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

Transforming Technology through Integration and Collaboration

August 18-20, 2015

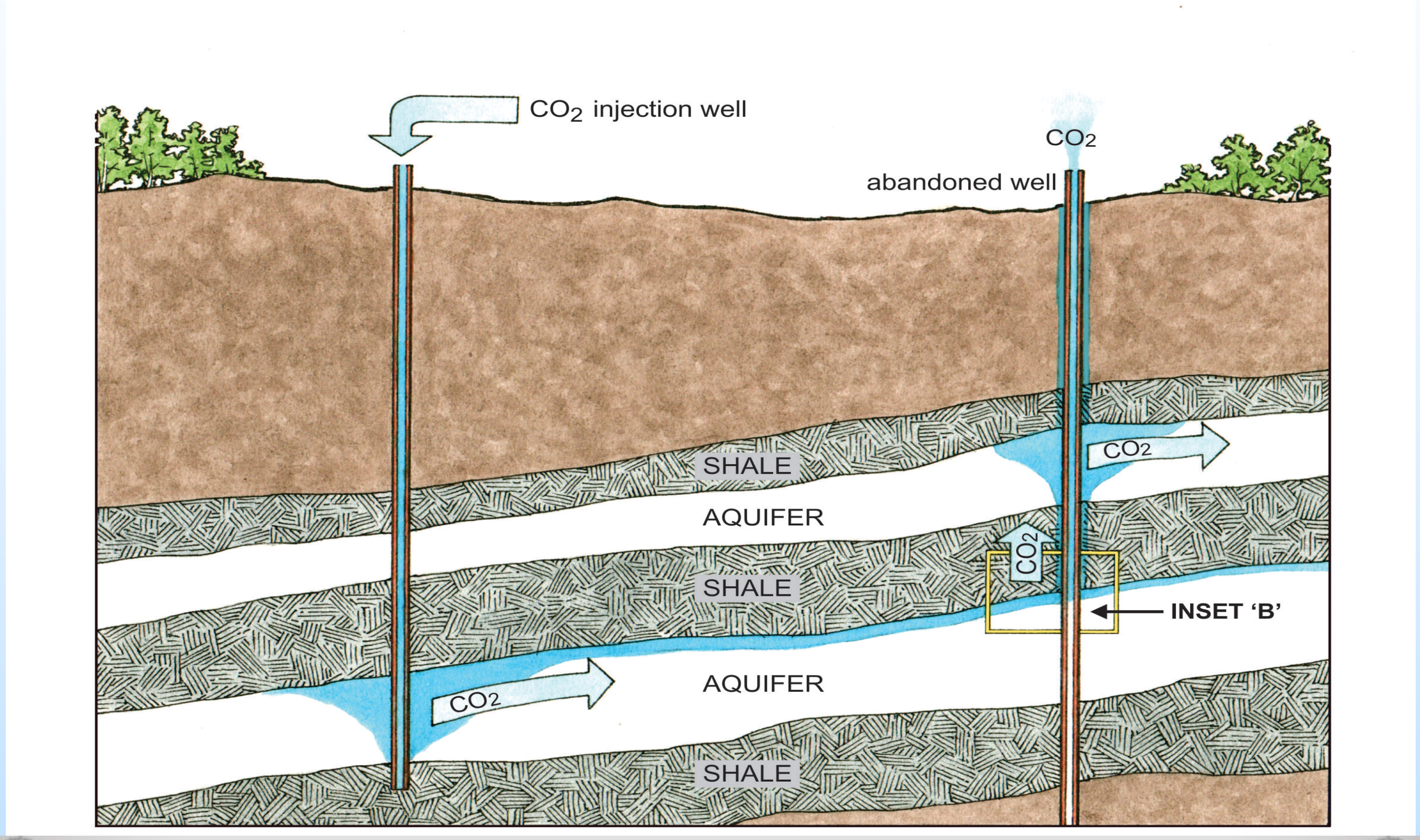
Presentation Outline

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

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

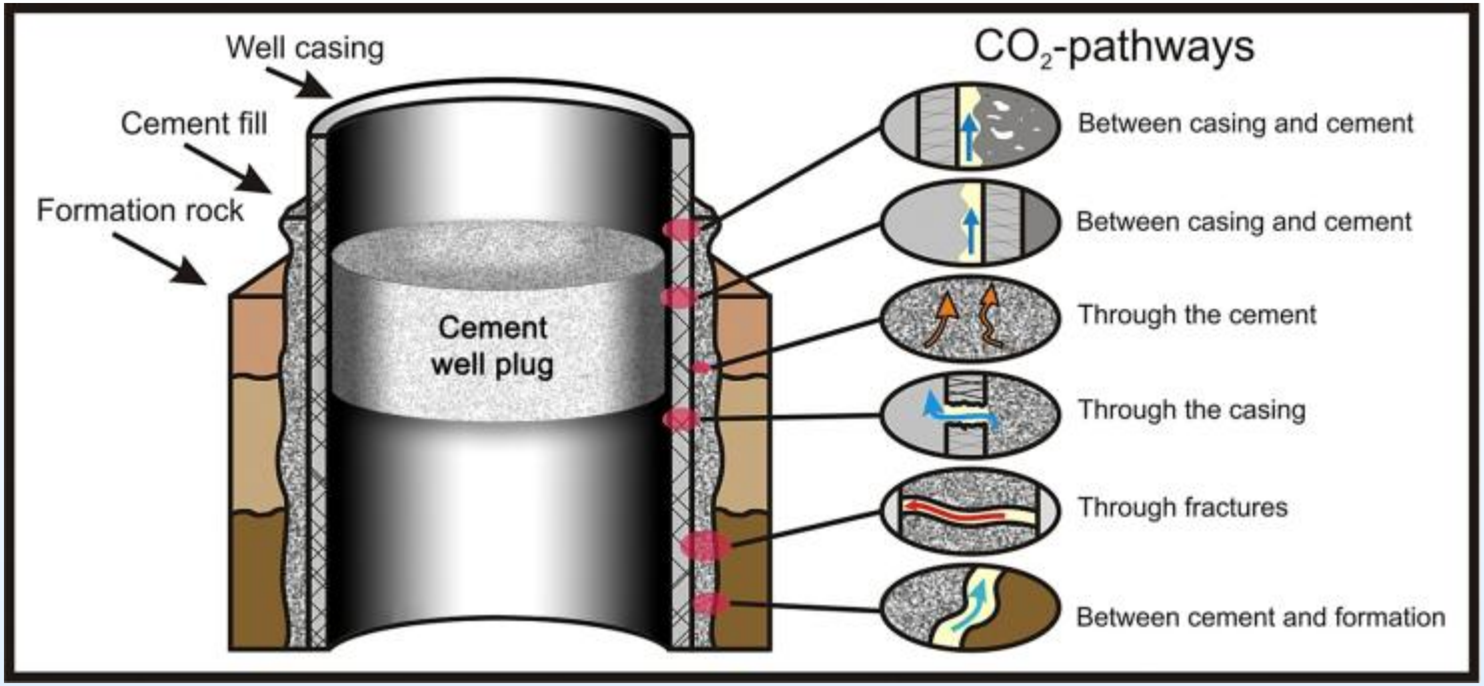
Project Concept

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



Project Concept

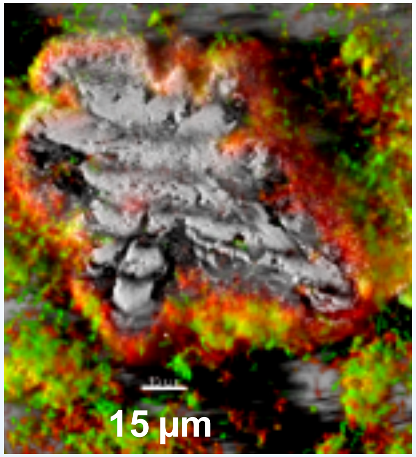
-MICP sealing with low-viscosity fluids-



