Advanced CO2 Leakage Mitigation using Engineered Biomineralized Sealing Technologies

Project Number FE0004478

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U.S. Department of Energy

National Energy Technology Laboratory

Carbon Storage R&D Project Review Meeting

Developing the Technologies and Building the Infrastructure for CO_2 Storage

August 21-23, 2012

Presentation Outline

- Motivation
- Background information
- Large core tests – ambient pressure
- Large core tests – high pressure

Benefit to the Program

Program goals being addressed.

Develop technologies to demonstrate that 99 percent of injected CO_2 remains in the injection zones.

Project benefits statement.

The Engineered Biomineralized Sealing Technologies project supports Storage Program goals by developing a leakage mitigation technology for small aperture leaks that can be delivered via low viscosity solutions.

Project Overview:
Goals and Objectives

The goal of this project is to develop a biomineralization-based technology for sealing preferential flow pathways in the vicinity of injection wells.

- **Objective 1) Construct and test mesoscale high pressure rock test system (HPRTS).**
- **Objective 2) Develop biomineralization seal experimental protocol.**
- **Objective 3) Creation of biomineralization seal in different rock types and simulating different field conditions.**

Target metrics for technology performance.

- ***1) Demonstrate the ability to control the spatial distribution of the biobarrier on the 1 meter scale.***
- ***2) Achieve a 3-4 order of magnitude reduction in permeability and a 10 to 25 fold increase in capillary entry pressure.***
- ***3) Develop a barrier growth protocol consistent with field deployment***

Abandoned Well Leakage Mitigation Using Biomineralization

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Richard Esposito – Southern Company

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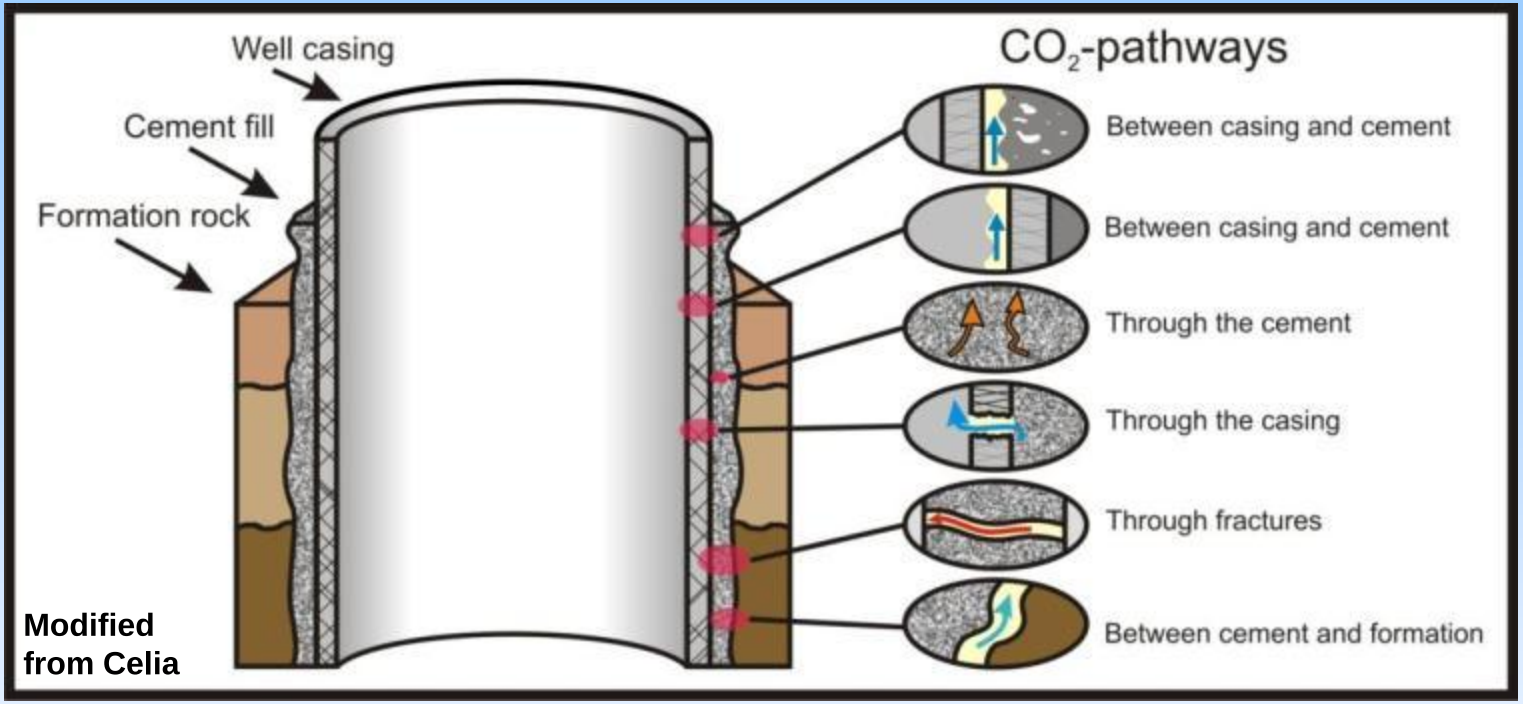
How Can We Plug Small Aperture Leaks?



Cement is a good technology for large aperture leaks, but is too viscous to plug small aperture leaks such as small fractures or interfacial delaminations

In some problematic cases it may be desirable to plug the rock formation around the well.

A missing tool is a plugging technology that can be delivered via low-viscosity fluids

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How Can We Plug Small Aperture Leaks?

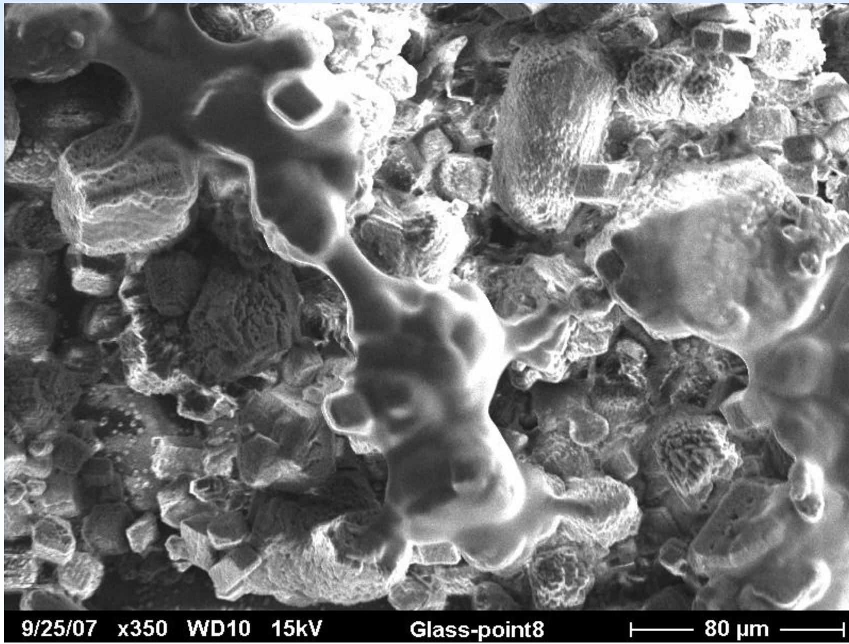
Approach

Deliver materials separately in low-viscosity aqueous solutions and grow the barrier in place

