Field Test and Evaluation of Engineered Biomineralization Technology for Sealing Existing wells

Project Number: FE0009599

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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

Note: This presentation combines results from two closely related DOE projects:

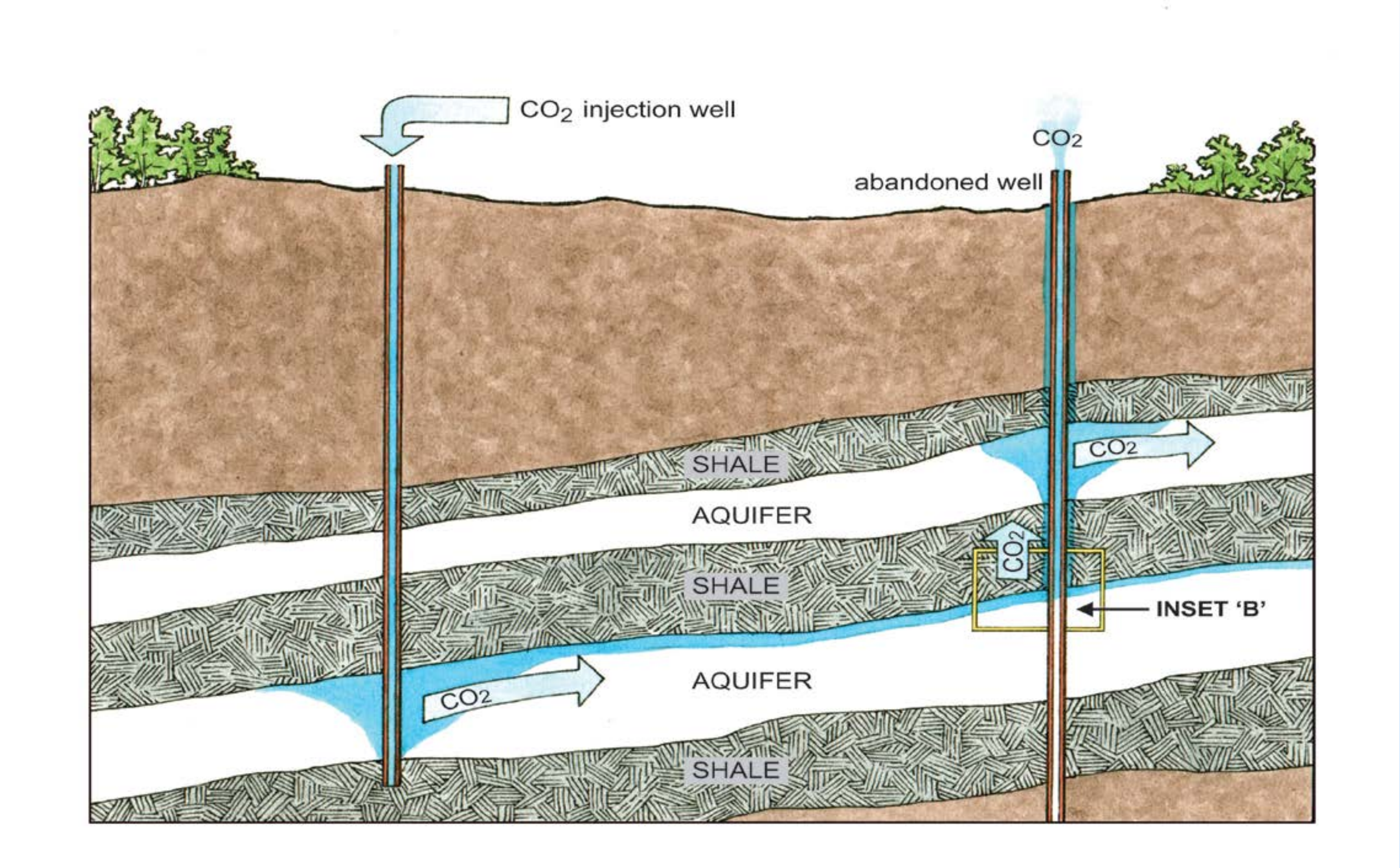
***Project DE-FE0009599, Field Test and Evaluation of Engineered Biomineralization Technology for Sealing Existing wells* (October 1, 2012 – September 30, 2015)**

Project DE-FE0004478, *Advanced CO_2 Leakage Mitigation using Engineered Biomineralized Sealing Technologies (October 1, 2011- March 31 2015)*

- Project Concept
- Benefit to the Program
- Goal and Objectives
- Technical Status
- Accomplishments to Date
- Summary
- Future work

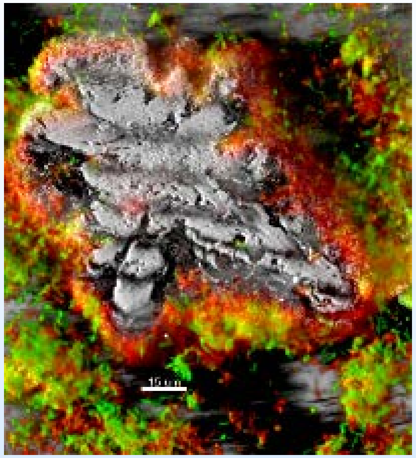
Project Concept

- Sealing unwanted flow paths, underground gas storage
- **Microbially induced calcite precipitation (MICP)**
- Results from lab scale, field scale, and simulation modeling will be reported



Calcite Biomineralization (MICP) Using Ureolytic Bacteria

- $NH_2CONH_2 + H^+ + H_2O \leftrightarrow 2NH_4 + HCO_3^-$ (1)
- $Ca^{+2} + 2HCO_3^- \leftrightarrow CaCO_3(s) + CO_2 + H_2O$ (2)

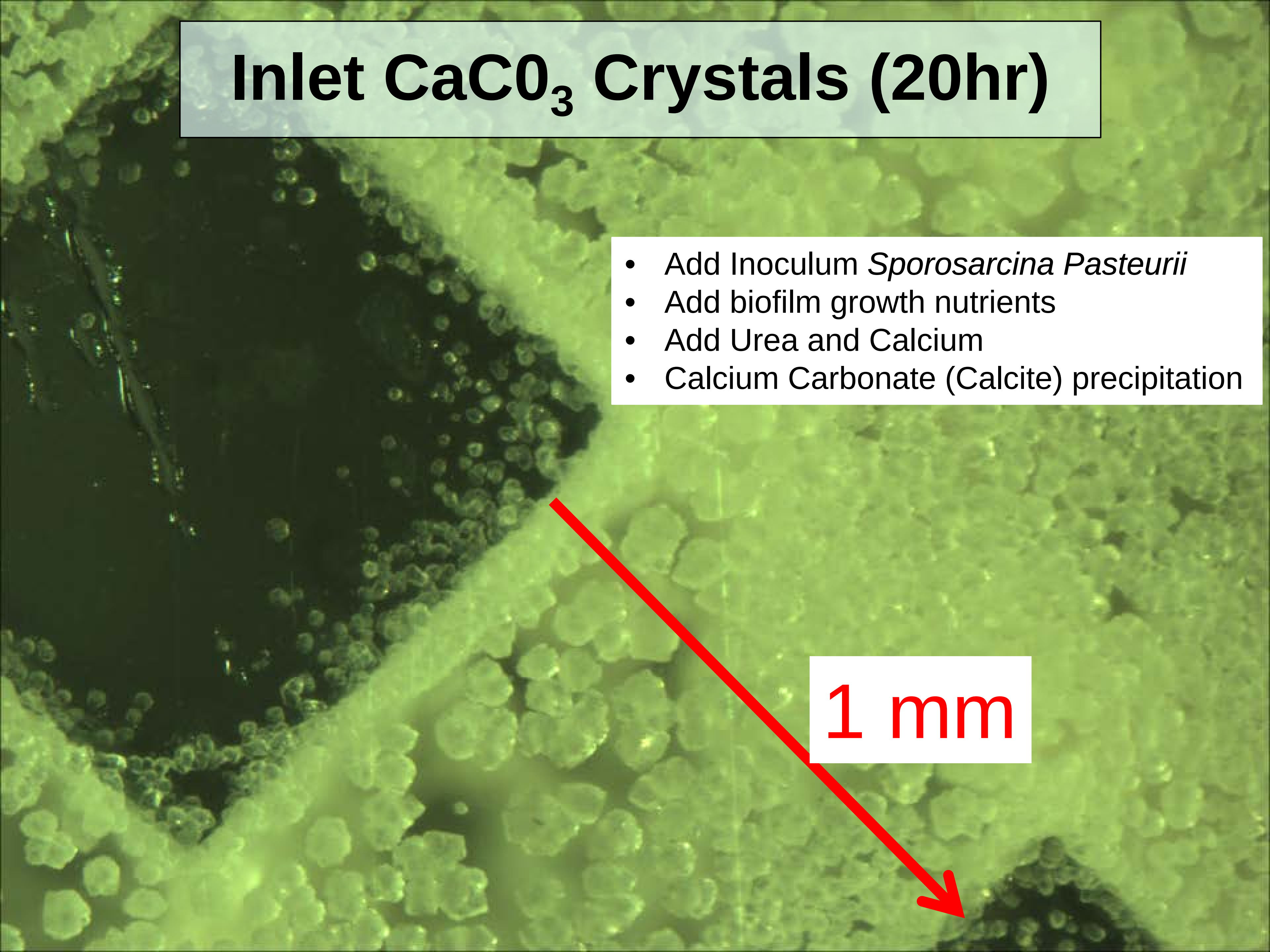


L.Schultz/B.Pitts

- The enzyme urease present in some bacteria (i.e. (*Sporosarcina pasteurii*) hydrolyzes urea to form ammonium which increases pH
- HCO_3^- is subsequently produced which in the presence of Ca^{+2} precipitates calcium carbonate (Calcite)

