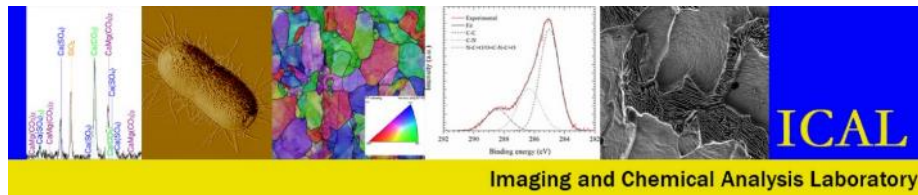


Biomining for Improving Wellbore Integrity & Developing Sustainable Building Materials

May 2021

Adie Phillips

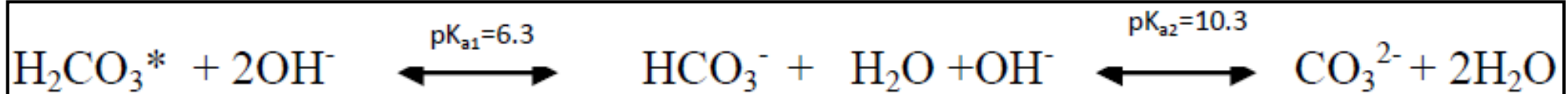
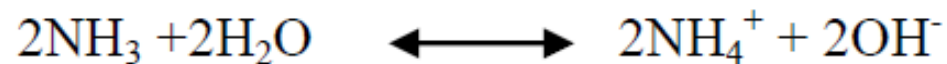
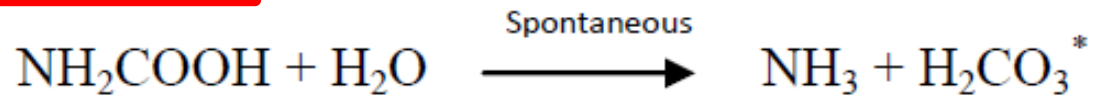
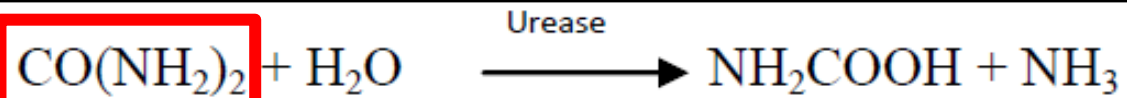
Center for Biofilm Engineering
Energy Research Institute
Civil Engineering
Montana State University



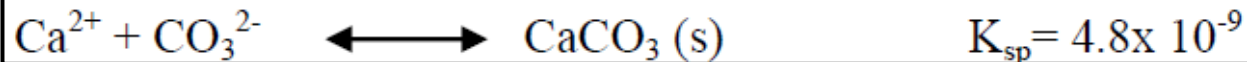
Robin Gerlach, Chelsea Heveran, Erika Espinosa-Ortiz, Lee Spangler, Al Cunningham, Catherine Kirkland, Arda Akyel, Abby Thane, Sobia Anjum, Micah Coburn, Cecily Ryan, Ellen Lauchnor, Montana Emergent Technologies