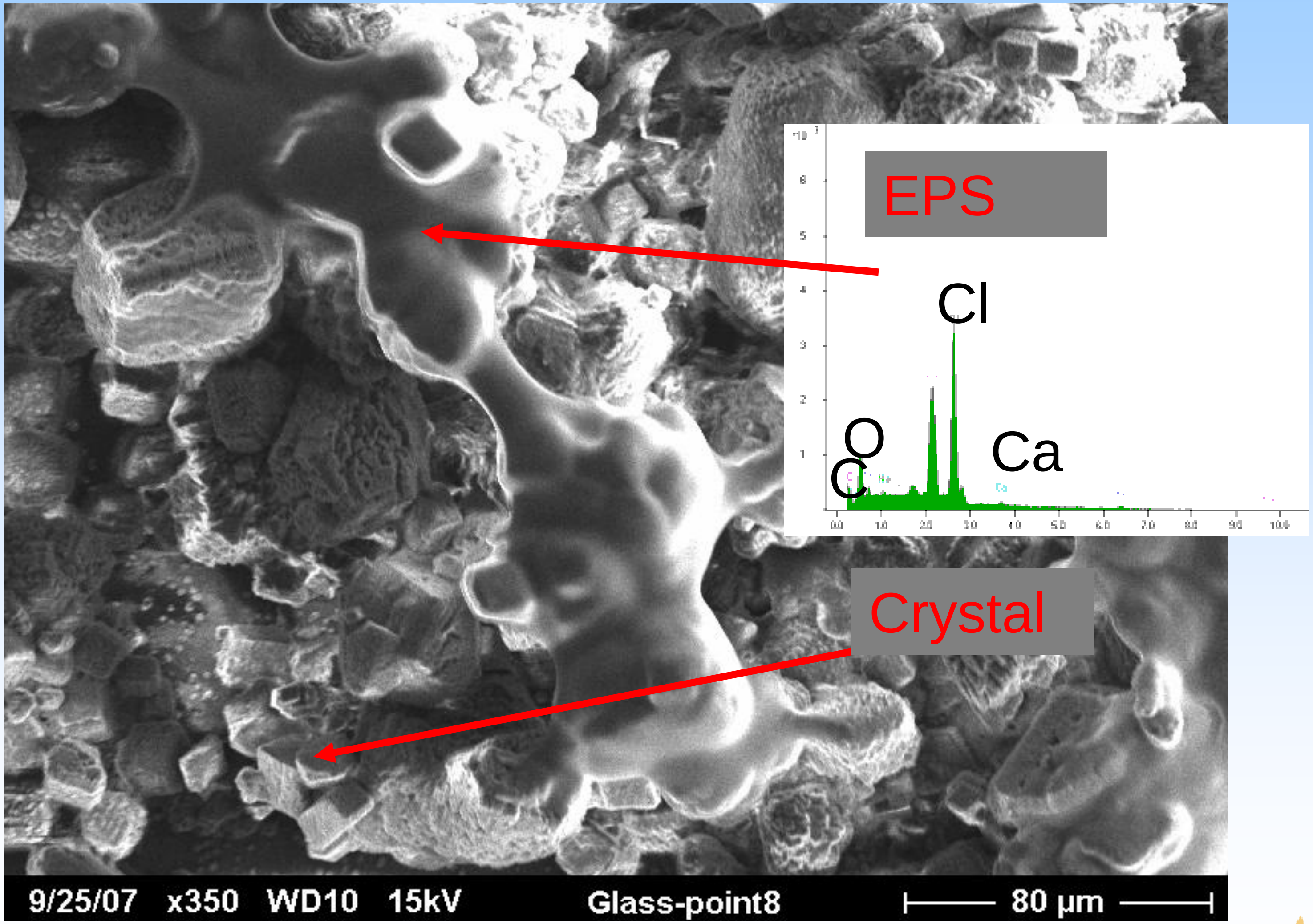
Bacteria with urealytic enzyme

Nutrients – induce biofilm growth

Urea – Induce biomineralization



Biomineralizing Biofilms



Multiple Groups are Investigating Applications for Biomineralization

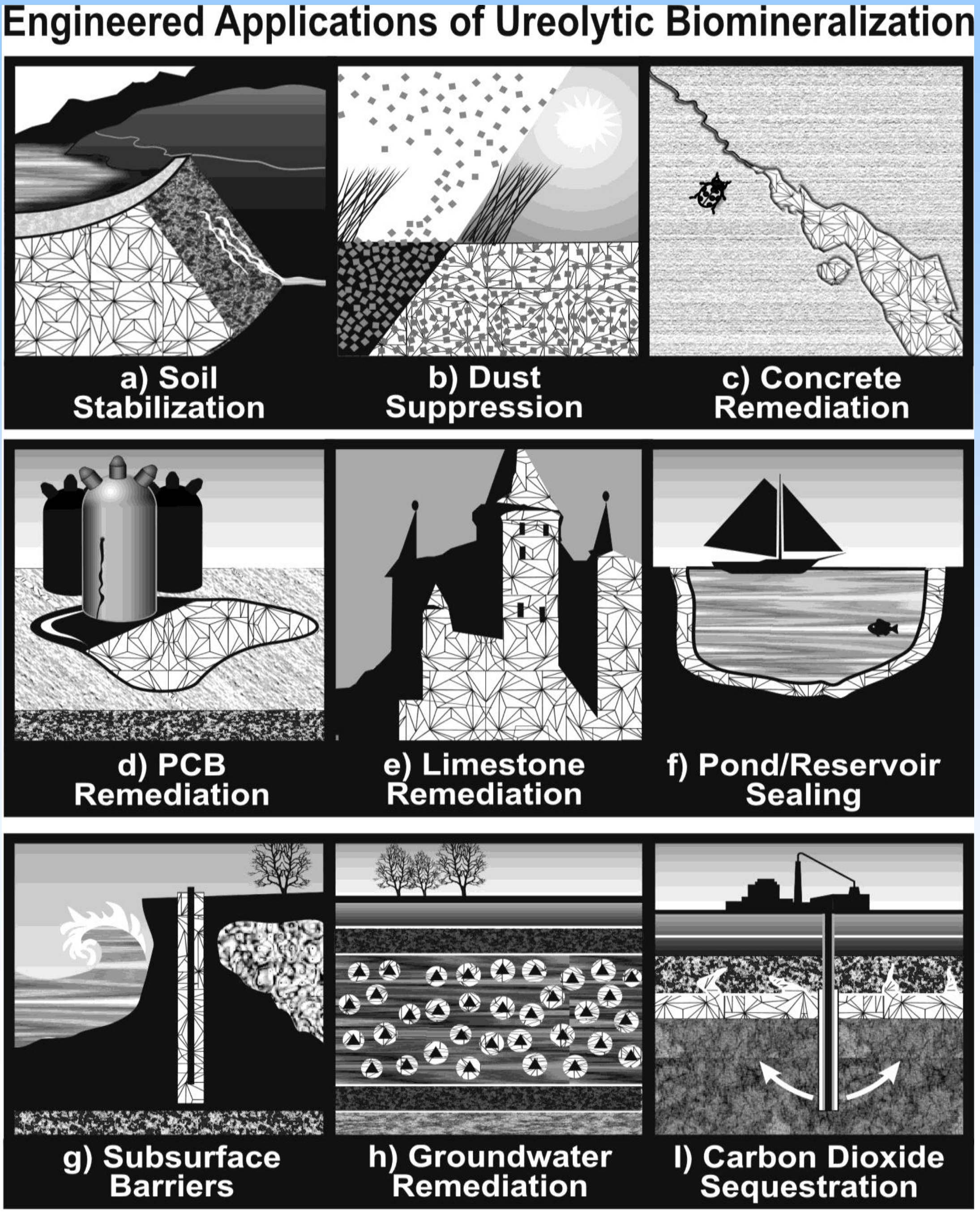


Figure 1. Several potential (but not limited to) engineering applications for ureolysis-driven MICP. Note: in this figure the white crystal hatch pattern represents calcium carbonate a) strengthening earthen dams or consolidating porous materials, b) application to soils to prevent dust c) remediating concrete fractures d) coating PCB-oil contaminated concrete resulting from leaky transformers e)treating or coating limestone or concrete to reduce risk of corrosive fluid infiltration f)creating ponds or reservoirs by sealing porous materials g) forming subsurface barriers to prevent unwanted fluids like salt water intrusion or contaminated groundwaters into drinking water aquifers h) remediating subsurface groundwater contaminated with radionuclides or heavy metals(represented by triangles) with co-precipitation of $CaCO_3$ i) treating fractures in cap rock to mitigate leakage from geologically sequestered carbon dioxide injection sites or coating well bore concrete to provide a sacrificial coating to prevent concrete degradation from supercritical CO_2.

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Research Challenges

To move this technology forward it must be demonstrated that:

- **Mineral deposits can be formed at a field relevant scale under environmental conditions appropriate to subsurface reservoirs**
- **Mineral deposition can be kept uniform over relevant distances (meter scale)**
- **The degree of sealing in disturbed rock, cement, and cement-well bore interface reaches an acceptable level**
- **Biomineral deposits are stable when exposed to brine/$ScCO_2$**
- **Ureolytic organisms can be isolated from the field**
- **Acceptable field injection protocols can be developed**

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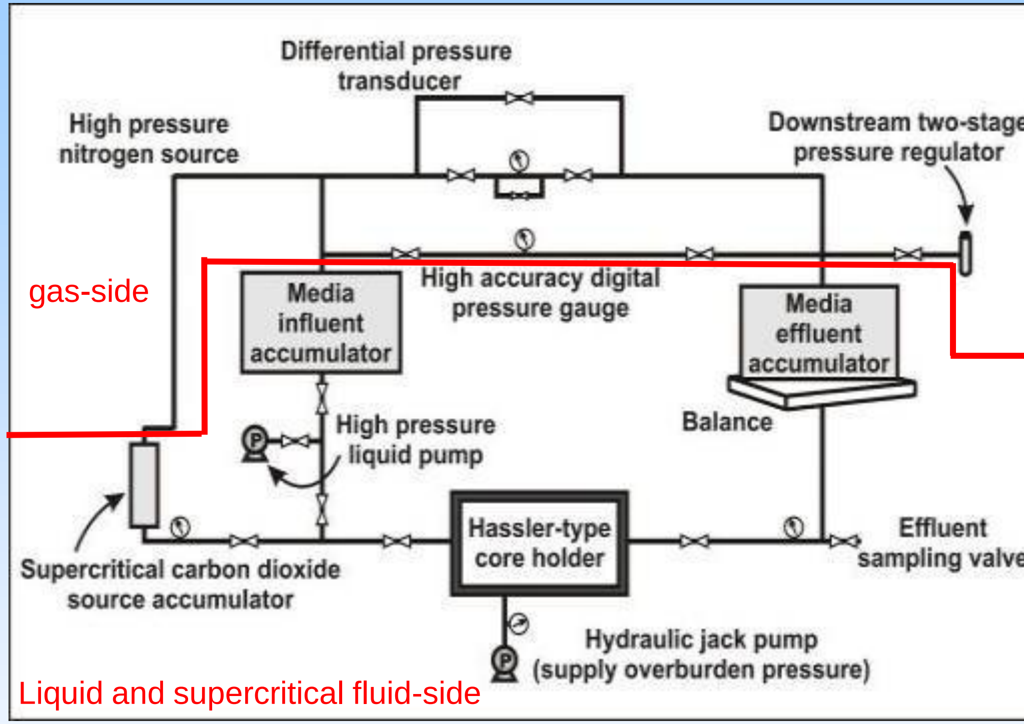
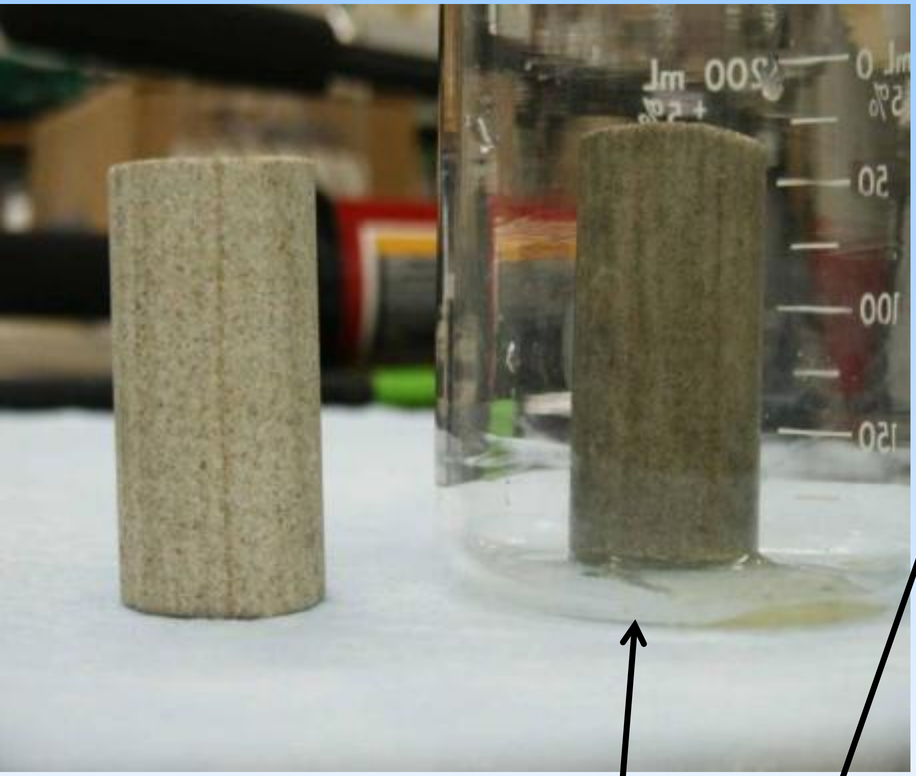
High Pressure Biofilm Growth and Biomineralization Test System



- **p up to 2000 psi (130 bar), T ambient to 65 C**
- **consolidated and unconsolidated material up to 6 in length**

MITCHELL, A.C.; PHILLIPS, A.J.; HIEBERT, R.; GERLACH, R.; SPANGLER, L.; CUNNINGHAM, A.B. (2009): Biofilm enhanced geologic sequestration of supercritical CO_2. The *International Journal on Greenhouse Gas Control*. 3:90-99. doi:10.1016/j.ijggc.2008.05.002