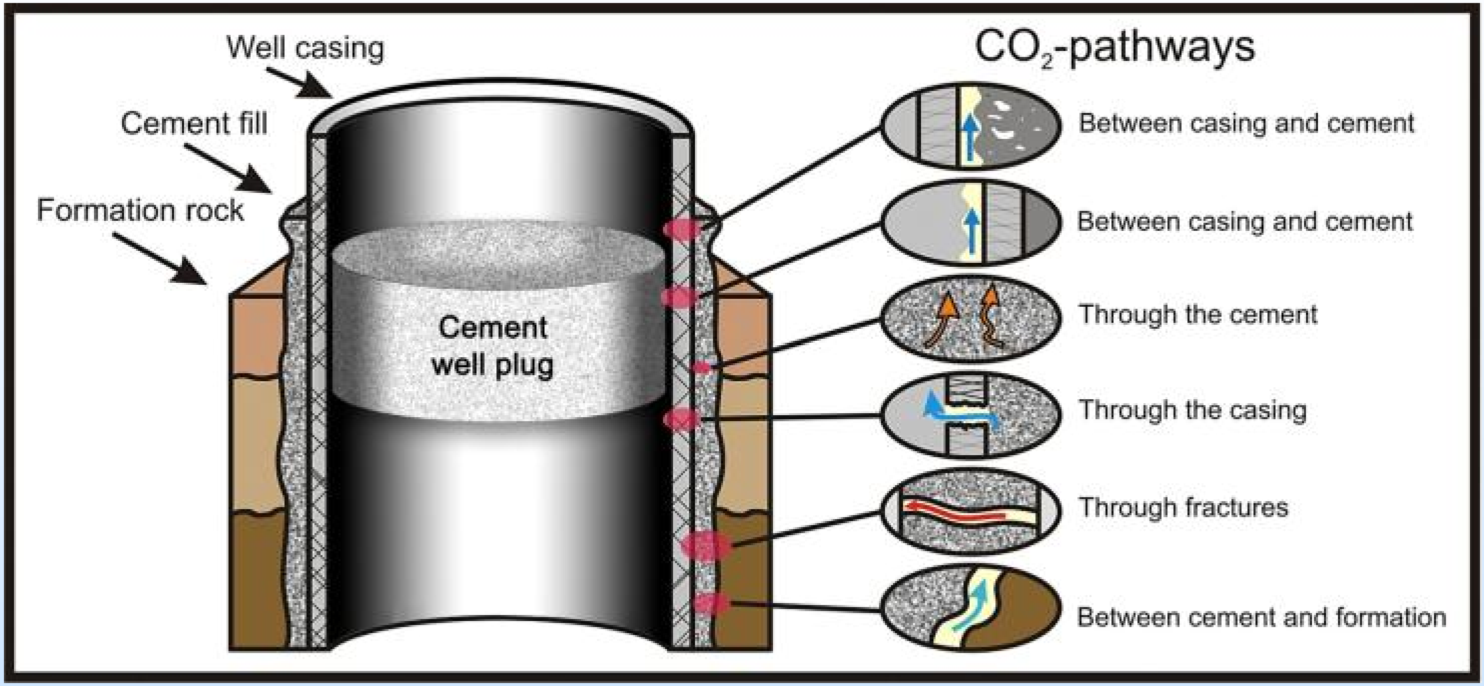
Inlet CaC0$_3$ Crystals (20hr)

- Add Inoculum *Sporosarcina Pasteurii*
- Add biofilm growth nutrients
- Add Urea and Calcium
- Calcium Carbonate (Calcite) precipitation



Project Concept

-MICP sealing with low-viscosity fluids-



After Nordbotten and Celia, Geological Storage of CO_2, 2012

- **Cement is a good technology for large aperture leaks, but is too viscous to plug small aperture leaks (small fractures or interfacial delaminations).**
- **In some cases it is also desirable to plug the rock formation near the well.**
- **A missing tool is a plugging technology that can be delivered via low-viscosity fluids**

Benefit to the Program

Program goals being addressed:

Develop and validate technologies to ensure 99 percent storage performance.

Project benefits statement:

The Engineered Biomineralized Sealing Technologies (MICP) projects support Storage Program goals by developing a leakage mitigation technology for small aperture leaks that can be delivered via low viscosity solutions. The technology, if successfully applied, could provide an alternative technology to cement for plugging preferential CO_2 leakage pathways in the vicinity of wellbores.

Project Overview:

Goals and Objectives (Project FE0004478)

GOAL: Demonstrate the biomineralization technology for sealing preferential flow pathways in the vicinity of injection wells, thus addressing the DOE goal of storage permanence. This goal is supported by the following **Objectives** from *Project FE0004478 Advanced CO_2 Leakage Mitigation using Engineered Biomineralized Sealing Technologies:*

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

Project Overview:
Goals and Objectives (Project FE0009599)

GOAL: Demonstrate the biomineralization technology for sealing preferential flow pathways in the vicinity of injection wells, thus addressing the DOE goal of storage permanence. This goal will be accomplished with the following **objectives**:

(1) Characterize the Alabama well test site. (Completed)

(2) Design protocol for field injection test. (Completed)

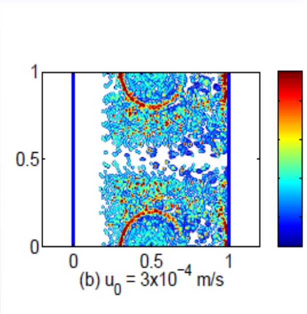
(3) Perform field injection test. (Completed)

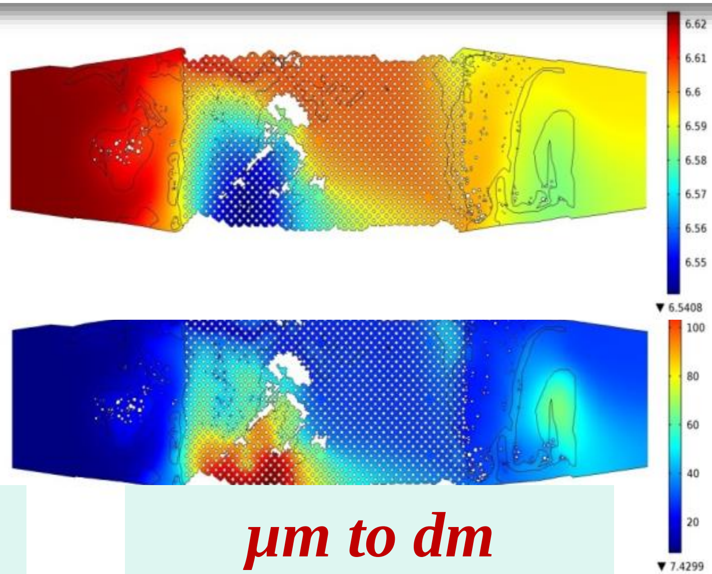
(4) Evaluate results of field test. (Ongoing)

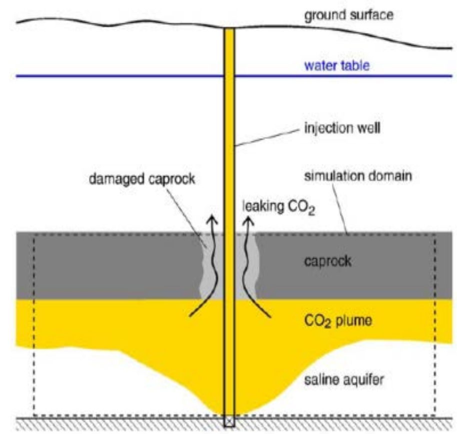
Technical Status

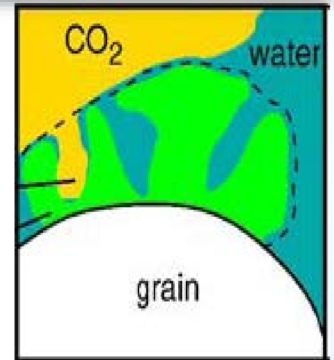
- Focus the remaining slides, logically walking through the project. Focus on telling the story of your project and highlighting the key points as described in the Presentation Guidelines
- When providing graphs or a table of results from testing or systems analyses, also indicate the baseline or targets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

