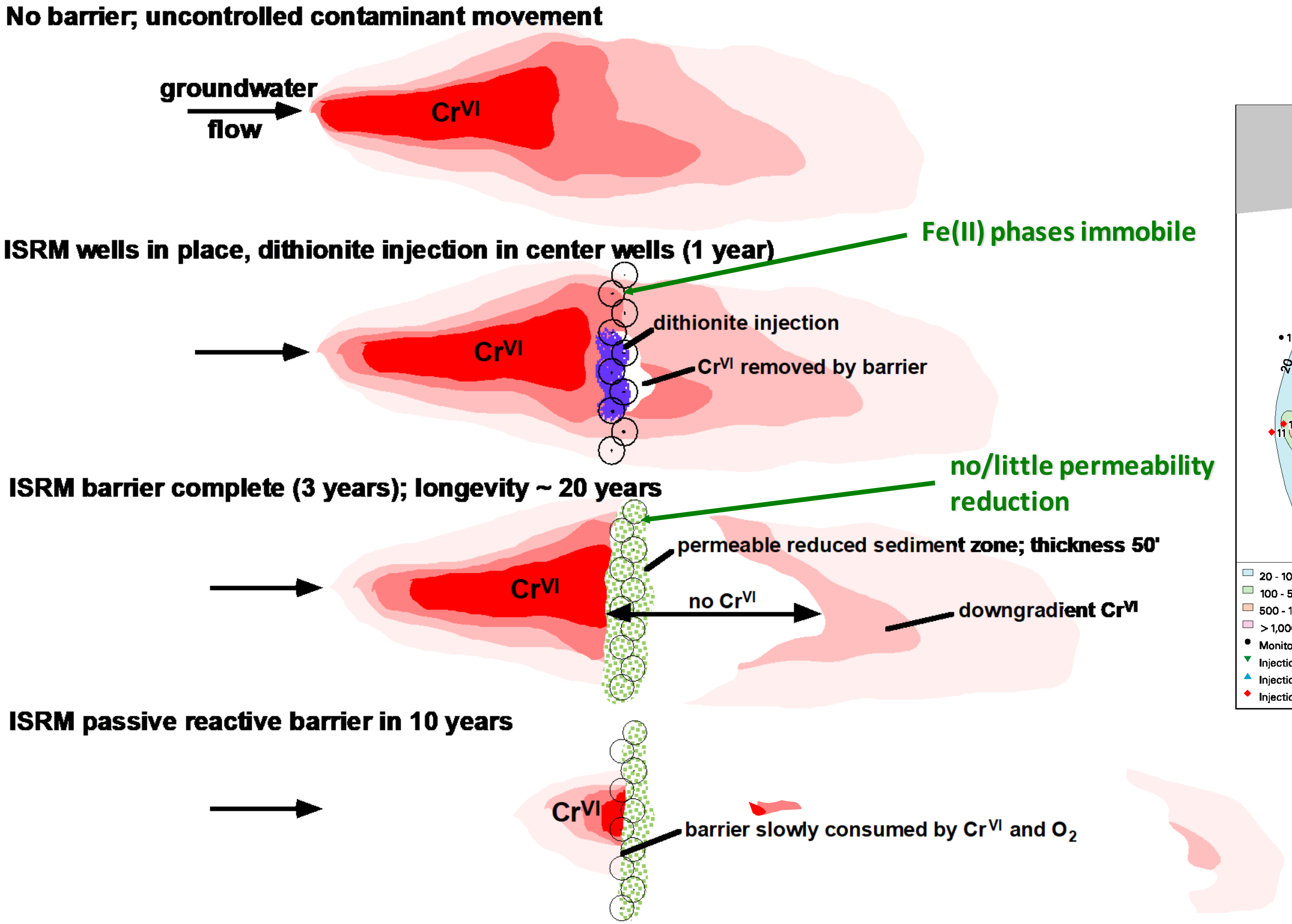

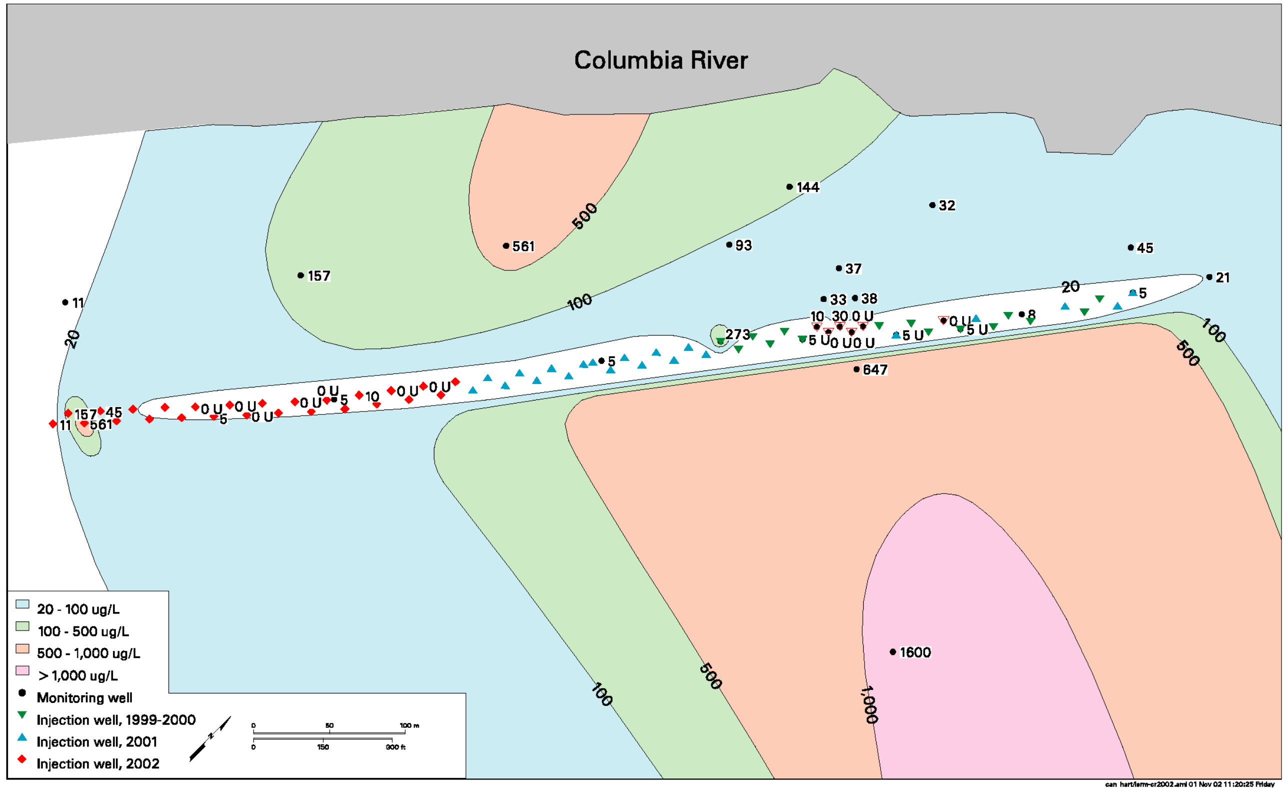

- measure PRB performance over time: monitoring well data (for mobile contaminants that have low sorption)
- can SIP be used to evaluate PRB performance where well data is sparse or sorbing contaminants or to characterize heterogeneity effects?