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**

Calcite Biomineralization (MICP) Using Ureolytic Bacteria

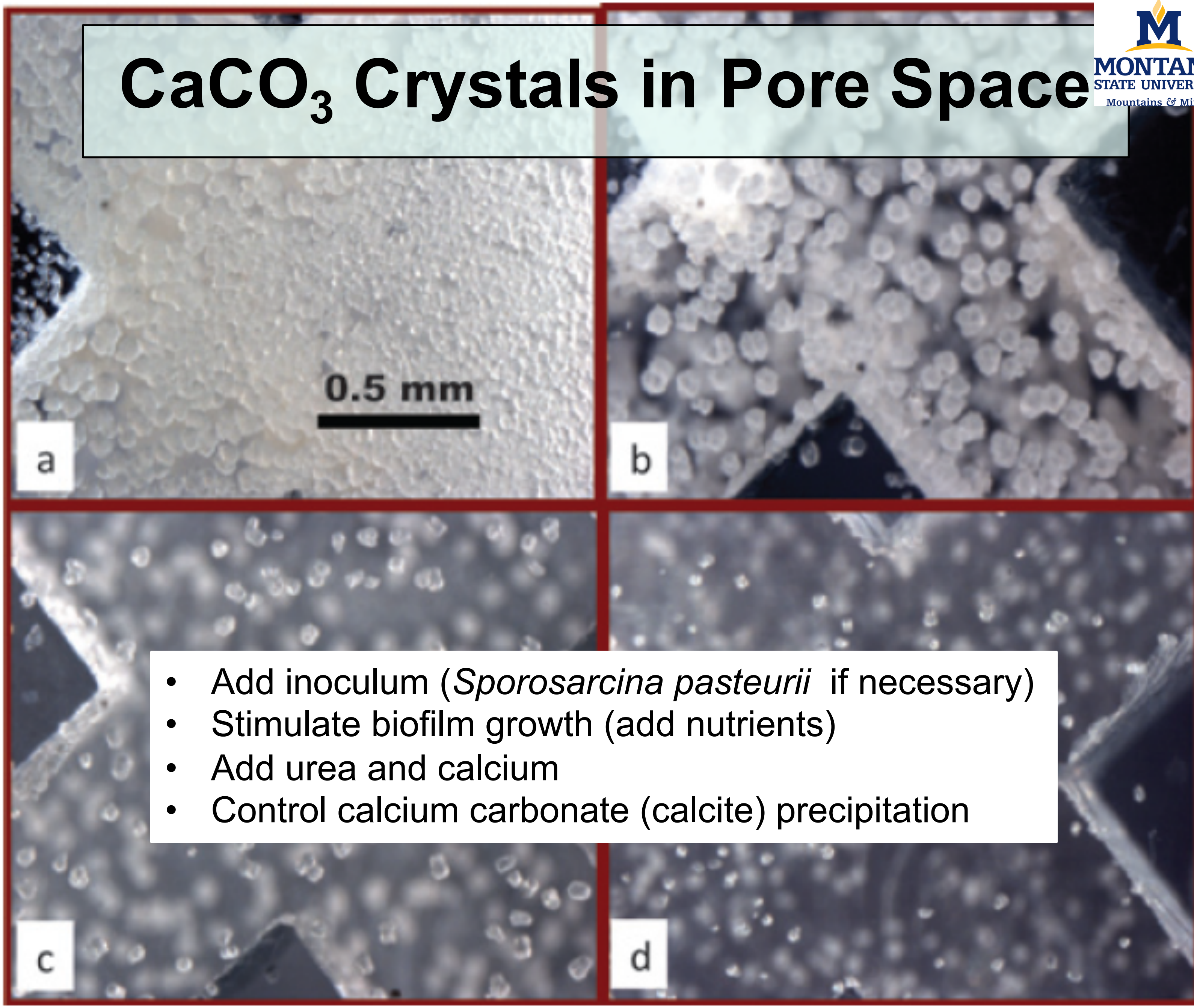


- $NH_2CONH_2 + H^+ + H_2O \leftrightarrow 2NH_4^+ + HCO_3^-$ (1)
- $Ca^{2+} + 2HCO_3^- \leftrightarrow CaCO_3(s) + CO_2 + H_2O$ (2)

- The enzyme urease present in some bacteria (e.g. (*Sporosarcina pasteurii*) hydrolyzes urea to form ammonium and carbonates, which increases alkalinity
- In the presence of Ca^{2+}, saturation can be exceeded and calcium carbonate (Calcite) precipitates

SCHULTZ, L.; PITTS, B.; MITCHELL, A.C.; CUNNINGHAM, A.B.; GERLACH, R. (2011). *Microscopy Today*. September 2011:10-13.

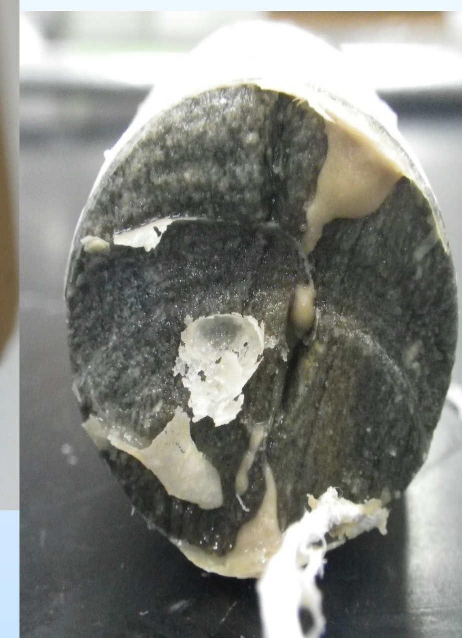
$CaCO_3$ Crystals in Pore Space



- Add inoculum (*Sporosarcina pasteurii* if necessary)
- Stimulate biofilm growth (add nutrients)
- Add urea and calcium
- Control calcium carbonate (calcite) precipitation

SCHULTZ, L.; PITTS, B.; MITCHELL, A.C.; CUNNINGHAM, A.B.; GERLACH, R. (2011). *Microscopy Today*. September 2011:10-13.

Biocementation of Sand and Sealing of Fractures



Benefit to the Program

Program goals being addressed:

Develop and validate technologies to ensure 99 percent storage performance.

Project benefits statement:

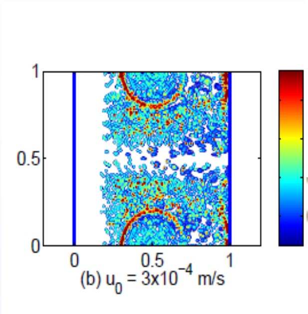
The Engineered Biomineralized Sealing Technologies (MICP) projects support Storage Program goals by developing a leakage mitigation technology for small aperture leaks that can be delivered via low viscosity solutions. The technology, if successfully applied, could provide an alternative technology to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

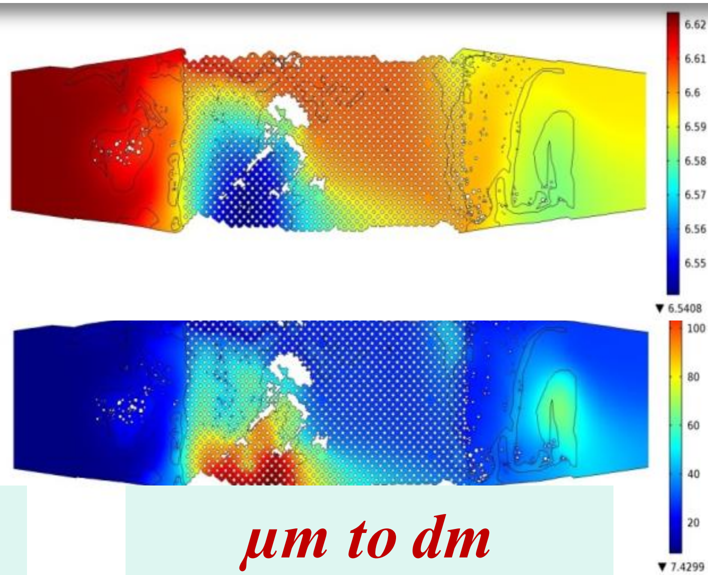
Precursor Project

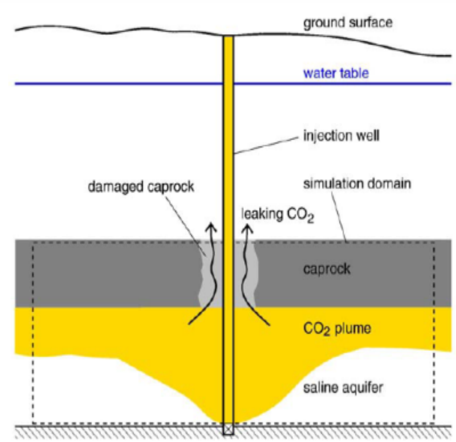
Project FE0004478 Advanced CO_2 Leakage Mitigation using Engineered Biomineralized Sealing Technologies

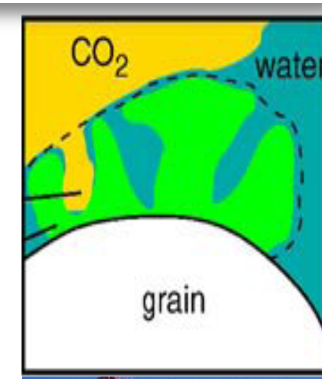
1) Construct and test mesoscale high pressure rock core test system (HPRTS). (Completed)
2) Develop biomineralization seal experimental protocol. (Completed)
3) Creation of biomineralization seal in different rock types and simulating different field conditions. (Completed)

Technical Status









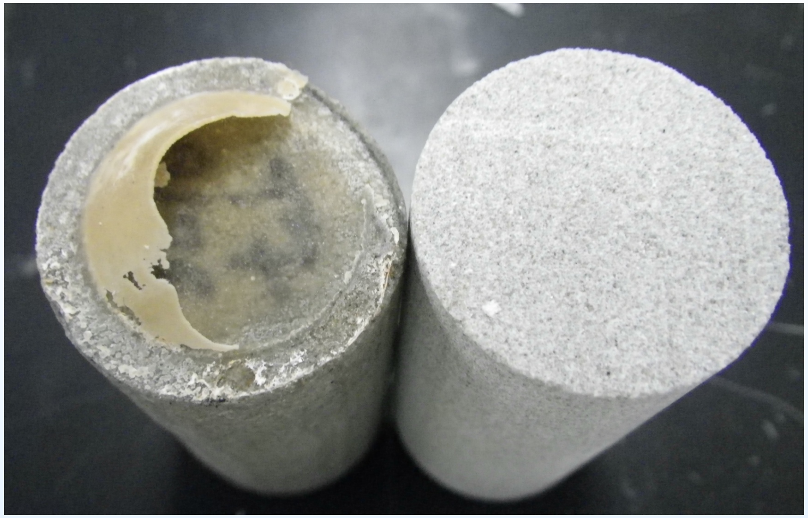
nm to cm

µm to dm

cm to 100s of m

Biomineralization in Sand(stone)

60 cm column



5 cm rock cores *high P*

30 cm radial fracture *high P*

sandpack around simulated perforations *high P*

Project Overview:
Goals and Objectives (Project FE0009599)

Project Duration: **October 1, 2012 – September 30, 2015**

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)