Scales of Experimentation and Modeling





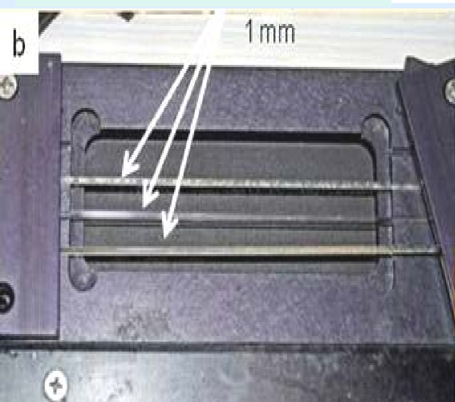




nm to cm

µm to dm

cm to 100s of m



Large Sandstone Core
Boyles sandstone formation, Alabama

76.2 cm (30 inch) x 38.1 cm (15 inch) sandstone core procurement and packer design for "***Radial flow***"

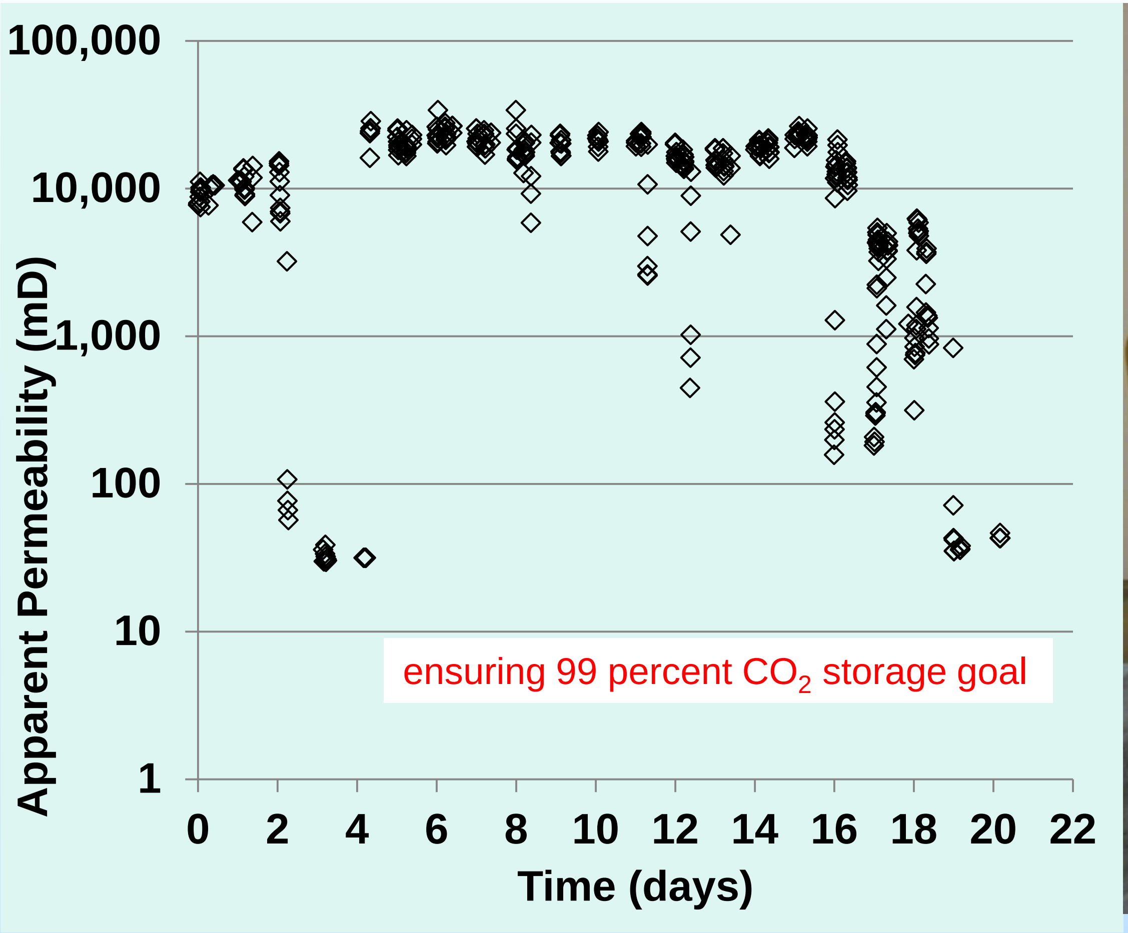
Phillips et al. (2013) Environmental Science and Technology. 47(1):142–149.
DOI: 10.1021/es301294q

Radial Flow High Pressure Vessel

Designed and built by Joe Eldring & Alaskan Copper, Seattle, WA USA

Phillips, AJ, Eldring, J, Hiebert, R, Lauchnor, E, Mitchell, AC, Gerlach, R, Cunningham, A, and Spangler, L. High pressure test vessel for the examination of biogeochemical processes. In preparation for J. Petrol. Sci. Eng.

Fracture Sealing at 45 bar



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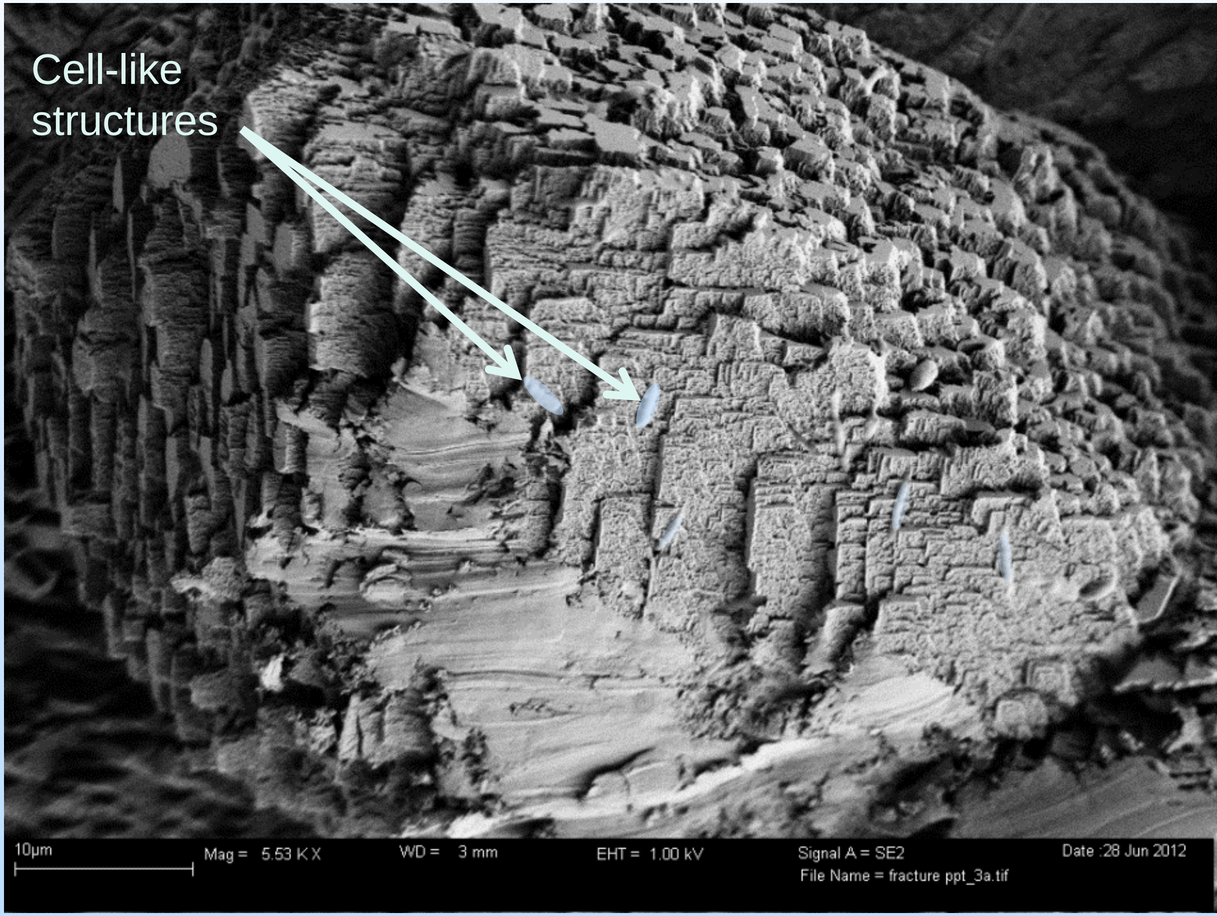
Biominerals Formed