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Abiotic Redox Reactions and SIP

Redox Capacity and Potential: different e^- donors

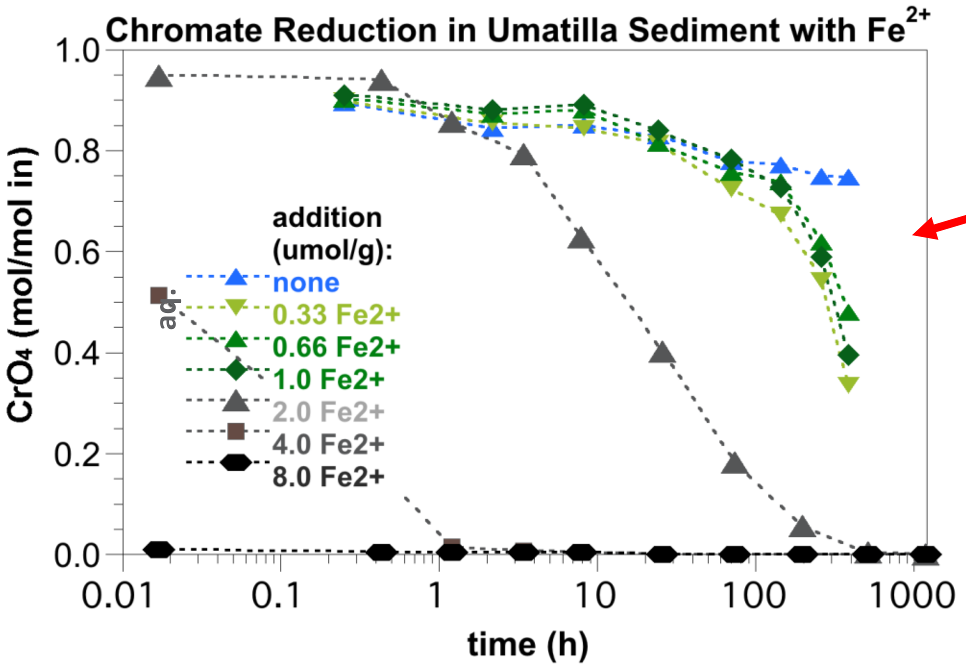
- measure by Fe extractions

$Fe^{2+}(aq) \Leftrightarrow Fe^{3+} + e^-$

PRB

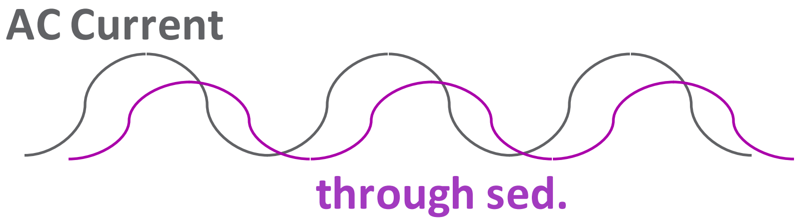
clay[Fe^{2+}], clay≡Fe^{2+}
Fe-oxide≡Fe^{2+}
FeS, FeS_2
microbes

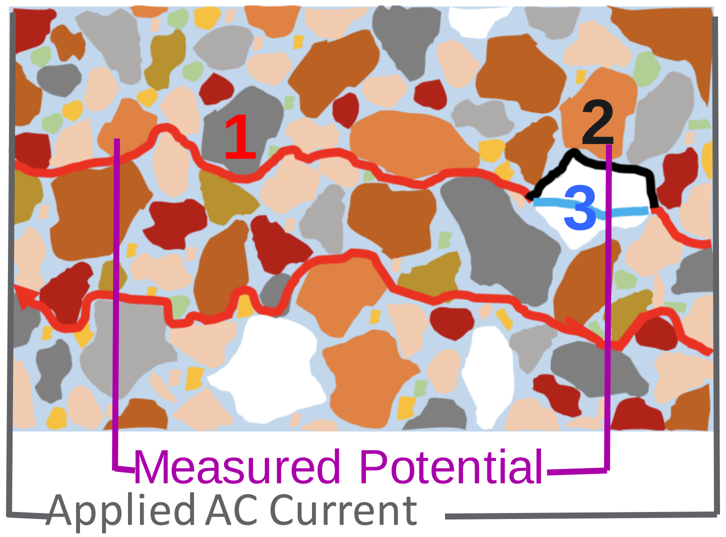
- measure e- acceptor (CrO_4, NO_3, RDX) degradation rate



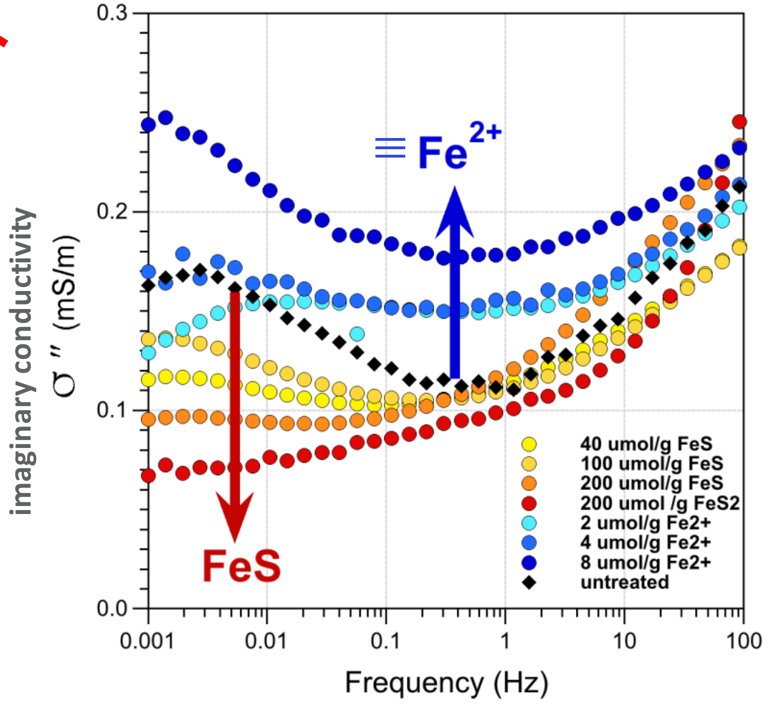
predict?

