Advanced CO_2 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
Infrastructure for CCS

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Presentation Outline

- Motivation & Benefit to the Program (required)
- Benefit to the Program and Project Overview (required)
- Background Information
- Accomplishments to Date
  - Injection strategy development (control and prediction)
  - Large core tests – ambient pressure
  - Large core tests – high pressure
  - Small core tests – high pressure
  - MCDP, permeability and porosity assessments
- Progress Assessment and Summary

Benefit to the Program

Program goals being addressed.

Develop and validate technologies to ensure 99 percent storage permanence.

Project benefits statement.

The Engineered Biomineralization Sealing Technology project <u>supports Storage Program goals</u> by developing a <u>leakage mitigation technology for small aperture leaks</u> that can be <u>delivered via low viscosity solutions</u>. The technology, when successfully demonstrated, will provide an <u>alternative to existing cement-based sealing technologies</u>.

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 minimum capillary displacement pressure (MCDP).

3) Develop a barrier growth protocol consistent with field deployment

Technical Status

- Focus the remaining slides, logically walking through the project. Focus on telling the story of your project and highlighting the key points as described in the Presentation Guidelines
- When providing graphs or a table of results from testing or systems analyses, also indicate the baseline or targets that need to be met in order to achieve the project and program goals.

Abandoned Well Leakage Mitigation Using Biomineralization

A. Phillips, A.C. Mitchell, J. Eldring, E. Lauchnor, R. Gerlach , A. Cunningham, L. Spangler

Energy Research Institute

Center for Biofilm Engineering

Montana State University

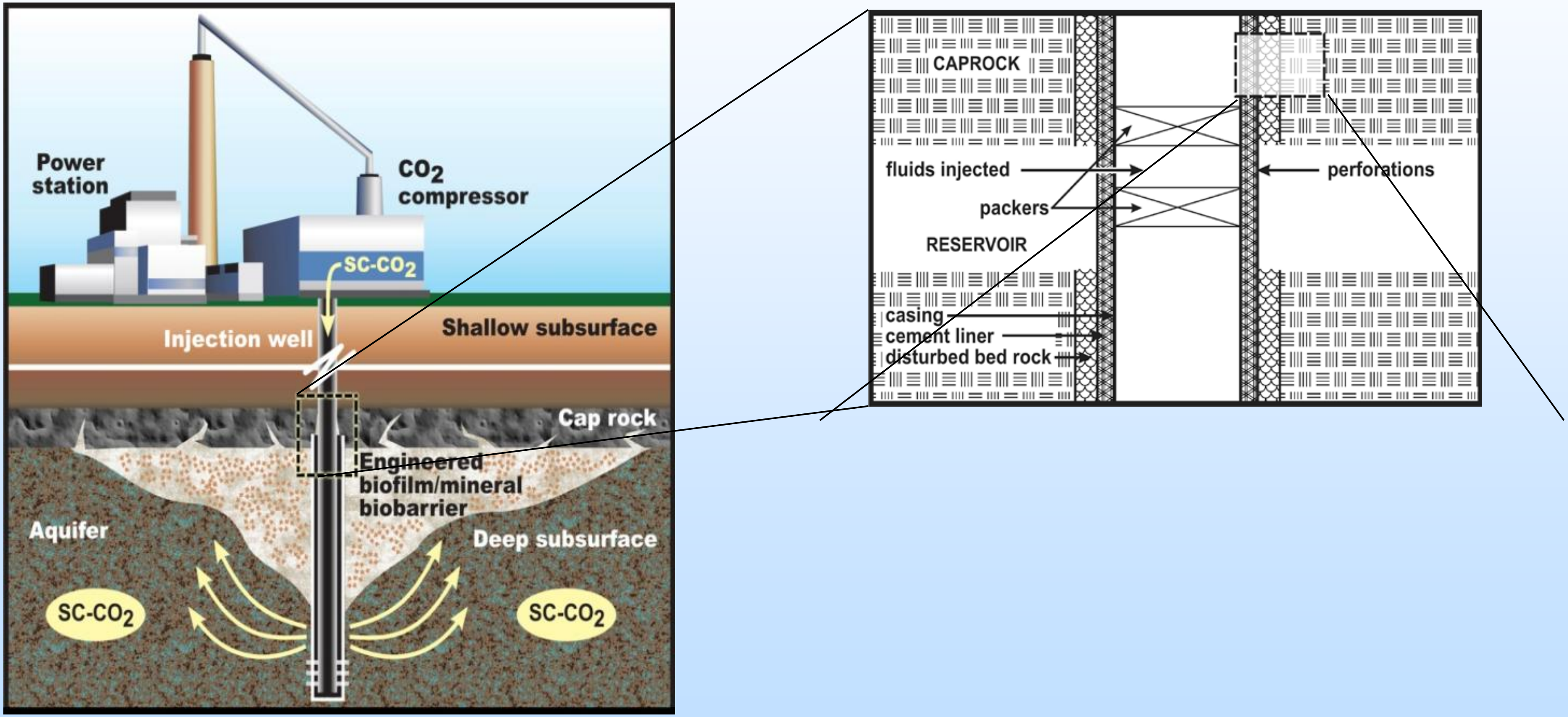