Rock Core after Biofilm Growth & $ScCO_2$ Challenge



Clean

Biofilm-Affected

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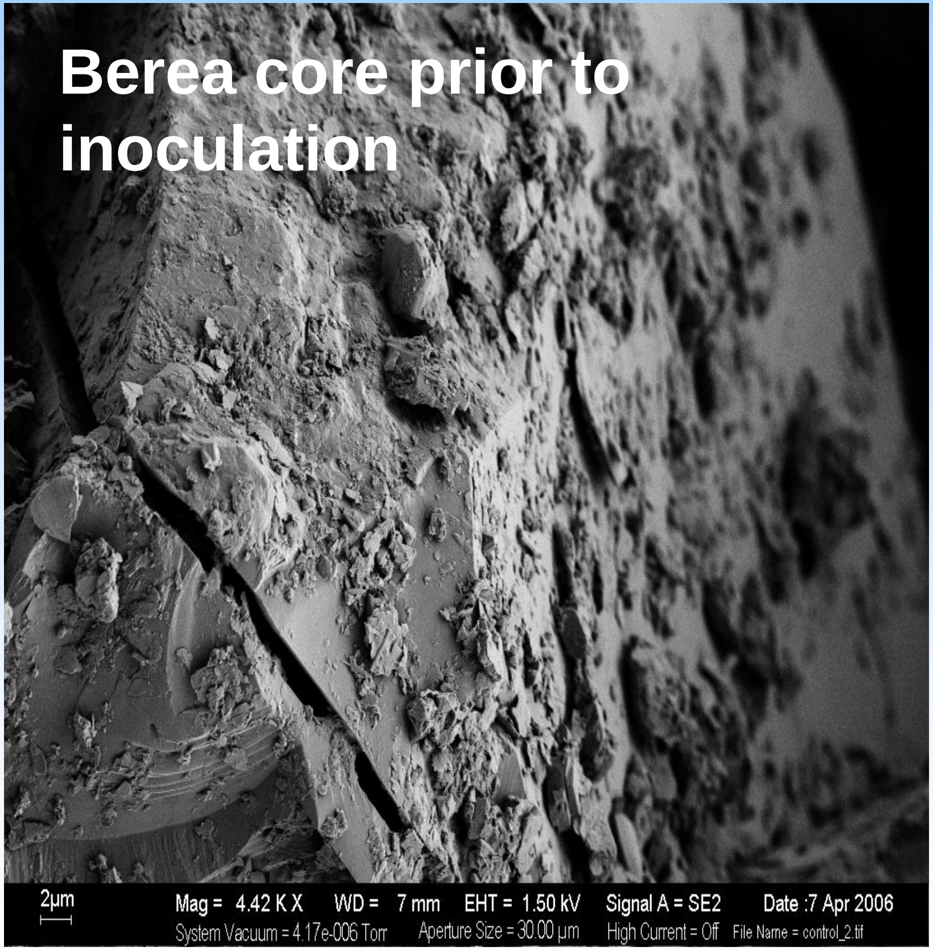
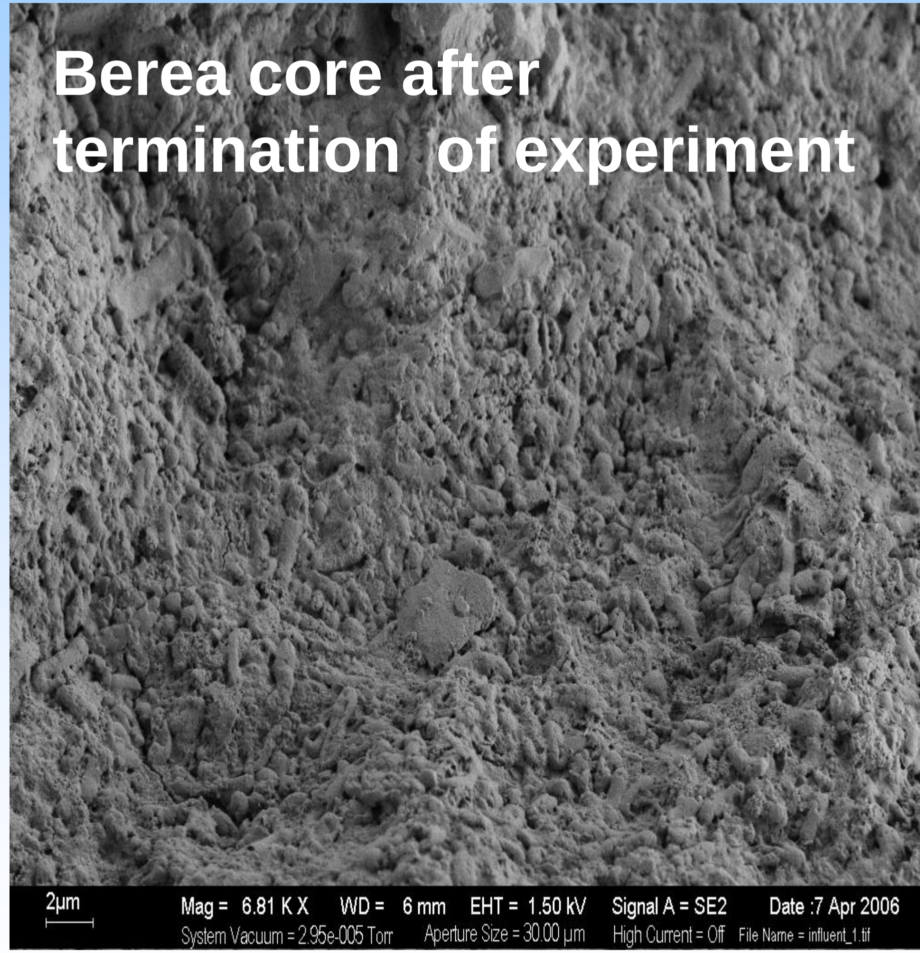
Rock Core after Biofilm Growth & $ScCO_2$ Challenge – SEM Images & Summary





MITCHELL ET AL. (2009) *IJGGC*. 3:90-99.
doi:10.1016/j.ijggc.2008.05.002

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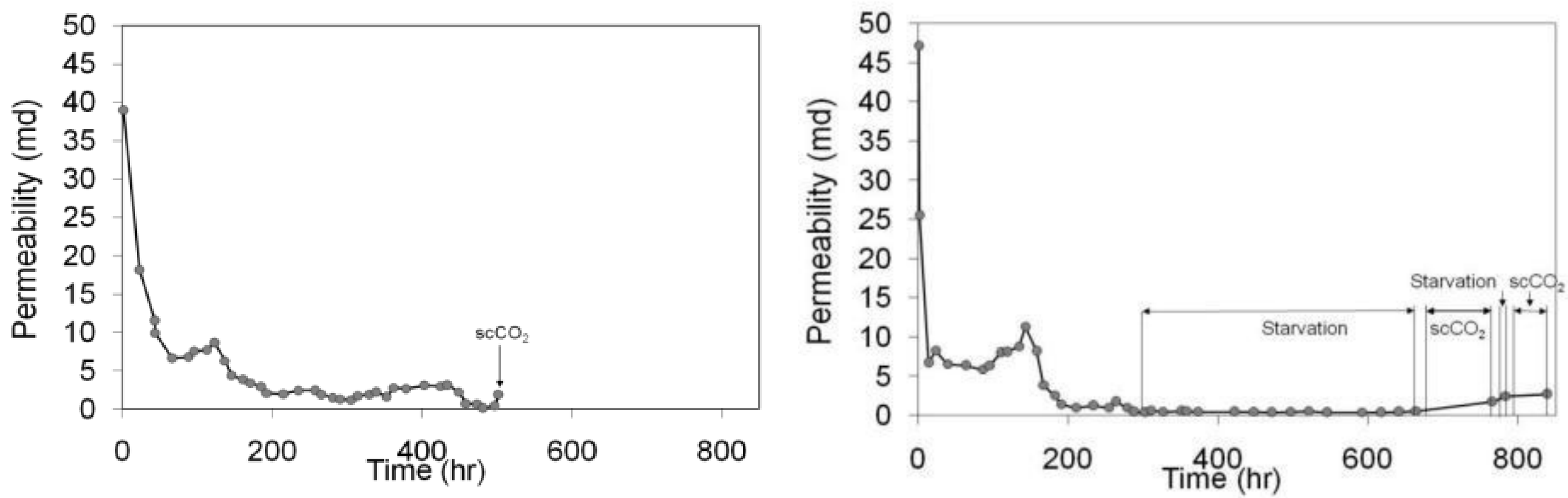
Biofilm growth and permeability reduction at high pressure



MITCHELL, A.C.; PHILLIPS, A.J.; HIEBERT, R.; GERLACH, R.; SPANGLER, L.; CUNNINGHAM, A.B. (2009): Biofilm enhanced geologic sequestration of supercritical CO_2. The *International Journal on Greenhouse Gas Control*. 3:90-99. doi:10.1016/j.ijggc.2008.05.002

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Ureolysis driven carbonate precipitation

+ pH and alkalinity (increase in OH^- and HCO_3^-) increase SATURATION STATE OF CALCITE

$$CO(NH_2)_2 + H_2O \rightarrow NH_2COOH + NH_3$$
$$NH_2COOH + H_2O \rightarrow NH_3 + H_2CO_3$$

$$CO(NH_2)_2 + 2\ H_2O \rightarrow 2\ NH_3 + H_2CO_3 \qquad \text{(Urea hydrolysis)}$$

$$2NH_3 + 2H_2O \leftrightarrow 2NH_4^+ + 2OH^- \qquad \text{(pH increase)}$$

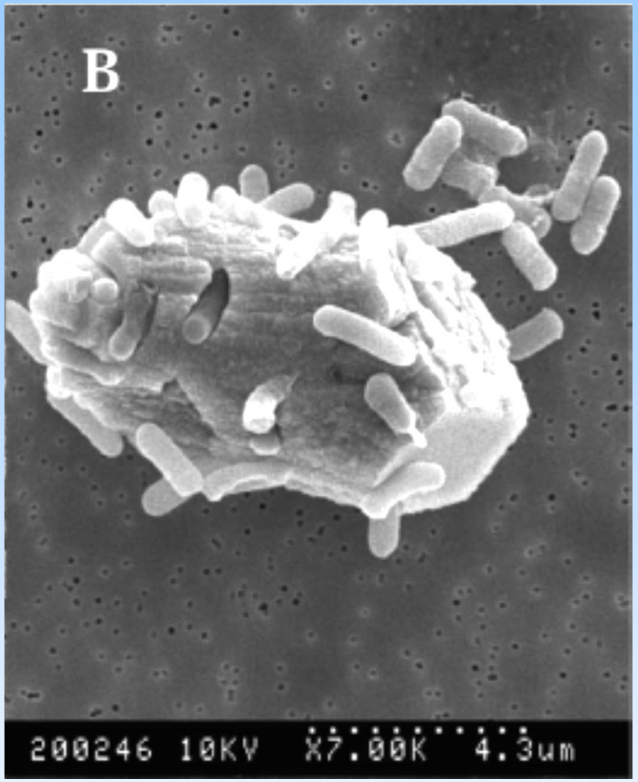
$$H_2CO_3 + 2OH^- \leftrightarrow HCO_3^- + H_2O + OH^- \leftrightarrow CO_3^{2-} + 2\ H_2O$$

$$CO_3^{2-} + Ca^{2+} \leftrightarrow CaCO_3 \qquad \text{(carbonate precipitation)}$$

(i) Permeability reduction

(ii) Co-precipitation of metals

(iii) Mineralization of CO_2



Mitchell, AC and Ferris, FG (2006) *Geomicrobiology Journal* , 23, 213-226.