Spectral Induced Polarization: e^- flux (soln, surface), e^- storage





- measure:
  - real conductivity (sol'n)
  - imaginary conductivity (~surface)
  - phase angle (capacitance)



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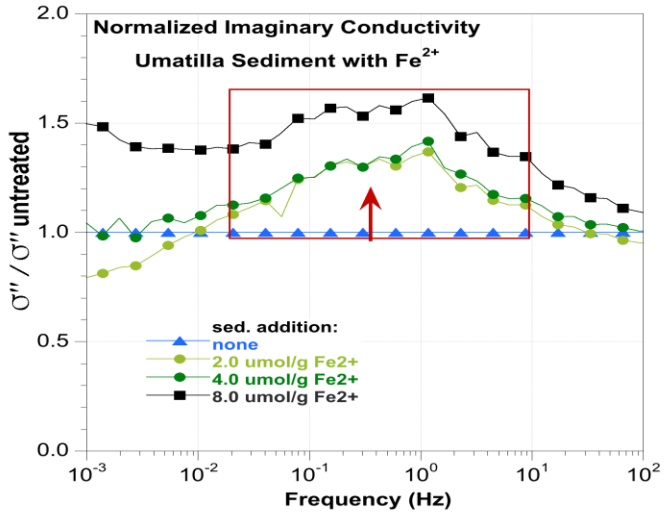
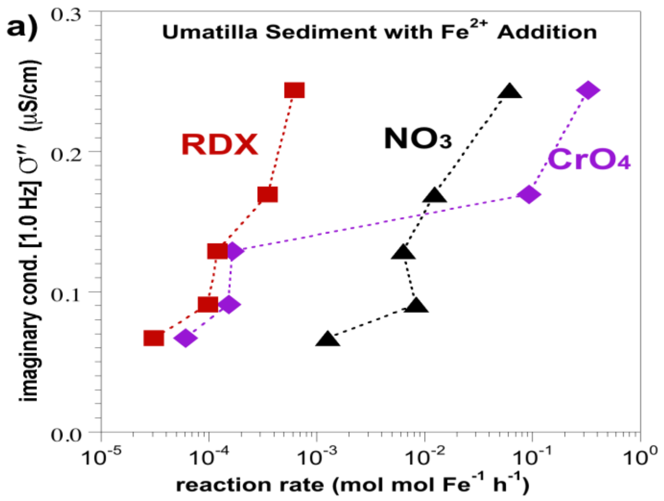
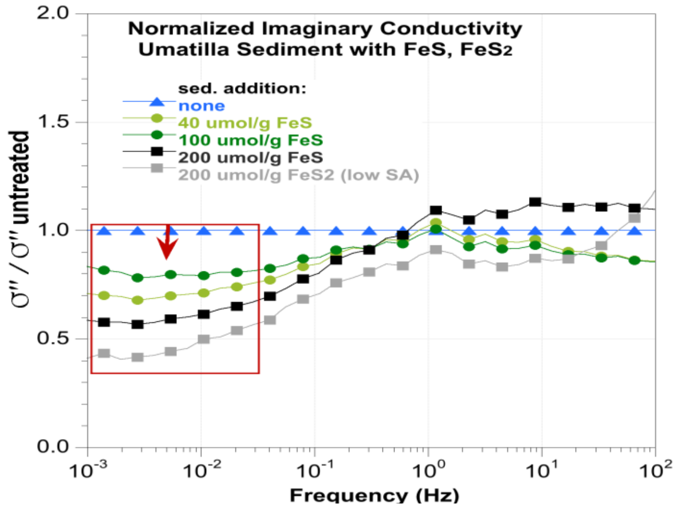
Reductive Component Additions to a Sediment

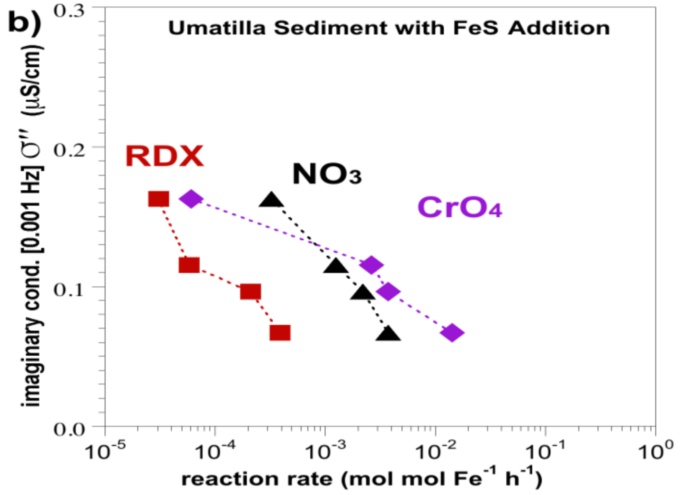
adsorbed Fe^{2+} addition



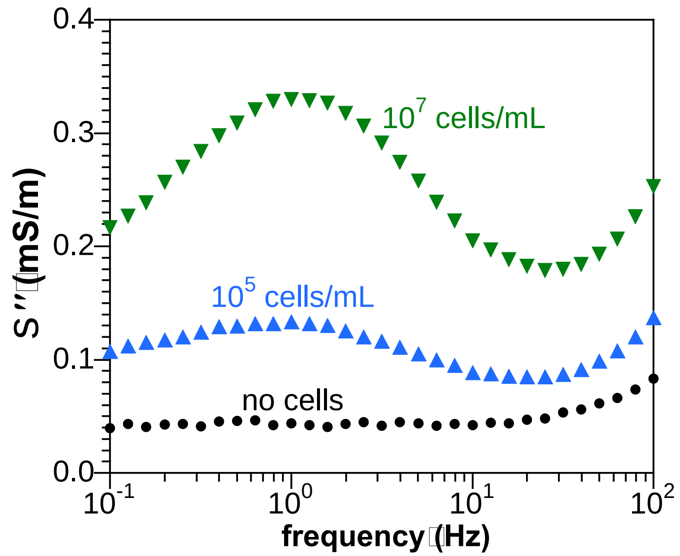


FeS, FeS_2 addition





microbial isolate addition



- real sediment with adsorbed Fe^{2+}, FeS, microbial biomass addition: frequency specific SIP changes
- good geochemical-SIP correlations in a real sediment with model additions