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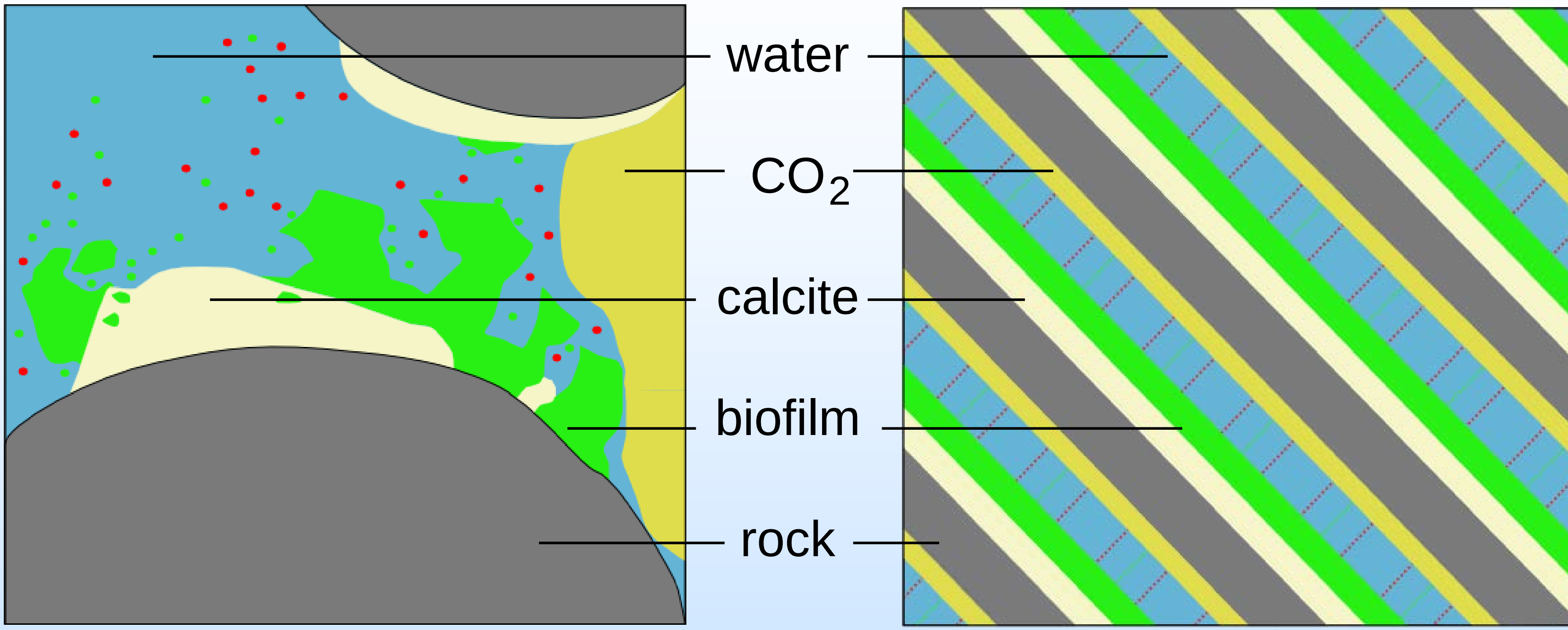
MICP Model concept

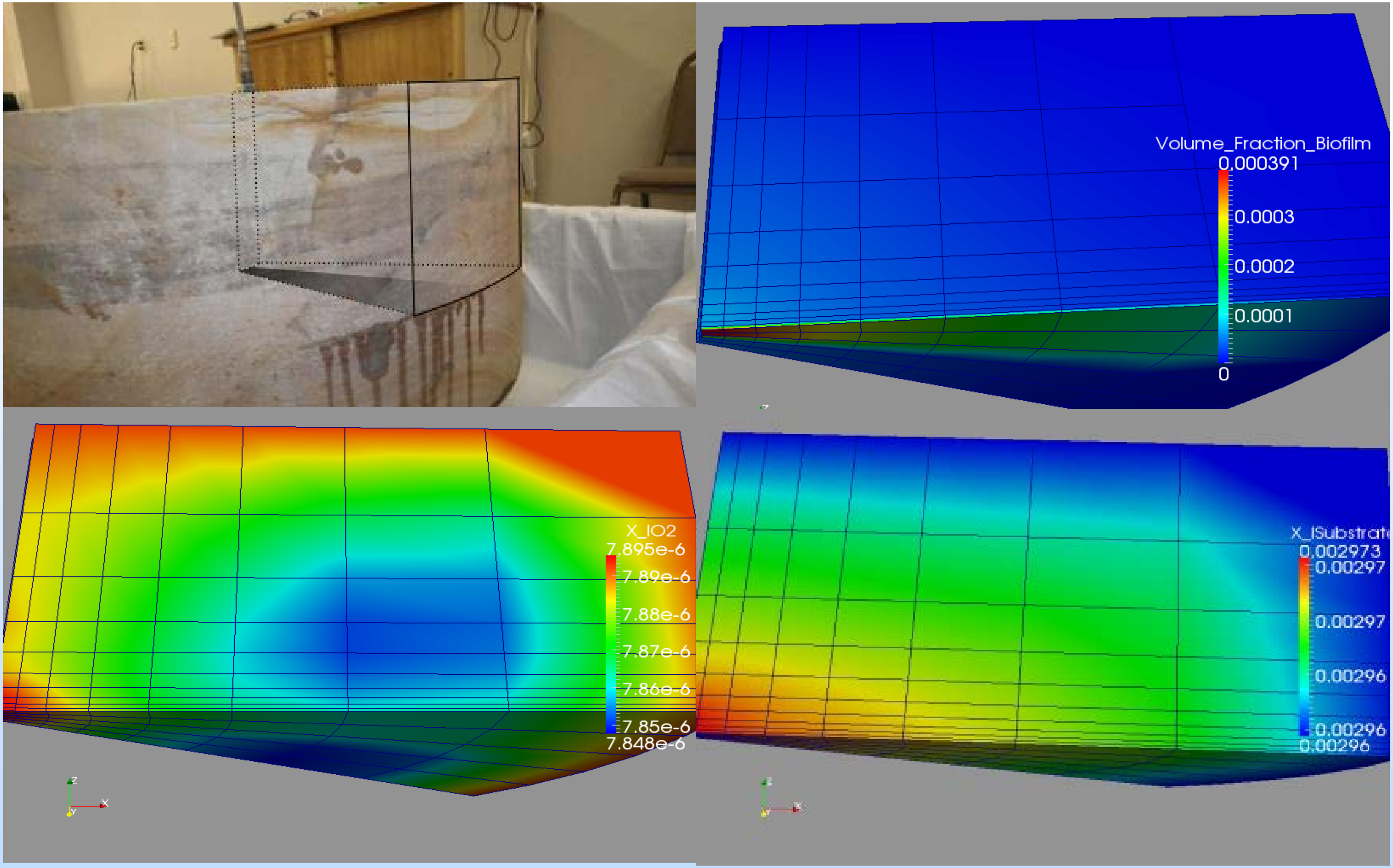


(modified after Ebigbo et. al., *WRR* 2012)