Biofilm-Induced CaCO_3 Precipitation

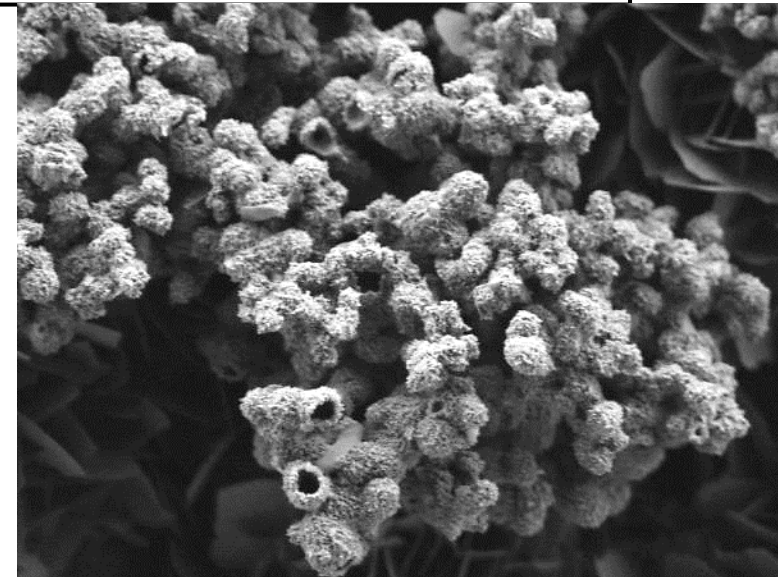
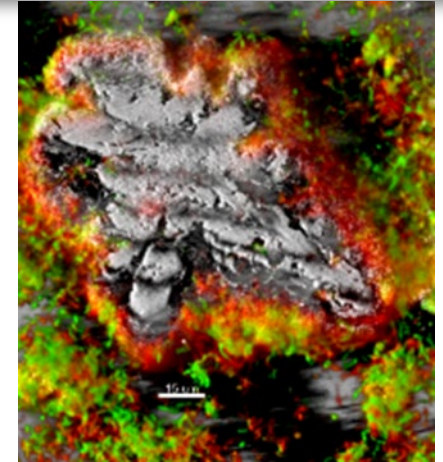
Ureolysis Driven



$$(\Omega \text{ or } S) = a(\text{Ca}^{2+})a(\text{CO}_3^{2-})/K_{sp} \quad \text{or} \quad \text{SI} = \log(S)$$