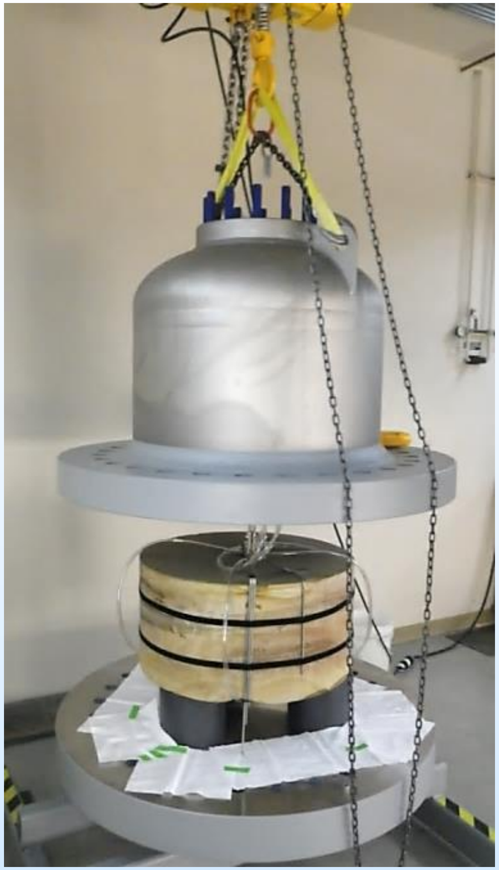
(4) Evaluate results of field test. (Ongoing)

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, 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

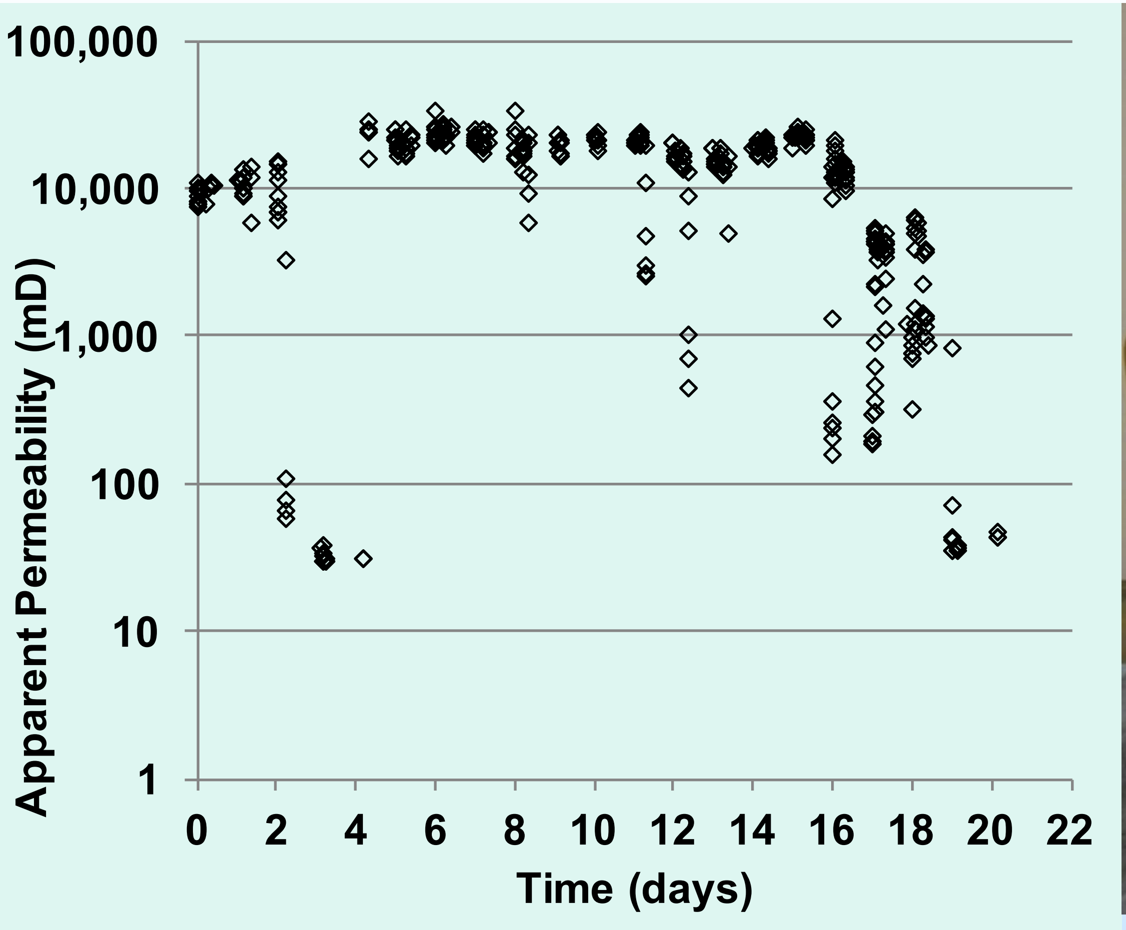
Radial Flow High Pressure Vessel



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. J. Petrol. Sci. Eng. 126, February 2015:55-62, DOI: 10.1016/j.petrol.2014.12.008

Fracture Sealing at 45 bar



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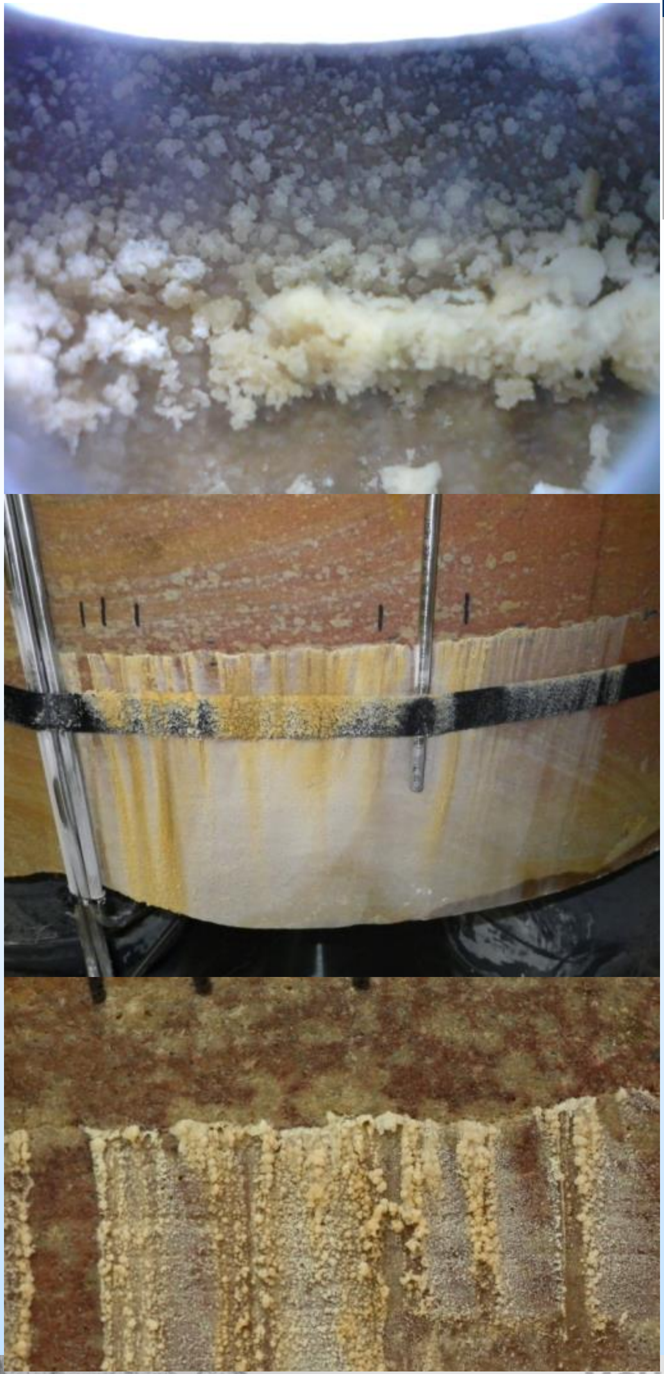
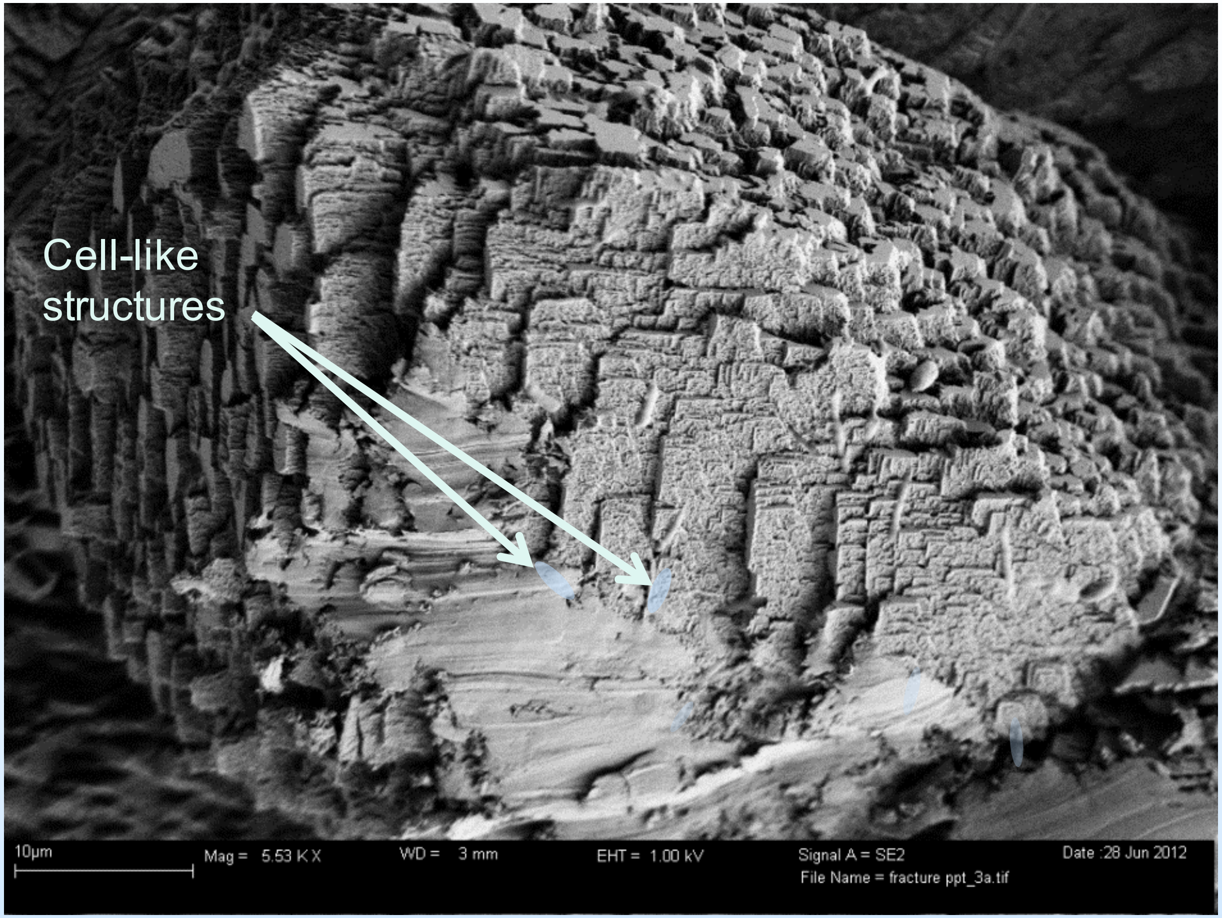
Biominerals Formed