Bozeman MT, 59717

Richard Esposito – Southern Company

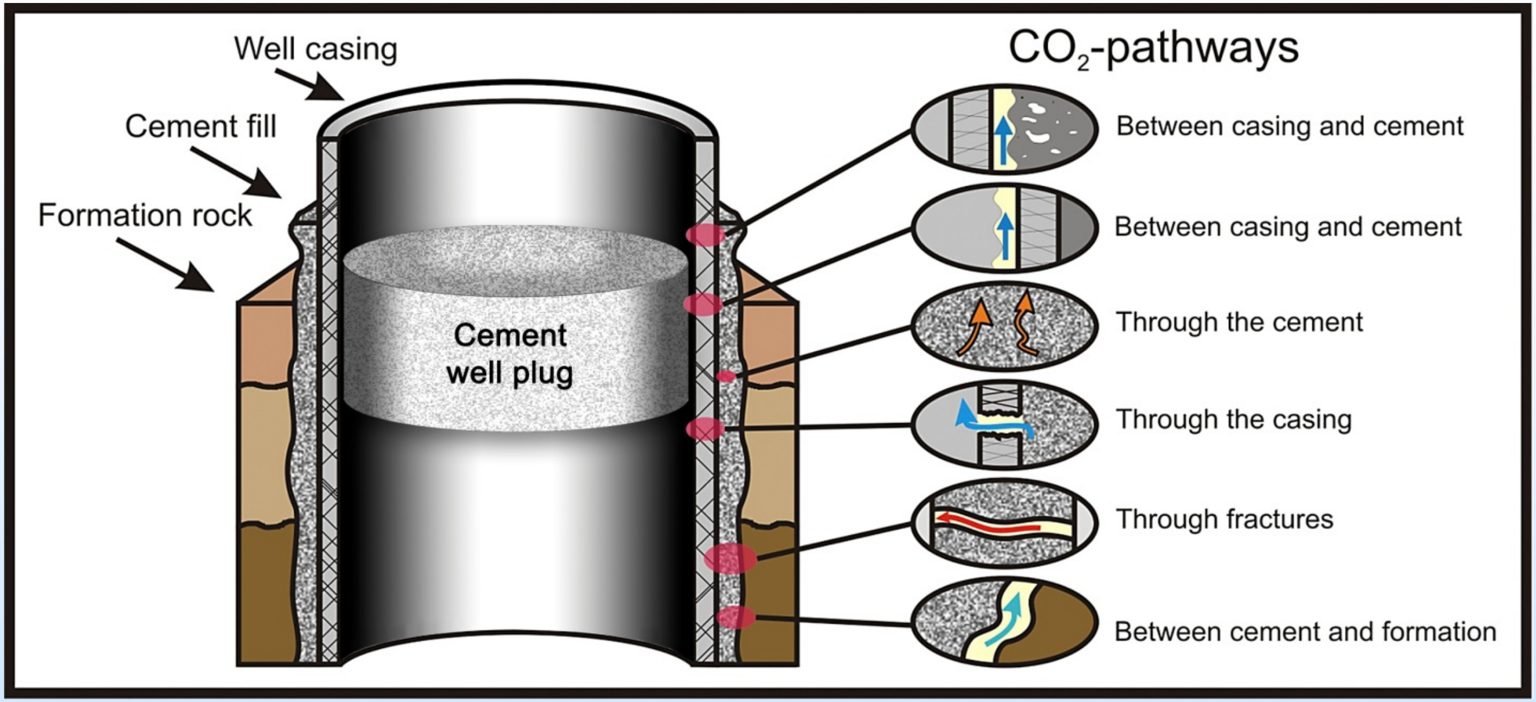
Rainer Helmig, Holger Class, Johannes Hommel – University of Stuttgart

Peter Walsh – University of Alabama-Birmingham

Concept/Motivation



Concept



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- **Cement is a good technology for large aperture leaks, but is sometimes considered 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**

Underlying Biogeochemistry

Urea hydrolysis increases alkalinity and thus the saturation state of many minerals (e.g. calcium carbonate)

$$CO(NH_2)_2 + H_2O \xrightarrow{\text{urease}} NH_2COOH + NH_3$$

$$NH_2COOH + H_2O \rightarrow NH_3 + H_2CO_3$$

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

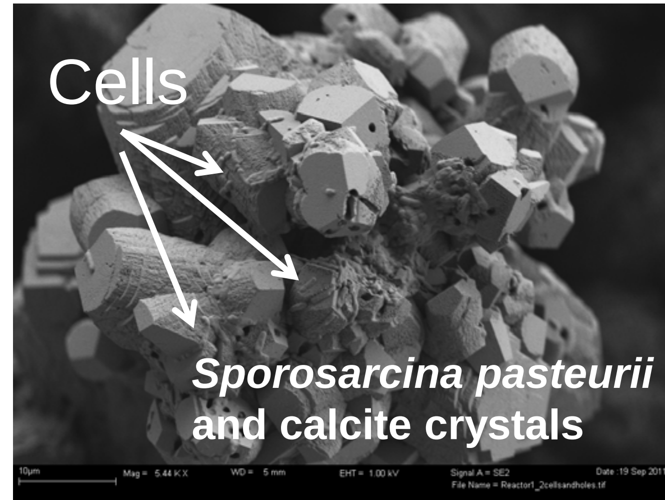
$$2NH_3 + 2H_2O \leftrightarrow 2NH_4^+ + \boxed{2OH^- \qquad \text{(pH increase)}}$$

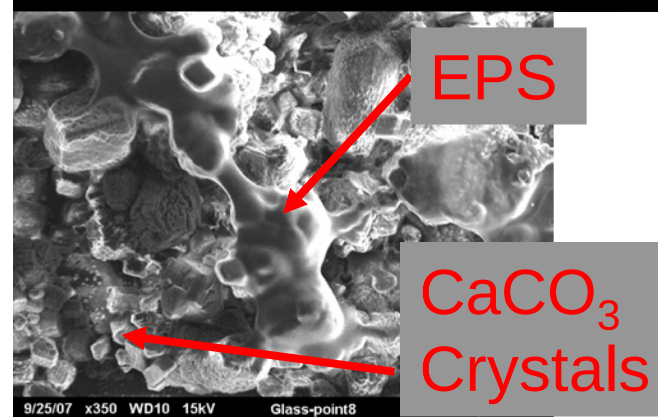
$$H_2CO_3 + 2OH^- \leftrightarrow HCO_3^- + H_2O + OH^- \leftrightarrow \boxed{CO_3^{2-}} + 2\,H_2O$$

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

$$\boxed{\mathbf{CO(NH_2)_2 + Ca^{2+} + 2H_2O \longleftrightarrow 2NH_4^+ + CaCO_3}}$$

Mitchell AC, Dideriksen K, Spangler LH, Cunningham AB Gerlach R. (2010). *Environ Sci Technol*. 44(13):5270-5276. doi: 10.1021/es903270w



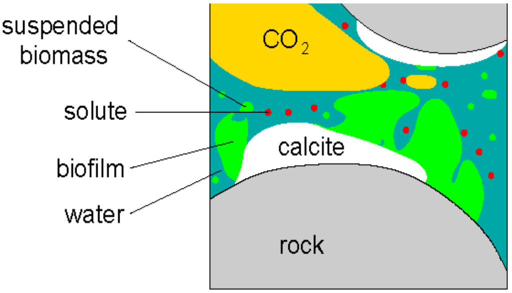


Accomplishments to Date

- Demonstrated ability to control mineralization distribution
- Developed computational tools to simulate mineral distribution
- Successful collection of large diameter cores
- Demonstrated ability to seal fractures under ambient pressure using the biomineralization approach
- Designed and constructed a high pressure vessel for large diameter core experiments
- Performed high pressure sealing experiment on large diameter core and sandpack
- Continuing to perform small and meso-scale experiments to better understand and control distribution of biomineral seals

