Integrating induced polarization & spectroscopy into microfluidics to map apatite precipitation for subsurface remediation

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Summary

We tested whether the noninvasive, low-cost induced polarization (IP) method can directly track hydroxyapatite precipitation and resulting pore clogging. In a microfluidic pore network relevant to U/Sr remediation, injecting pre-formed apatite particles produced a strong IP signal diagnostic of blockage; co-located optical microscopy and Raman confirmed hydroxyapatite in pores. A flow-through test with calcium–citrate–phosphate solutions generated a smaller IP signal because clogging was limited. These results quantitatively link precipitation to IP signatures and support monitoring and scale-up for field remediation at the Hanford river corridor.

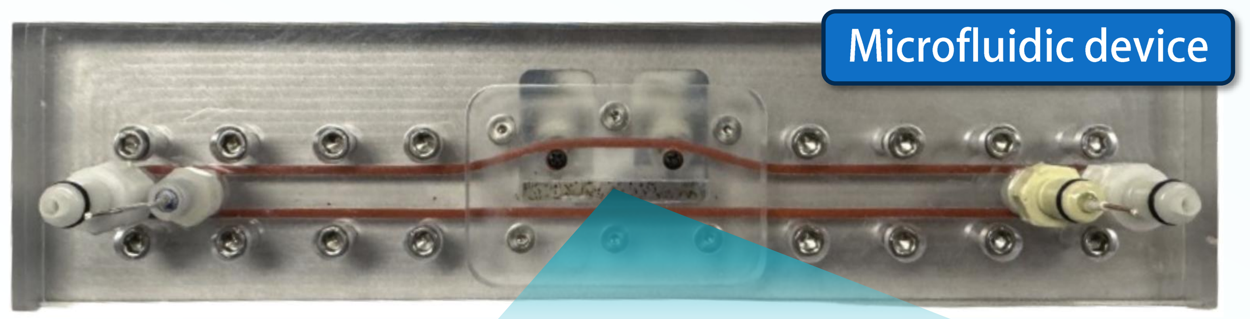
Introduction

- In situ precipitation of hydroxyapatite is a common approach for sequestration of radionuclides like uranium and strontium
- Monitoring formation of hydroxyapatite in these conditions is often challenging and expensive
- Geoelectrical methods like induced polarization (IP) may be an effective, non-invasive, low-cost approach for monitoring mineral-surface changes underground
- Challenge: Pinpointing the mechanisms controlling the IP response in these complex systems is understudied
- Utilizing a microfluidic pore network, we can investigate hydroxyapatite precipitation under controlled conditions

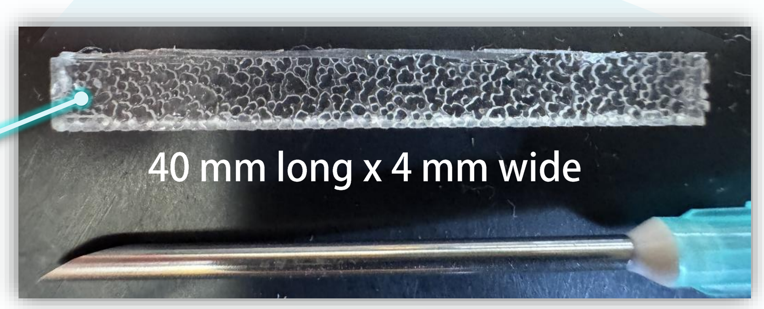
Materials

- The microfluidic cell consists of a synthetic pore network, two current electrodes, two sensing (potential) electrodes, and fluid flow ports on each ends
- Calcium citrate phosphate solutions slowly precipitate hydroxyapatite as citrate is degraded by microbes

Microfluidic device



Synthetic pore network



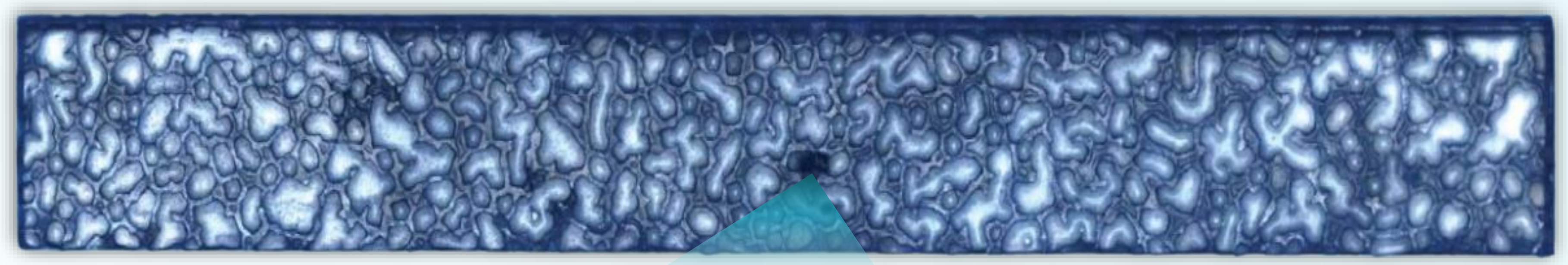
Induced polarization measurements will be supplemented with Raman spectroscopy & optical microscopy