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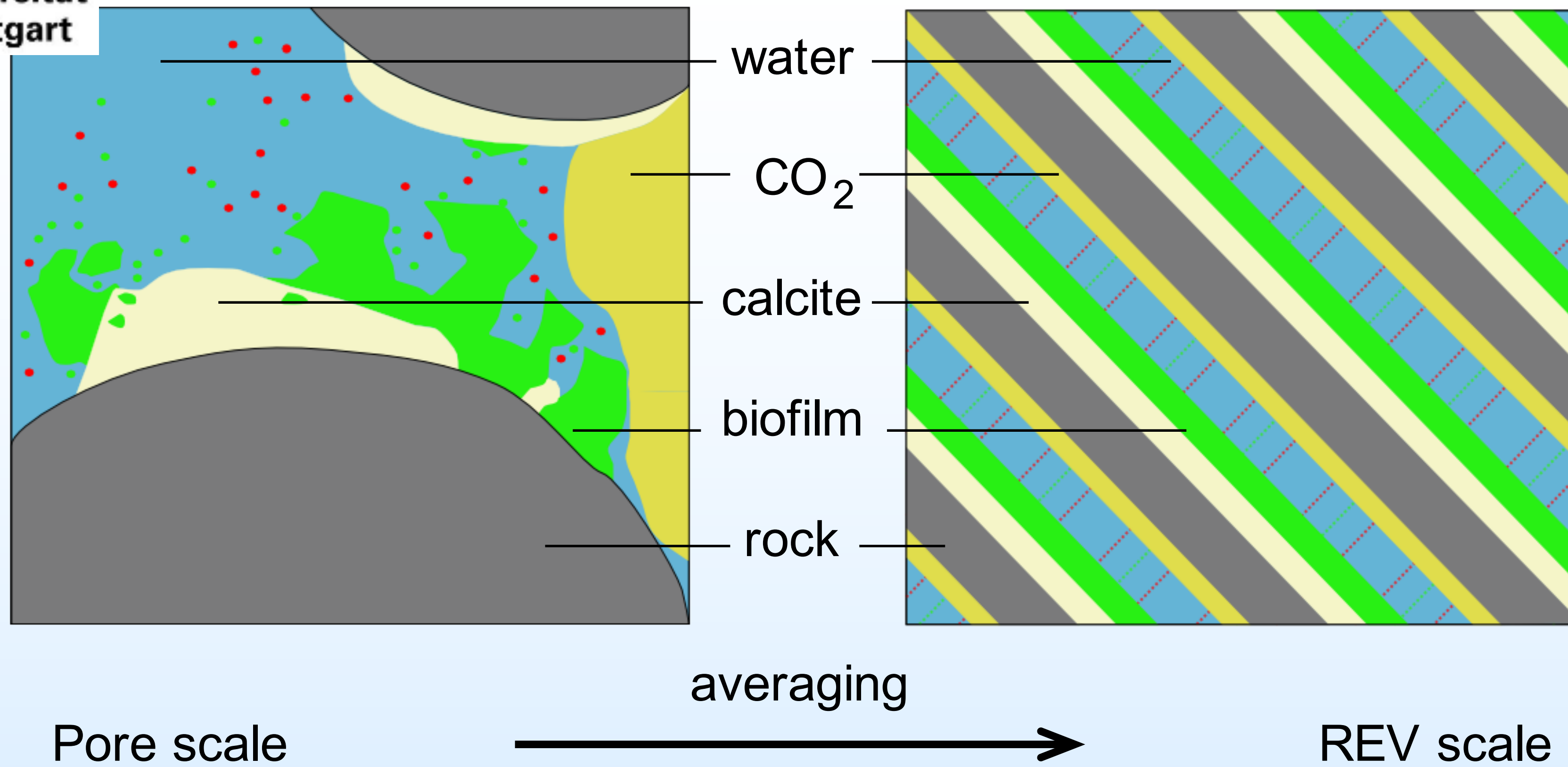
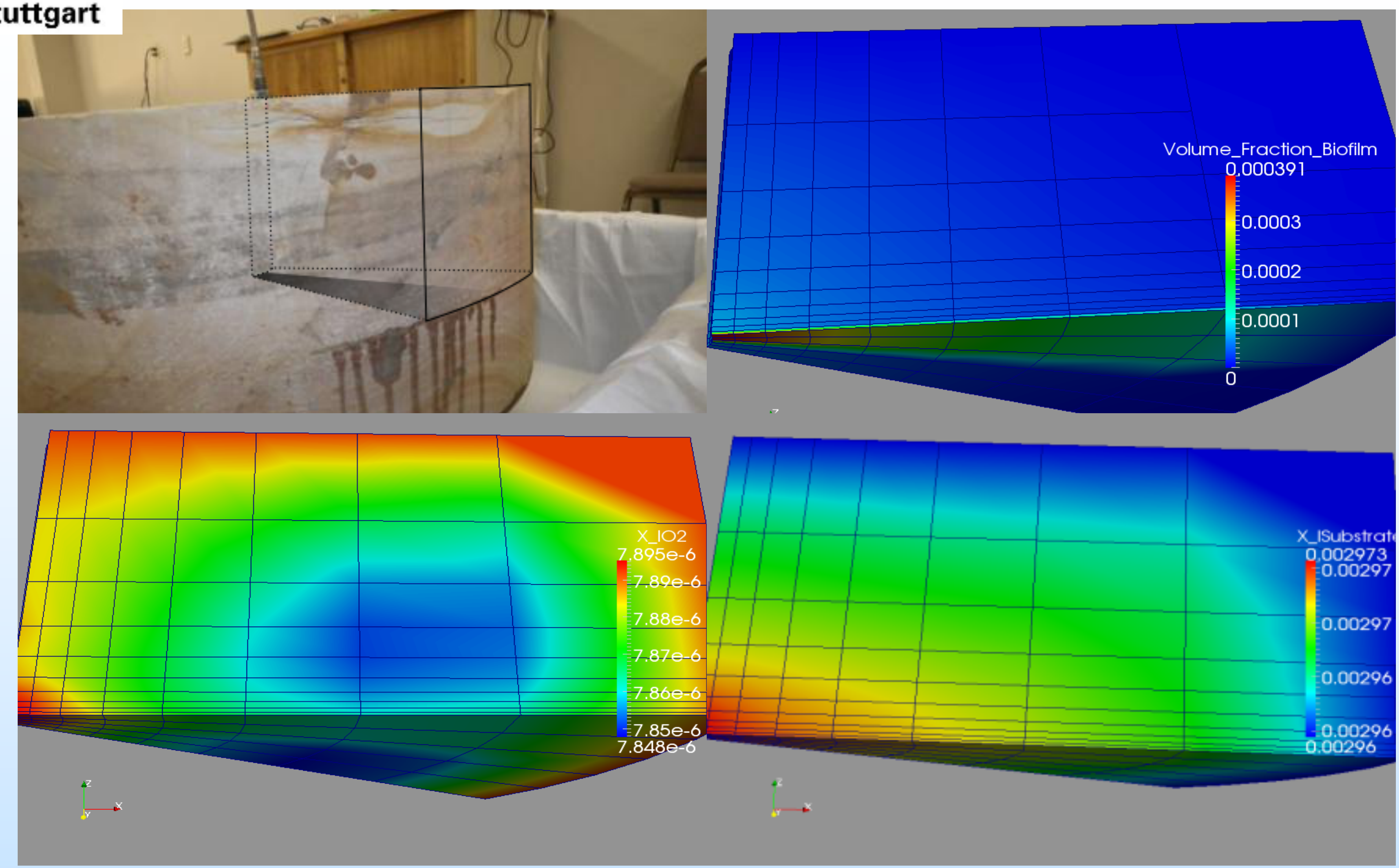
MICP Model