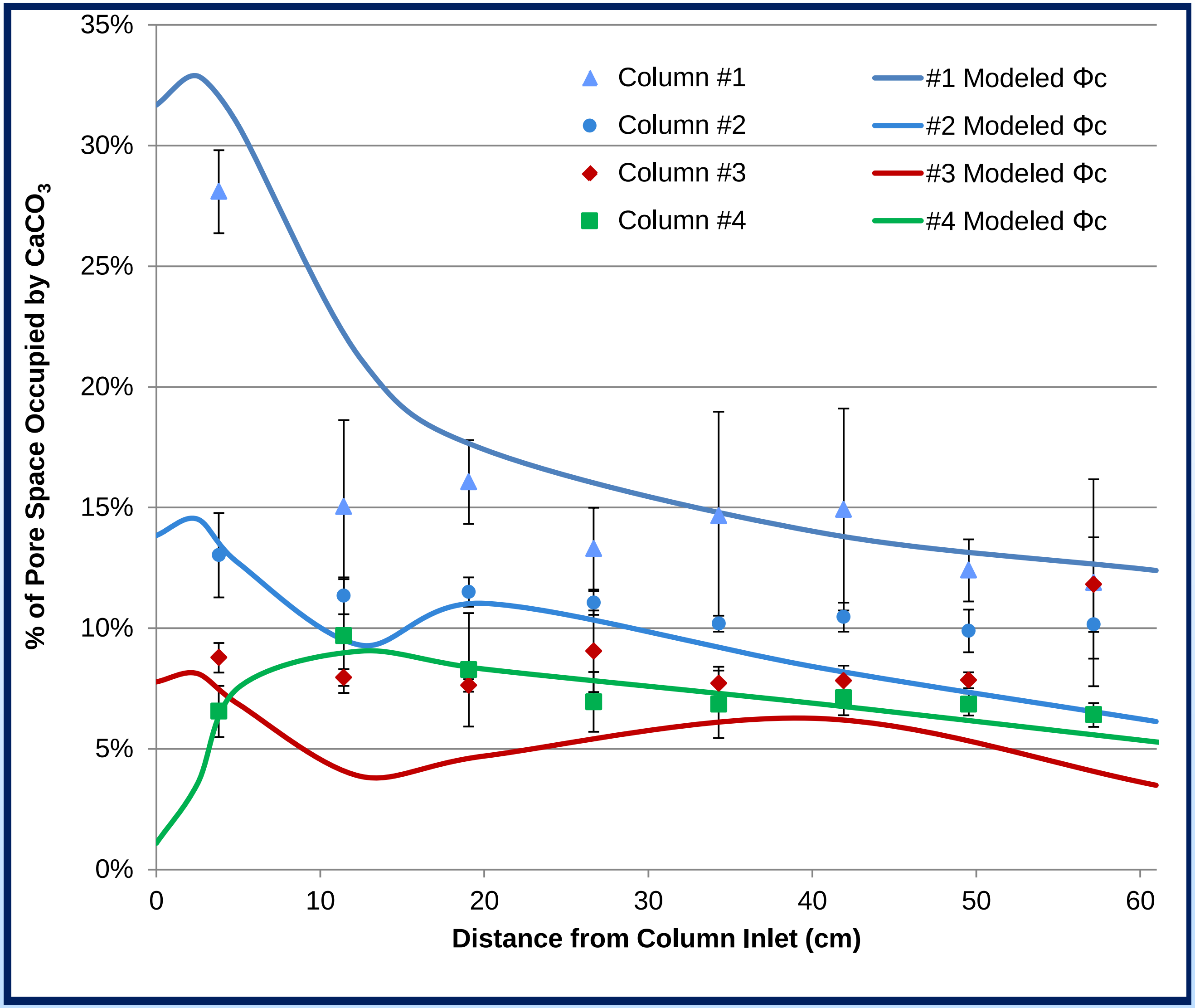
Darcy-scale model

Objective 2) Develop biomineralization seal experimental protocol.



Calibration (columns 1 & 2)

Predict future experiments and injection strategies



Ebigbo, A; Phillips, A; Gerlach, R; Helmig, R; Cunningham, AB; Class, H; Spangler, LH. Darcy-scale modeling of microbially induced carbonate mineral precipitation in sand columns. Water Resour. Res. 2012, 48 (7), W07519.

Injection strategy development

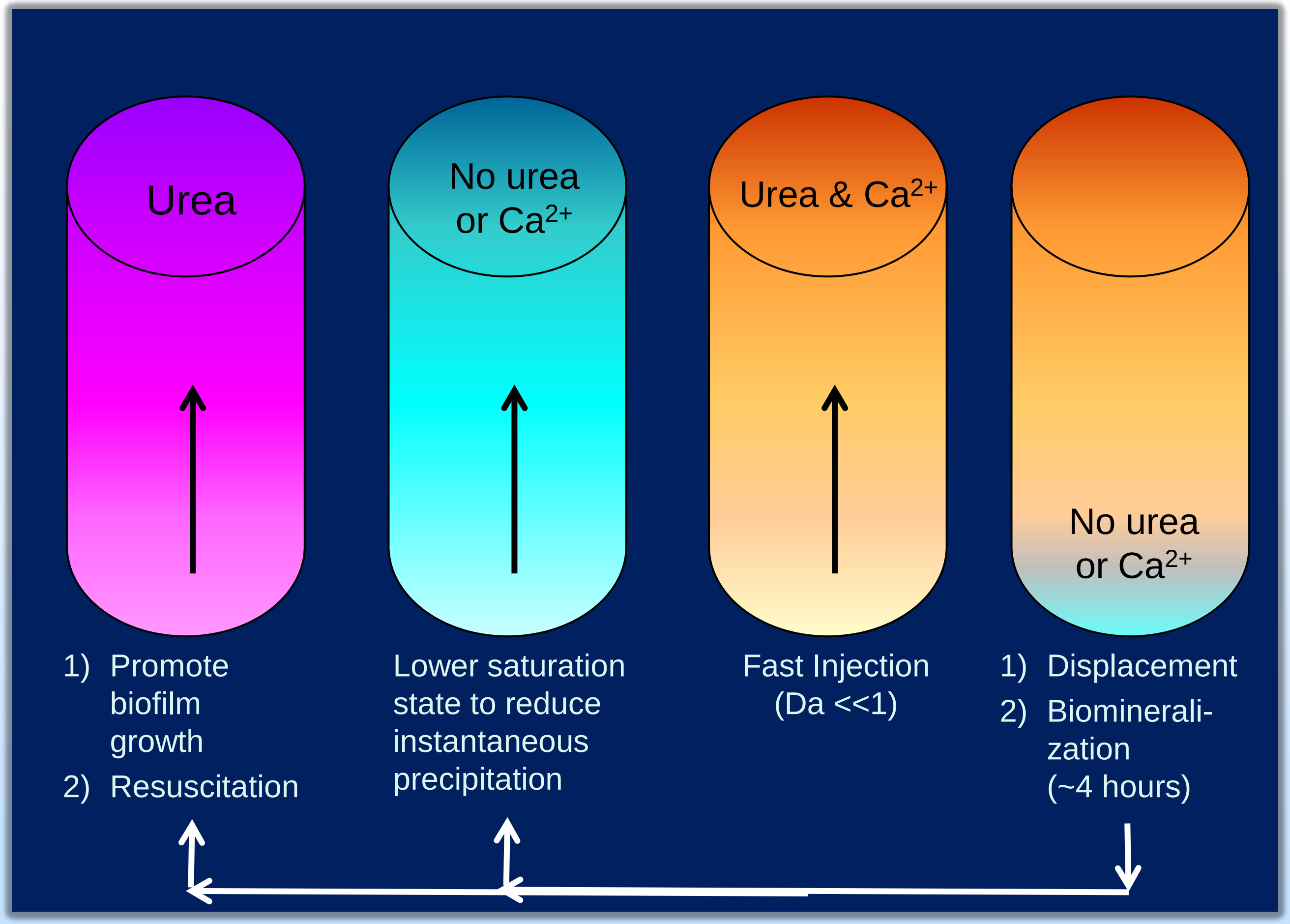
Objective 2) Develop biomineralization seal experimental protocol.

