MONTANA STATE UNIVERSITY
Energy Research Institute

CENTER FOR BIOFILM ENGINEERING

Methods to Enhance Wellbore Cement Integrity with Microbially-Induced Calcite Precipitation (MICP)

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Adrienne Phillips, Al Cunningham, Robin Gerlach and Lee Spangler

Montana State University

U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology, Innovation and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 16-18, 2016

Presentation Outline

- Project Benefits
- Goals and Objectives
- Methodology
- Accomplishments to date
- Synergy opportunities
- Summary
- Organization chart
- Gantt Chart
- Bibliography

Benefit to the Program

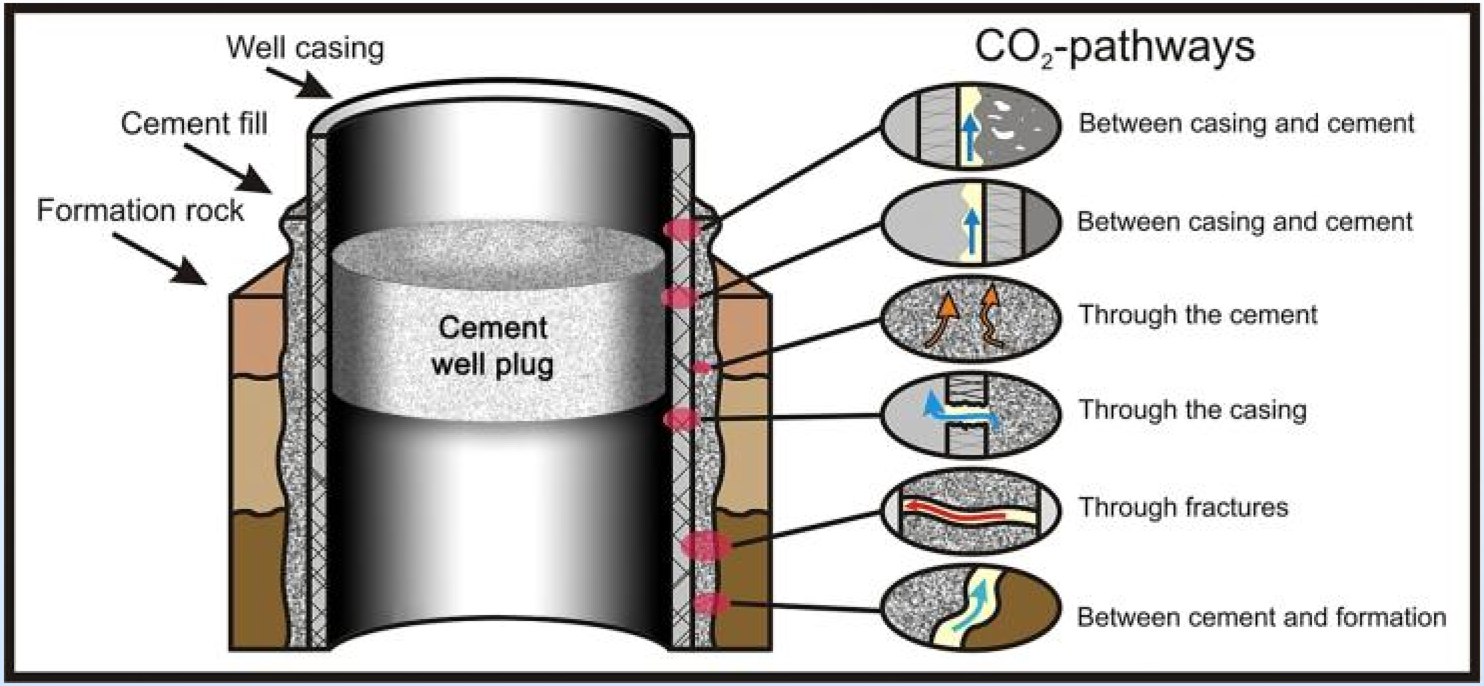
- Environmentally-Prudent Unconventional Resource Development
- Objective to minimize environmental impacts and improve the efficiency of UOG development wells.
- Technology development activities related to:
  - Assurance of long-term wellbore integrity and
  - Demonstration of technologies for the effective mitigation of impacts to surface and groundwater resources, ambient air quality/impact, as well as other ecological impacts.
- Project includes a field data collection, validation, and/or demonstration phase

Project Overview:
Goals and Objectives

Project goal: develop improved methods for sealing compromised wellbore cement in leaking natural gas and oil wells, thereby reducing the risk of unwanted upward gas migration through laboratory testing, simulation modeling and field testing.

- Objective 1: Laboratory testing of MICP sealing, develop a field test protocol for effective MICP placement and control.
- Objective 2: Prepare for and conduct an initial MICP field test aimed at sealing a poor well cement bond.
- Objective 3: Analyze results from first field test, conduct a second MICP test using improved MICP injection methods.

Mitigating subsurface leakage



After Nordbotten and Celia, Geological Storage of CO_2, 2012

Cement is viscous

Microbes are small – thereby creating a niche treatment technology for small aperture fractures that can be delivered via <u>low-viscosity</u> fluids

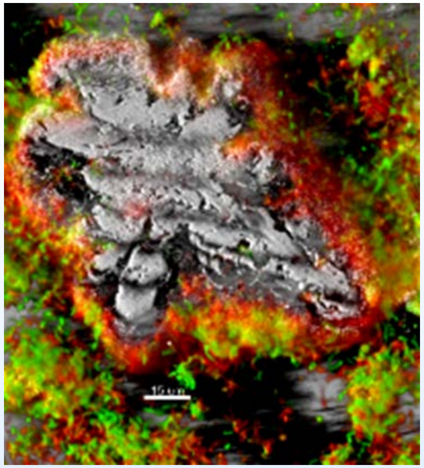
Microbially-Induced $CaCO_3$ Precipitation (MICP)

Ureolysis-driven

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

$$NH_2COOH + H_2O \xrightarrow{\text{Spontaneous}} NH_3 + H_2CO_3^{*}$$

$$2NH_3 + 2H_2O \longleftrightarrow 2NH_4^{+} + 2OH^{-}$$



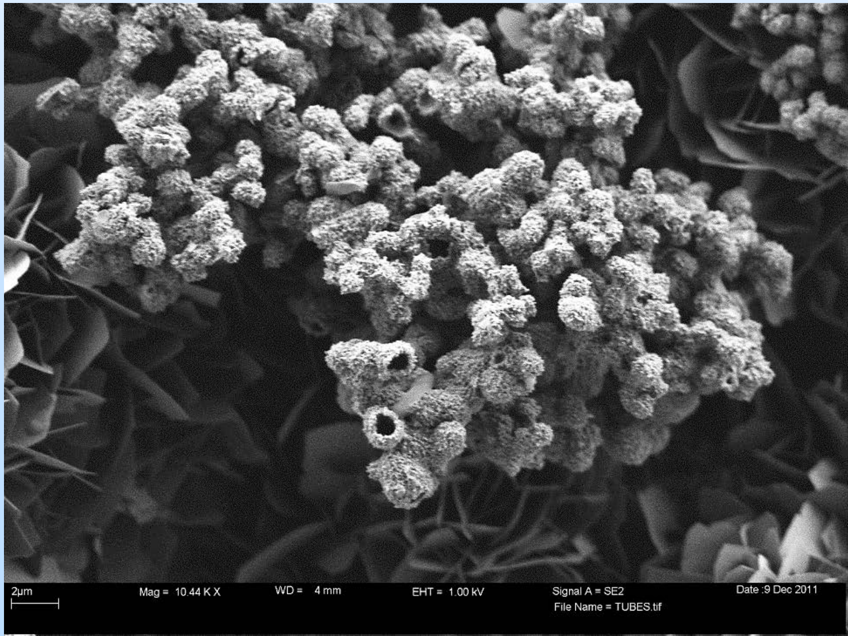
$$H_2CO_3^{*} + 2OH^{-} \xleftrightarrow{pK_{a1}=6.3} HCO_3^{-} + H_2O + OH^{-} \xleftrightarrow{pK_{a2}=10.3} CO_3^{2-} + 2H_2O$$

$$(\Omega \text{ or } S) = a(Ca^{2+})a(CO_3^{2-})/K_{sp} \quad \text{or} \quad SI = \log(S)$$