- 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.
- Lauchnor, E.; Topp, D.; Parker, A.; Gerlach, R. (2015): Whole cell kinetics of ureolysis by *Sporosarcina pasteurii*. Journal of Applied Microbiology. 118(6):1321-1332. DOI: 10.1111/jam.12804
- Hommel, J.; Lauchnor, E.; Phillips, A.J.; Gerlach, R.; Cunningham, A.B.; Helmig, R.; Ebigbo, A.; Class, H. (2015): A revised model for microbially induced calcite precipitation - improvements and new insights based on recent experiments. Water Resources Research. 51(5):3695–3715. doi:10.1002/2014WR016503

MICP Modeling of Sandstone core



J. Hommel et al.

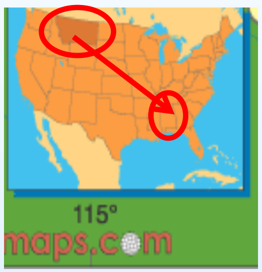
MICP Field Demonstration

MONTANA STATE UNIVERSITY Mountains & Minds
CENTER FOR BIOFILM ENGINEERING

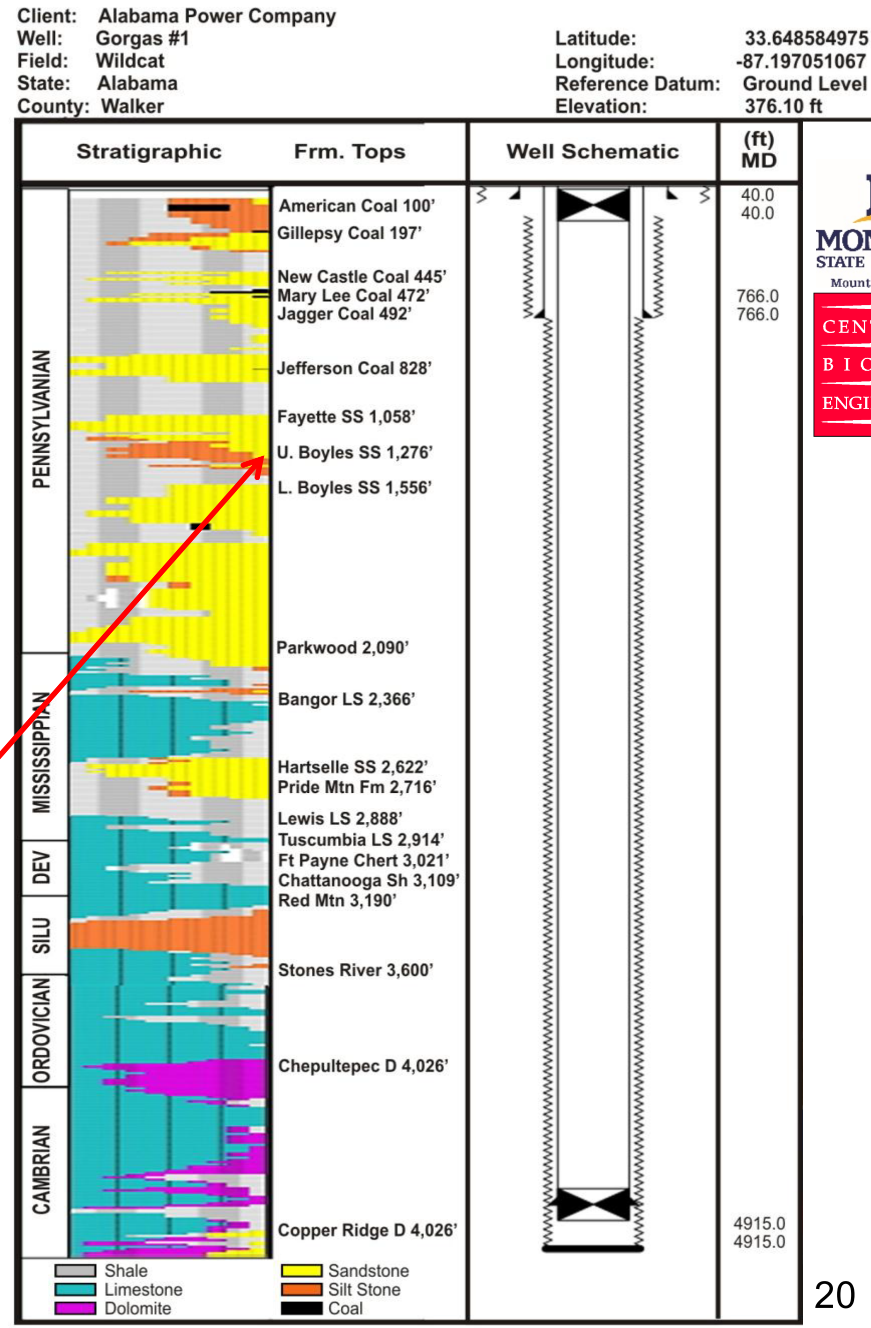
Date	April 1 – 11, 2014
Location:	Gorgas Power Plant near Jasper Alabama
Injection Zone:	Horizontal hydraulic fracture at 1118 feet bgs
Collaborators:	Southern Company & Schlumberger Carbon Services

SOUTHERN COMPANY

Schlumberger



Gorgas Well and Test Site



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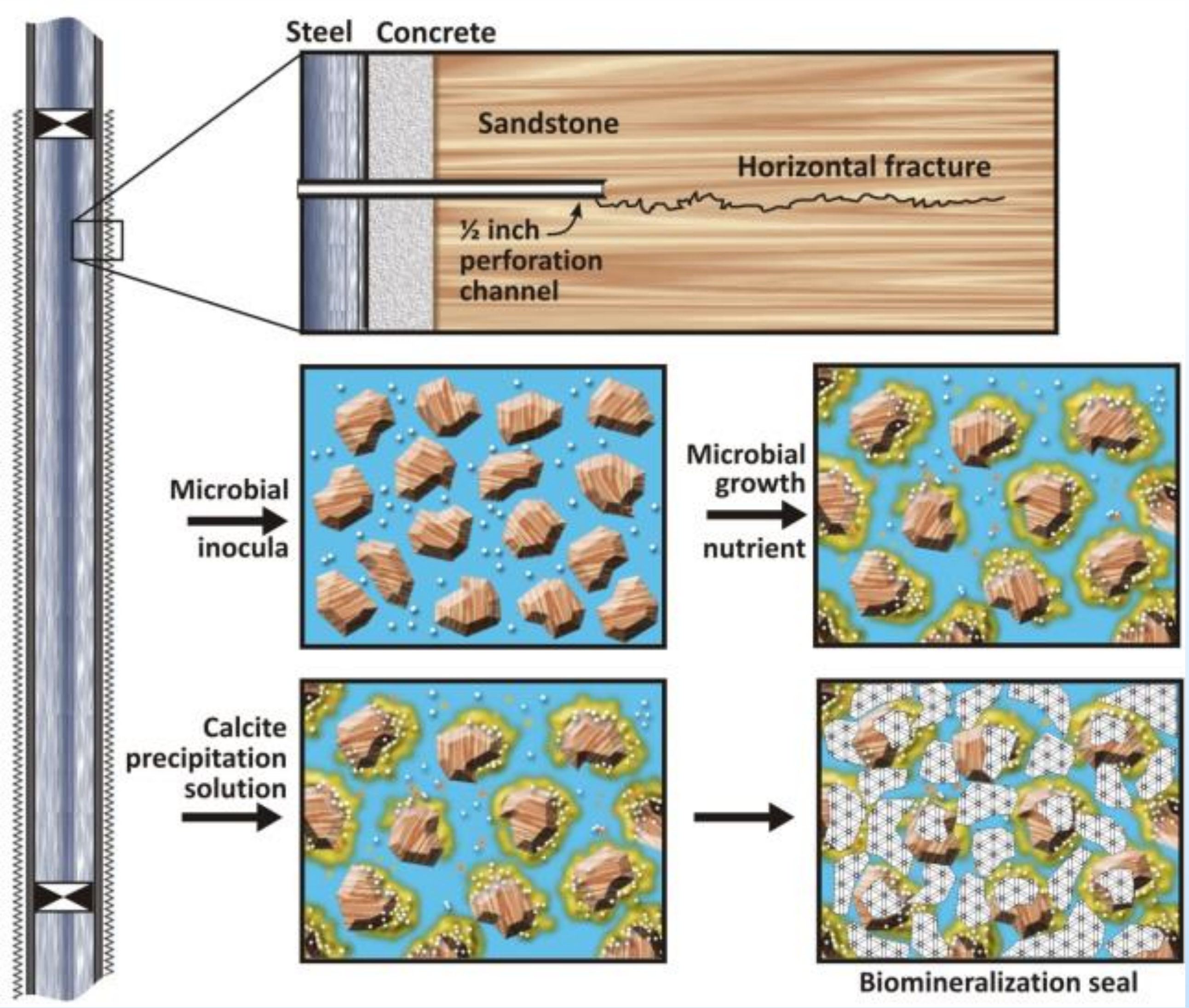
Mountains & Minds
CENTER FOR BIOFILM ENGINEERING