Promote homogeneous distribution

Prevent near-injection-point plugging

Promote efficient precipitation

Manipulating saturation state



Ebigbo, A; Phillips, A; Gerlach, R; Helmig, R; Cunningham, AB; Class, H; Spangler, LH. Darcy-scale modeling of microbially induced carbonate mineral precipitation in sand columns. Water Resour. Res. 2012, 48 (7), W07519.

Large Sample Procurement

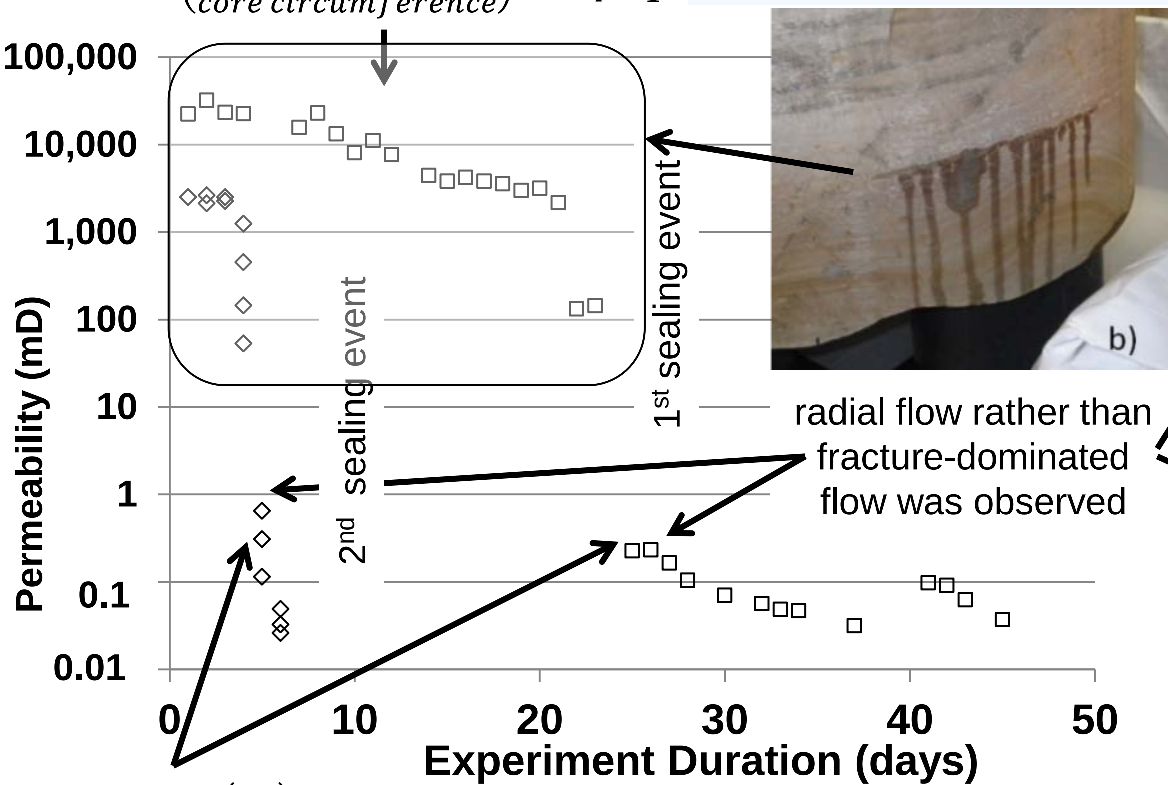
Objective 1) Construct and test mesoscale high pressure rock test system (HPRTS).

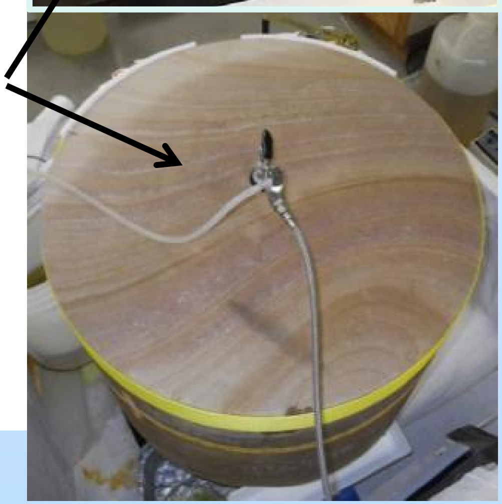
Phillips, A.J.; Lauchnor, E.G.; Eldring, J.; Esposito, R.; Mitchell, A.C.; Gerlach, R.; Cunningham, A.B.; Spangler, L.H. (2013): Potential CO_2 Leakage Reduction through Biofilm-Induced Calcium Carbonate Precipitation. Environmental Science and Technology. 47(1):142–149. DOI: 10.1021/es301294q

Ambient Pressure Experiments with Large Cores

Objective 2) Develop biomineralization seal experimental protocol.

$$K = Q \frac{ln\left(\frac{r_0}{r_w}\right)}{\left(\frac{fracture\ length}{core\ circumference}\right) 2\pi\ \Delta p\ b_1}$$



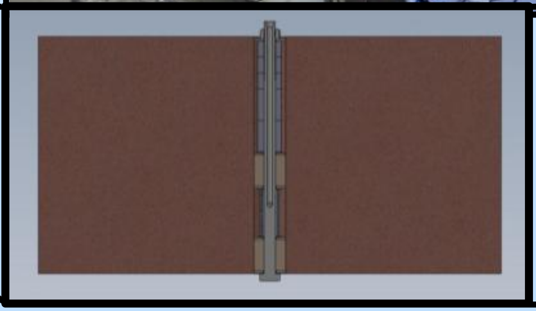


$$K = Q \frac{\ln\left(\frac{r_0}{r_w}\right)}{2\pi\ \Delta p\ b_2}$$

Phillips, A.J.; Lauchnor, E.G.; Eldring, J.; Esposito, R.; Mitchell, A.C.; Gerlach, R.; Cunningham, A.B.; Spangler, L.H. (2013): Potential CO_2 Leakage Reduction through Biofilm-Induced Calcium Carbonate Precipitation. Environmental Science and Technology. 47(1):142–149. DOI: 10.1021/es301294q