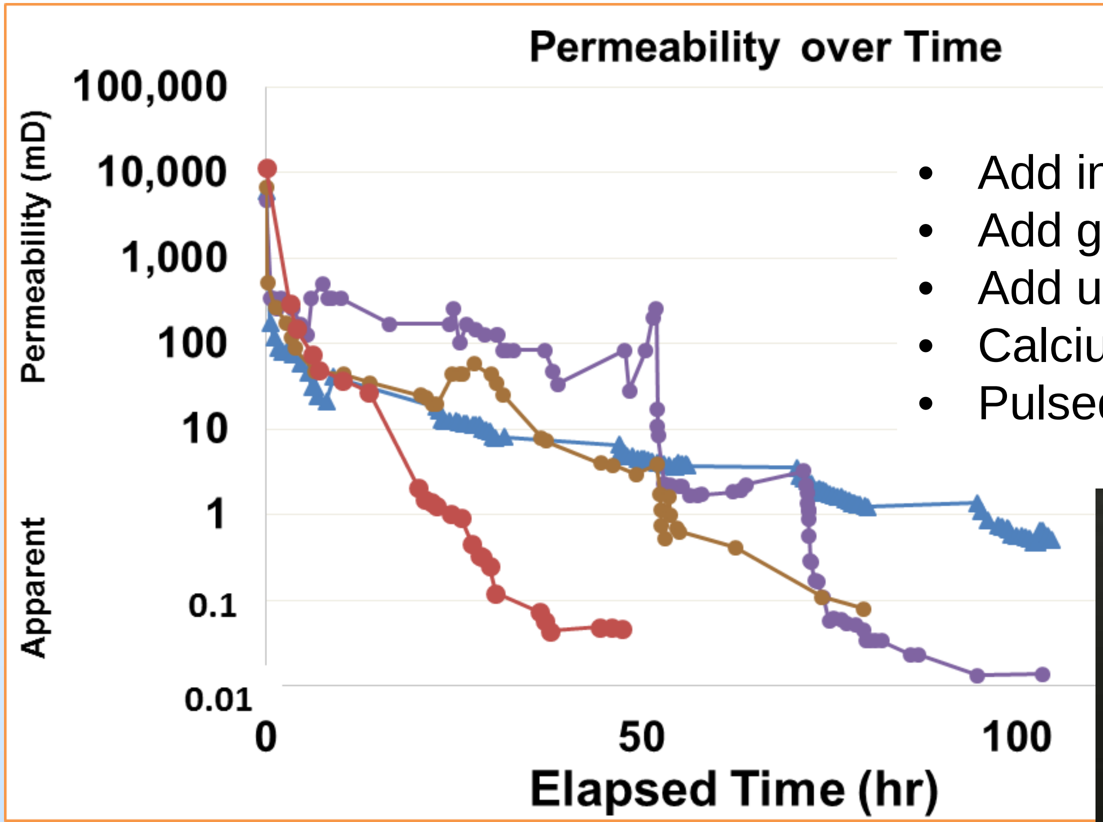
$$Ca^{2+} + CO_3^{2-} \longleftrightarrow CaCO_3\,(s) \qquad K_{sp} = 4.8 \times 10^{-9}$$

Schultz, L, Pitts, B, Mitchell, AC, Cunningham, A, Gerlach, R. Imaging biologically induced mineralization in fully hydrated flow systems. Microscopy Today 2011, 19, (5), 12-15

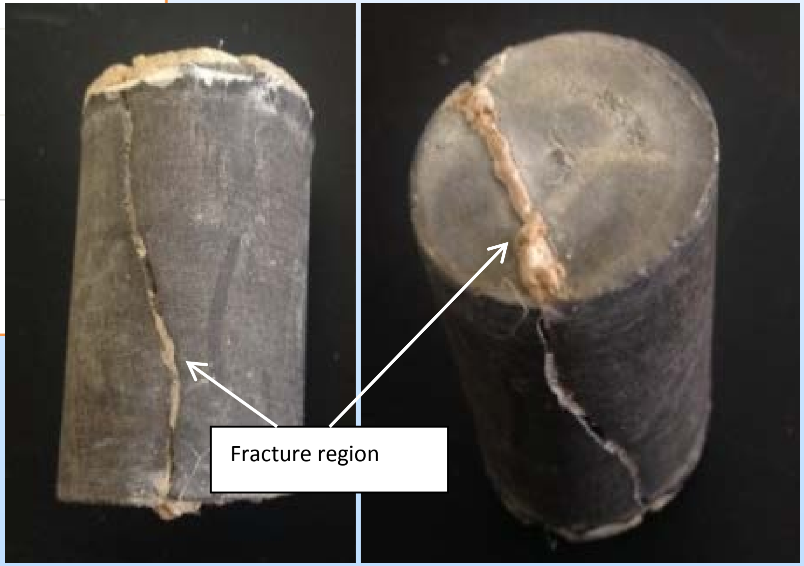
Phillips AJ, Gerlach, R, Lauchnor, E, Mitchell, AC, Cunningham, A, Spangler, L. (2013) Engineered applications of ureolytic biomineralization: a review. Biofouling. 29 (6) 715-733



Lab Scale: One inch diameter fractured shale cores

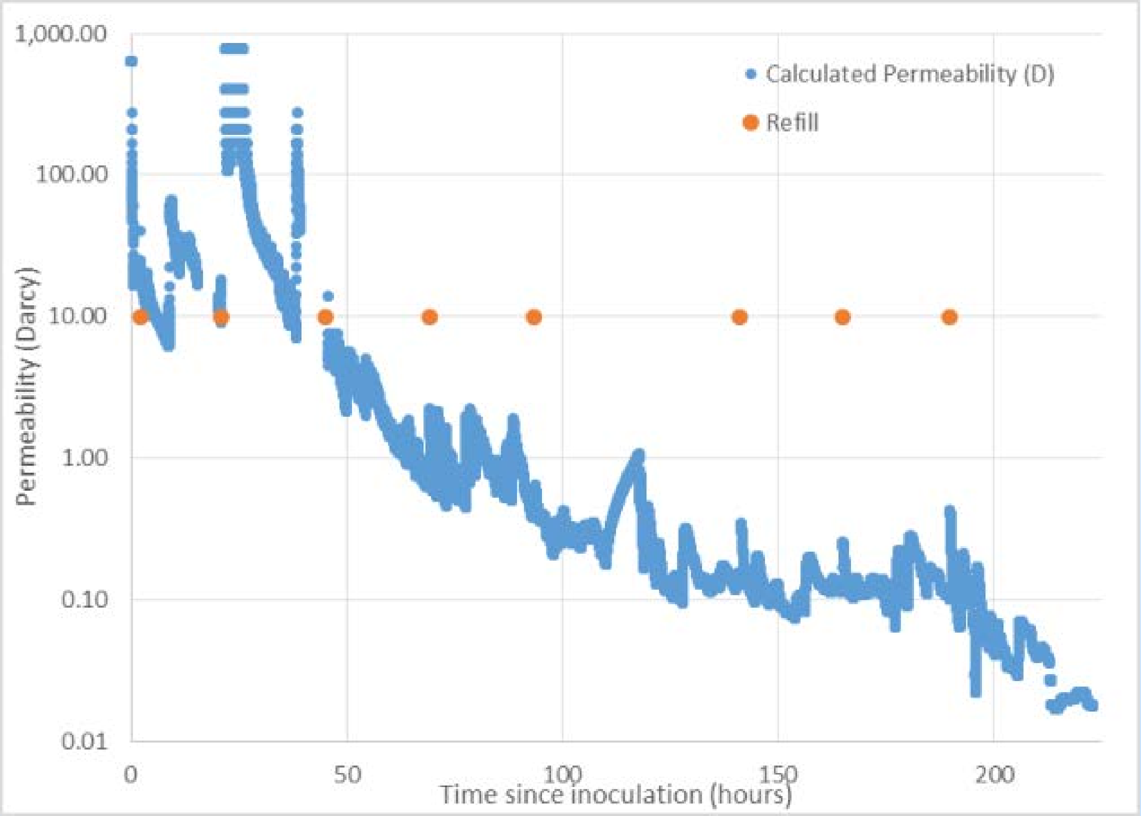


- Add inoculum *Sporosarcina pasteurii*
- Add growth nutrients
- Add urea and calcium
- Calcium carbonate (calcite) precipitation
- Pulsed injection strategy