Mitchell, AC and Ferris, FG (2006) *Environmental Science and Technology, 40, 1008-1014.*

Mitchell, AC and Ferris FG (2005) *Geochimica et Cosmochimica Acta, 69, 4199-4210.*

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Ureolysis-Driven $CaCO_3$ Formation at High Pressure under Pulse-Flow Conditions

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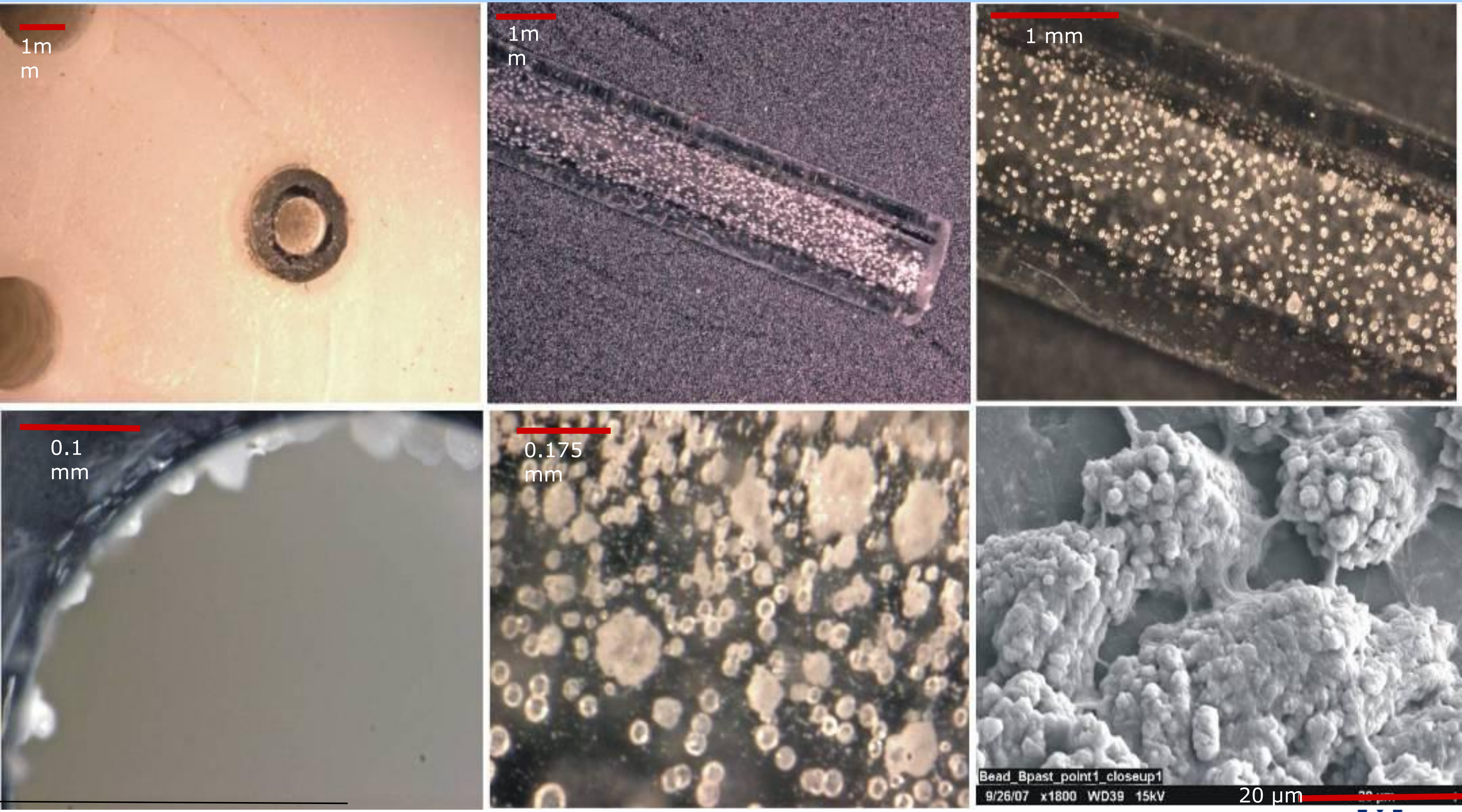
Ureolysis driven $CaCO_3$ formation at 89 bar under pulse-flow conditions



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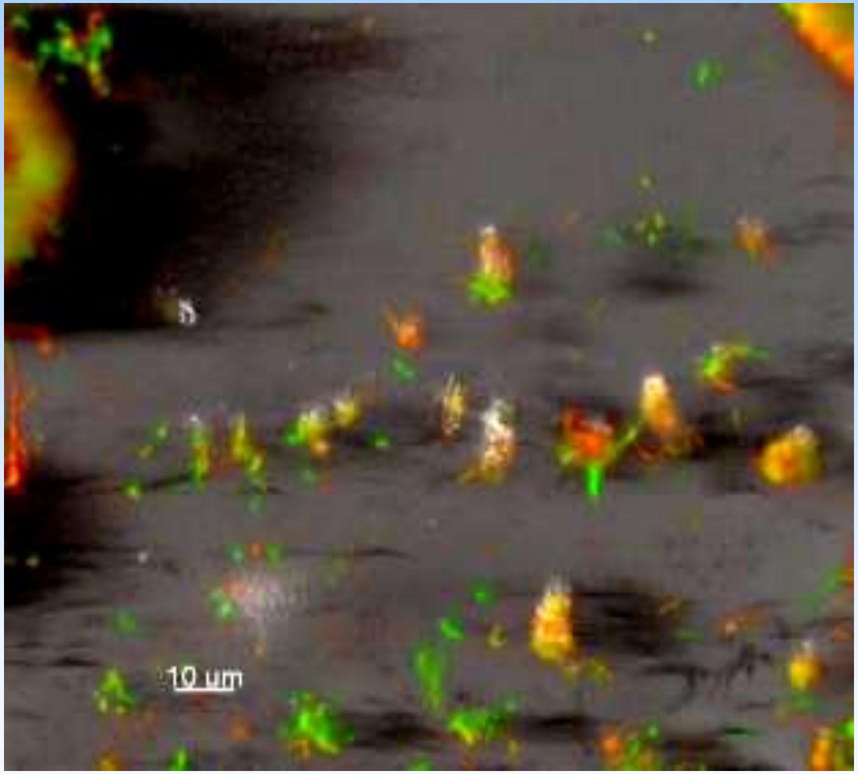
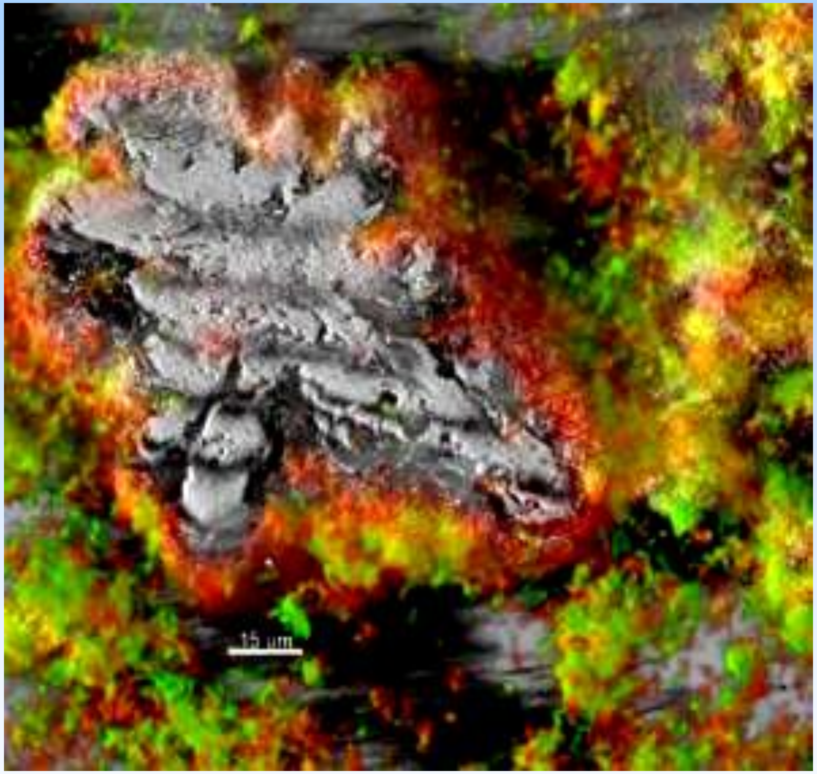
Ureolysis-driven $CaCO_3$ formation





Schultz, Pitts, Mitchell, Cunningham, Gerlach submitted to Microscopy Today

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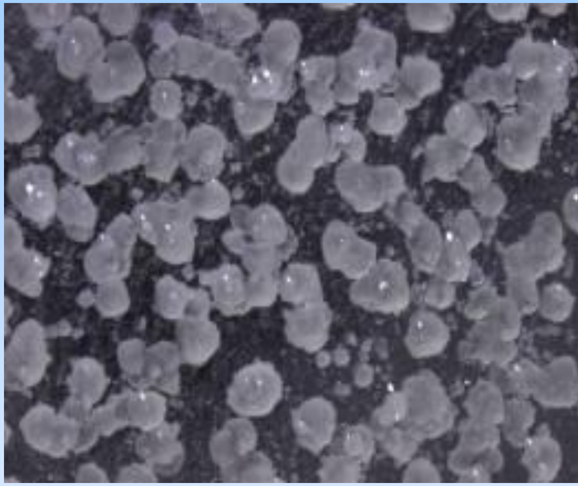
$CaCO_3$/Biofilm Deposits Resist Dissolution