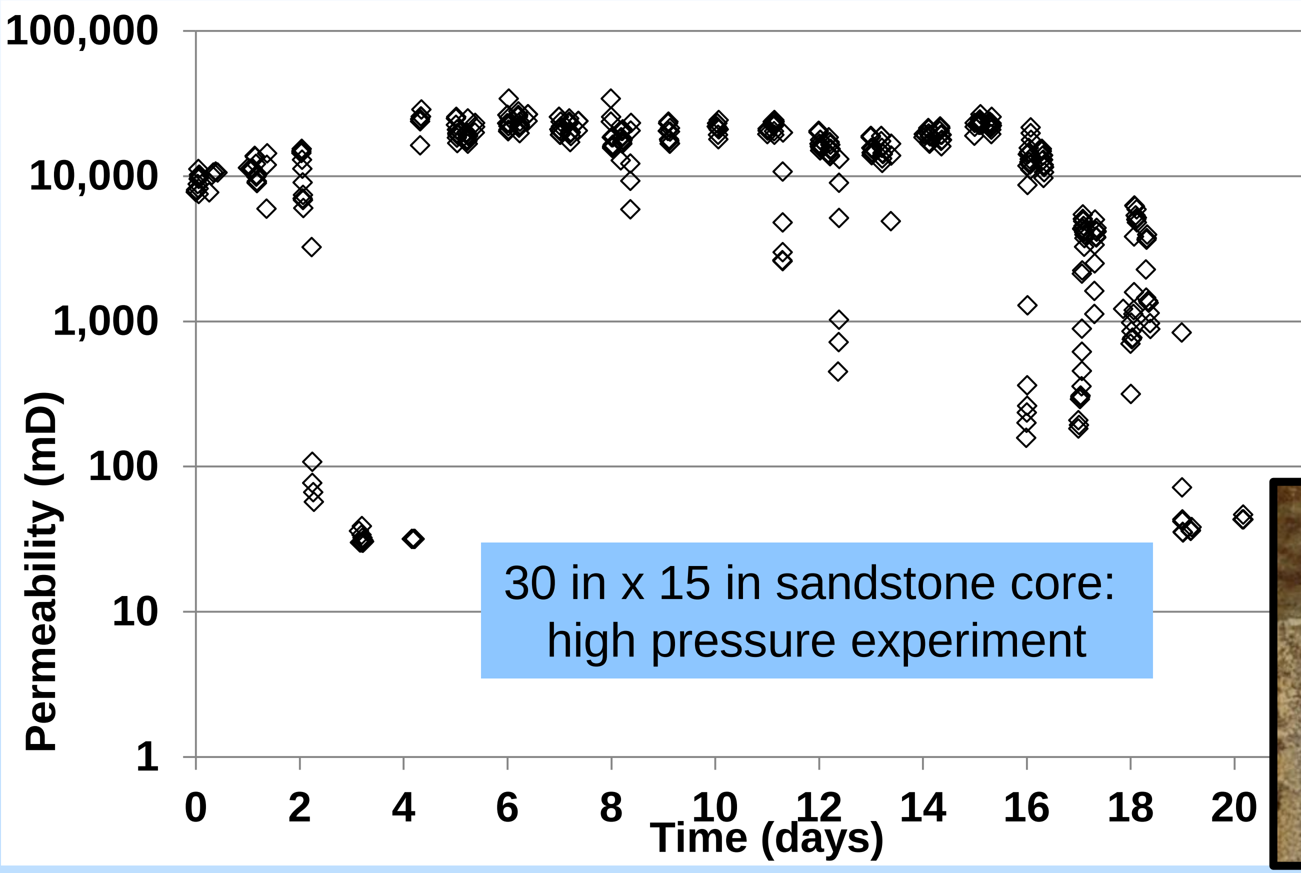
Meso-Scale
High Pressure Vessel

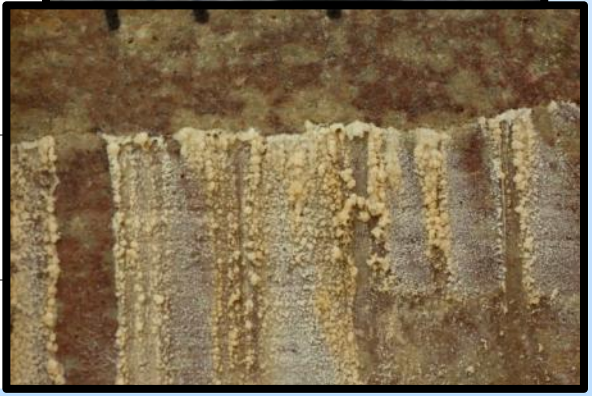
Objective 1) Construct and test mesoscale high pressure rock test system (HPRTS).



High Pressure Experiments with Large Cores

Objective 1) Construct and test mesoscale high pressure rock test system.
Objective 2) Develop biomineralization seal experimental protocol.
Objective 3) Creation of biomineralization seal in different rock types …





Axial flow high pressure core testing system

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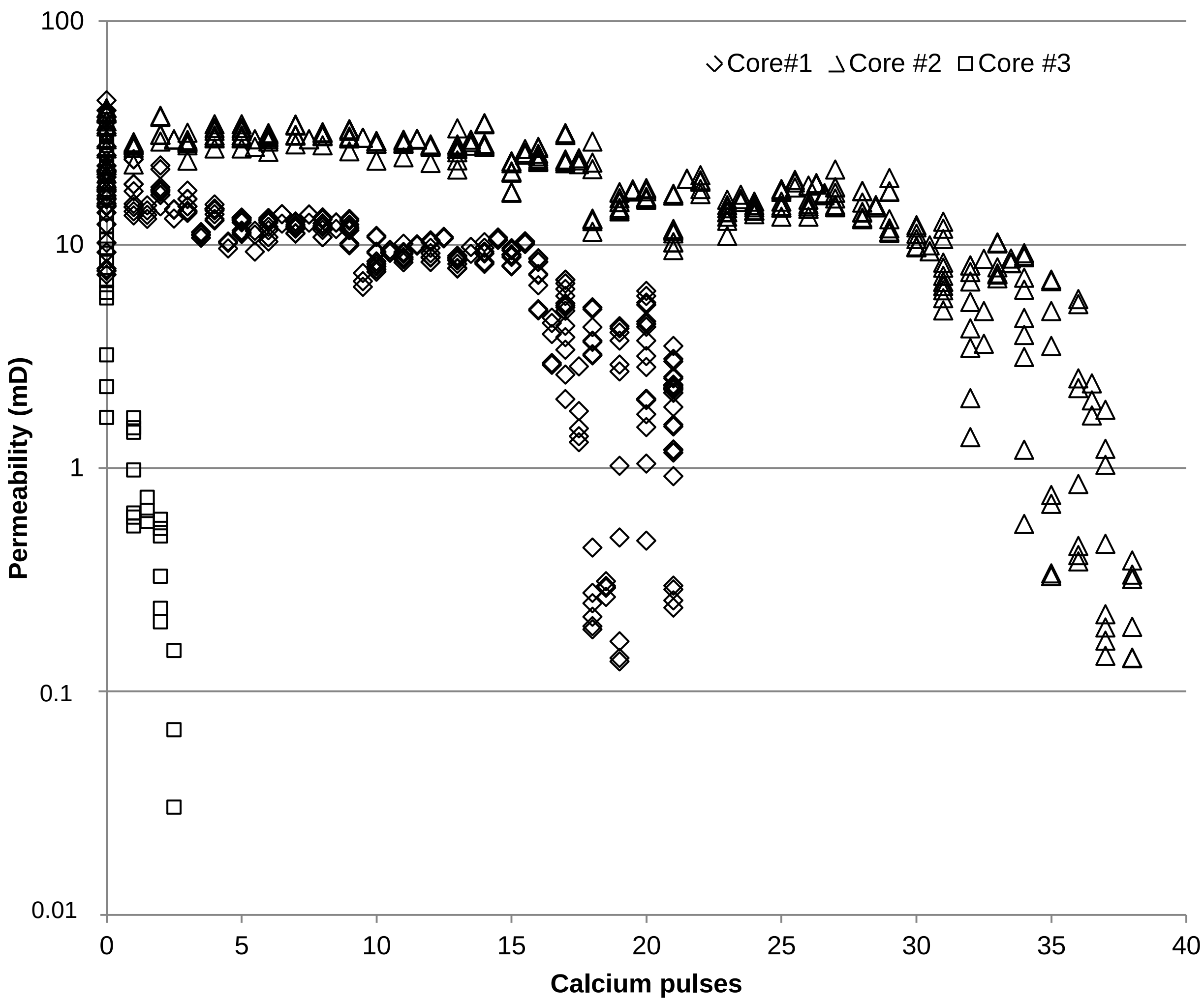
Objective 2) Develop biomineralization seal experimental protocol.
Objective 3) Creation of biomineralization seal in different rock types …