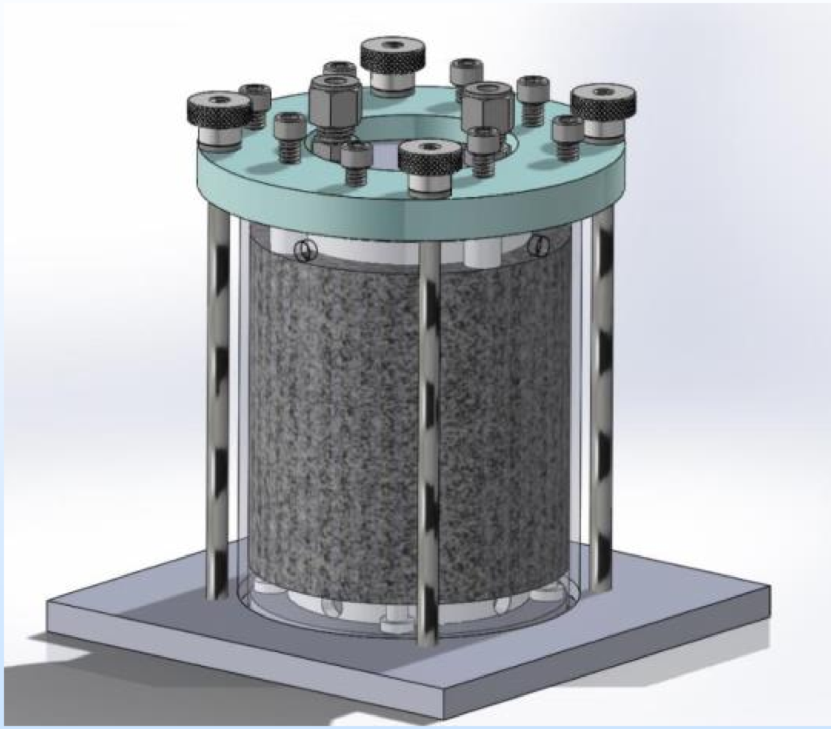


Cunningham, AB, Gerlach, R, Phillips, AJ, Lauchnor, E, Rothman, A, Hiebert, R, Busch, A, Lomans, B, and Spangler, L. (2015) Assessing potential for biomineralization sealing in fractured shale and the Mont Terri Underground Research Facility, Switzerland, Carbon Dioxide Capture for Storage in Deep Geologic Formations Vol. 4, Chapter 48 pg 887 -903

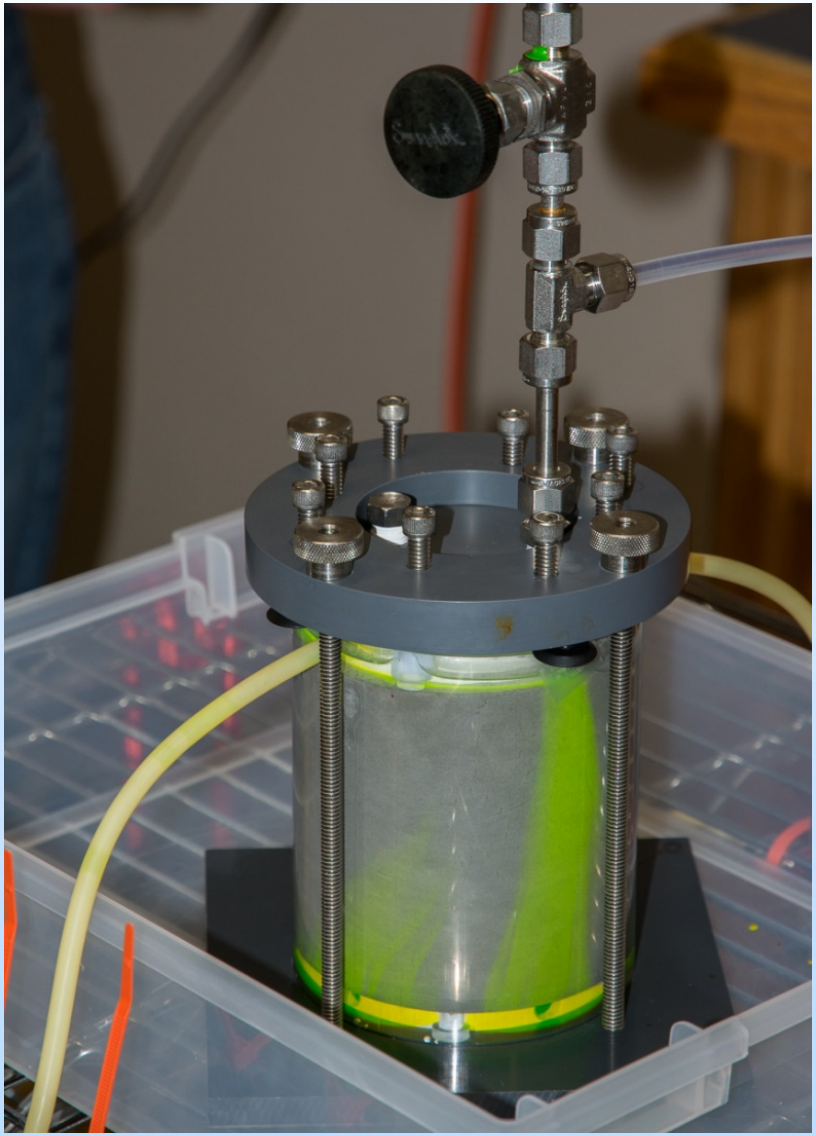
Methods to Enhance Wellbore Cement Integrity with MICP



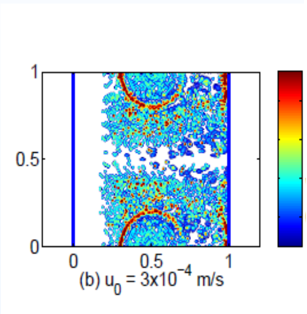
Laboratory- Wellbore Analog- Visualization

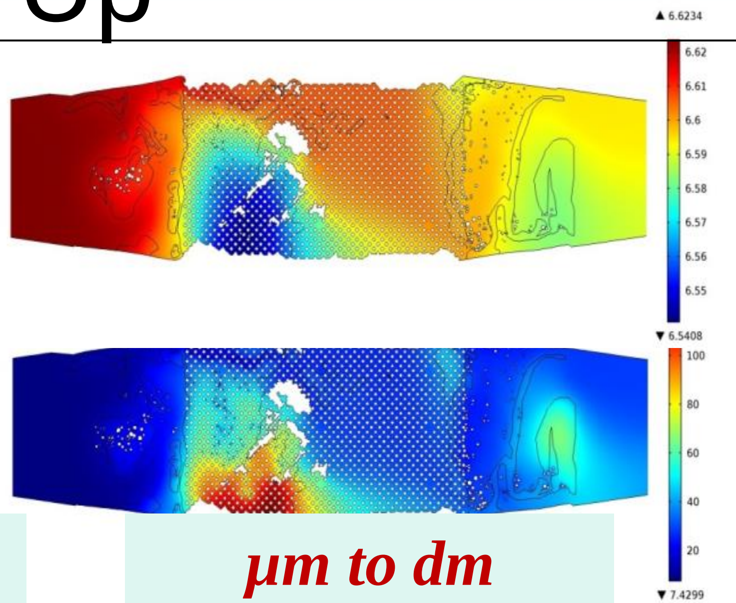


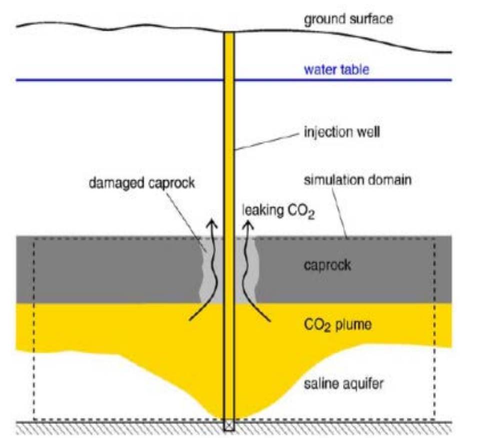
MICP Experiment – 250 µm gap
5 days, 5 orders of magnitude