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

Hydraulic fracture sealing: Conceptual model



Characterize and prepare the Alabama Test site

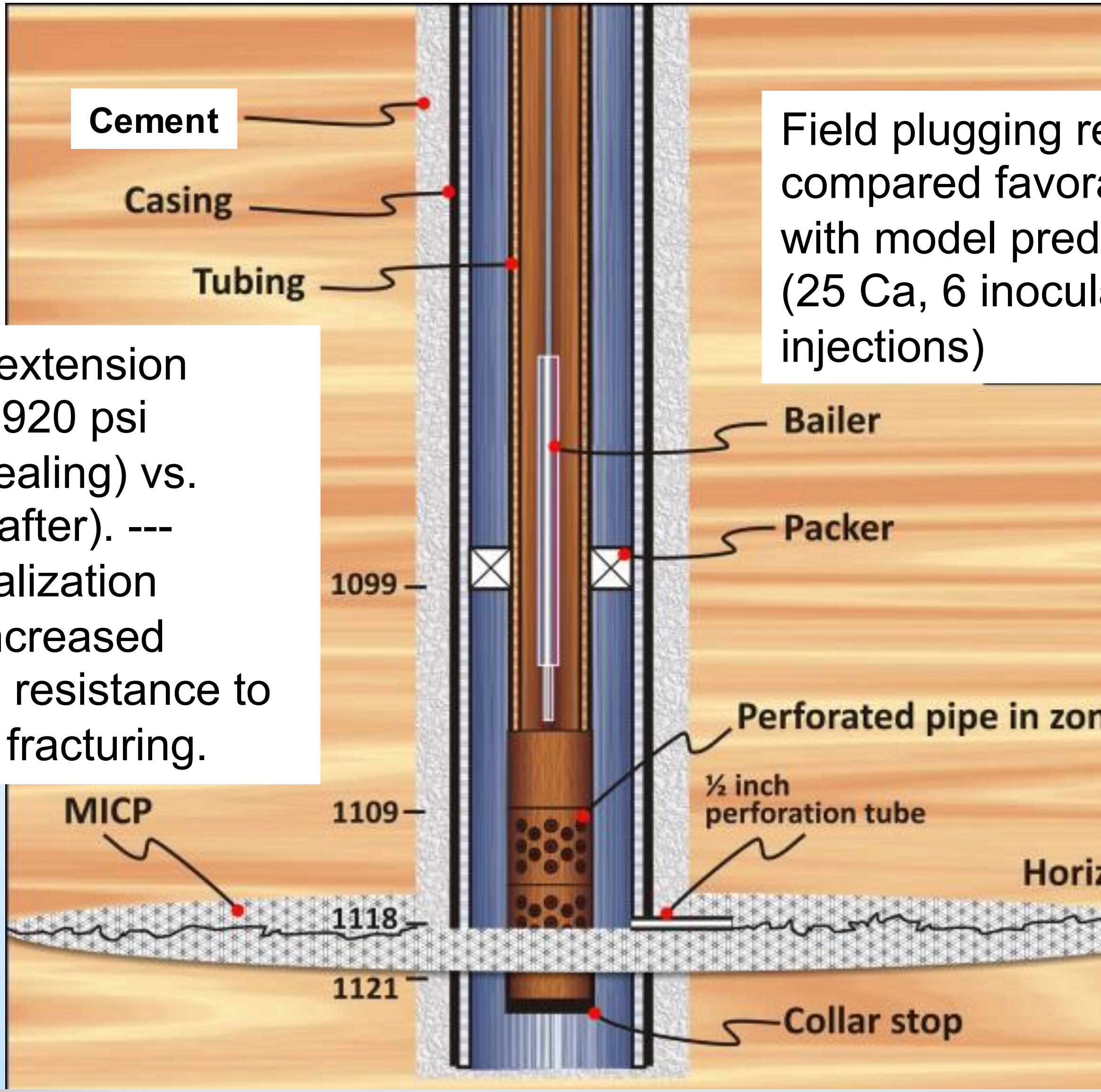
- Injection test
- Formation fractured at approx. 960 psi – horizontal pancake fracture at 1118 ft bgs
- Injection test at 0.5 gpm for 4.5 hours at just over 500 psi
- Falloff analysis indicates approx. 11 mD formation permeability

Field Deployment Fracture Sealing

- Bailer delivery system
- Injection strategy
- Mobile laboratory for inoculum preparation
- Sampling

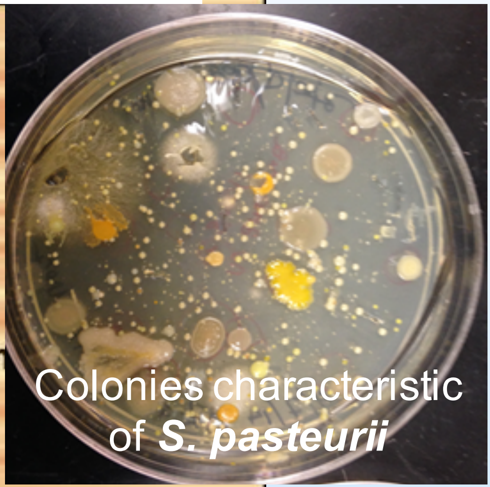

FILL PORT
TOP

Complete sealing after ~3 days:
24 calcium injections, 6 inoculum inj., 15 kg Ca



Field plugging results compared favorably with model predictions (25 Ca, 6 inoculation injections)

Fracture extension pressure 920 psi (before sealing) vs. 1140psi (after). --- Biomineralization sealing increased formation resistance to hydraulic fracturing.



Colonies characteristic of ***S. pasteurii***

Observations one year later

- Well was full of fluid ! – indicates that no to very little fluid was lost to the formation over the last year. Thus, the MICP treatment continued to plug off the well even after (partial) refracturing.
- Indication of calcite like material in side wall cores [XRD, microscopy (calcite autofluorescence)]

Accomplishments to Date

The following list summarizes **completed and ongoing project objectives** from Project FE0009599 (October 1, 2012 – September 30, 2015)

- 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)*
- Evaluate results of field test *(9599 Objective 4 – ongoing)*

Synergy Opportunities

Mesoscale high pressure vessel for scale up work – radial flow, samples up to ~70 cm diameter, ~50 cm height

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. J. Petrol. Sci. Eng. 126, February 2015:55-62, DOI: 10.1016/j.petrol.2014.12.008

Synergies (and Synergy Opportunities)

- Made possible further R&D/new projects:
  - Methods to enhance well bore cement integrity with microbially-induced calcite precipitation (MICP) – Montana State University et al. (DE-FE0024296)
  - Wellbore Leakage Mitigation using Advanced Mineral Precipitation Strategies – Montana State University et al. (DOE FOA 1240)
- Possible synergies with other NETL & FE projects, e.g.
  - Wellbore Seal Repair Using Nanocomposite Materials - University of New Mexico - John Stormont (DE- FE0009562)
  - Novel Materials for Robust Repair of Leaky Wellbores in CO_2 Storage Formations - University of Texas at Austin - Matt Balhoff, Steven Bryant (DE-FE0009299)
  - Bill Carey (LANL) - Wellbore and Seal Integrity

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**.

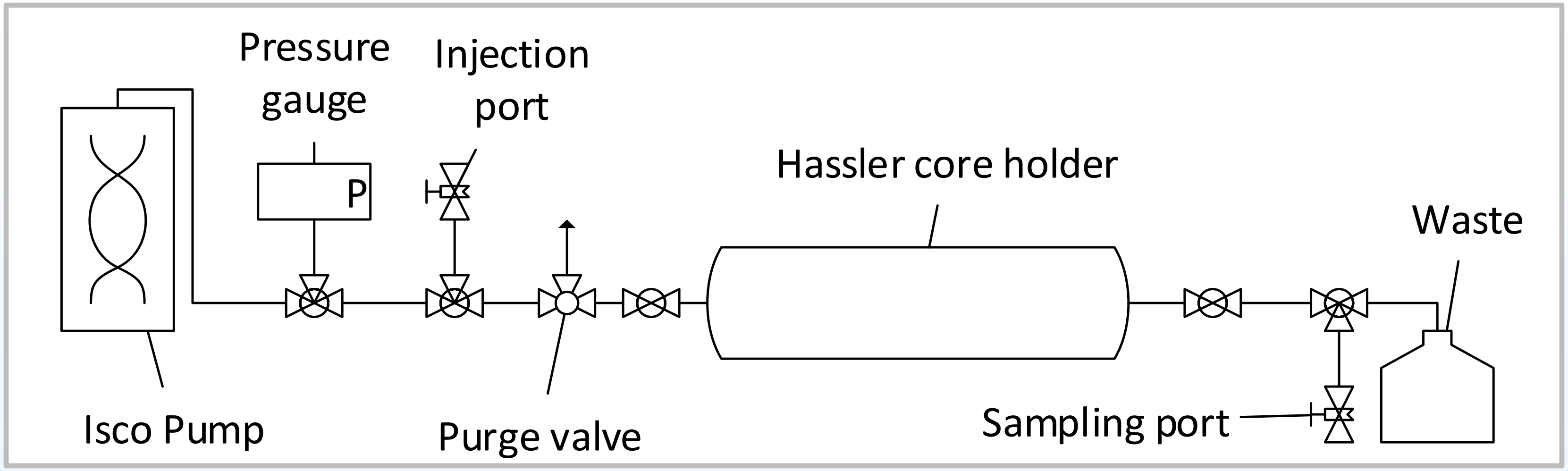
Lessons Learned

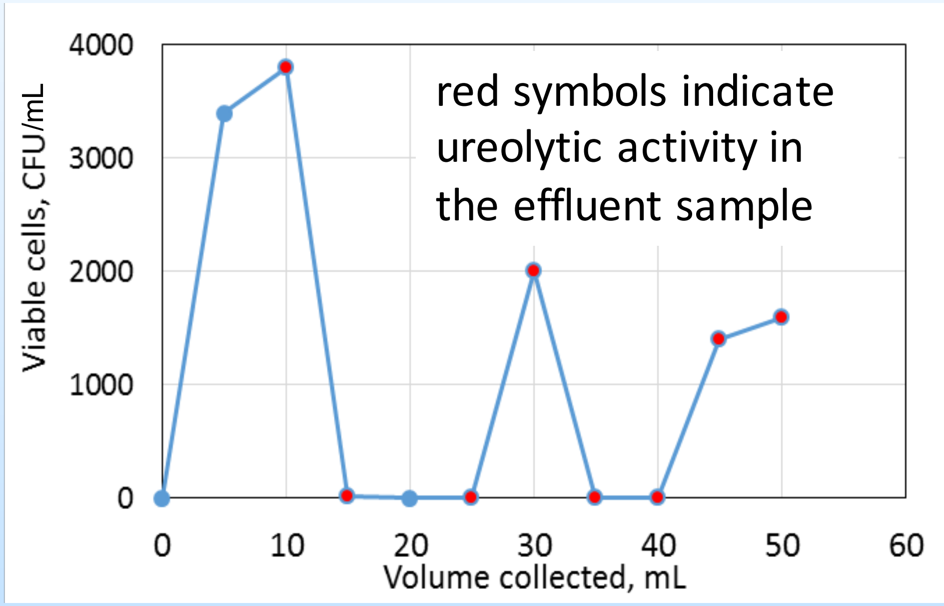
- Conventional oil field technology can be used to promote MICP in subsurface applications.