- Specifications:
  - Hassler-type core holder
  - 1” diameter cores
  - Up to 6” length
  - Axial flow
  - 2000 psi, 60°C
  - Constant pressure/ constant flow rate operation (ISCO pumps)
  - Data Acquisition
    - Δp
    - flow rate
    - pH
    - conductivity

Axial flow ~76 bar (1100 psi)

Objective 2) Develop biomineralization seal experimental protocol.

Objective 3) Creation of biomineralization seal in different rock types …



Axial flow ~76 bar (1100 psi)

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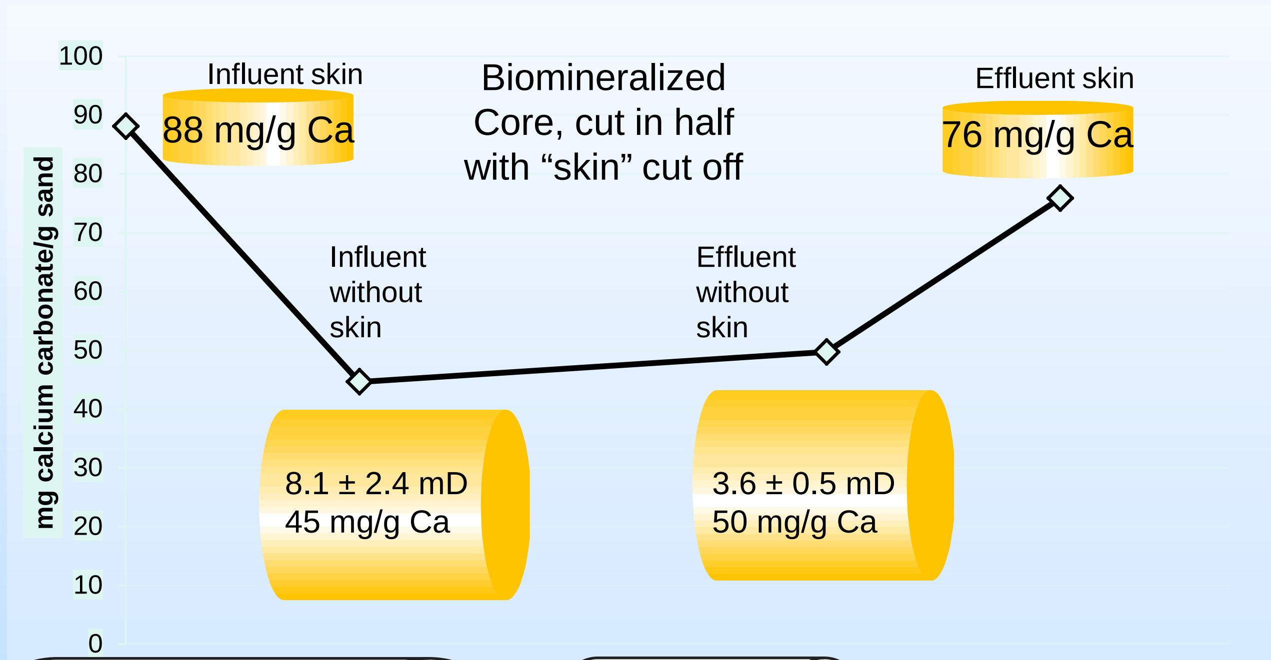
Biomineralized Core, cut in half with “skin” on

Direction of flow

2.4 mD Biomineralized core, whole

1.4 mD

1.9 mD



30 mD

29 mD
2 mg/g Ca
Quartz only

30.4 mD
1 mg/g Ca
Quartz only

Control core, whole

Control core, cut in half

Pore (Throat) Size Distribution

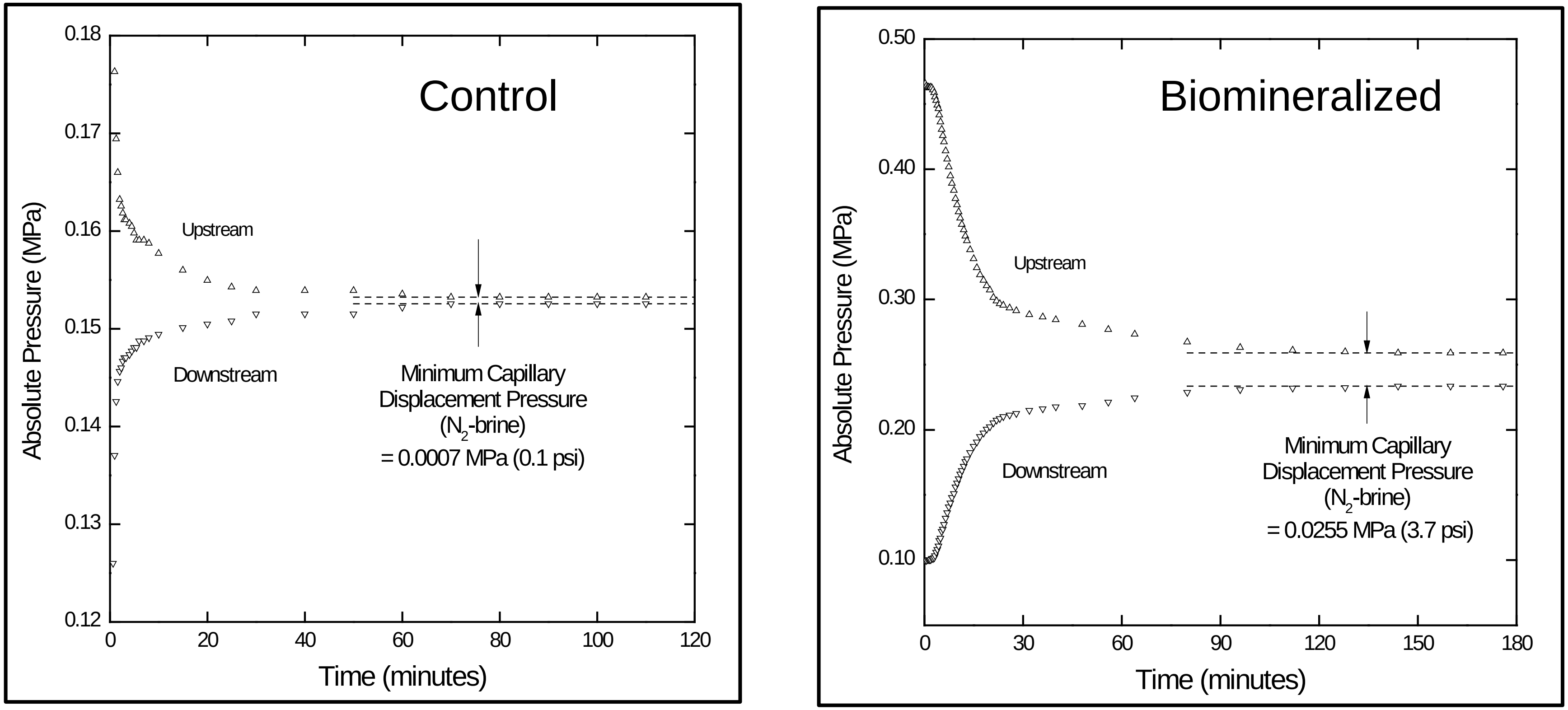
- Reduction in overall porosity by 24%
- Porosity decreased more on effluent end than influent end
- Pore (throat) size distribution changed