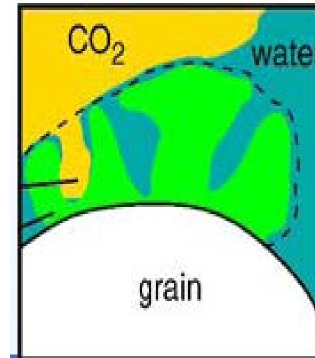


Scale Up





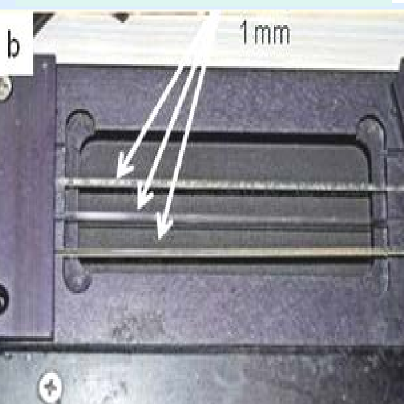


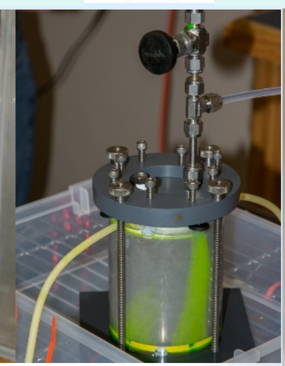


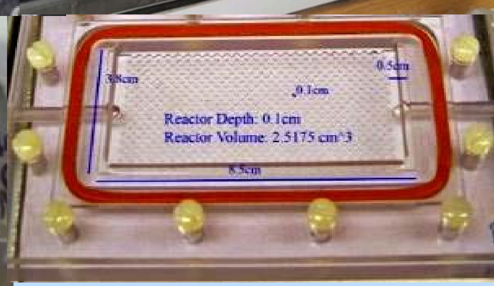
nm to cm

µm to dm

cm to 100s of m



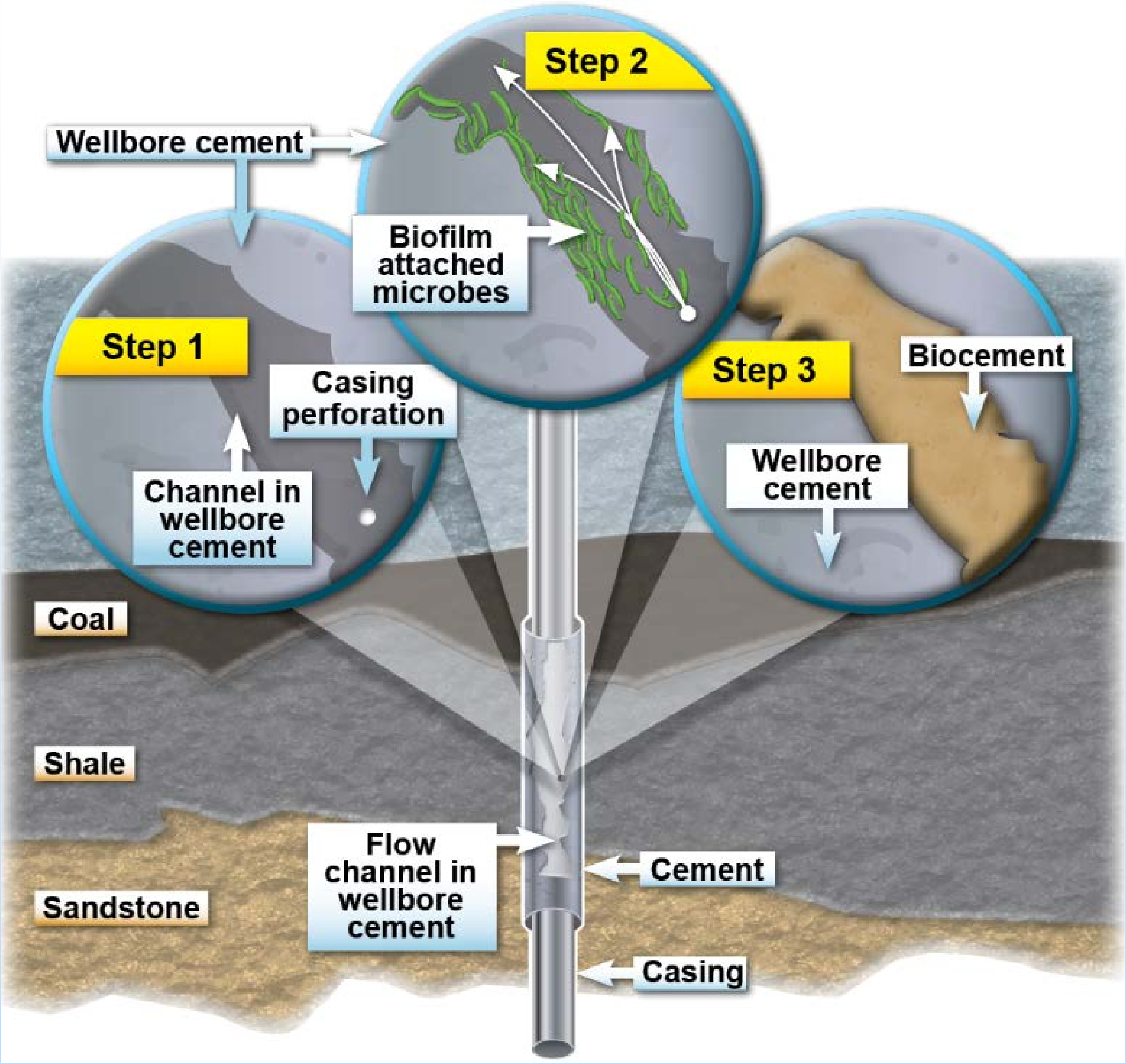




Wellbore sealing

Gorgas well

Side wall coring and injection test



Cement channel sealing

Bailer delivery
Concentrated solutions followed by brine
Inject over 4 days
25 calcium pulses
10 microbial injections