Approach

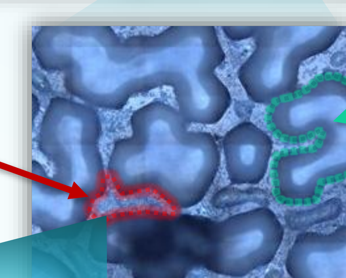
Experimental workflow

1. Microfluidic cell is saturated with river water → Measure IP signal; Image pore network
2. Cell is (a) treated with calcium citrate phosphate to form hydroxyapatite or (b) injected with pre-formed hydroxyapatite → Measure IP signal; Image pore network
3. Cell is flushed with river water → Measure IP signal

Hydroxyapatite detection (imaging)

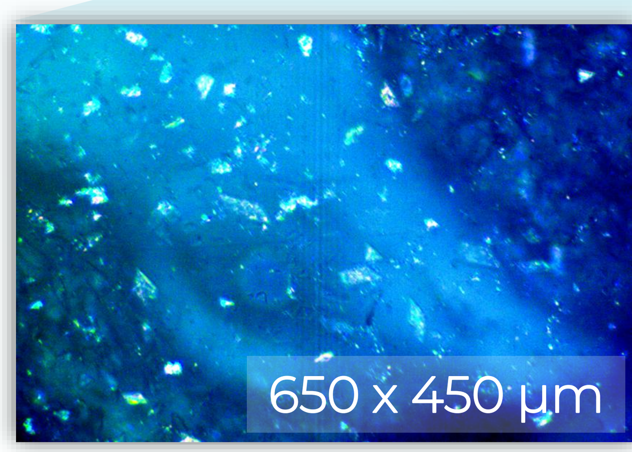


Preliminary imaging of apatite-filled pore network

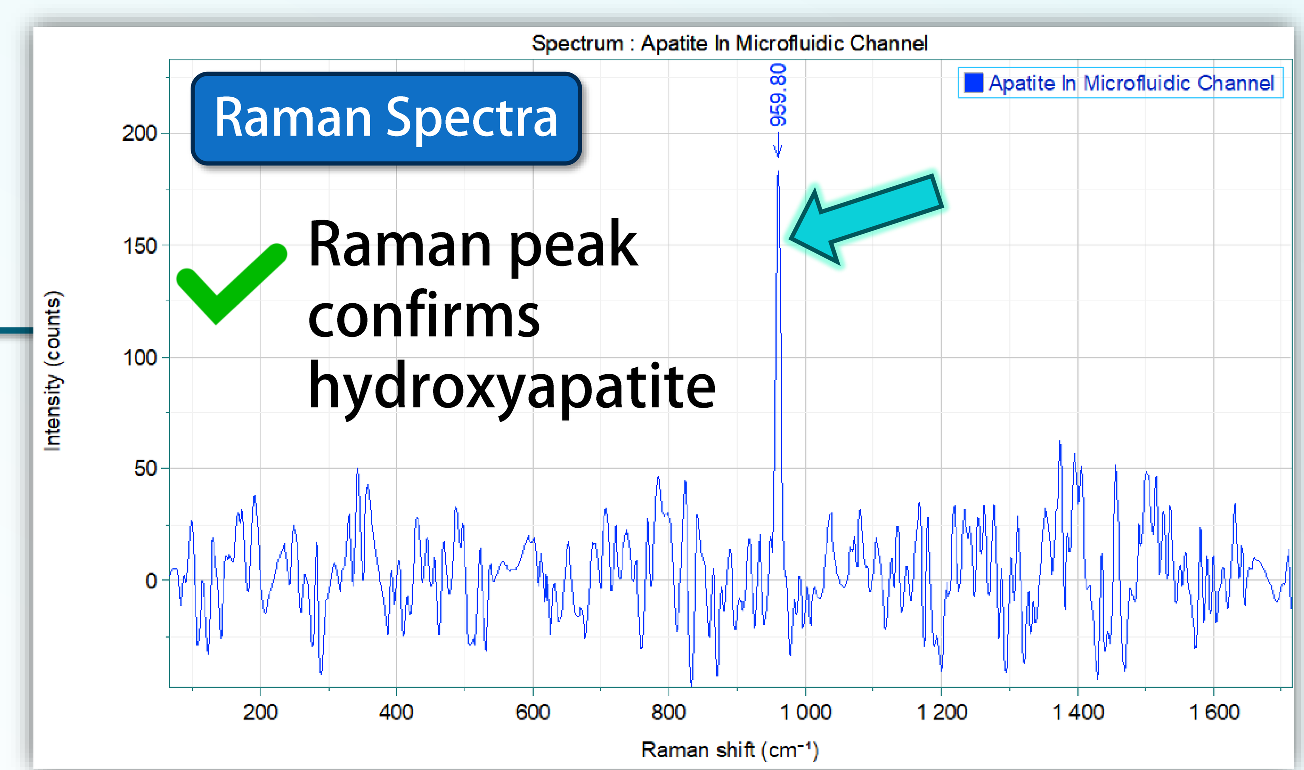


Pore space filled with hydroxyapatite

Pore wall



Lighter crystals are hydroxyapatite