Pore volume diameter	Control average	Biomin Influent Average	Biomin Effluent Average
less than 1 µm	15%	22%	28%
1-10 µm	33%	26%	38%
10-100 µm	42%	29%	22%
100-1000 µm	10%	23%	13%
6-16 µm	51%	33%	31%

MCDP Results

Core is initially saturated with brine. $ScCO_2$ is forced through under pressure until pressure difference stabilizes. ΔP is MCDP (Hildebrand et al. 2002)

- MCDP is the minimum pressure across the length of a brine-saturated rock core which results in $ScCO_2$ breakthrough.
- MCDP can the thought of as a measure of the resistance to $ScCO_2$ penetrating through cap rock.



A. Hildenbrand, S. Schlömer, and B. M. Krooss, "Gas breakthrough experiments on fine-grained sedimentary rocks," *Geofluids 2,* **2002**, 3-23.

Summary Table with permeability, porosity and MCDP results

Exp. #	Perm. initially (mD)	Perm. before sent to UAB (mD)	Porosity	Perm. with N_2 (mD)	MCDP (bar)	24 hr $scCO_2$?	Perm. w/ N_2 after $scCO_2$ (mD)	MCDP after scCO2 (bar)
1	37	0.2	14.7%	NM	NM	No	NM	NM
2	37.6	0.2	NM	5.9±3.1	0.255	Yes	4.27±0.1	NM
3	34	0.02	14.5%	0.011±0.06	0.8±0.1	Yes	NM	0.7
Control	27	27	19.2%	71.6±0.8	0.007	No	NM	NM

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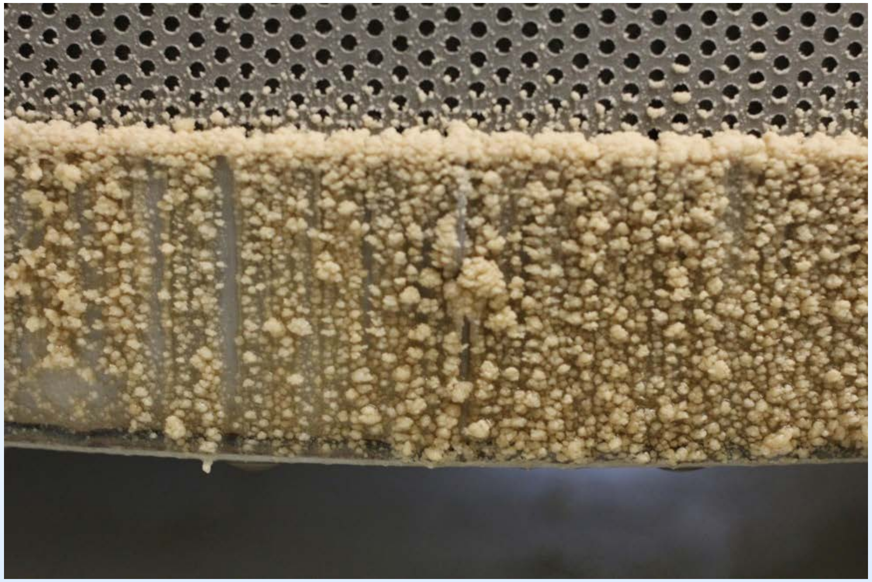
High Pressure Sandpack Experiment

High Pressure Sandpack Experiment



Progress - Summary

Goal: Develop a biomineralization-based technology

Objective 1) Construct and test mesoscale high pressure rock test system (HPRTS). – completed

Objective 2) Develop biomineralization seal experimental protocol. – achieved for 1-D (axial) and 2-D (radial) systems, in progress for quasi-3D system (radial flow meso-scale system)

Objective 3) Creation of biomineralization seal in different rock types and simulating different field conditions. – achieved for sandstone, (unconsolidated) sandpacks, in progress for fractured cement, cement-steel interfaces, cement-sandstone interfaces

Progress

Target metrics for technology performance.

1) Demonstrate the ability to control the spatial distribution of the biobarrier on the 1 meter scale. **– achieved (large core diameter experiments)**

2) Achieve a 3-4 order of magnitude reduction in permeability and a 10 to 25 fold increase in minimum capillary displacement pressure (MCDP). ***– achieved in fractured sandstone core, in 1 in diameter sandstone cores***

3) Develop a barrier growth protocol consistent with field deployment **– in progress – see next presentation for more detail**

Progress

<u>Goal: Develop a biomineralization-based technology for well sealing</u>

Workplan generally on track

<u>but</u>: it has been challenging to procure large diameter rock cores of suitable permeability (i.e 50 mD and above) which can be used to run radial flow experiments in the meso-scale high pressure vessel