3 measures of success
- Injectivity reduced
- Pressure decay
- USIT Logs

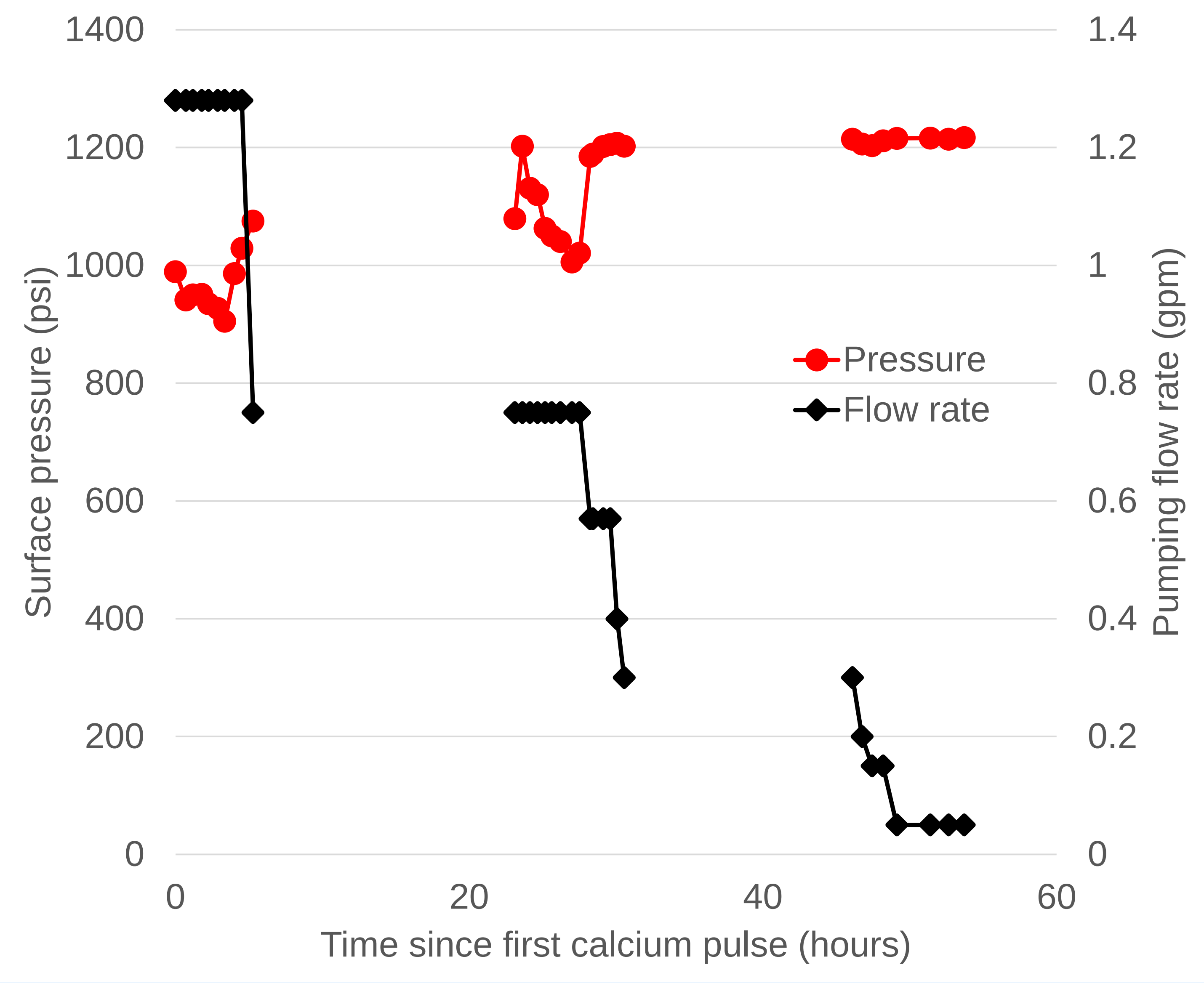
Schlumberger

SOUTHERN COMPANY

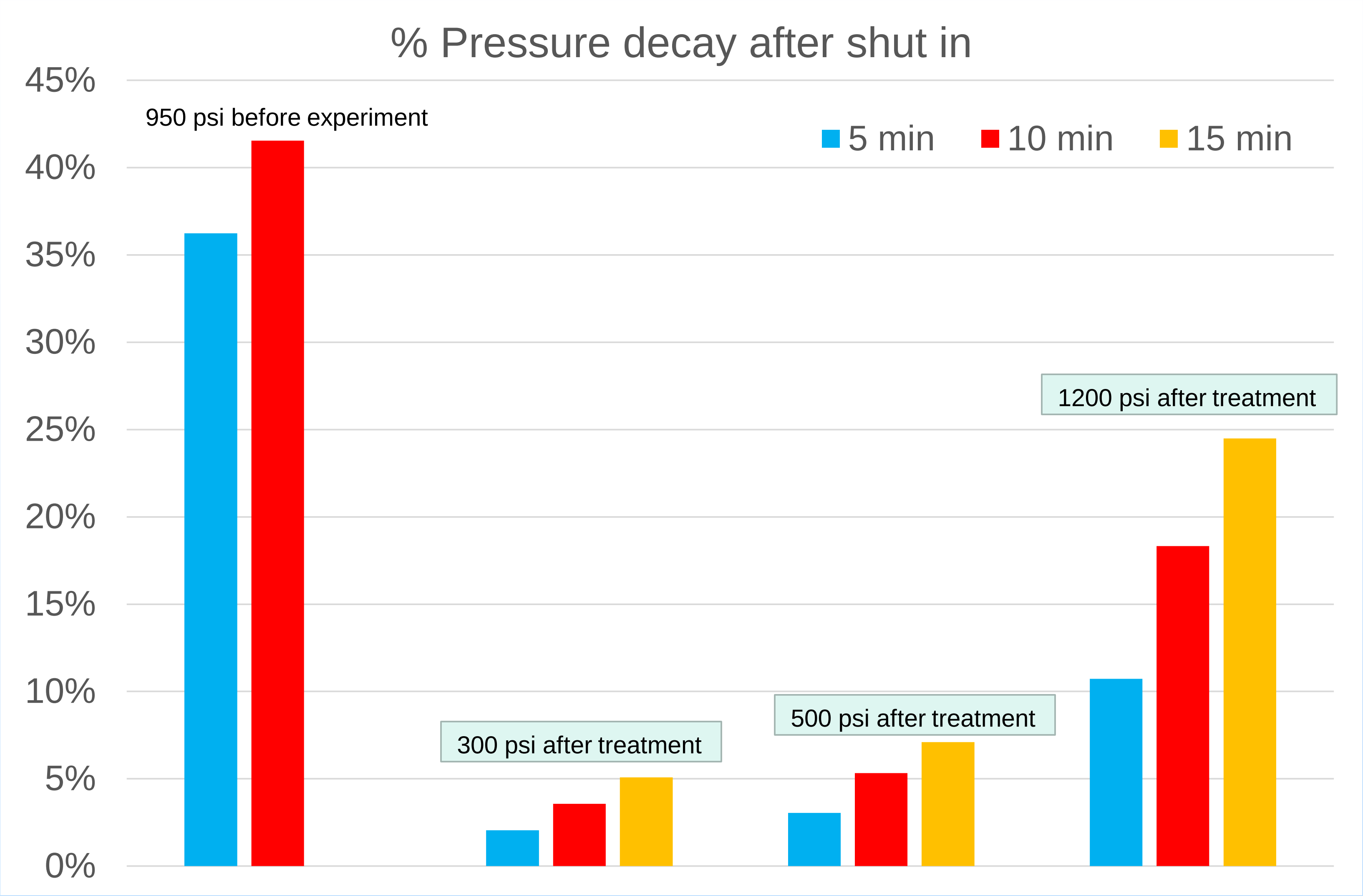
Injectivity

Reduced injectivity-pressure increased and flow rate decreased

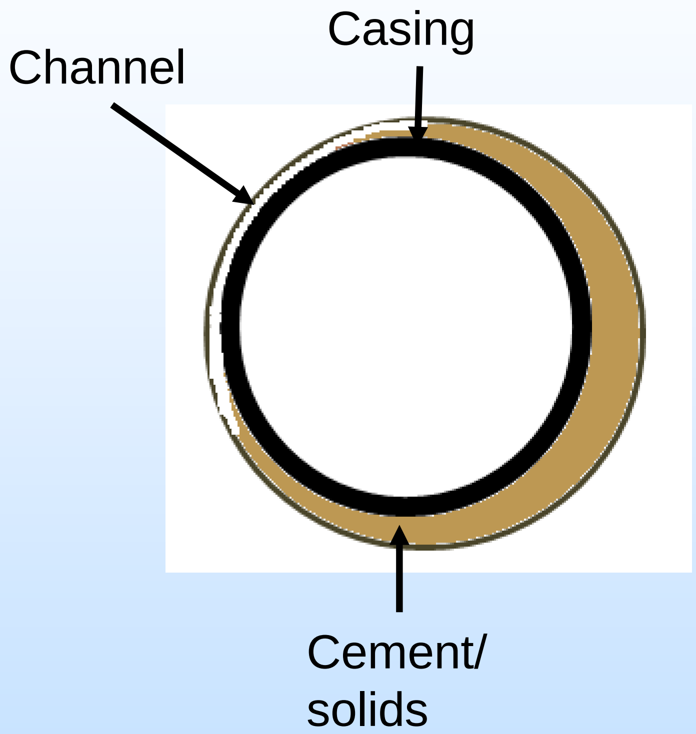
Threshold pressure



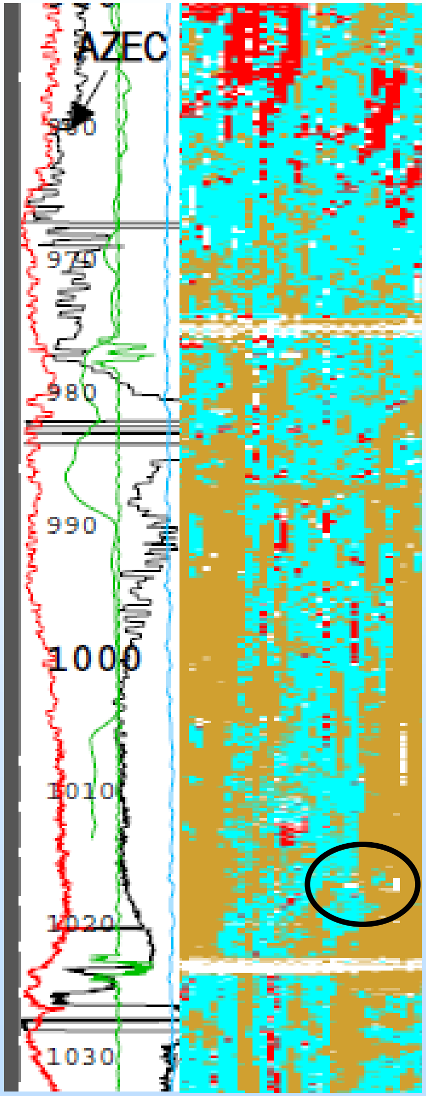
Mechanical Integrity Test



USIT logs



Channel
Casing
Cement/
solids



AZEC
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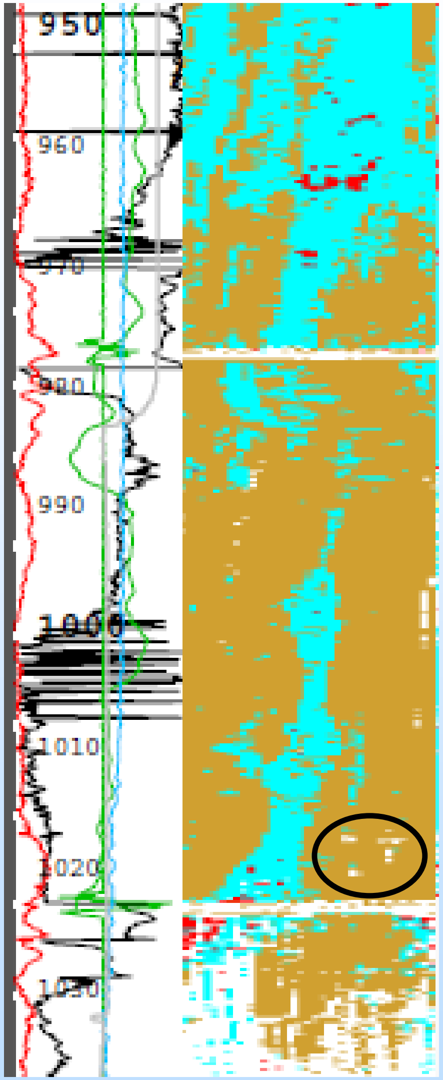