averaging

Pore scale → REV scale

MICP Modeling of Sandstone

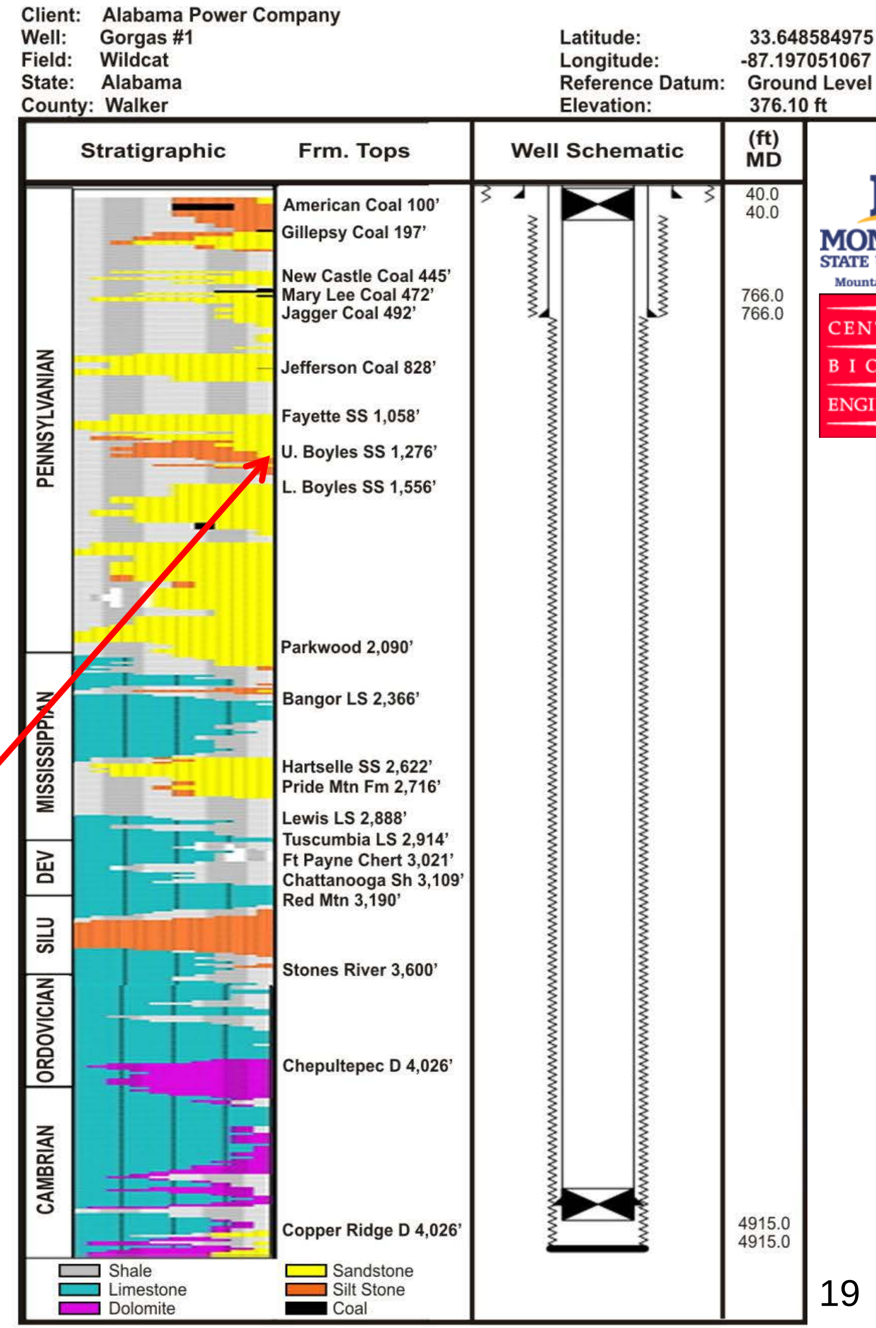


MICP Field Test

Date April 1 – 11, 2014
Location: Gorgas Power Plant near Jasper Alabama
Injection Zone: Horizontal hydraulic fracture at 1118 feet bgs
Collaborators: Southern Company & Schlumberger Carbon Services

SOUTHERN COMPANY Schlumberger

Gorgas well and Test site



Total well depth 4915 ft
Test was conducted at 1118 ft, bgs

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Characterize and prepare the Alabama Test site

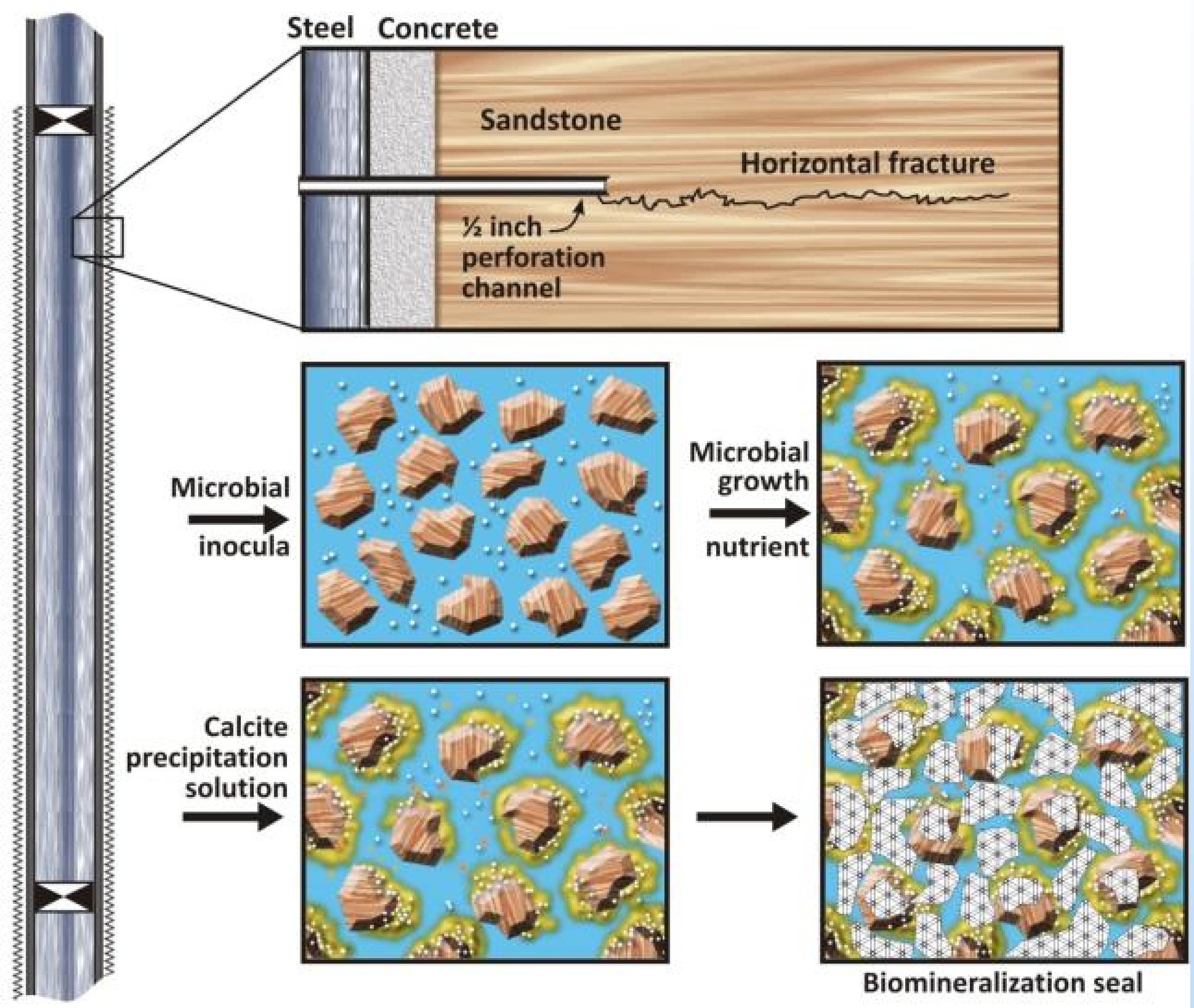
- Injection test

- Formation fractured at approx. 960 psi – horizontal pancake fracture at 1118 ft. bgs

- Injection test at 0.5 gpm for 4.5 hours at just over 500 psi

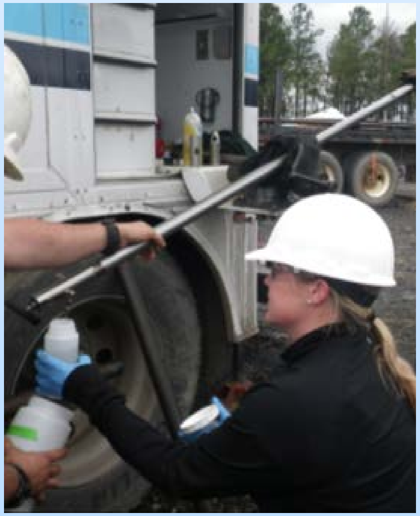
- Falloff analysis indicates approx. 11 mD formation permeability

Hydraulic fracture sealing: Conceptual model



Field Deployment- Fracture Sealing

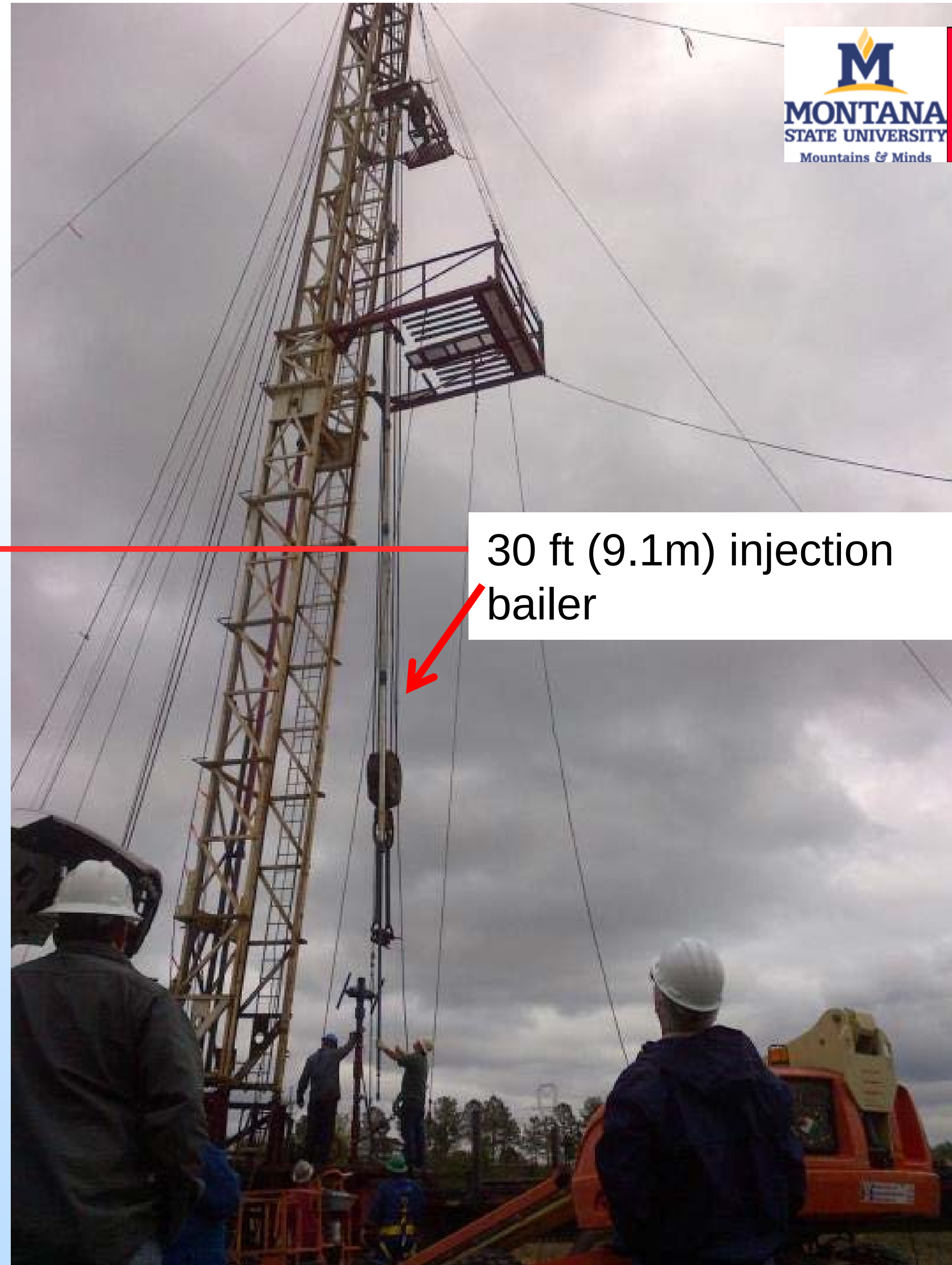
- Bailer delivery system
- Injection strategy
- Mobile laboratory- microbe cultivation
- Sampling