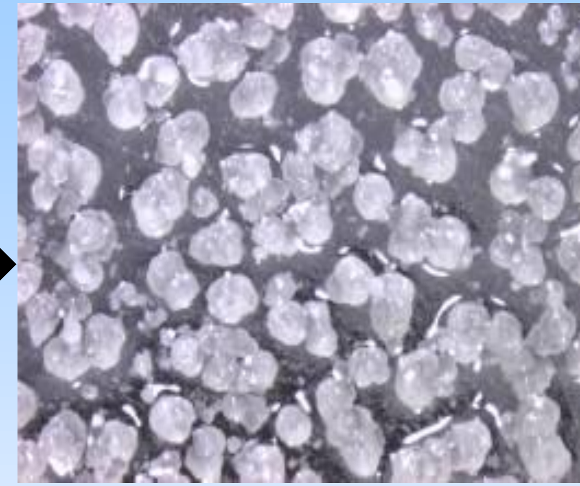
Before exposure

After exposure

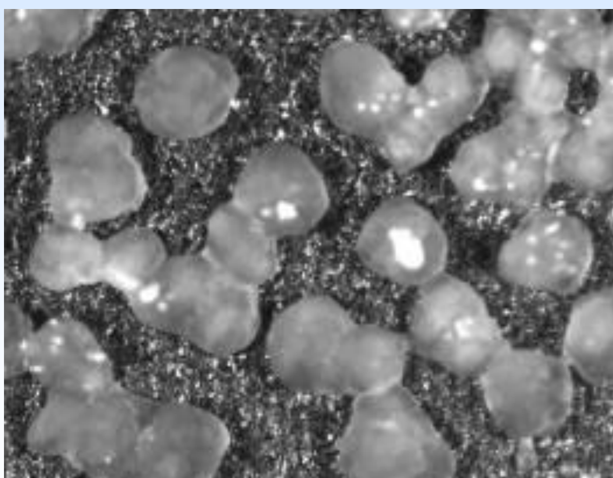
40x



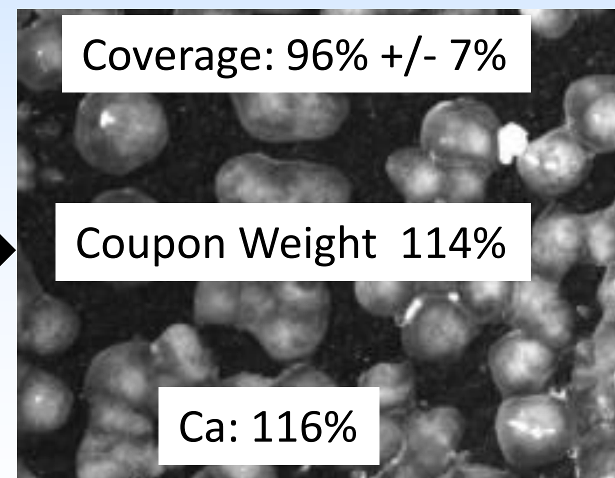
Unsaturated Brine



80x

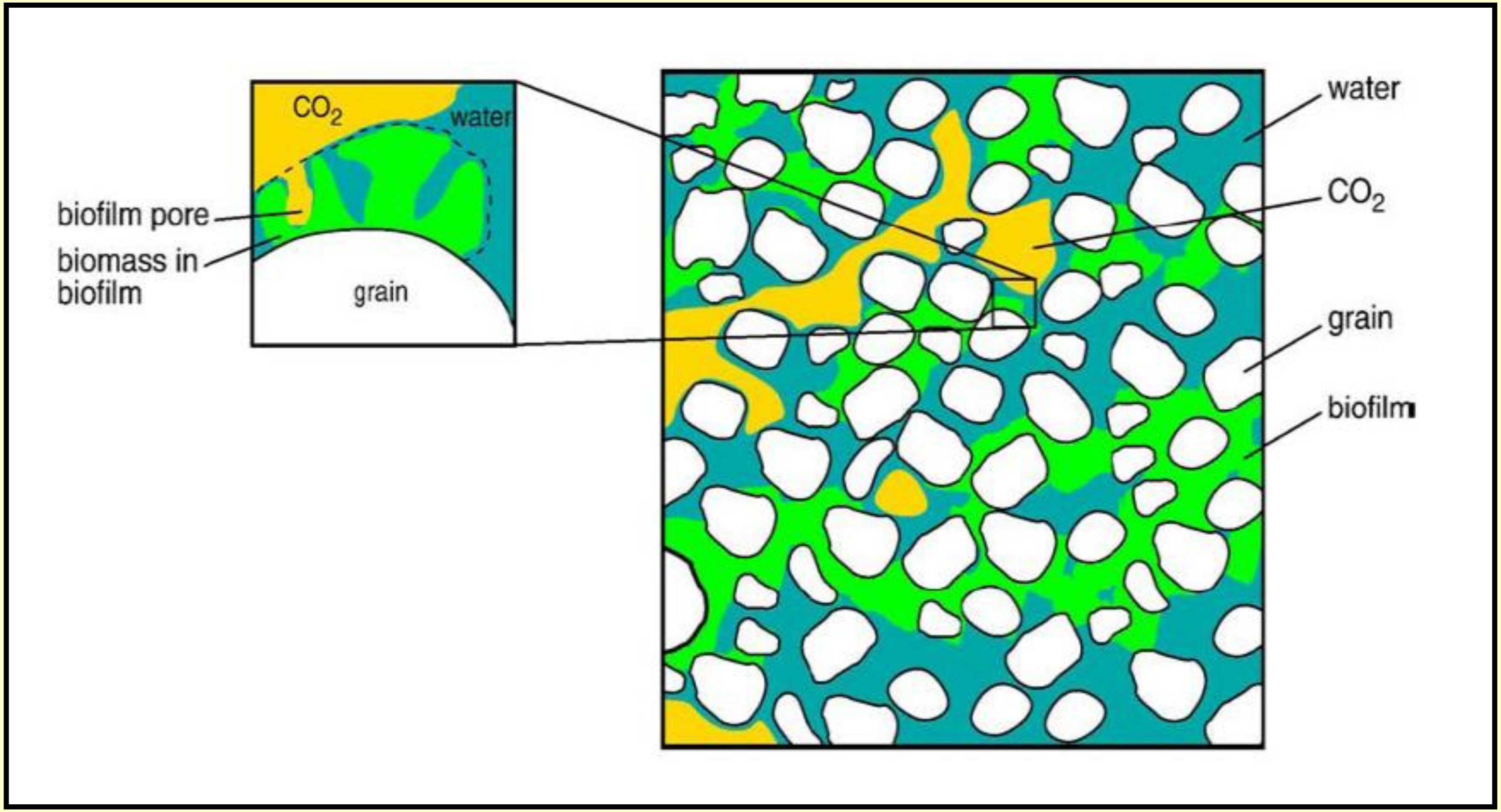


$scCO_2$



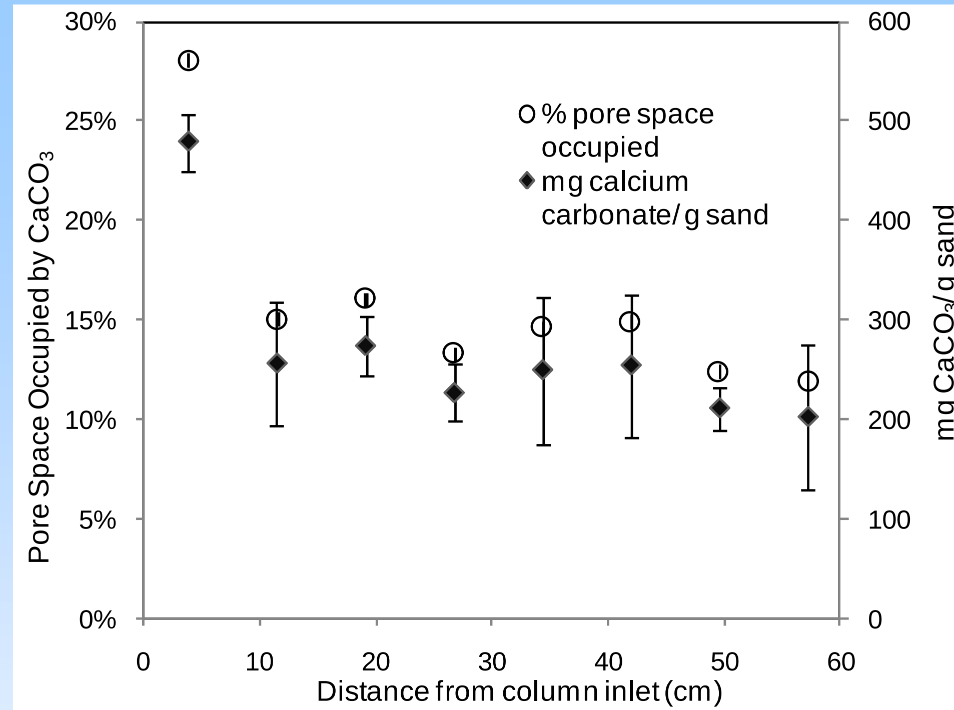
S. Parks

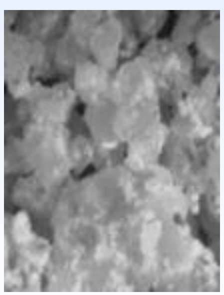
Modeling of Biofilm-ScCO_2 Interactions

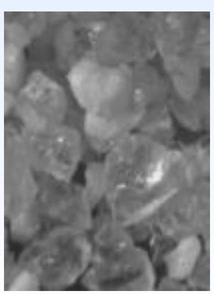


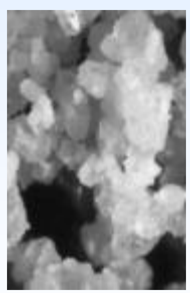
Ebigbo, Helmig, Cunningham, Class, Gerlach (2010) Advances in Water Resources, doi:10.1016/j.advwatres.2010.04.004

Biomineralization along a 2-foot sand column









Volume fraction of calcium carbonate-occupied pore space and $CaCO_3$ concentrations over the distance of a 60 cm column.

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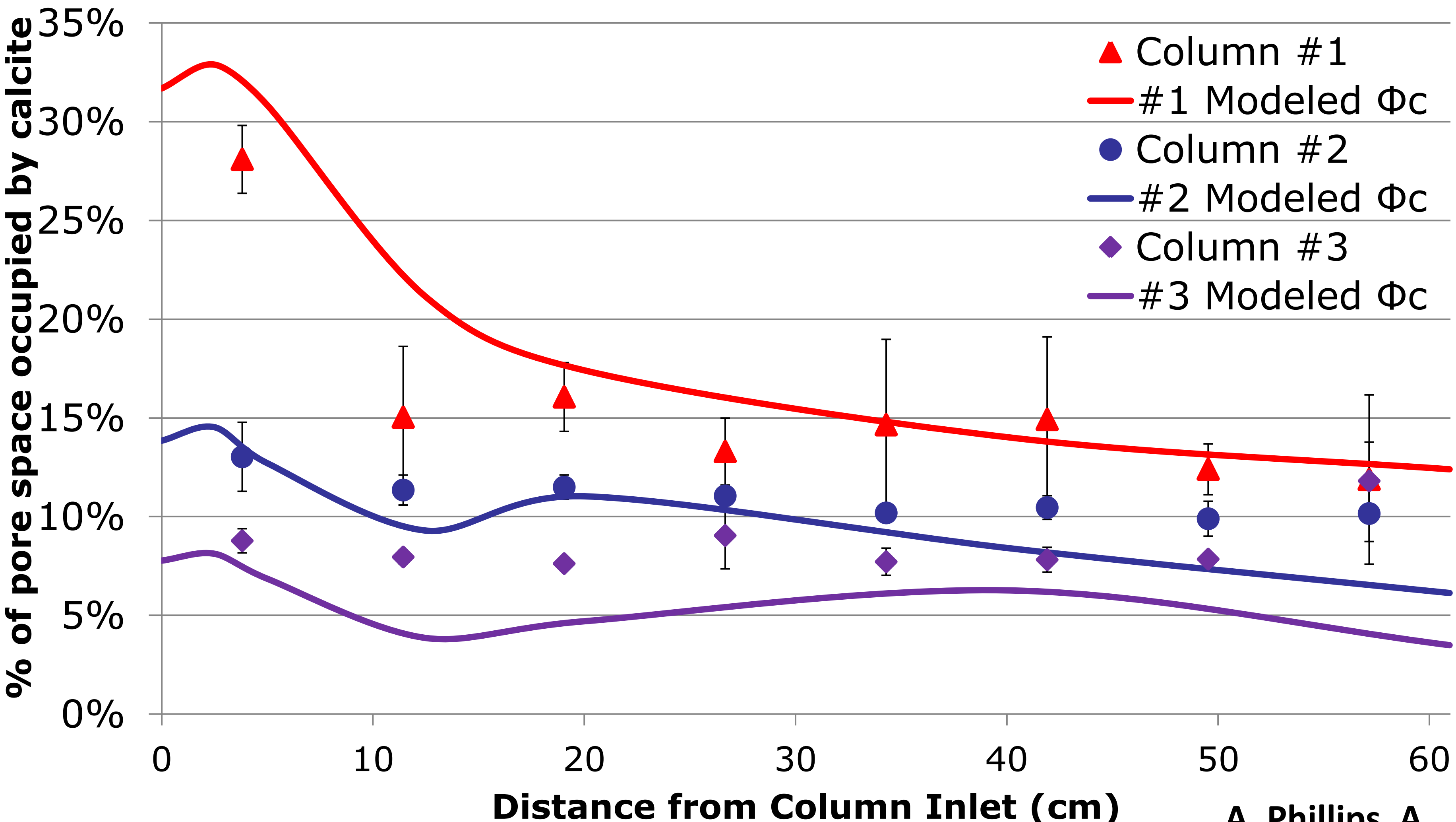
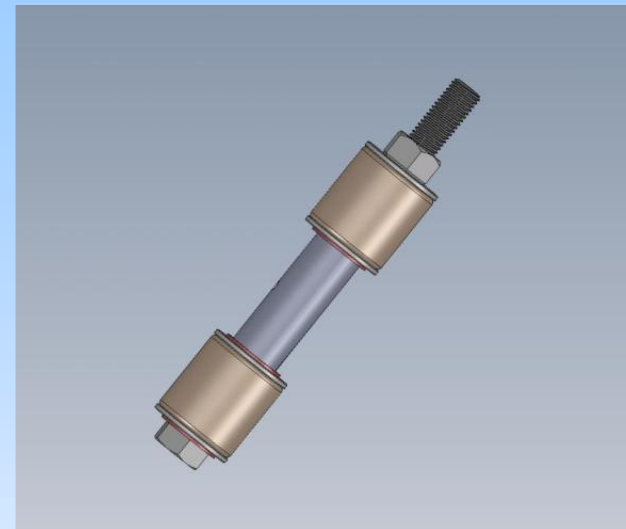
Biofilm Induced Calcium Carbonate Precipitation (2 ft columns)