950
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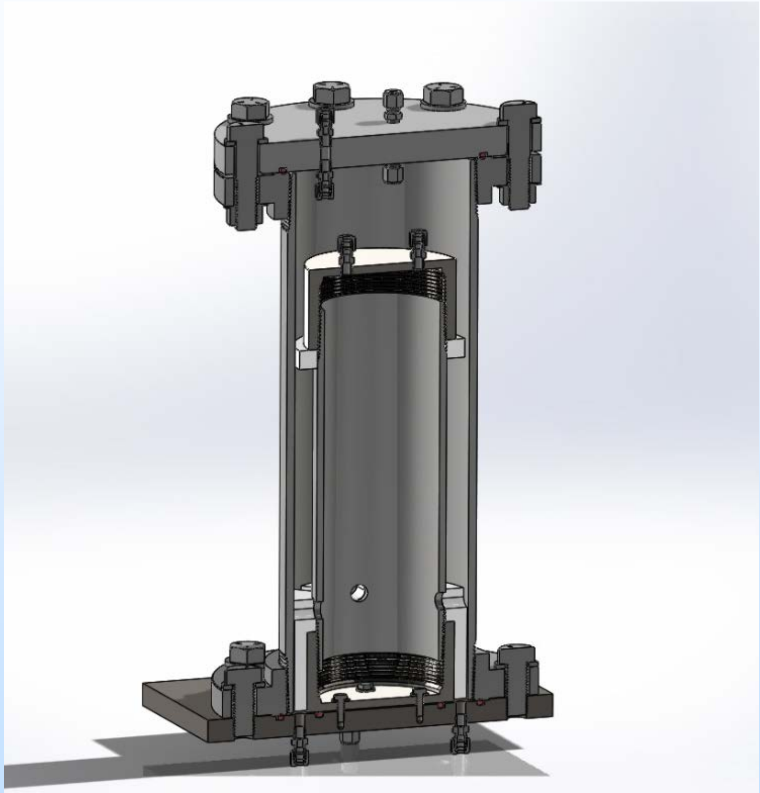
Accomplishments to Date

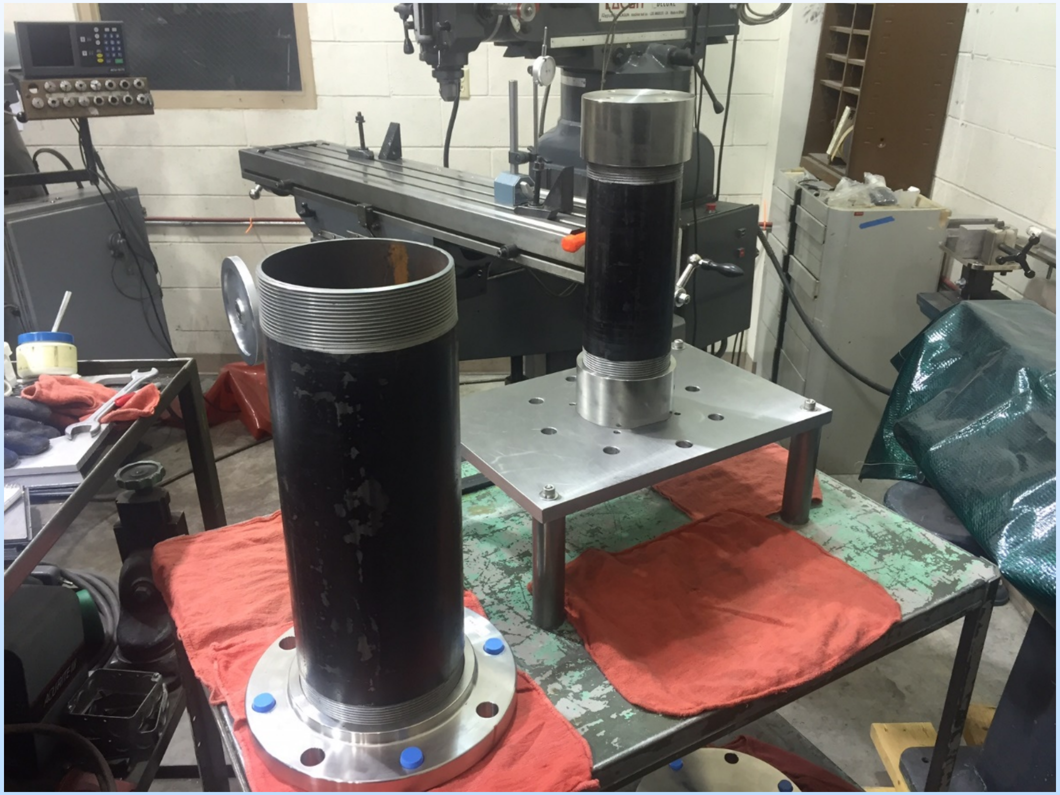
– Laboratory testing to develop injection strategies
– Field demonstration with successful results

Laboratory -Wellbore Analog- Surface Casing



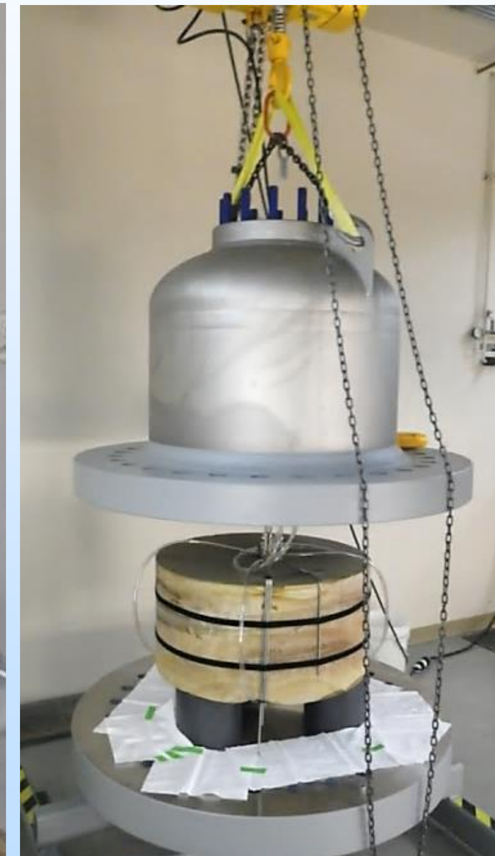
Resistance to gas flow

Subsurface pressures



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)

- Additional R&D projects:
  - Wellbore Leakage Mitigation Using Advanced Mineral Precipitation Strategies – Montana State University- (DE-FE0026513)
- Possible synergies with other NETL & FE projects, e.g.
  - Wellbore Seal Repair Using Nanocomposite Materials - University of New Mexico - John Stormont (DE- FE0009562)
  - Programmable Sealant-Loaded Mesoporous Nanoparticles for Gas/Liquid Leakage Mitigation - C-Crete Technologies, LLC – Rice University Rouzbah Shasavari (DE-FE0026511)
  - Bill Carey (LANL) - Wellbore and Seal Integrity
  - Others

Summary

MICP: lab to field

Improve wellbore integrity

Commercial interest

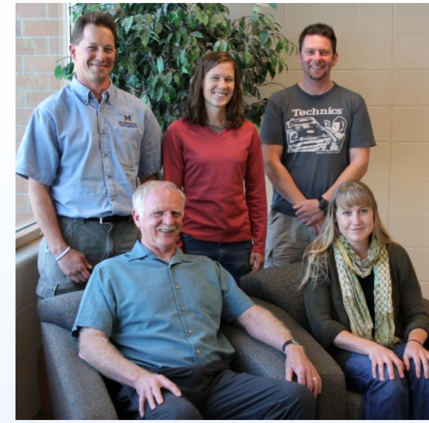
Characterization

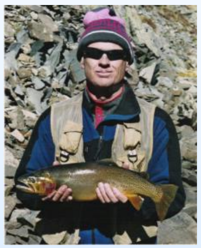
Additional lab work

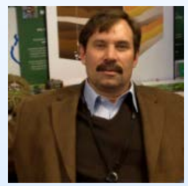
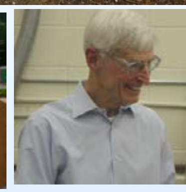
Second field demonstration