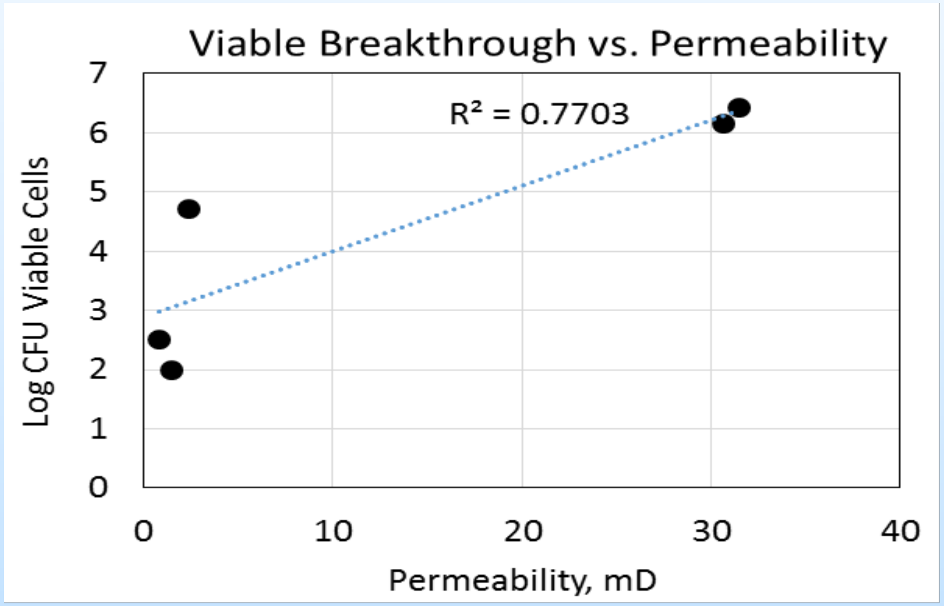
Future Plans

- Evaluate results of field test *(9599 Objective 4)*
- Expand efforts towards cement sealing (and healing)
- Expand technology application range to higher temperatures and other minerals/sealants

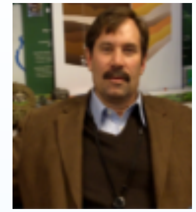
Transport of Microbes through Sandstone

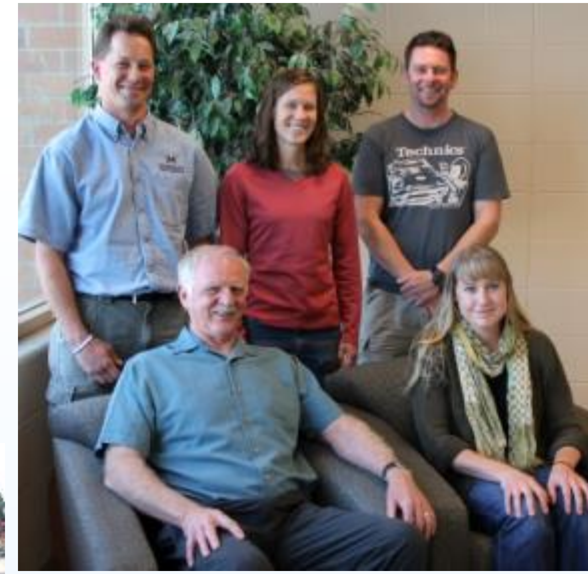


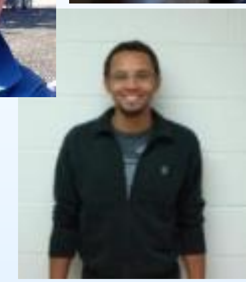




Acknowledgements







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SOUTHERN COMPANY

Schlumberger

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM

Knowledge that will change your world

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

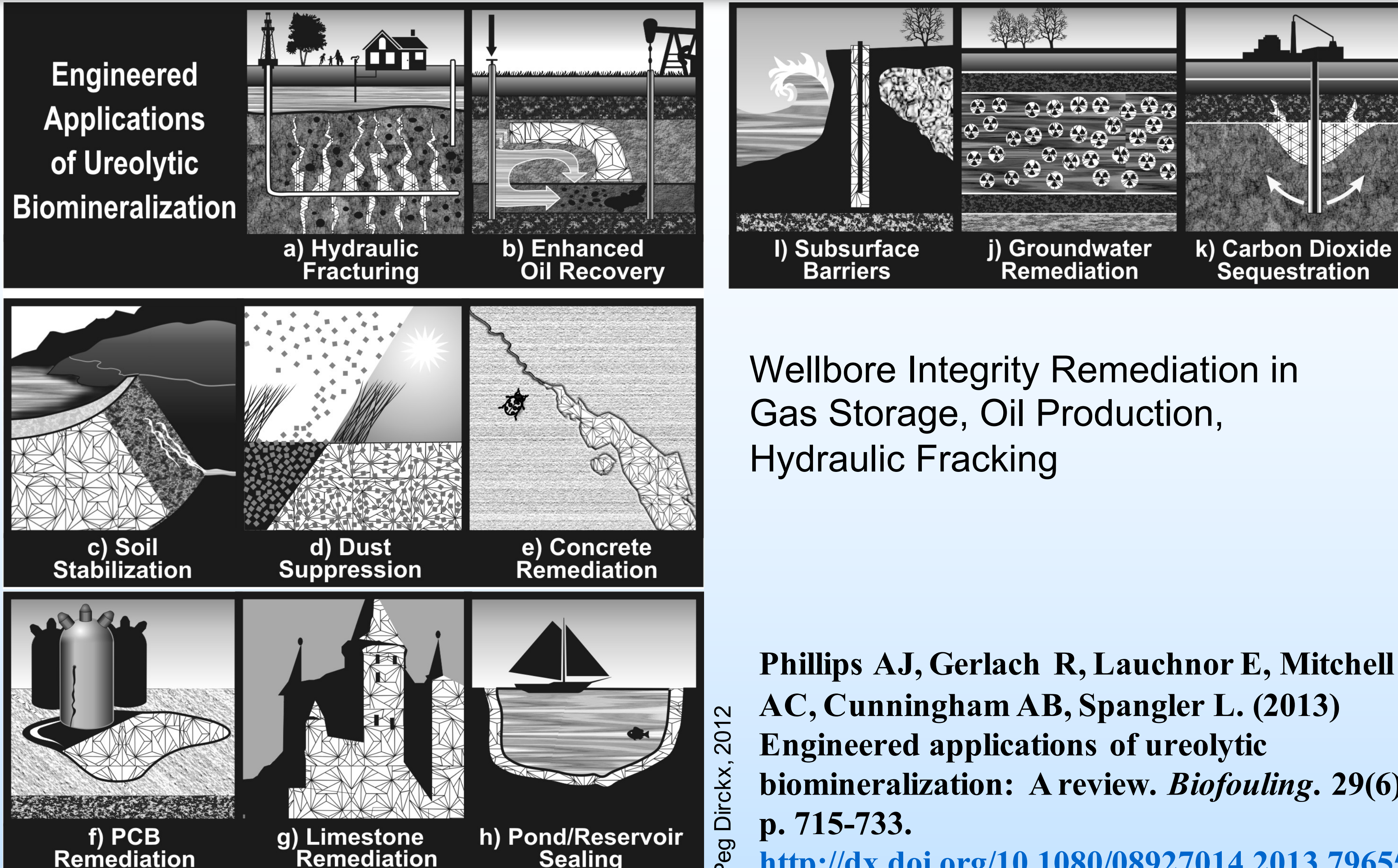
Joe Westrich, Bart Lomans, Andreas Busch, Shell

Eric Troyer

Universität Stuttgart

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

Engineered Applications of MICP



Wellbore Integrity Remediation in Gas Storage, Oil Production, Hydraulic Fracking