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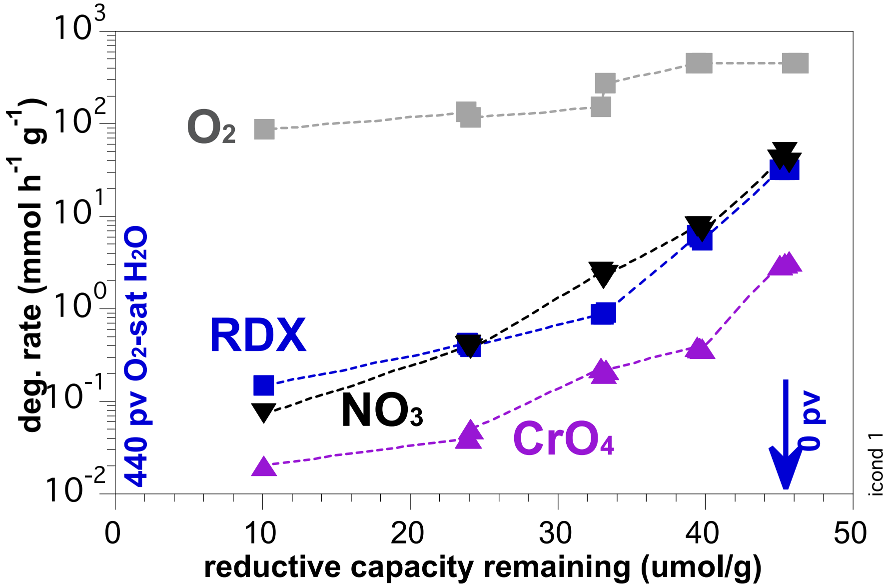
Abiotic Reduction: Na-dithionite and SIP

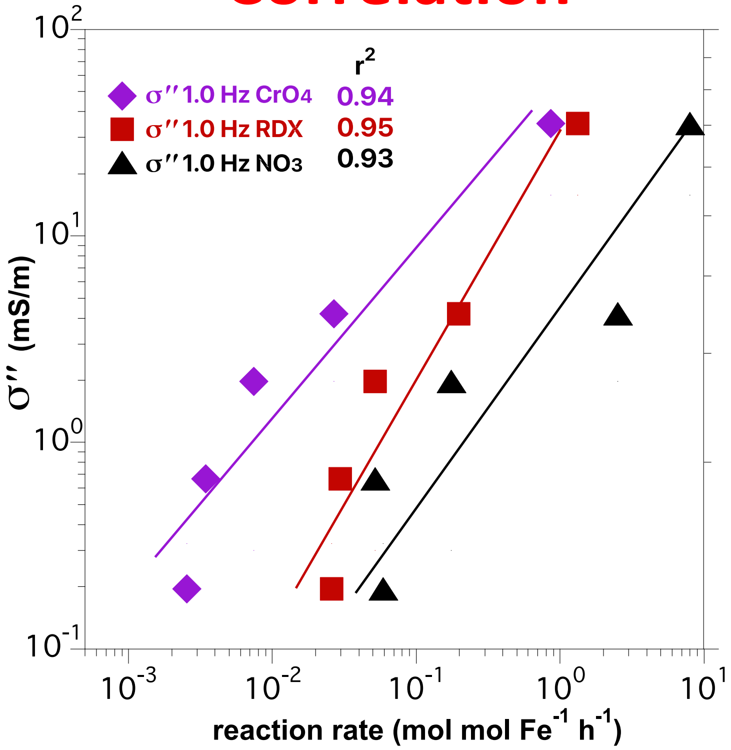
Geochemical Response

Treatment	ads. Fe^{2+}	FeS/ $FeCO_3$
none	0.032	16.3
Na-dith. reduced	52.5	24.7
Na-dith. red./ox.	<0.01	22.5