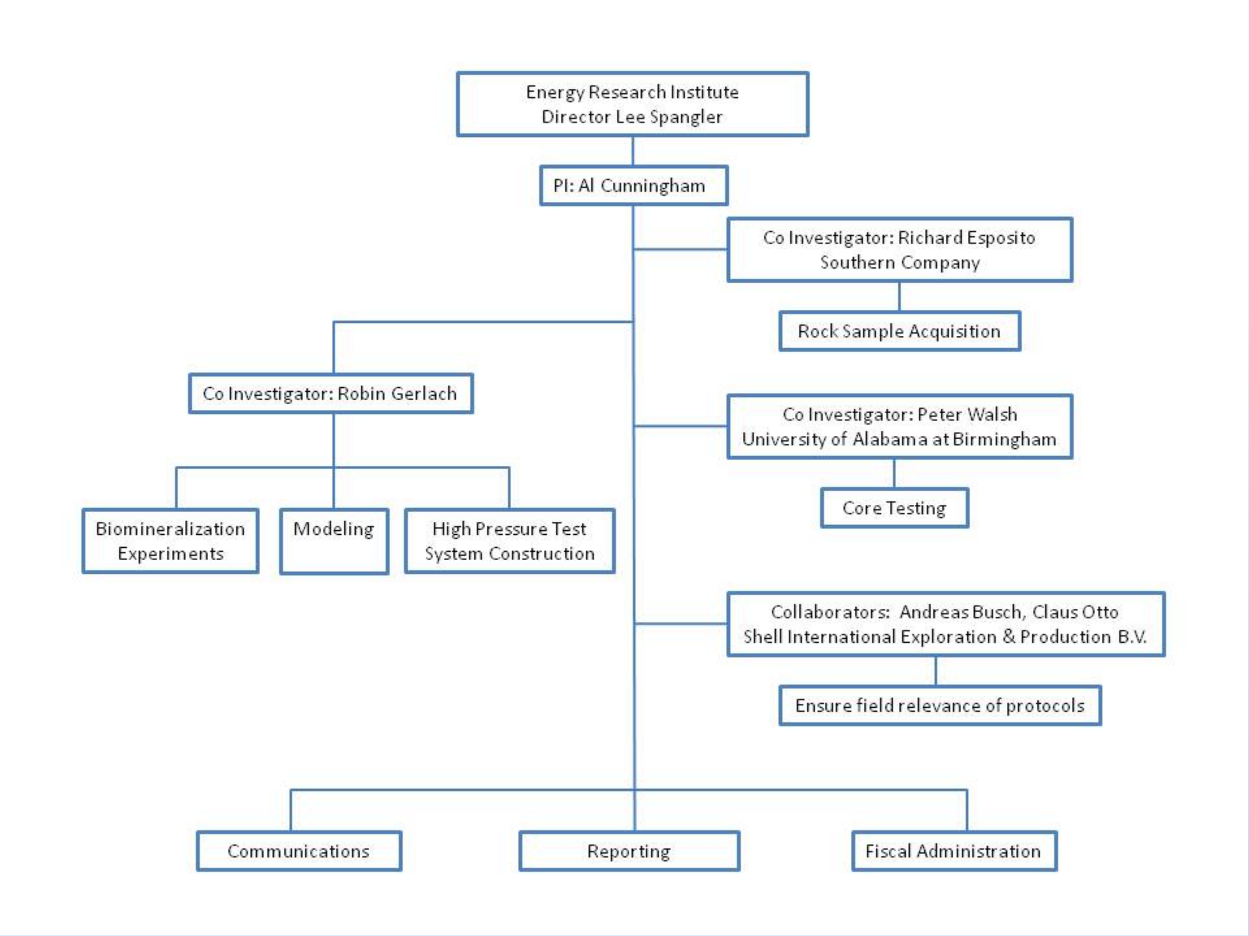
Summary

- 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
- In-Well demonstration is being pursued (next presentation)

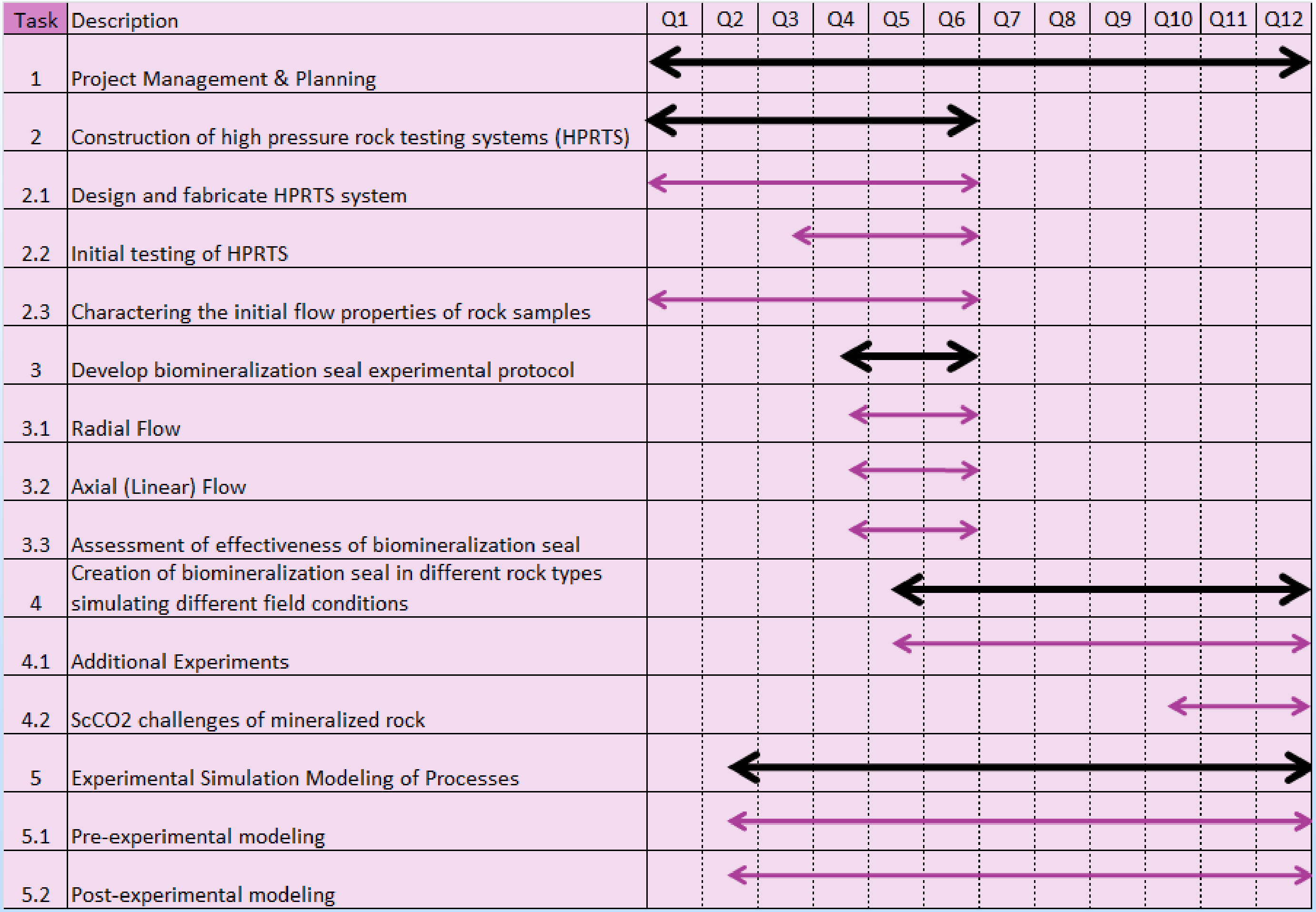
Appendix

– These slides will not be discussed during the presentation, but are mandatory

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

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