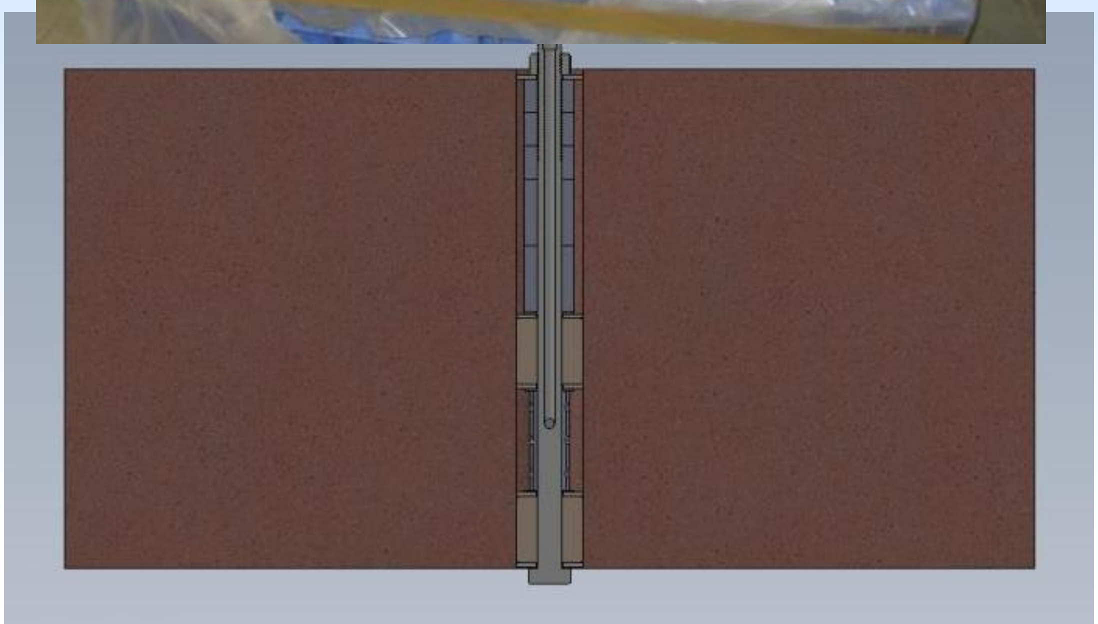


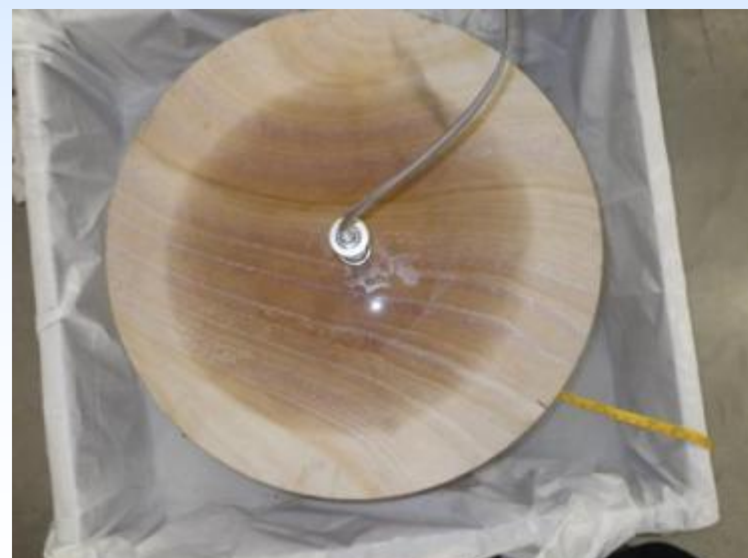
A. Phillips, A. Ebigbo

Mesoscale Biomineralization Research

***Figure 1a**. Sandstone core (30-inch diameter) being extracted in Alabama. **Figure 1b**. Sandstone core undergoing hydraulic testing in the MSU laboratory.*







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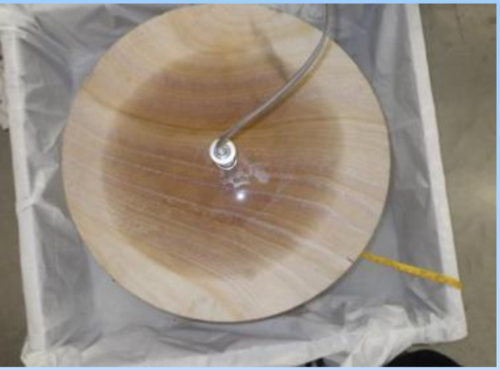
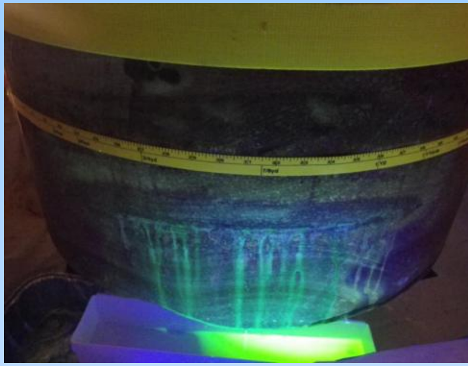
Sealing Fractures