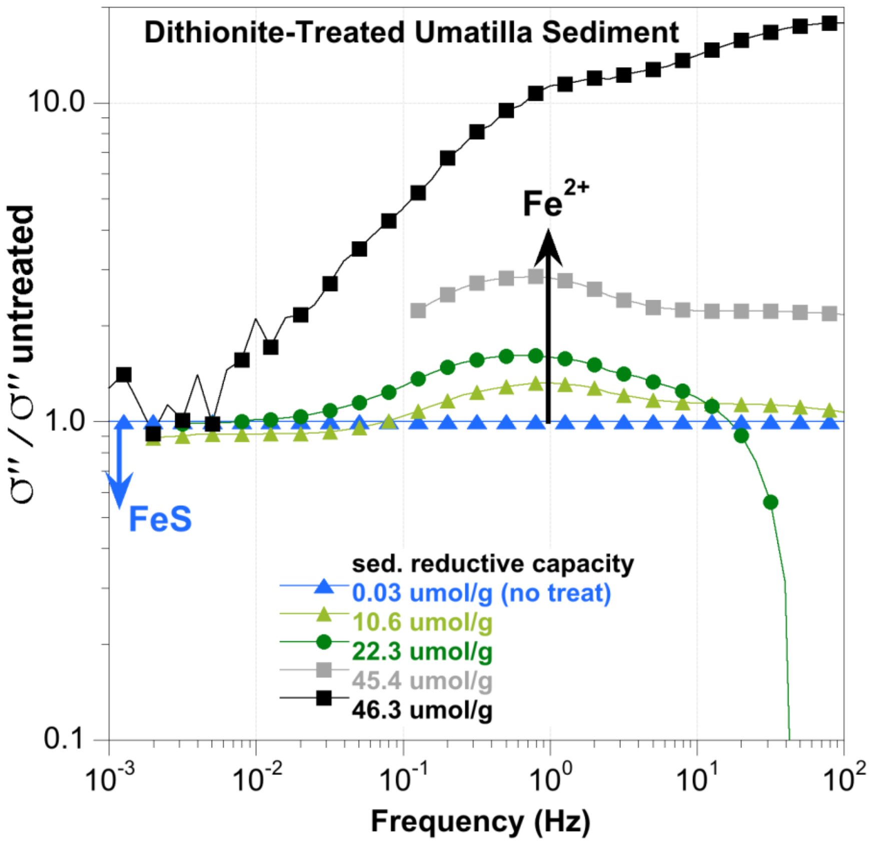
* umol/g



Geochemical-SIP Correlation



SIP Response



σ'' increase at > 0.1 Hz

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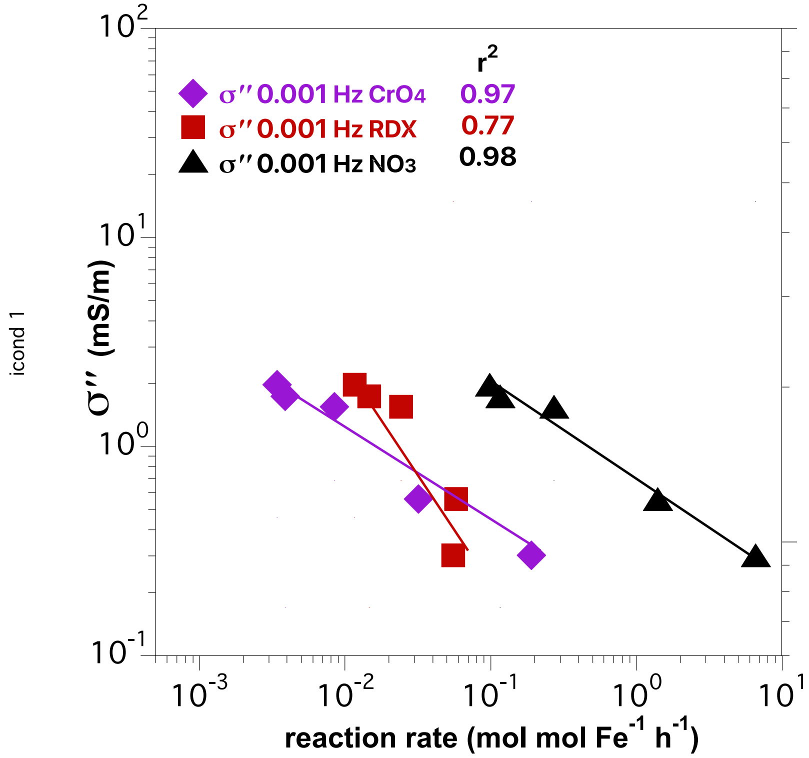
Abiotic Reduction: Ca-polysulfide and SIP

Geochemical Response

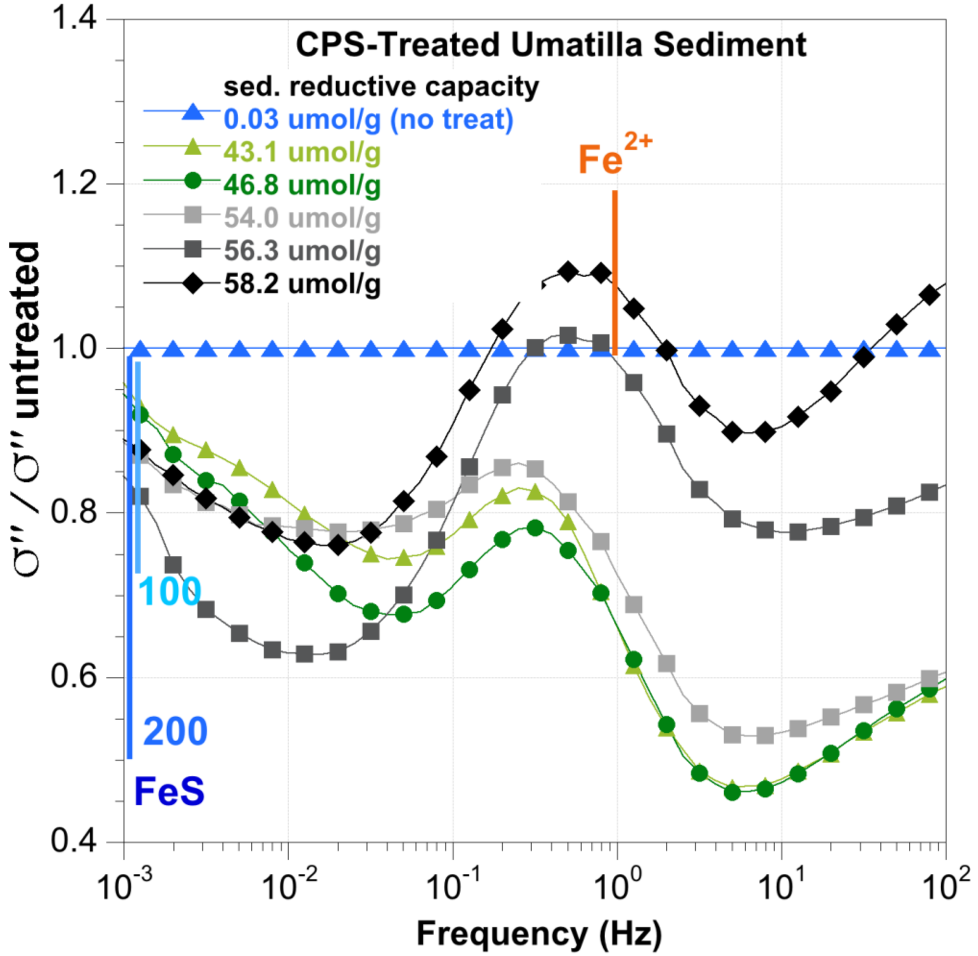
Treatment	ads. Fe^{2+}	FeS/ $FeCO_3$
none	0.032	16.3
Ca-polyS reduced	0.33	112.
Ca-polyS red/ox.	<0.01	36.2

* umol/g

Geochemical-SIP Correlation



SIP Response



σ'' decrease at 0.01 Hz

Abiotic Reduction: nZVI addition

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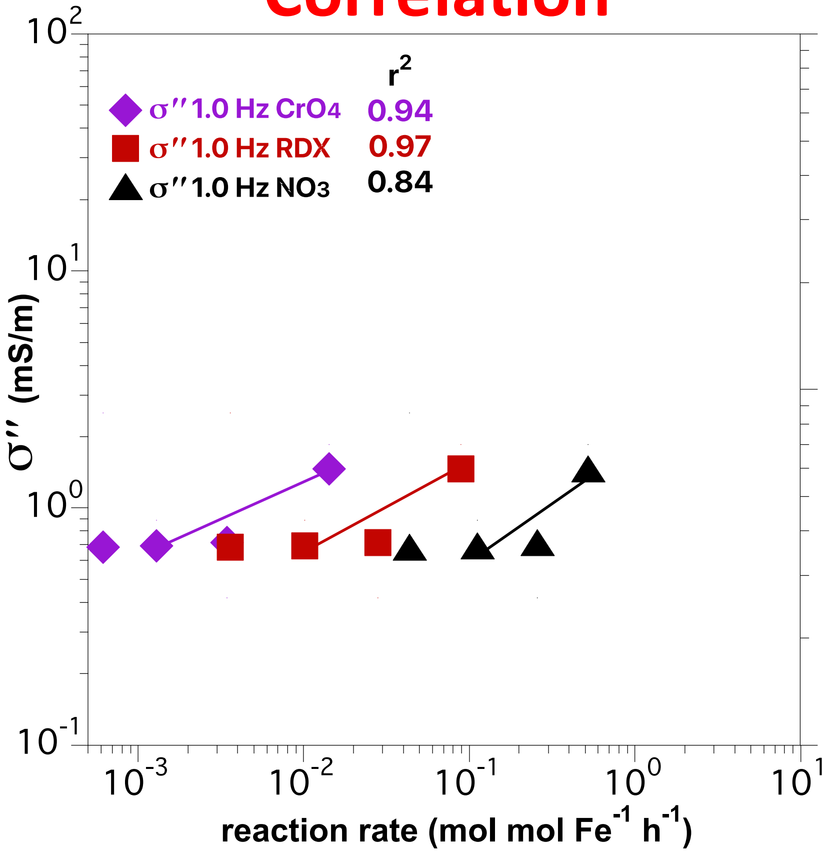
Geochemical Response