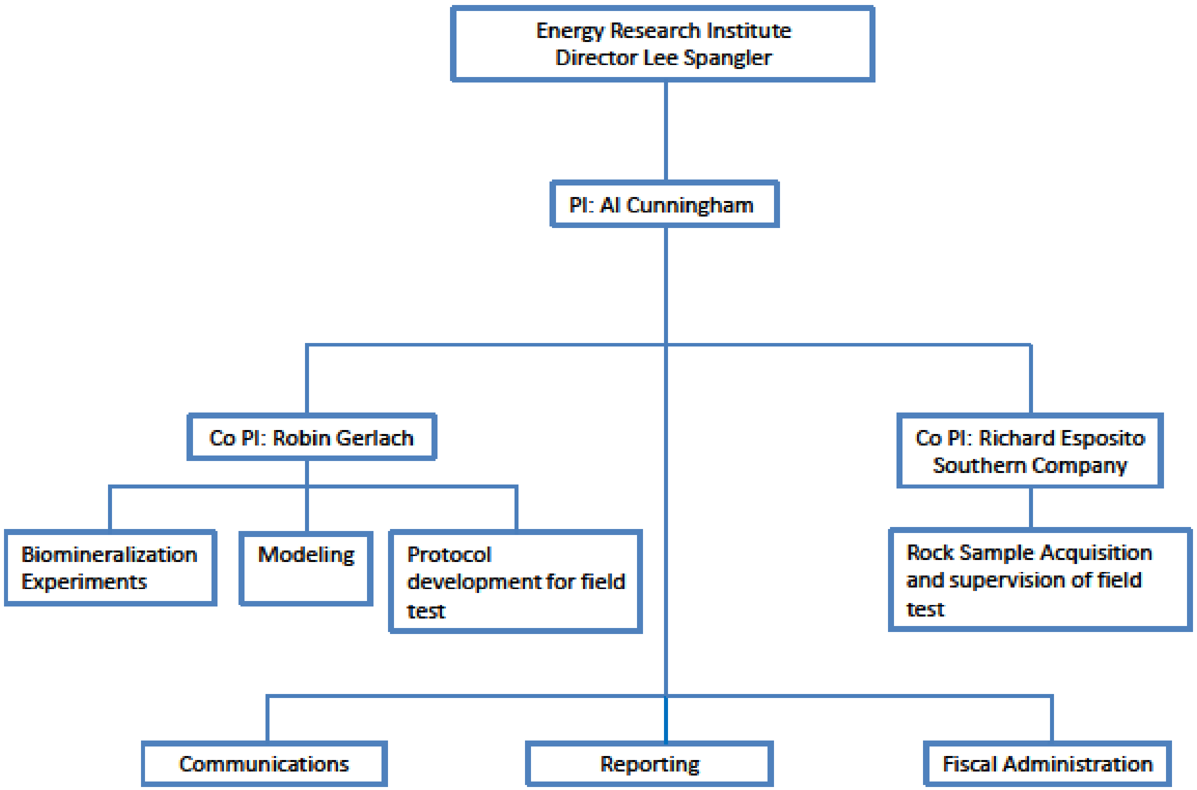
Phillips AJ, Gerlach R, Lauchnor E, Mitchell AC, Cunningham AB, Spangler L. (2013) Engineered applications of ureolytic biomineralization: A review. *Biofouling*. 29(6): p. 715-733. http://dx.doi.org/10.1080/08927014.2013.796550

Appendix

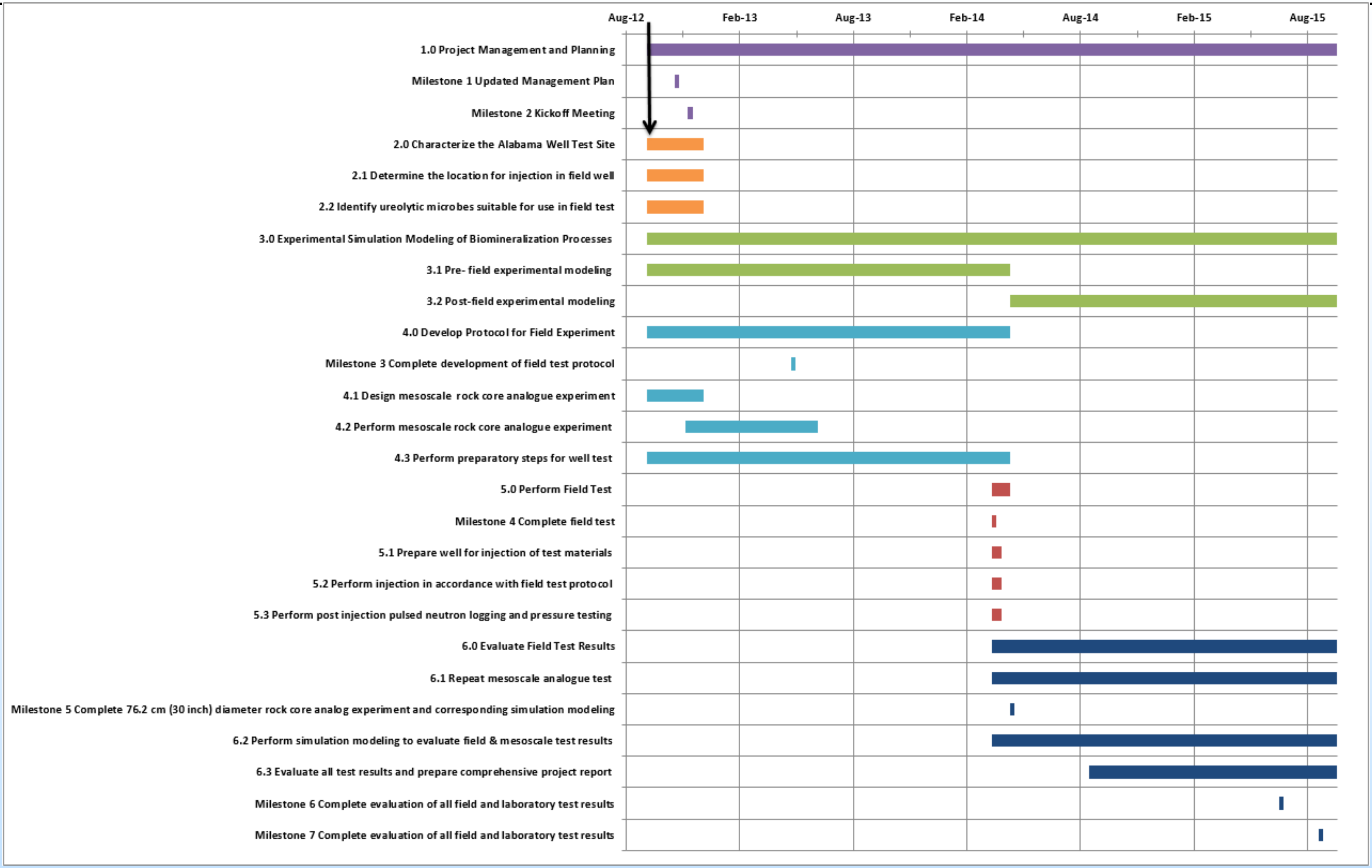
– These slides will not be discussed during the presentation, but are mandatory

Organization Chart

Project DE-FE0009599



Gantt Chart *Project DE-FE0009599*



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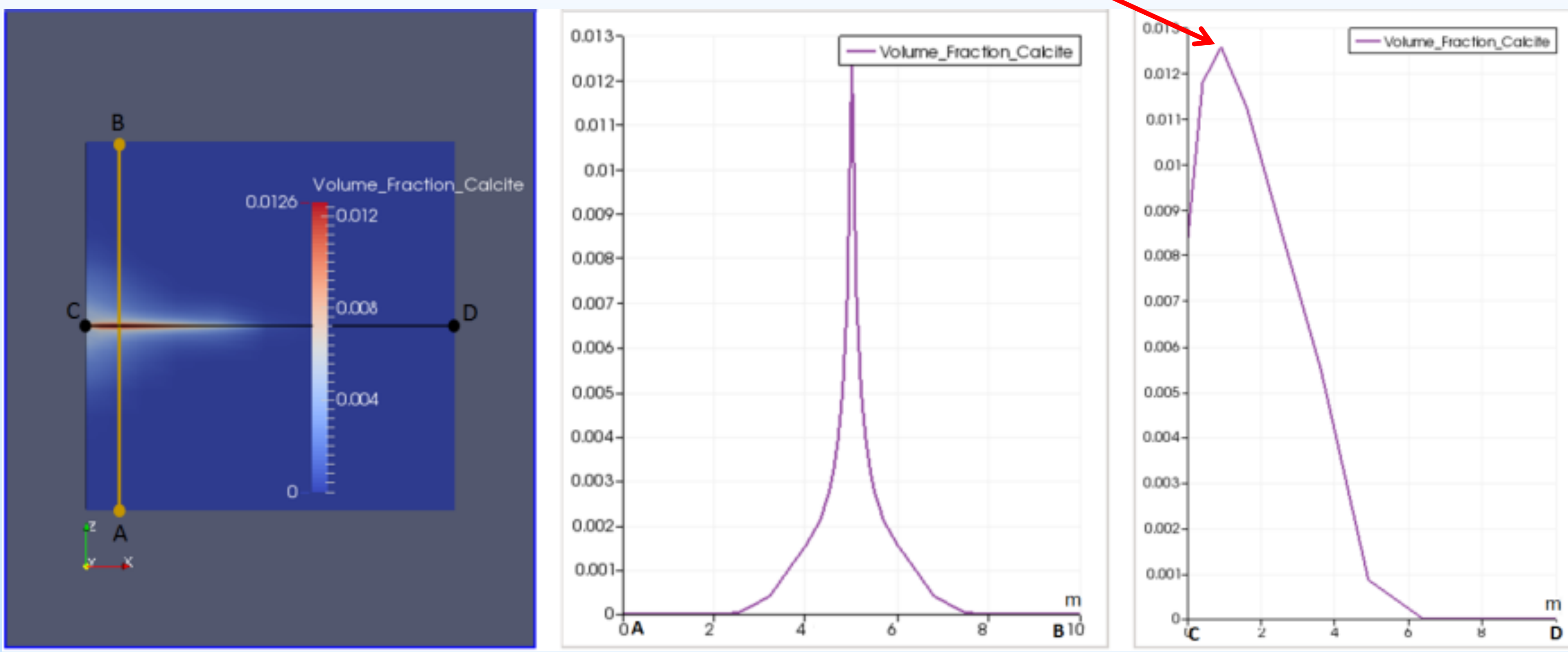
MICP model simulation using Gorgas field protocol made prior to field injection

Volume fraction of calcite (0.125 m³ $CaCO_3$/m³) at the end of the MICP simulation.

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



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