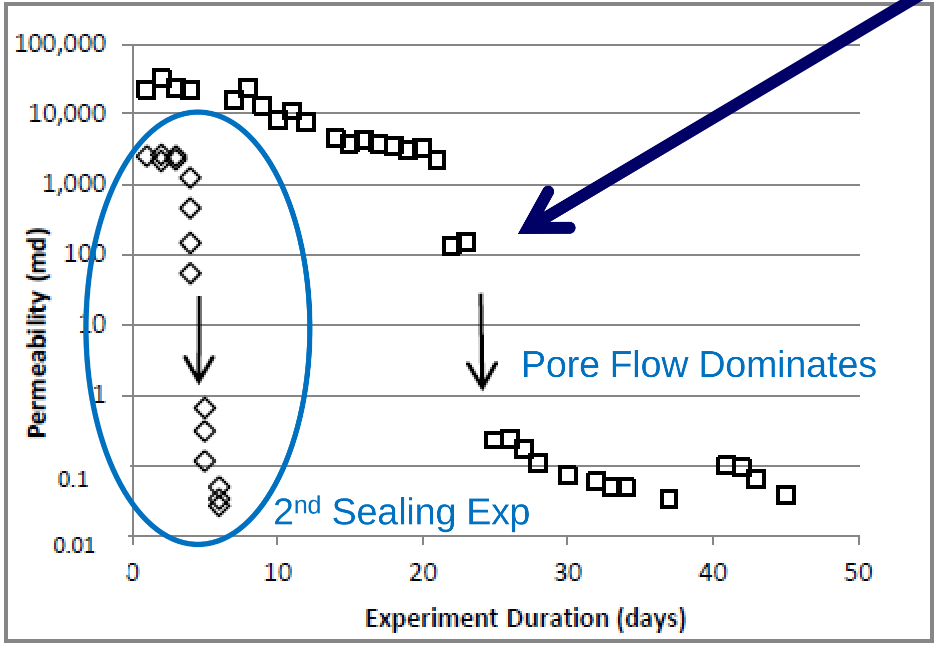


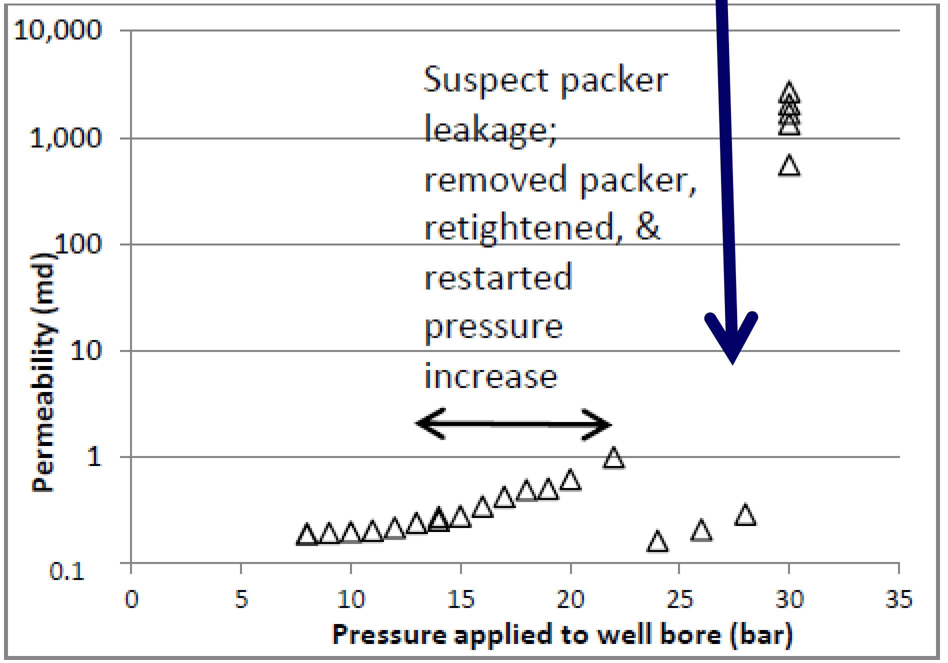
Start Hydrating Core

Fracture Occurs at **8 Bar**

Biomineralize and Seal Fracture

Hydrofrac Again **30 Bar** Required

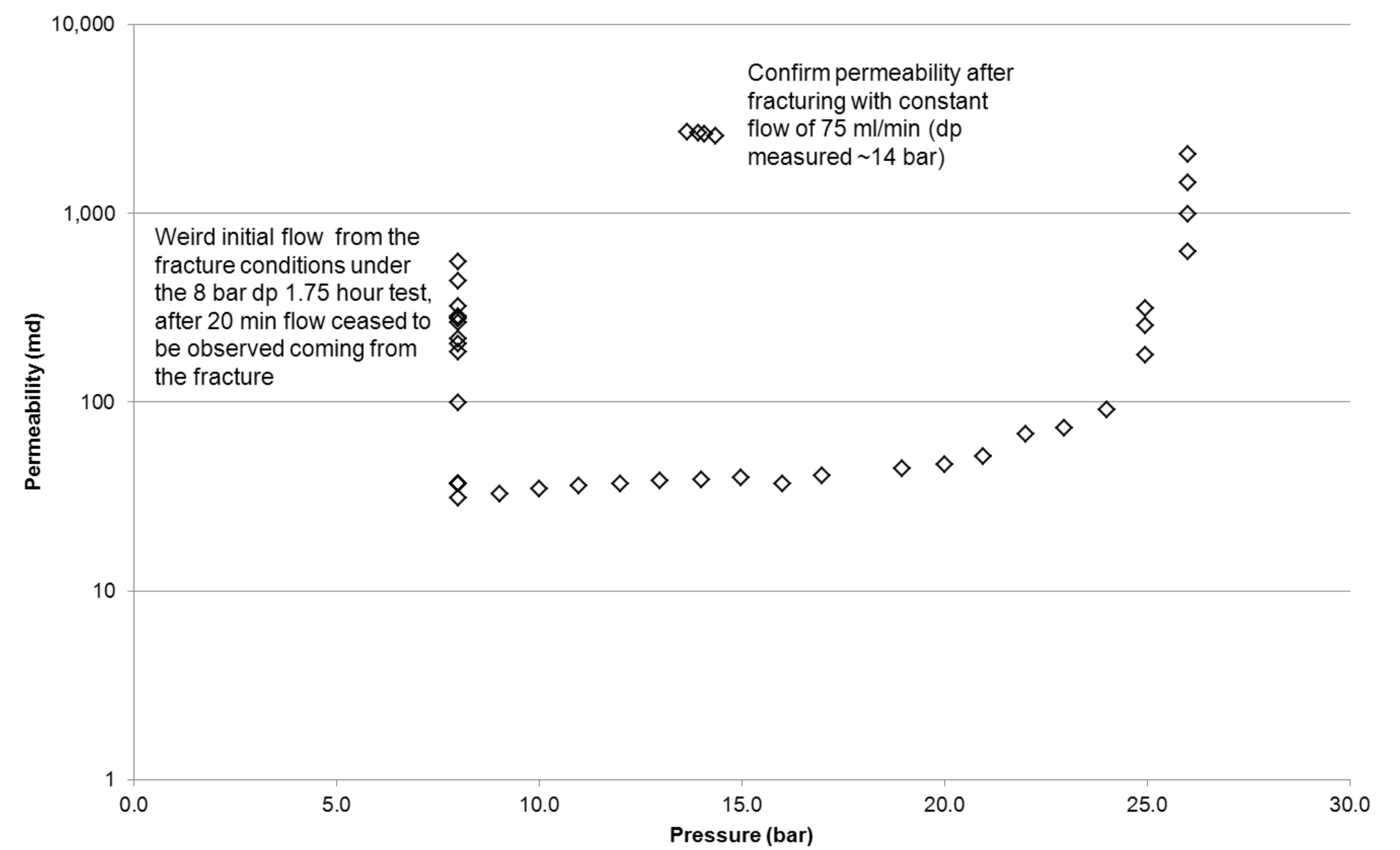




Hydraulic testing of the 71.1 cm (28-inch) diameter Bremen core

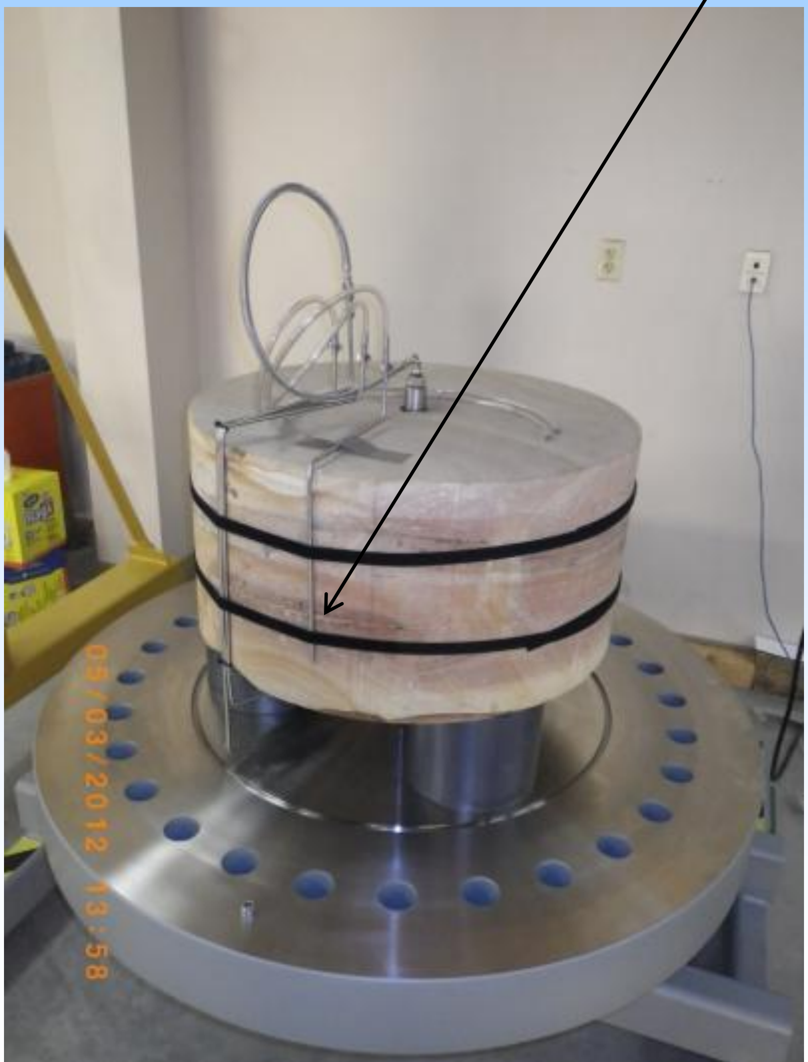
High Pressure Vessel for 30” Cores

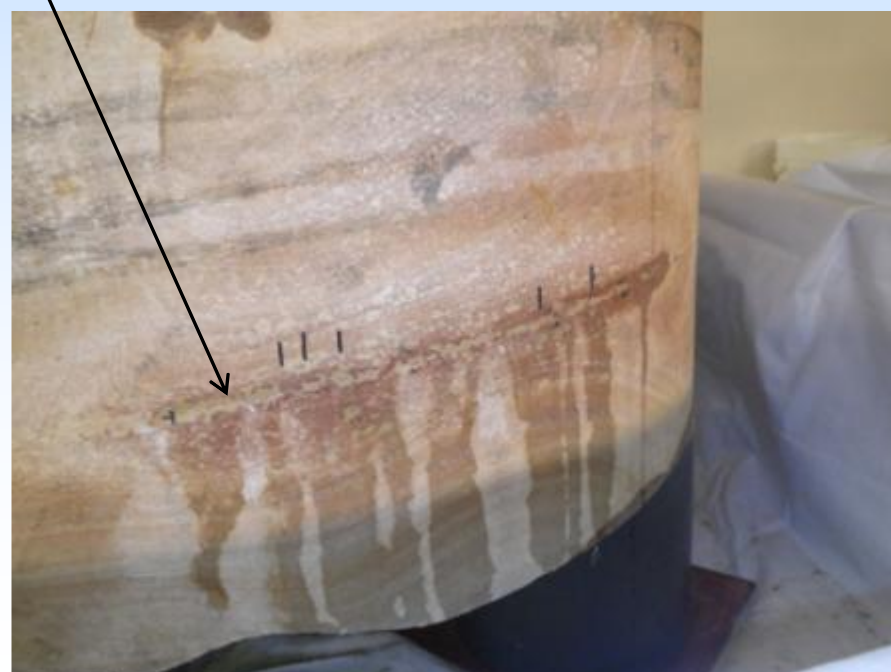
Re-fracturing under ambient conditions after sealing under high pressure



Before Images

Region of fracture





The core was hydraulically fractured under ambient conditions right before loading into the vessel. Distinct flow channels were formed.

During Images

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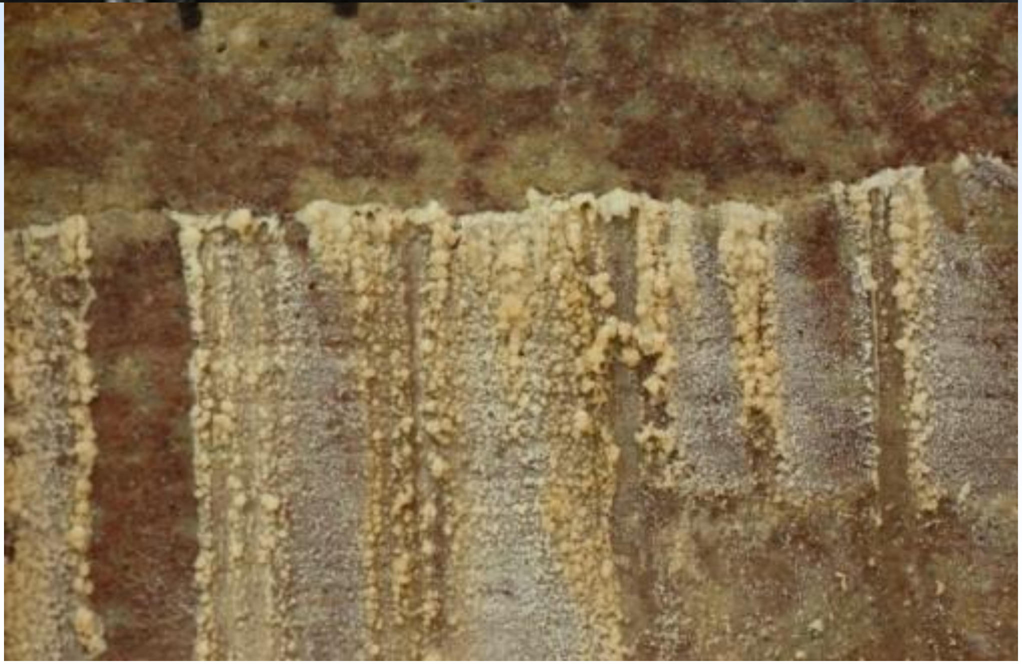
After Images of fracture zone