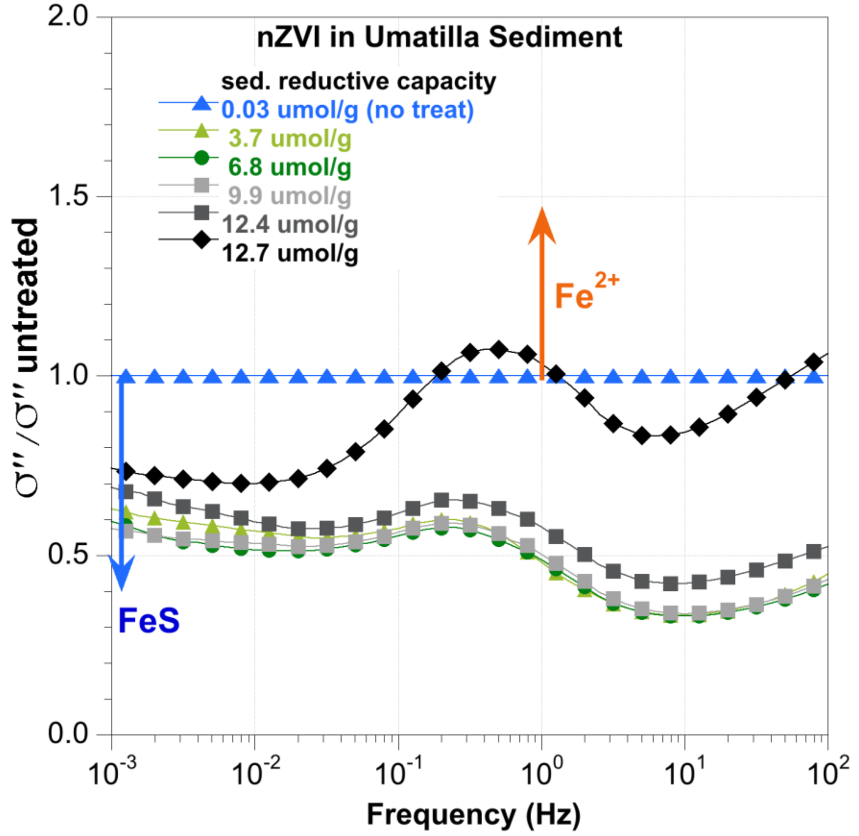
Treatment	ads. Fe^{2+}	FeS/ $FeCO_3$
none	0.032	16.3
nZVI addition	12.7	14.2
nZVI added/ox.	4.5	

* umol/g

Geochemical-SIP Correlation



SIP Response



σ'' decrease, uncorrelated

σ'' increase at 10,000 Hz
(within measurement error)

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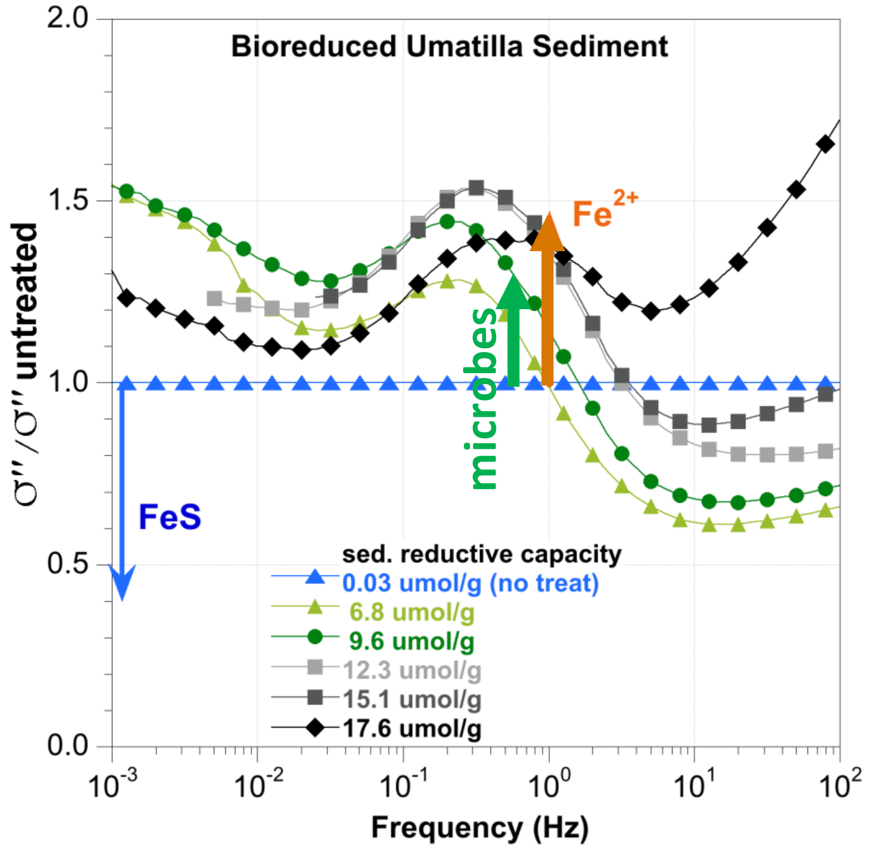
Bioreduction