SOUTHERN COMPANY

Schlumberger

30 ft (9.1m) injection bailer



Protocol for biomineralization testing in the field

Inoculation injection Components:

S. pasteurii	2 to 5 E+7 CFU/ml
Urea	795 gr
NH4Cl	331 gr
Nutrient Broth	99 gr

Calcium Injection Components:

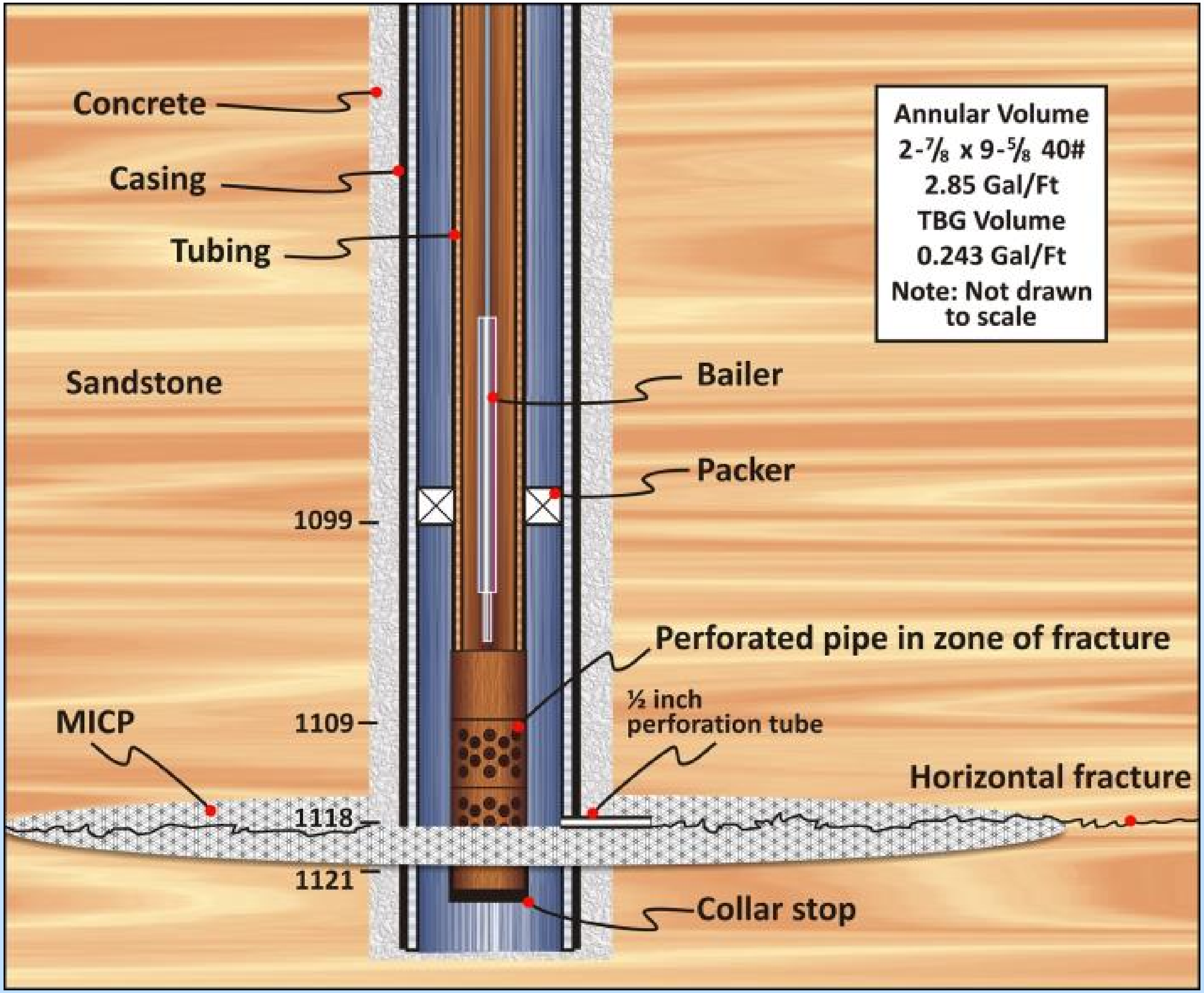
CaCl2	1285 gr
Urea	795 gr
NH4Cl	331 gr
Nutrient Broth	99 gr

Bailer capacity	**3 to 3.75 gallons**
Dilution Volume	**5 to 10 gallons**

Injection of brine through 2.75 inch tubing –
Injection of inoculum and calcium/urea fluids using a dump bailer

Complete sealing after 3 days:

24 calcium injections, 6 inoculation injections, 15 kg Ca

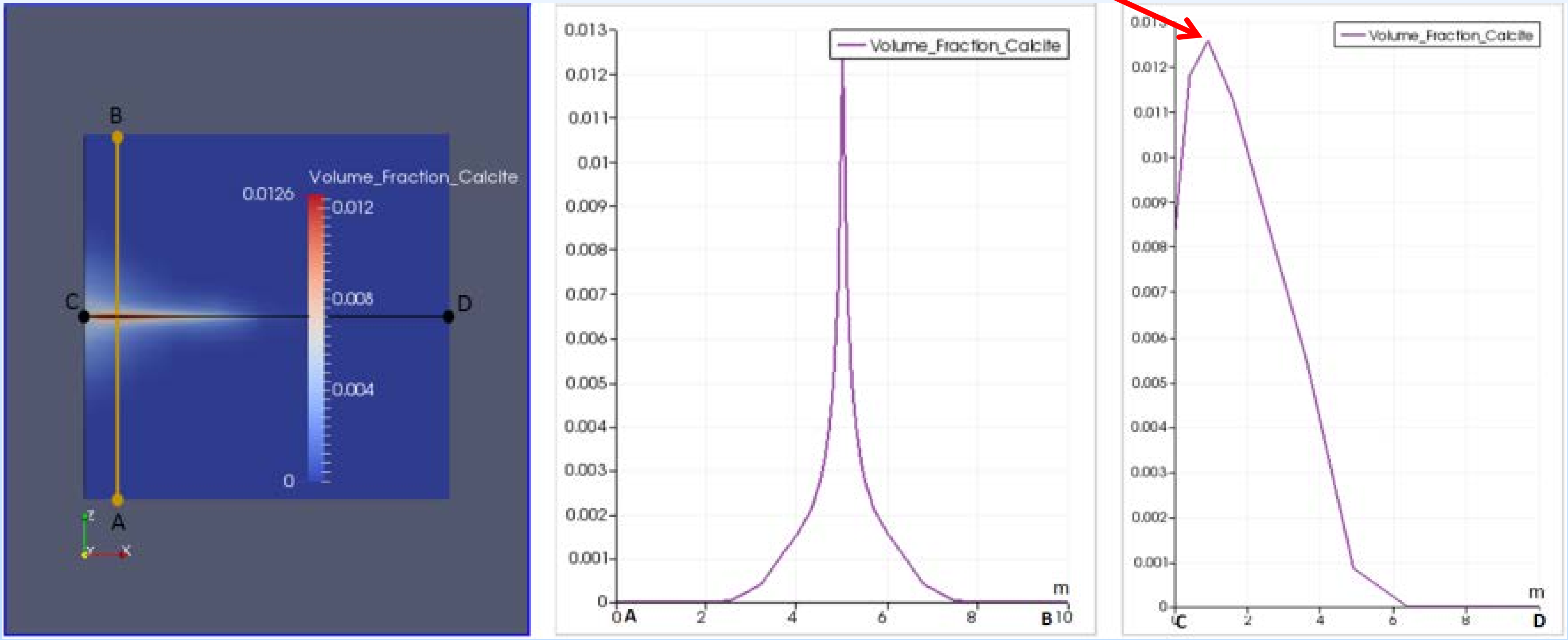


Yellow colonies
S. Pasteurii

MICP model simulation using Gorgas field protocol made prior to field injection

Volume fraction of calcite (0.125 m^3 $CaCO_3/m^3$) at the end of the MICP simulation.