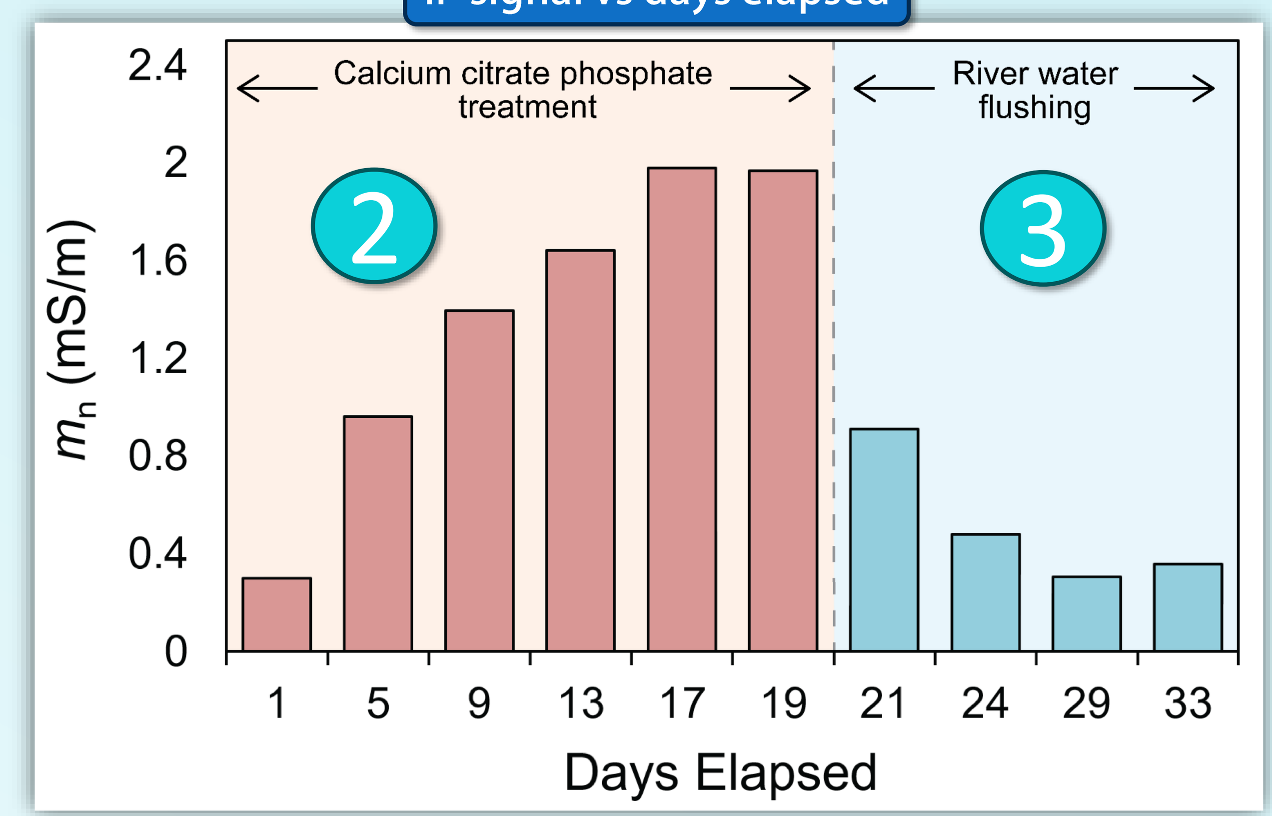


Results

Calcium Citrate Phosphate Precipitation/Dissolution

2 and 3 below refer to the experimental workflow

IP signal vs days elapsed



We observe a notable IP signal in the cell change after treatment

Conclusions

- IP signals, though small, can effectively track hydroxyapatite precipitation at the microfluidic scale
- Preliminary tests on pre-formed apatite show it is detectable in the cell via Raman spectroscopy & microscopy
- Results contribute to the conceptual model that will be used to interpret field-scale monitoring during remediation

Acknowledgements

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