Geochemical/Microbial Response

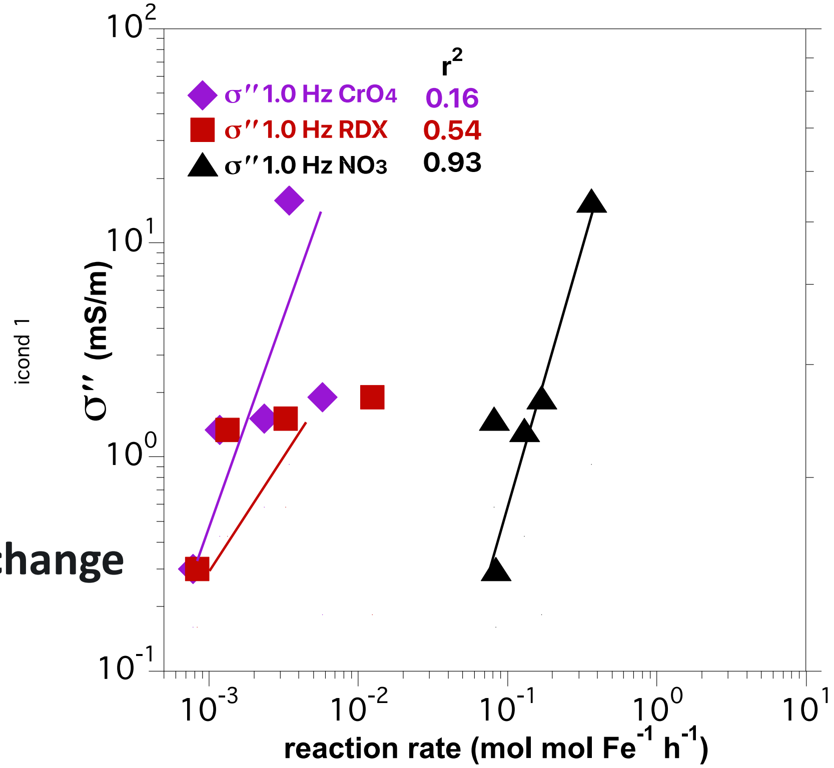
Treatment	ads. Fe^{2+}	FeS/ $FeCO_3$	biomass (CFU/g)
none	0.032	16.3	4.0E5
bioreduced	22.5	19.2	5.6E7
bioreduced/ox.	<0.01	17.7	

* umol/g

SIP Response



Geochemical-SIP Correlation



- small reaction rate change upon oxidation

σ'' increase at 0.1 to 1 Hz"
- adsorbed Fe2+ or microbial biomass?

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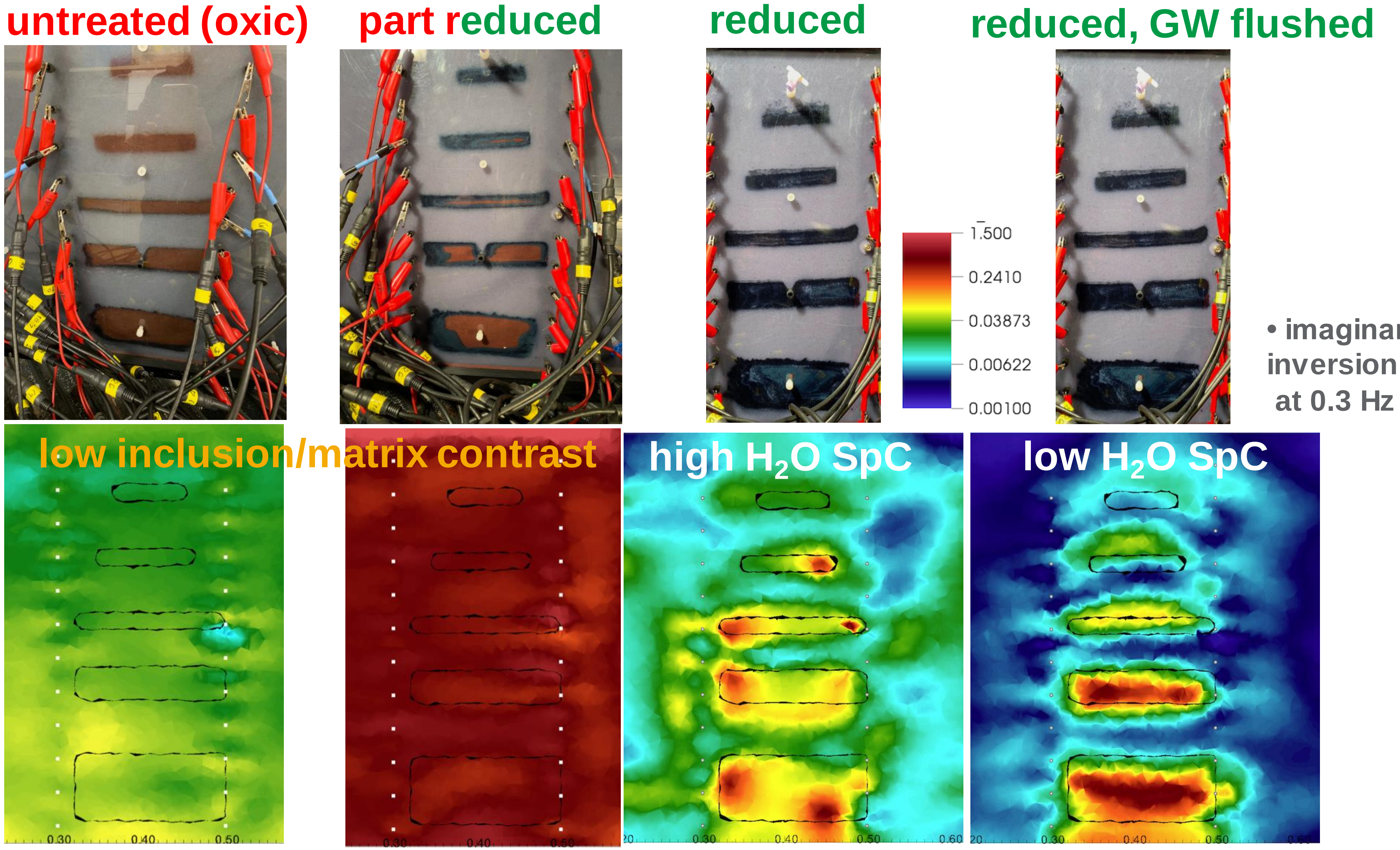
Heterogeneities: SIP Identification of Reduced Zones



• imaginary conductivity inversion modeling at at 0.3 Hz (FeS sensitive)

reduced zone identification:

- high solids contrast between inclusion and matrix
- low groundwater conductivity
- electrode spacing and survey type

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Key Points

- different ferrous iron phases control CrO_4, NO_3, RDX reduction and correlate to frequency-specific imaginary conductivity:

component	frequency (Hz)
ads. Fe^{2+}	0.1 to 10 Hz, increase
FeS, FeS2	0.001 to 0.1, decrease
2:1 clay(Fe^{2+})	0.001-0.01, increase
microbes	1.0 to 30, increase

- SIP imaginary conductivity response somewhat sediment specific, so technology response in one sediment may not be the same in a different sediment

- SIP could predict redox changes for two technologies (Na-dith., CPS), partial prediction for bioreduction (cannot correlate to Fe^{2+} or microbial biomass)

- SIP could be very useful at field scale to predict reduced PRB long-term performance; limitations can be evaluated using sediments in laboratory studies

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Questions?