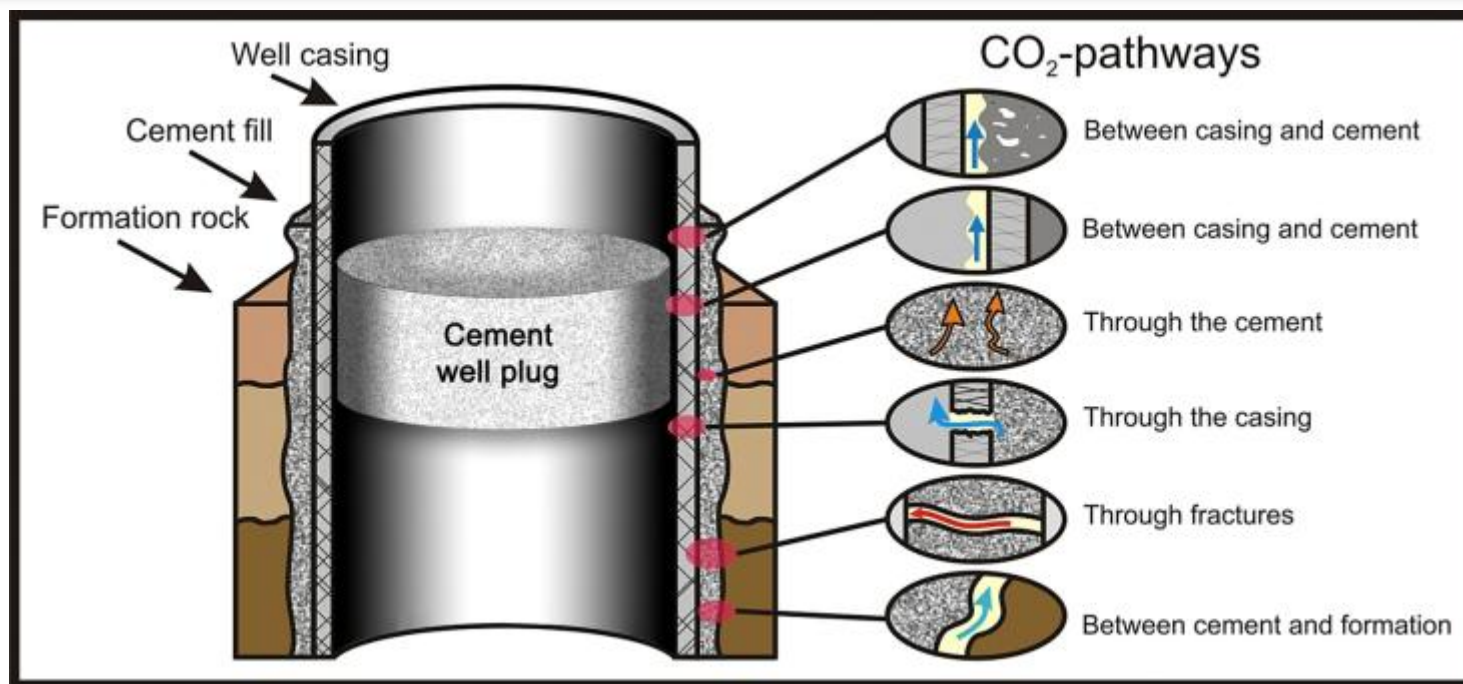
Bio-rocks



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

Mitigating subsurface leakage

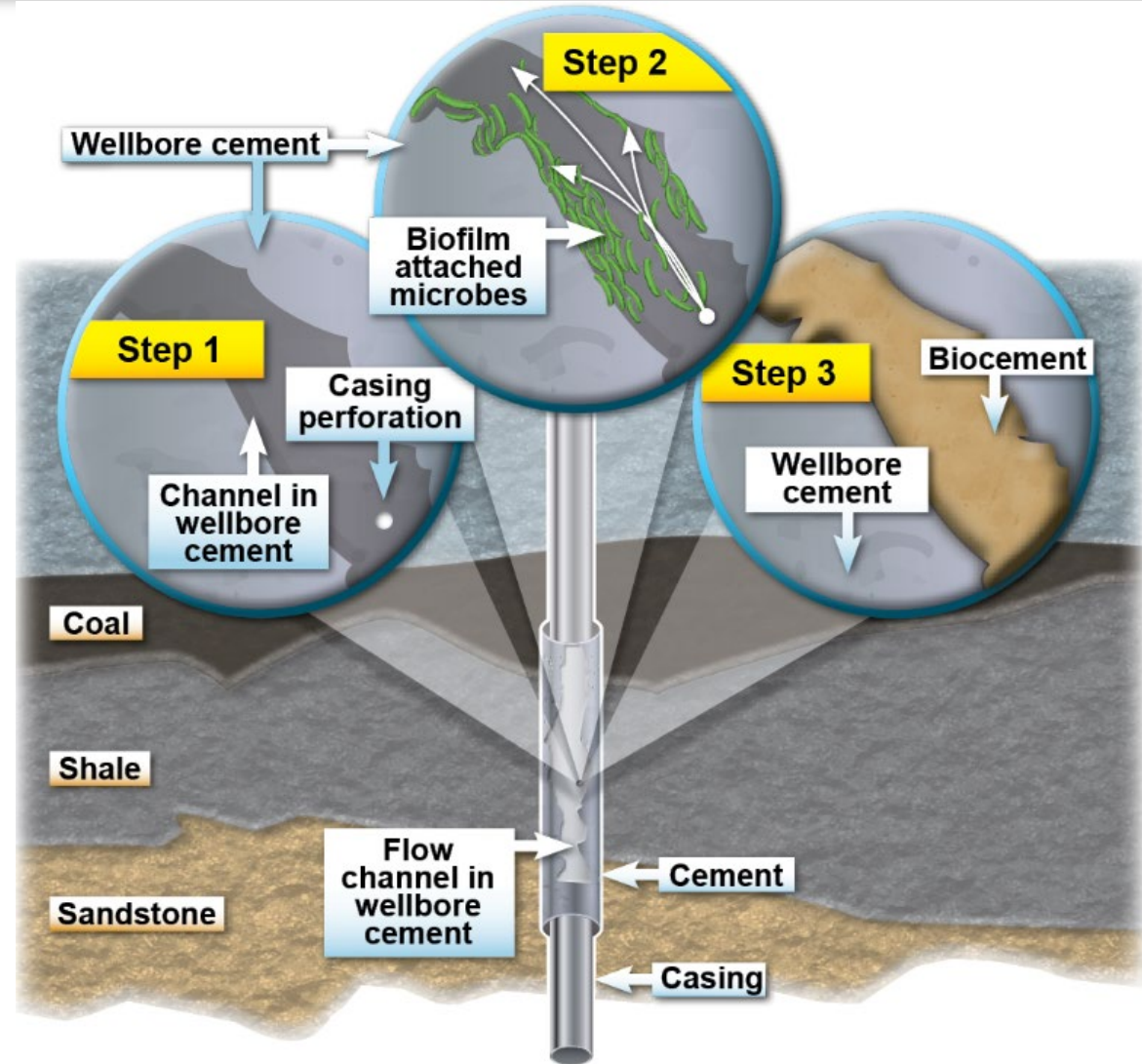


After Nordbotten and Celia, Geological Storage of CO₂, 2012

Cement is viscous- also CO₂ emissions

Microbes are small –for small aperture fractures that can be delivered via low-viscosity fluids