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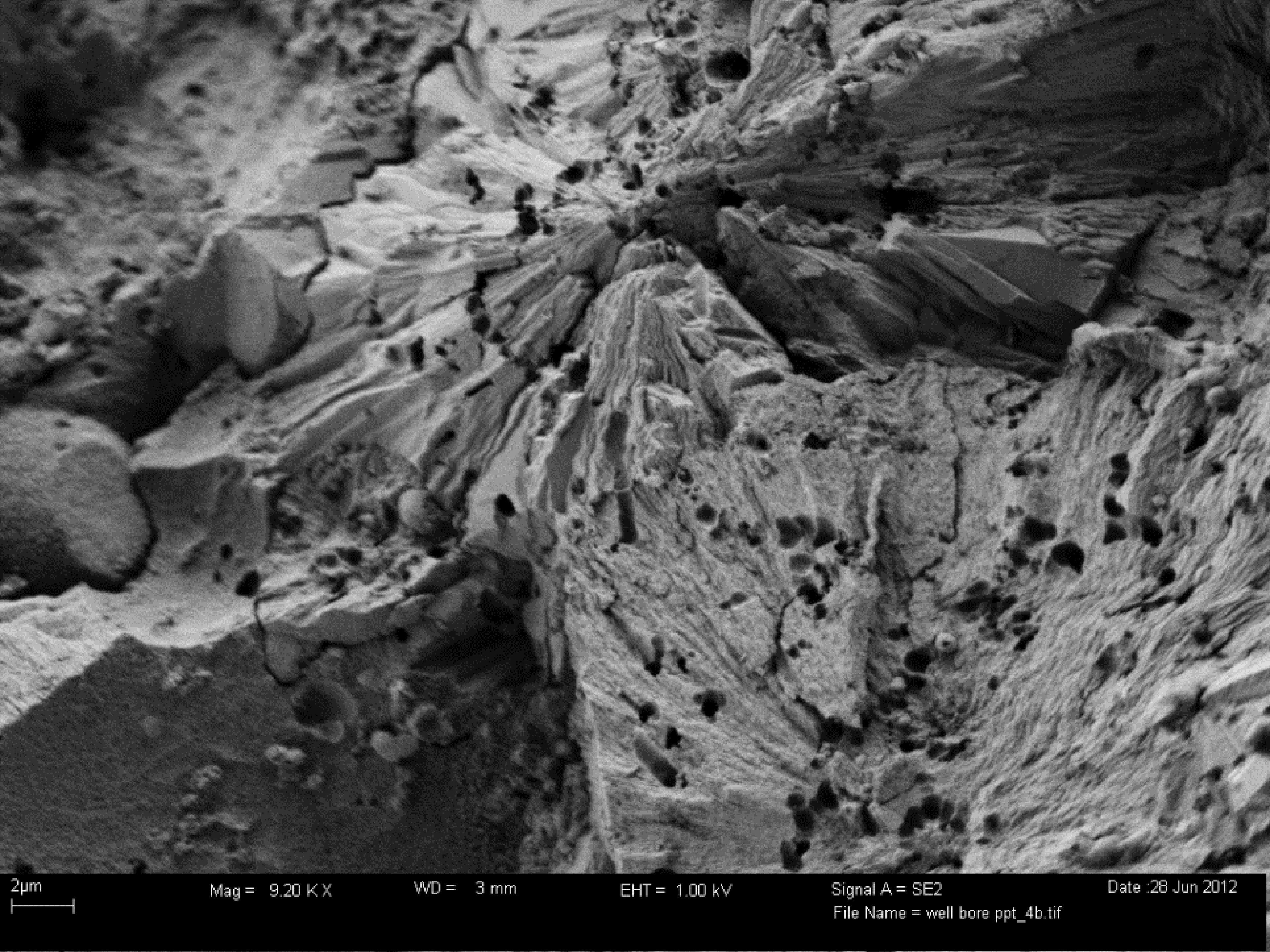

2µm
Mag = 9.20 K X
WD = 3 mm
EHT = 1.00 kV
Signal A = SE2
File Name = well bore ppt_4b.tif
Date :28 Jun 2012


Cell-like
structures?
Mag = 5.53 K X
WD = 3 mm
EHT = 1.00 kV
Signal A = SE2
File Name = fracture ppt_3a.tif
Date :28 Jun 201

Accomplishments to Date

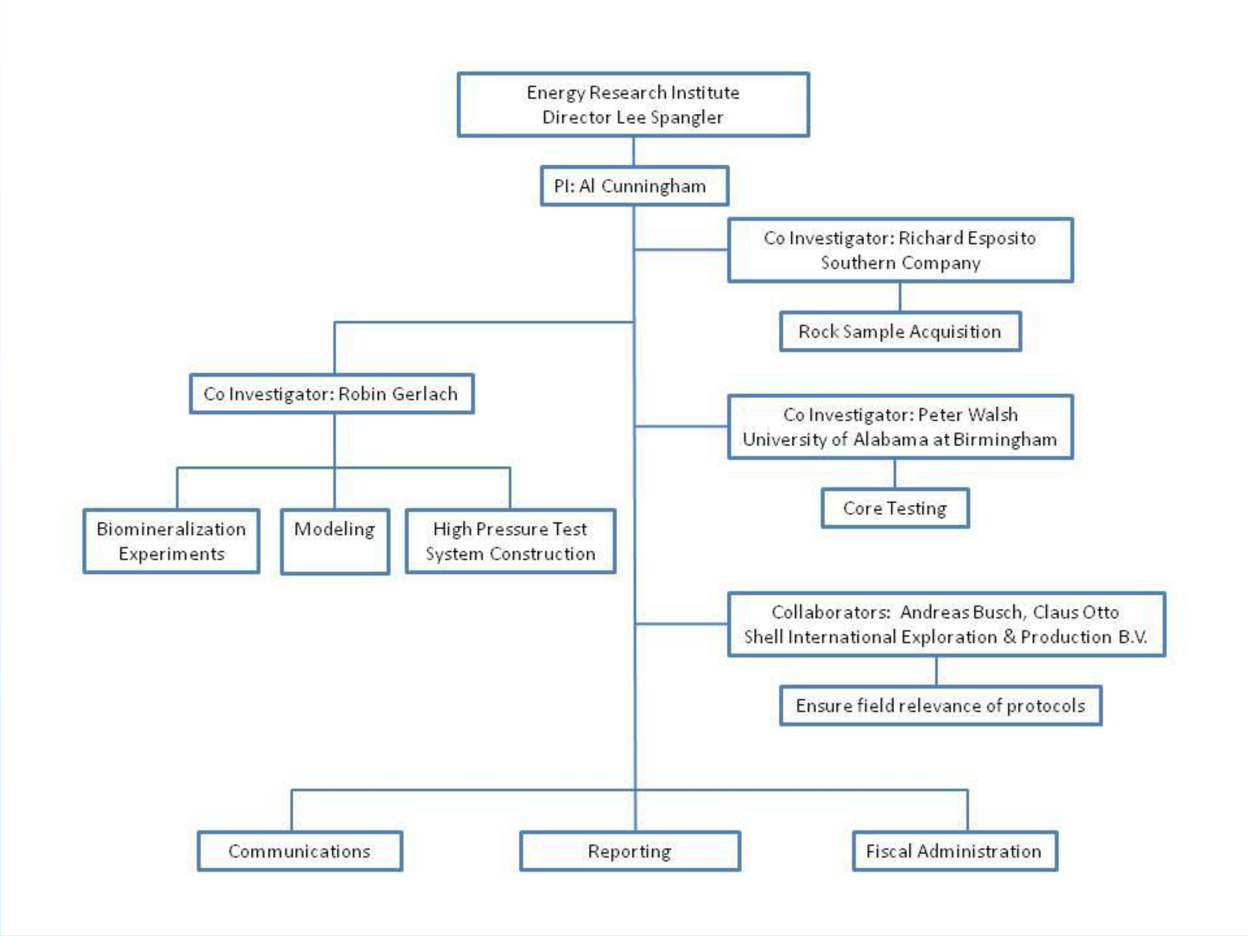
- Demonstrated ability to control mineralization distribution
- Developed computational tool to simulate mineral distribution
- Successful collection of large diameter core
- Demonstrated ability to mineralize small aperture fracture under ambient pressure
- Designed and constructed high pressure vessel for large diameter core experiments
- Performed first high pressure sealing experiment on large diameter core

Summary

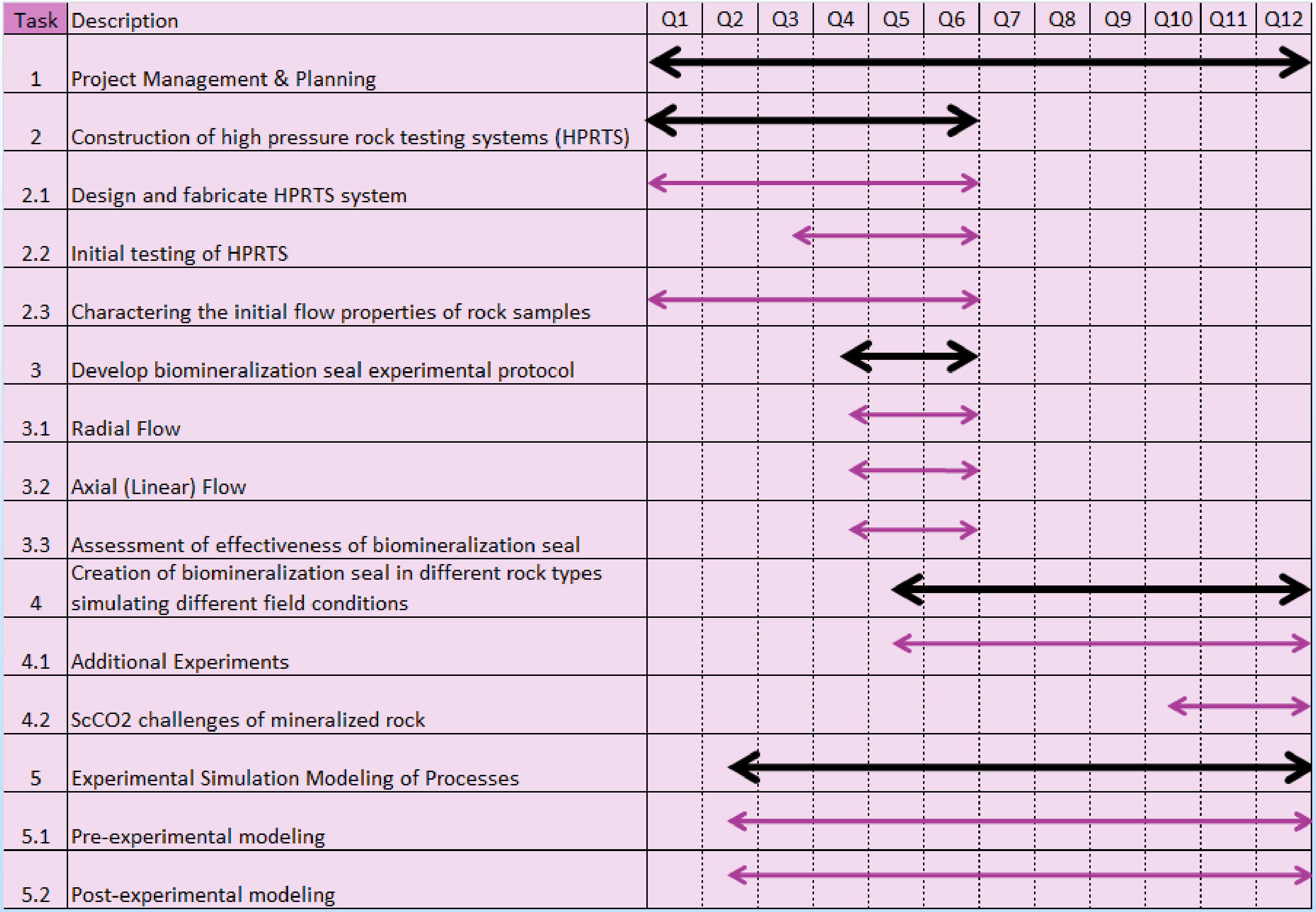
- Biofilm formation and biomineralization shows promise as a method to seal small aperture leaks in the subsurface
- Other mineralogy, porosity, permeability cores will be run
- Thought must be given to downhole delivery of fluids for sealing technology

Appendix

Organization Chart



Gantt Chart



Task
Description
Q1
Q2
Q3
Q4
Q5
Q6
Q7
Q8
Q9
Q10
Q11
Q12
1 Project Management & Planning
2 Construction of high pressure rock testing systems (HPRTS)
2.1 Design and fabricate HPRTS system
2.2 Initial testing of HPRTS
2.3 Charactering the initial flow properties of rock samples
3 Develop biomineralization seal experimental protocol
3.1 Radial Flow
3.2 Axial (Linear) Flow
3.3 Assessment of effectiveness of biomineralization seal
4 Creation of biomineralization seal in different rock types simulating different field conditions
4.1 Additional Experiments
4.2 ScCO2 challenges of mineralized rock
5 Experimental Simulation Modeling of Processes
5.1 Pre-experimental modeling
5.2 Post-experimental modeling

Bibliography

- There have been three presentations, one patent, and one computer simulation model produced from this project. A paper is being prepared for submission.