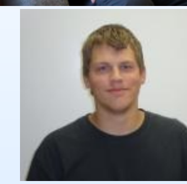
Acknowledgements








U.S. DEPARTMENT OF ENERGY

MONTANA

Schlumberger

NSF

SOUTHERN COMPANY

Collaborators

Robin Gerlach, Al Cunningham, Ellen Lauchnor, Lee Spangler, Joe Eldring,, James Connolly, Logan Schultz, Marnie Feder, Laura Dobeck, Peg Dirckx, Montana State University

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Richard Esposito, Southern Company

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Supporters

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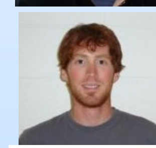
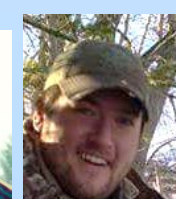
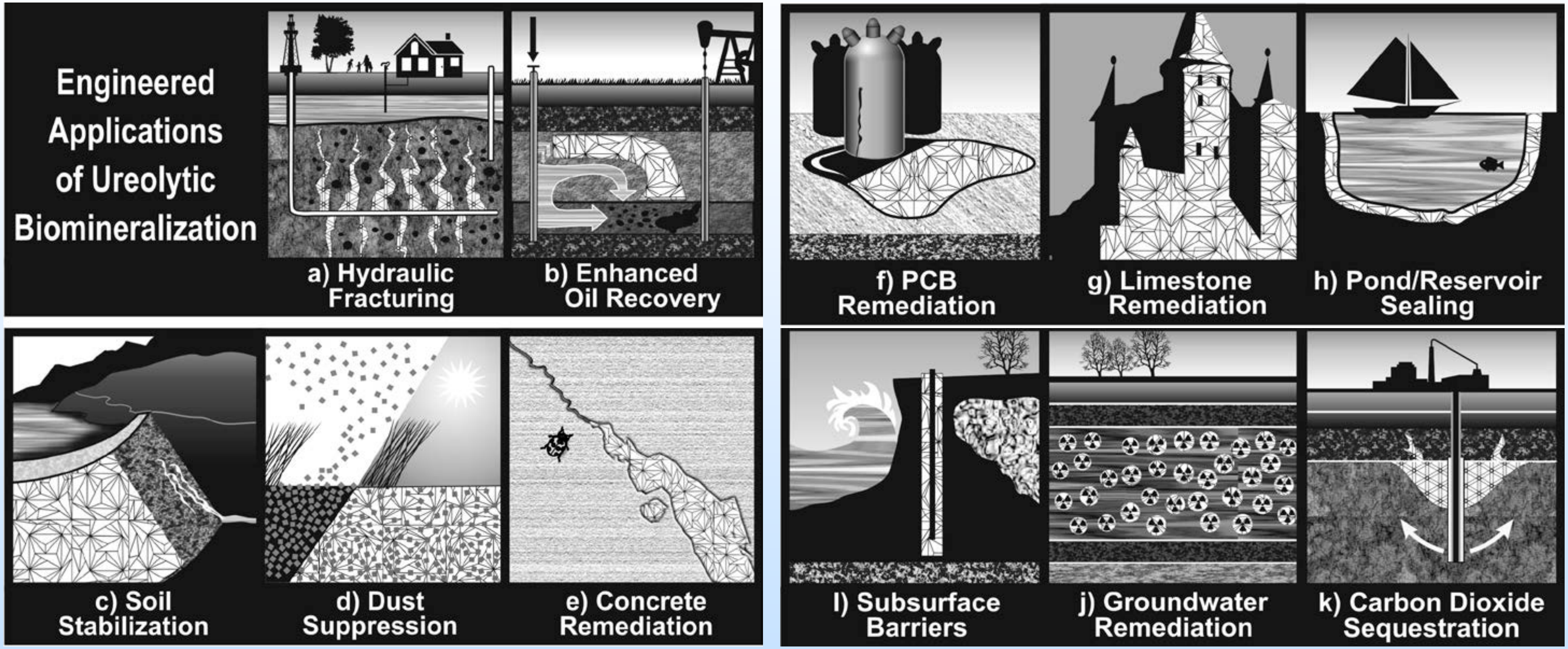


Engineered Applications- Biomineralization



Peg Dirckx, 2012

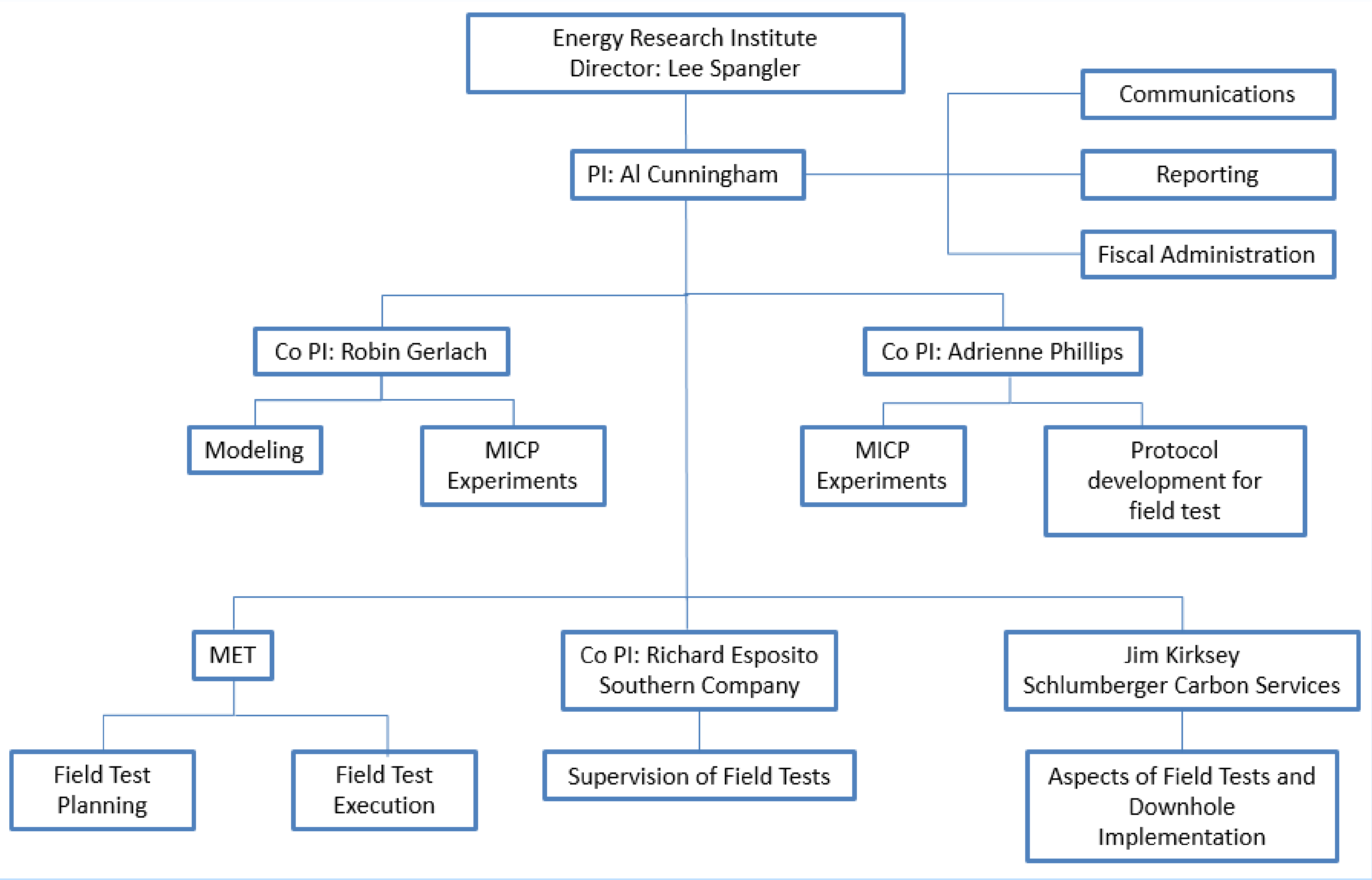
Phillips AJ, Gerlach, R, Lauchnor, E, Mitchell, A, Cunningham, A, Spangler, L. (2013) Engineered applications of ureolytic biomineralization: a review. *Biofouling.* 29 (6) 715-733