Wellbore Integrity



J Parchen

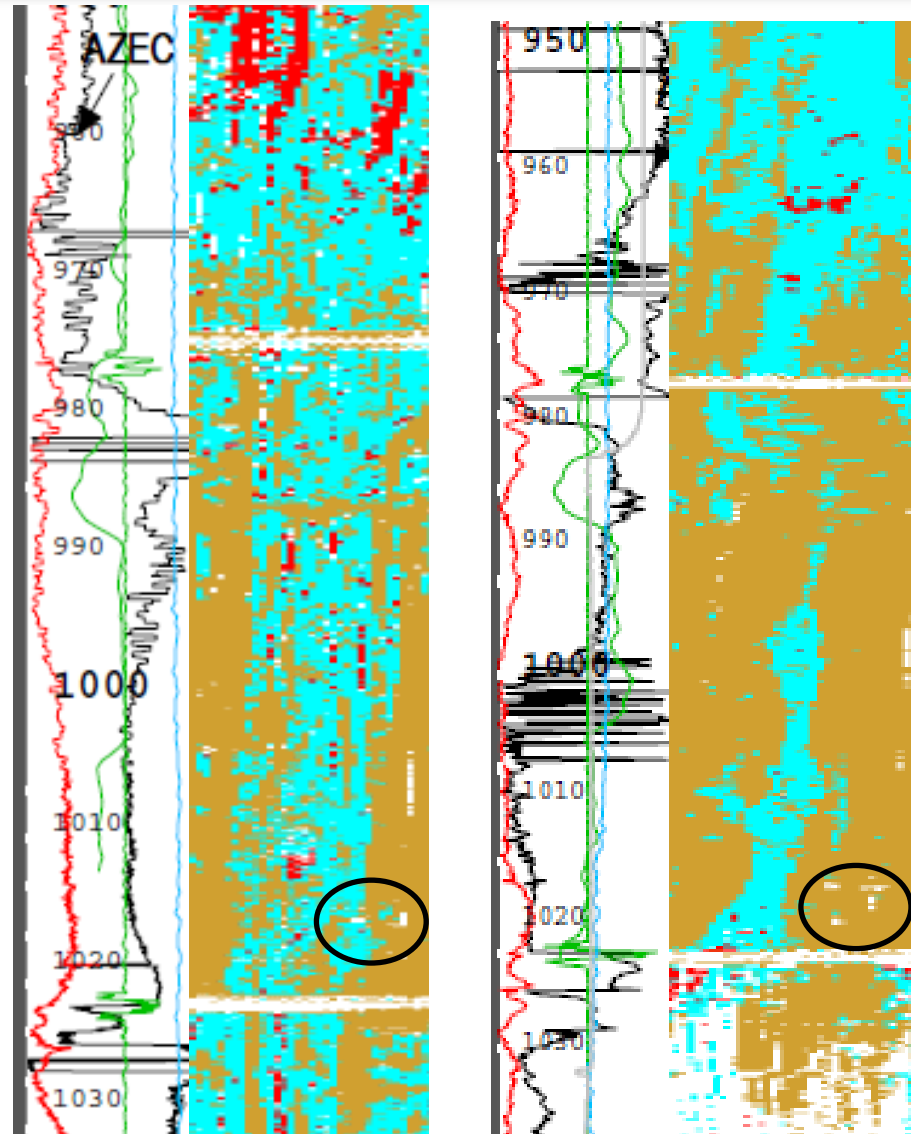
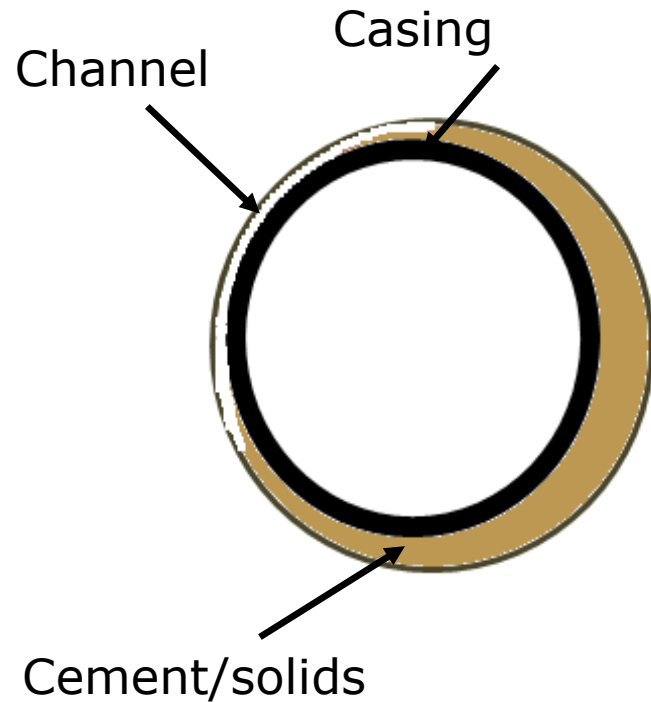
Phillips, AJ, Troyer, E, Hiebert, R, Kirksey, J, Rowe, W, R, Gerlach, R, Cunningham, A, Esposito, R, Spangler, L. Enhancing wellbore cement integrity with microbially induced calcite precipitation (MICP): a field scale demonstration (Journal of Petroleum Science and Engineering 2018)