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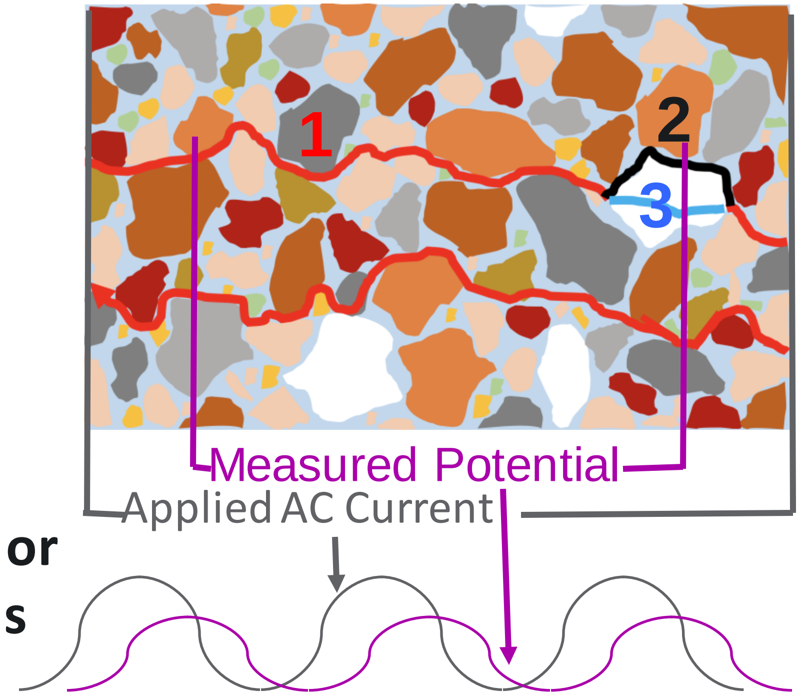
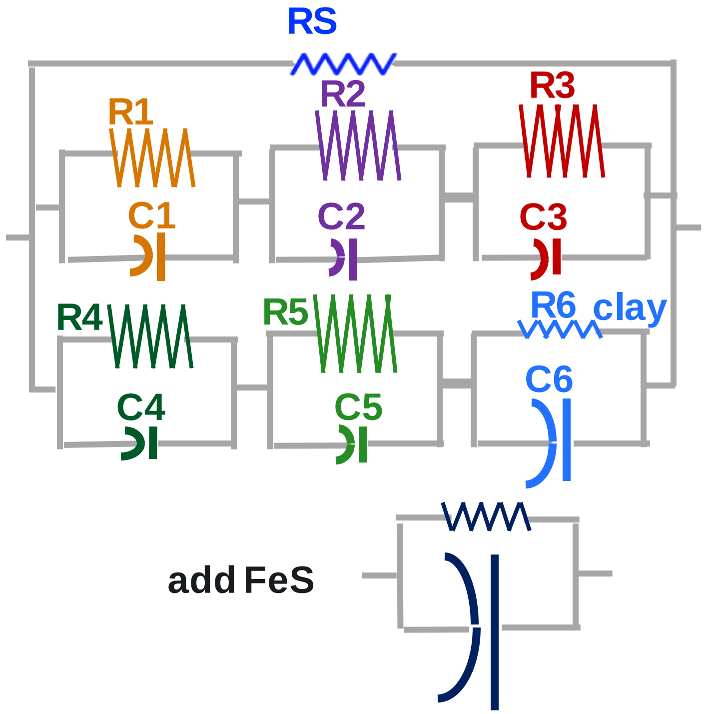
Spectral Induced Polarization (SIP) in Sediments

Electrical current (DC or AC) flow in:

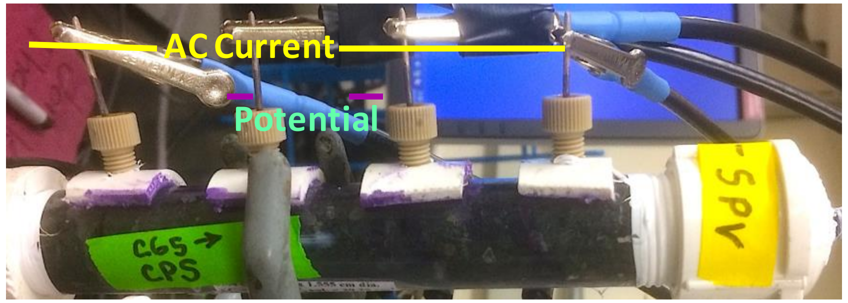
1. fluid (significant)
2. along surface, EDL (significant) [surface ppt., adsorbed ions]
3. in particles (small)





AC Raw Data: freq. vs resistivity, phase

φ phase angle: induced polarization or charge storage from ads. ions/solids (not solution ions)



Post-Model Data: w/system geometry

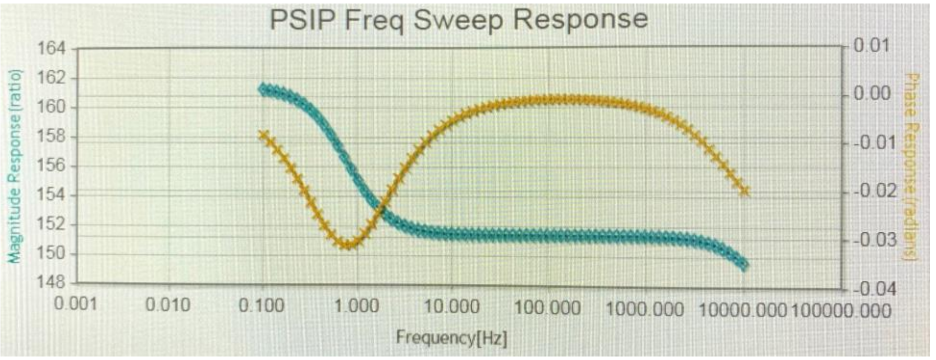
σ' real conductivity: pore water

σ'' imaginary conductivity: ~surface conductivity

$$\varphi = \tan^{-1}[\sigma''/\sigma']$$

$$\sigma' = (1/F)\,\sigma_w + \sigma'_{surf}$$

F = formation factor



larger capacitor = lower frequency shift