25 Ca injections, 11kg of Ca total, 6 Inoculation injections



Accomplishments to Date

The following list summarizes **completed project objectives** from Project FE0004478 and Project FE0009599

- Construct and test mesoscale high pressure rock core test system (HPRTS) *(4478 Objective 1)*
- Develop biomineralization seal experimental protocol *(4478 Objective 1)*
- Characterize the Alabama well test site (9599 Objective 1)
- Design protocol for field injection test (9599 Objective 2)
- Perform field injection test *(9599 Objective 3)*

Summary

Key Findings

- Mesoscale laboratory experiments, integrated with simulation modeling, were successfully used to develop the protocol for **sealing a horizontal hydraulic fracture** at the Alabama test well.
- Key microbial process - **ureolytic biomineralization-** was found to be robust under (non-sterile) down-hole conditions.

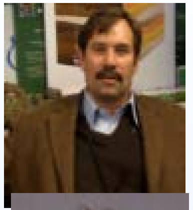
Lessons Learned

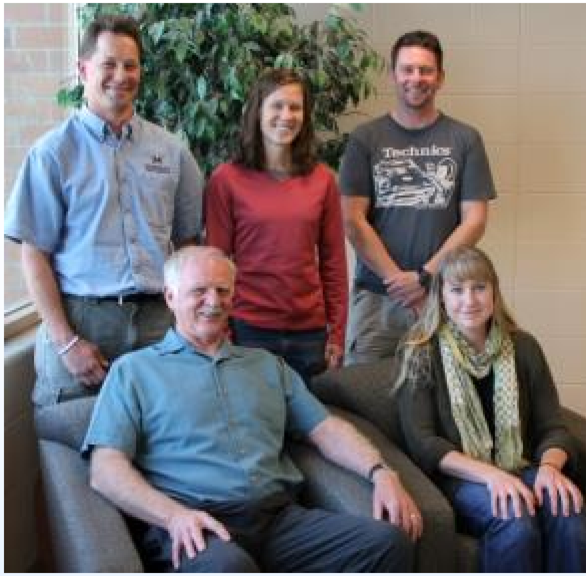
- Conventional oil field technology can be used to promote MICP in subsurface applications.

Future Plans

- Creation of biomineralization seal in different rock types and simulating different field conditions i.e. *sandstone, shale, cement, steel.* *(4478 Objective 3)*
- Evaluate results of field test. *(9599 Objective 4)*
- Continue development of MICP simulation model.

Acknowledgements





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Universität Stuttgart

Collaborators

Jim Kirksey and Dwight Peters,
Schlumberger

Richard Esposito, John Poole
Southern Company

Pete Walsh
University of Alabama Birmingham

Anozie Ebigbo, Johannes Hommel Holger Class, and Rainer Helmig
University of Stuttgart

Joe Westrich, Bart Lomans, Andreas Busch,
Shell

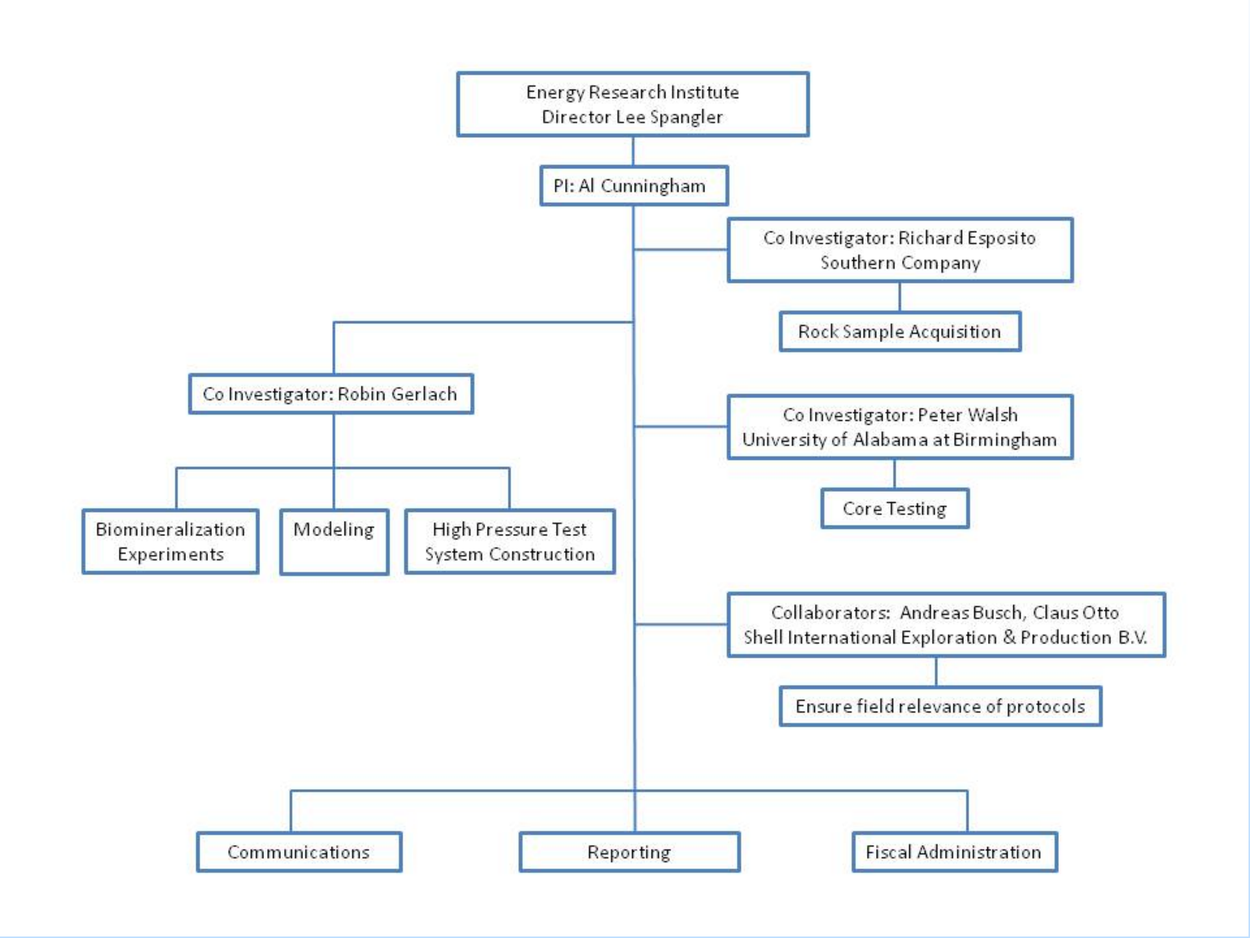
Randy Hiebert, Ellen Lauchnor, Lee Spangler, Joe Eldring, Andy Mitchell, James Connolly, Peg Dirckx, CBE/MSU