adrienne.phillips@montana.edu

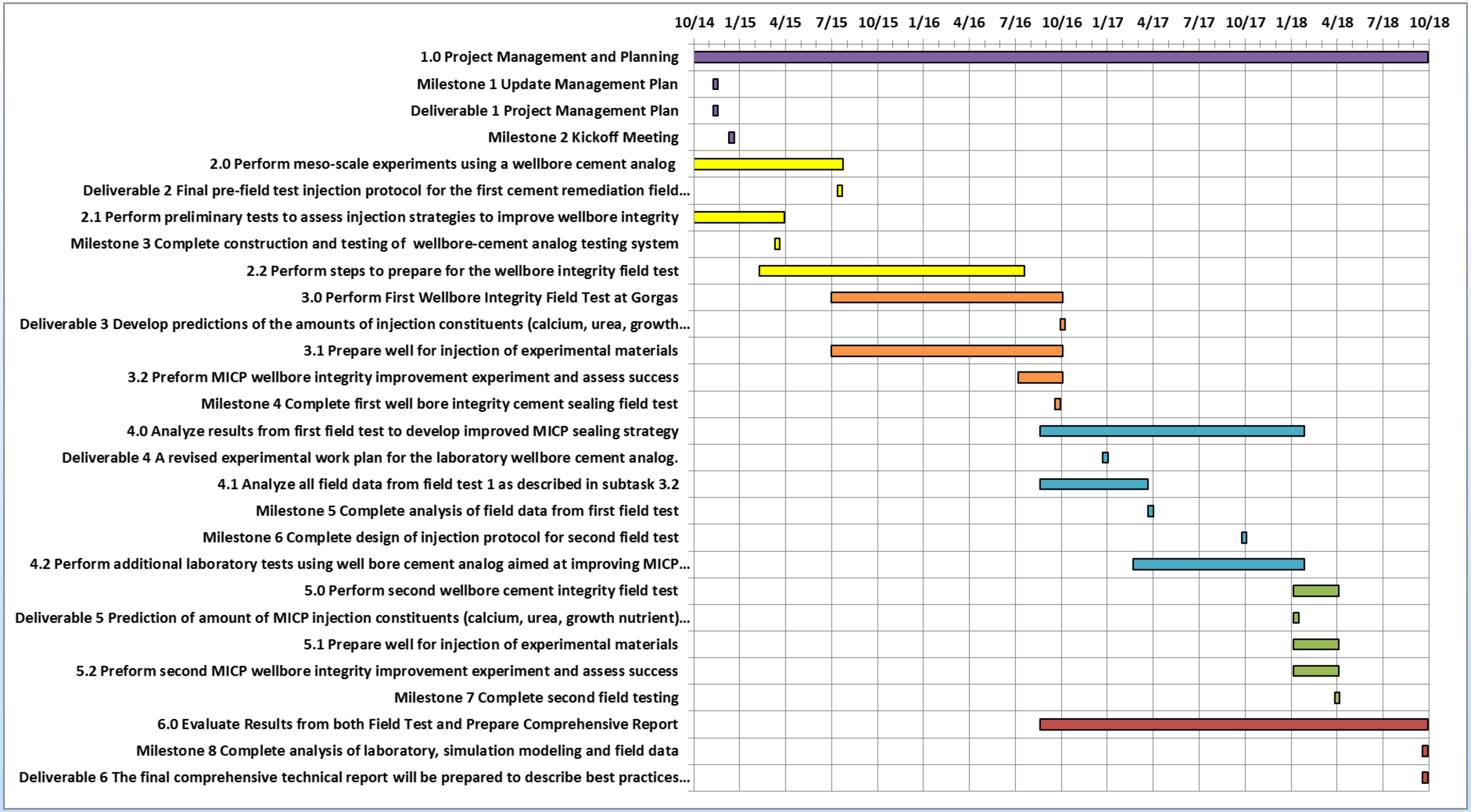
Appendix

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

Organization Chart



Gantt Chart


10/14 1/15 4/15 7/15 10/15 1/16 4/16 7/16 10/16 1/17 4/17 7/17 10/17 1/18 4/18 7/18 10/18
1.0 Project Management and Planning
Milestone 1 Update Management Plan
Deliverable 1 Project Management Plan
Milestone 2 Kickoff Meeting
2.0 Perform meso-scale experiments using a wellbore cement analog
Deliverable 2 Final pre-field test injection protocol for the first cement remediation field...
2.1 Perform preliminary tests to assess injection strategies to improve wellbore integrity
Milestone 3 Complete construction and testing of wellbore-cement analog testing system
2.2 Perform steps to prepare for the wellbore integrity field test
3.0 Perform First Wellbore Integrity Field Test at Gorgas
Deliverable 3 Develop predictions of the amounts of injection constituents (calcium, urea, growth...
3.1 Prepare well for injection of experimental materials
3.2 Preform MICP wellbore integrity improvement experiment and assess success
Milestone 4 Complete first well bore integrity cement sealing field test
4.0 Analyze results from first field test to develop improved MICP sealing strategy
Deliverable 4 A revised experimental work plan for the laboratory wellbore cement analog.
4.1 Analyze all field data from field test 1 as described in subtask 3.2
Milestone 5 Complete analysis of field data from first field test
Milestone 6 Complete design of injection protocol for second field test
4.2 Perform additional laboratory tests using well bore cement analog aimed at improving MICP...
5.0 Perform second wellbore cement integrity field test
Deliverable 5 Prediction of amount of MICP injection constituents (calcium, urea, growth nutrient)...
5.1 Prepare well for injection of experimental materials
5.2 Preform second MICP wellbore integrity improvement experiment and assess success
Milestone 7 Complete second field testing
6.0 Evaluate Results from both Field Test and Prepare Comprehensive Report
Milestone 8 Complete analysis of laboratory, simulation modeling and field data
Deliverable 6 The final comprehensive technical report will be prepared to describe best practices...

Bibliography

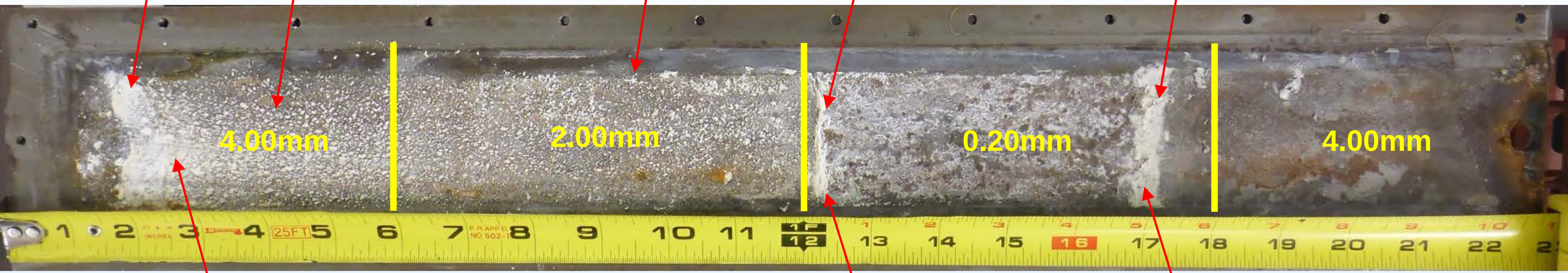
- Phillips AJ, Cunningham, A, Gerlach, R, Hiebert, R, Hwang, C, Lomans, B, Westrich, J, Mantilla, C, Kirksey, J, Esposito, R, and Spangler, L. (2016) Fracture sealing with microbially-induced calcium carbonate precipitation: A field study. *Environmental Science and Technology*, 50 (7), pp 4111–4117 http://pubs.acs.org/doi/abs/10.1021/acs.est.5b05559 DOI: 10.1021/acs.est.5b05559
- Kirkland, CM, Zanetti, S, Grunewald, E, Walsh, DO, Codd, SL, Phillips, AJ. Detecting microbially induced calcite precipitation (MICP) in a model well-bore using downhole low-field NMR *(In co-author review)*
- Phillips, AJ, Gerlach, R, Hiebert, R, Kirksey, J, Spangler, L, Esposito, R, and Cunningham, AB Biological influences in the subsurface: A method to seal fractures and reduce permeability with microbially-induced calcite precipitation. American Rock Mechanics Association 49th Annual Meeting Proceedings, June 28-July 1, 2015, San Francisco, CA. https://www.onepetro.org/conference-paper/ARMA-2015-490

Wellbore Analog and Fracture Fixture Experiment

3x concentrated calcium pulses delivered via a perforated pipe inside the clear 6” wellbore.

Measured height of the mineral precipitation

2.58mm 0.98mm 0.72mm 0.86mm 1.11mm



3.21mm 1.75mm 1.93mm

Carbonate seal on cement side of the fracture fixture formed right at the interface of the 0.2mm gap