Appendix

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

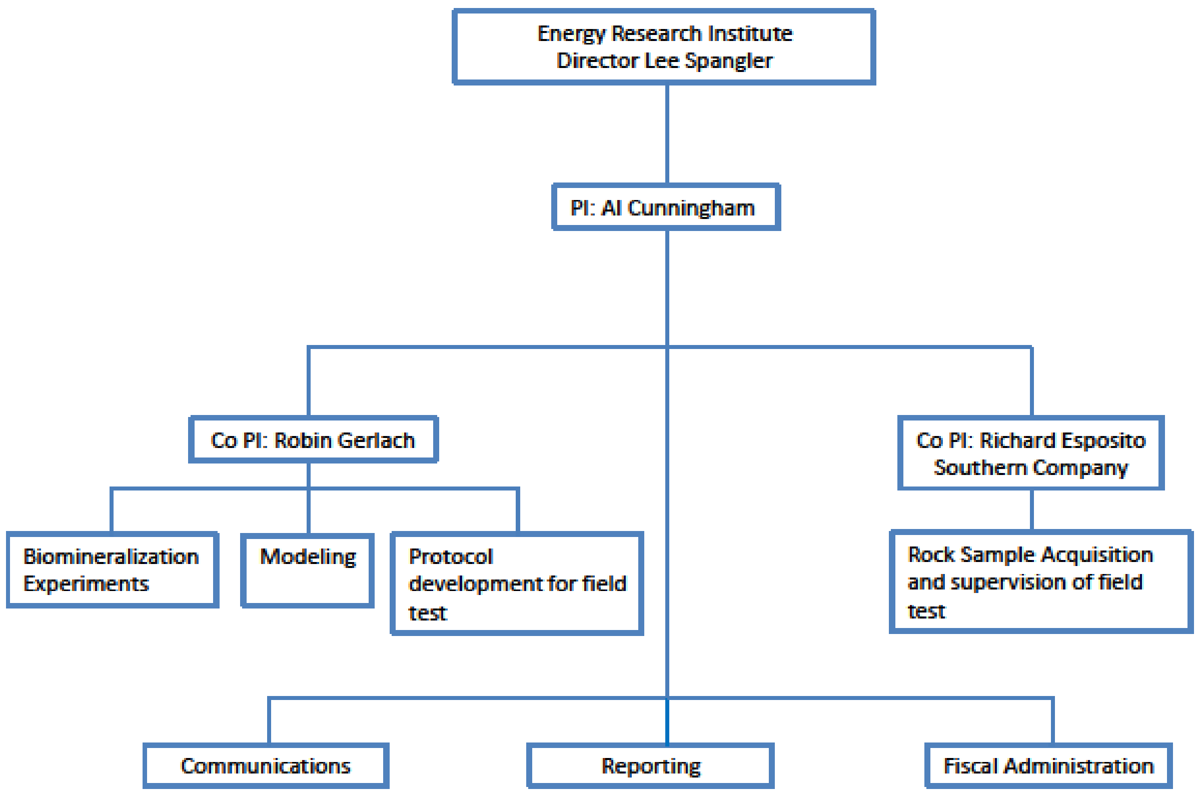
Organization Chart

Project DE-FE0004478



Organization Chart

Project DE-FE0009599



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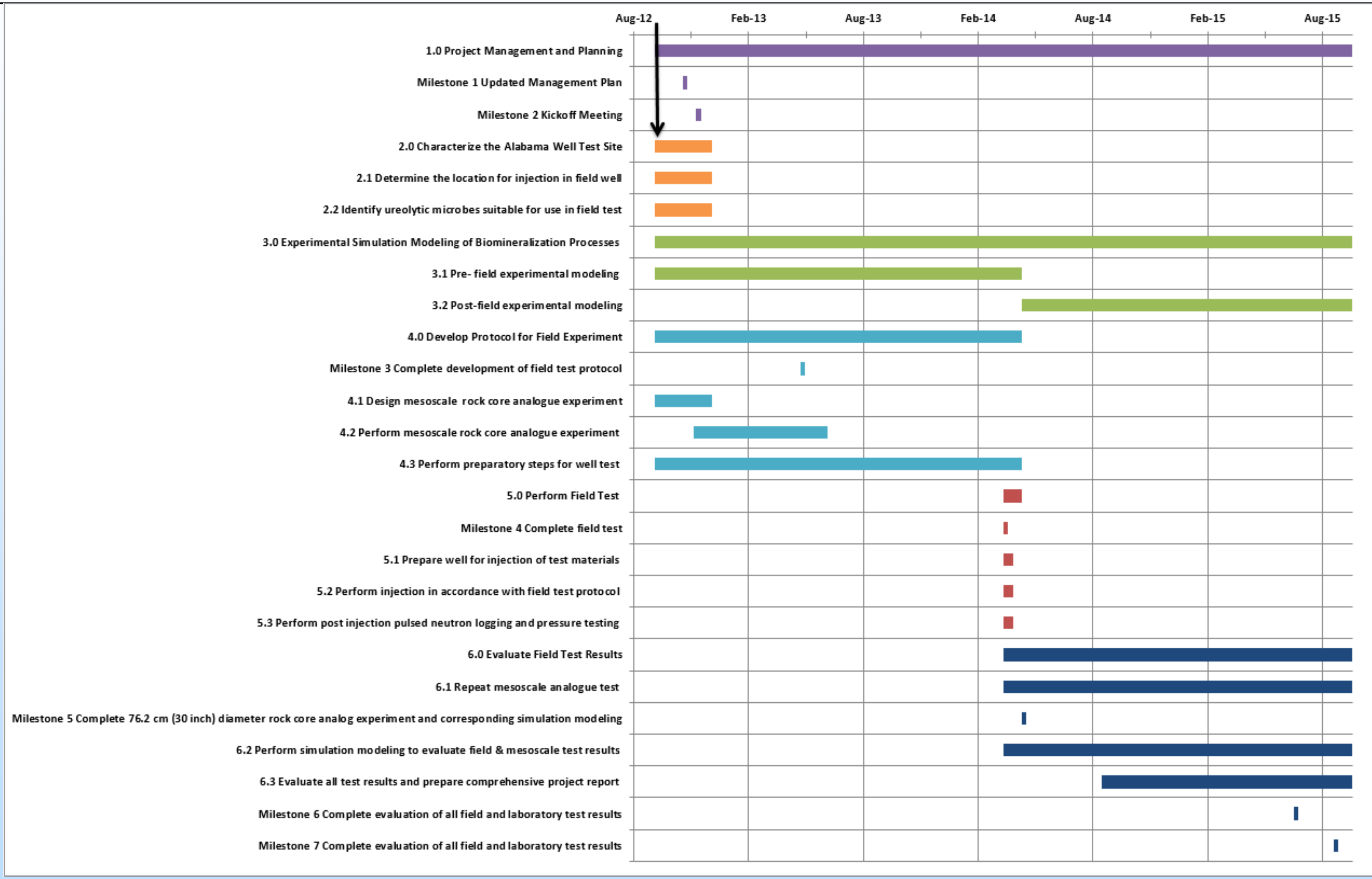
Gantt Chart Project DE-FE0004478

Task / Mileston	Description	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17
1	Project Management & Planning																	
M1	Milestone: Update Project Management Plan	❶																
M2	Milestone: Kickoff Meeting	❷																
2	Construction of high pressure rock testing systems (HPRTS)																	
M4	Mielstone: Acquire rock samples from field				❹													
M5	Milestone: Complete construction of high pressure rock testing system						❺											
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																	
M3	Milestone: Complete optimization of biomineralization experimental design for radial flow using the University of Stuttgart's simulation model			❸														
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																	
M6	Milestone: Complete first set of biomineralization sealing experiments							❻										
M7	Milestone: Complete final set of biomineralization sealing experiments																	⑦
4.1	Additional Experiments																	
4.2	ScCO2 challenges of mineralized rock																	
5	Experimental Simulation Modeling of Processes																	
M8	Milestone: Complete modeling of biomineralization sealing processes																	⑧
5.1	Pre-experimental modeling																	
5.2	Post-experimental modeling																	

* Shaded numbered circles are completed milestones

Gantt Chart *Project DE-FE0009599*



Bibliography

1. Connolly, J.; Kaufman, M.; Rothman, A.; Gupta, R.; Redden, G.; Schuster, M.; Colwell, F.; Gerlach, R., 2013, Construction of two ureolytic model organisms for the study of microbially induced calcium carbonate precipitation. *Journal of Microbiological* Methods. v. 94(3), p. 290-299. DOI: 10.1016/j.mimet.2013.06.028
2. Cunningham, A.B.; Lauchnor, E.; Eldring, J. Esposito, R.; Mitchell, A.C.; Gerlach, R.; Connolly, J.; Phillips, A.J.; Ebigbo, A.; Spangler, L.H. (2013): Abandoned Well CO_2 Leakage Mitigation Using Biologically Induced Mineralization: Current Progress and Future Directions. *Greenhouse Gas Sci. Technol.* 2:1–10. DOI: 10.1002/ghg.1331
3. Lauchnor, E.G.; Schultz, L.; Mitchell, A.C.; Cunningham, A.B.; Gerlach, R. (2013): Bacterially Induced Calcium Carbonate Precipitation and Strontium Co-Precipitation under Flow Conditions in a Porous Media System. *Environmental Science and Technology*. 47(3):1557–1564. http://dx.doi.org/10.1021/es304240y
4. Mitchell, A.C.; Phillips, A.J.; Schultz, L.N.; Parks, S.L.; Spangler, L.H.; Cunningham, A.B.; Gerlach, R. (2013): Microbial $CaCO_3$ mineral formation and stability in an experimentally simulated high pressure saline aquifer with supercritical CO_2. *International Journal of Greenhouse Gas Control*. 15(July):86-96. DOI: 10.1016/j.ijggc.2013.02.001
5. Phillips, A.J.; Gerlach, R.; Lauchnor, E.; Mitchell, A.C.; Cunningham, A.B.; Spangler, L. Engineered applications of ureolytic biomineralization: a review. *Biofouling*. 29(6): p. 715-733. DOI: 10.1080/08927014.2013.796550
6. 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
7. Ebigbo A.; Phillips, A; Gerlach, R.; Helmig, R.; Cunningham, A.B.; Class, H.; Spangler, L. (2012): Darcy-scale modeling of microbially induced carbonate mineral precipitation in sand columns. *Water Resources Research*. 48, W07519, doi:10.1029/2011WR011714.