Schlumberger

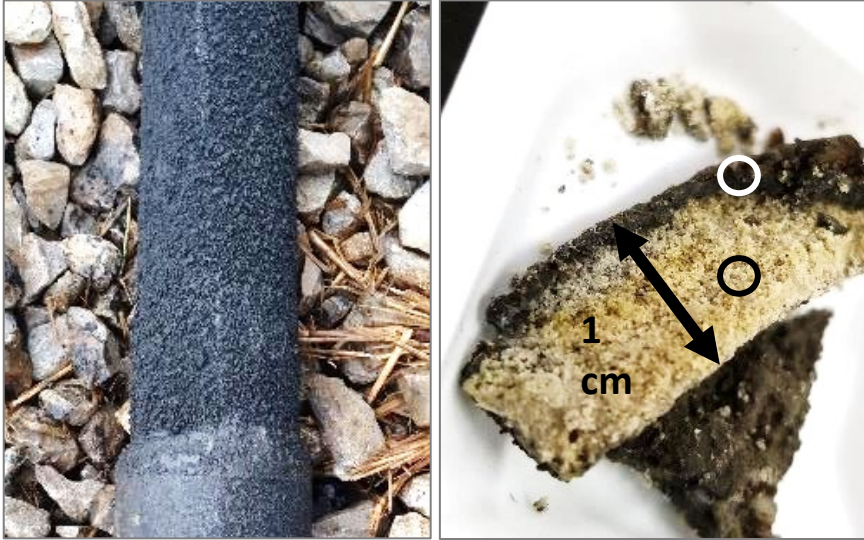
**SOUTHERN
COMPANY**

MONTANA EMERGENT TECHNOLOGIES

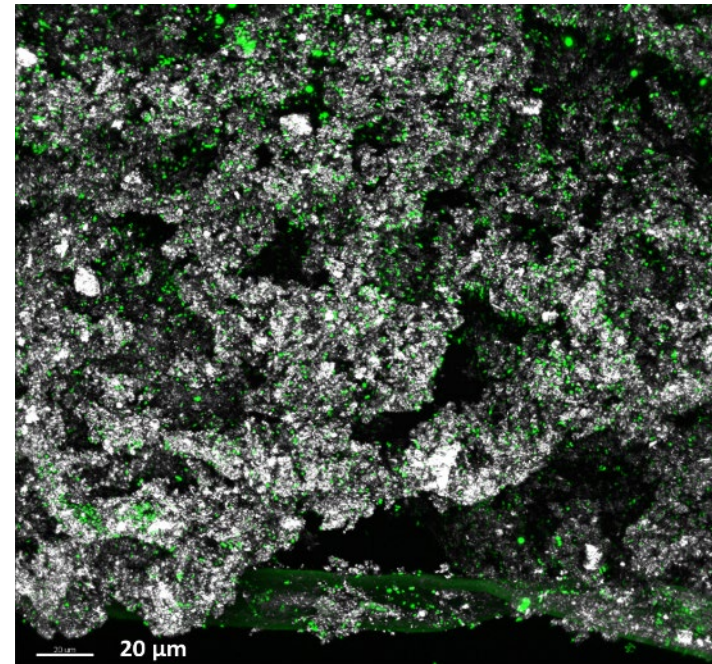
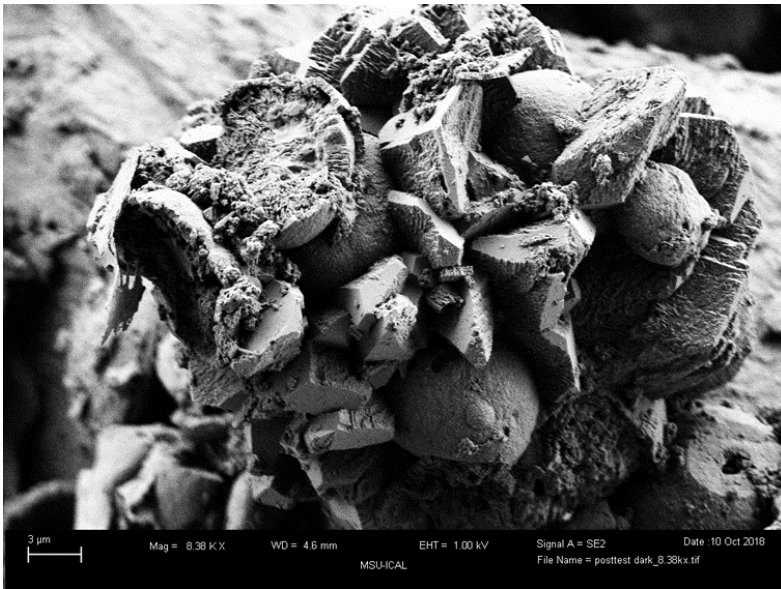
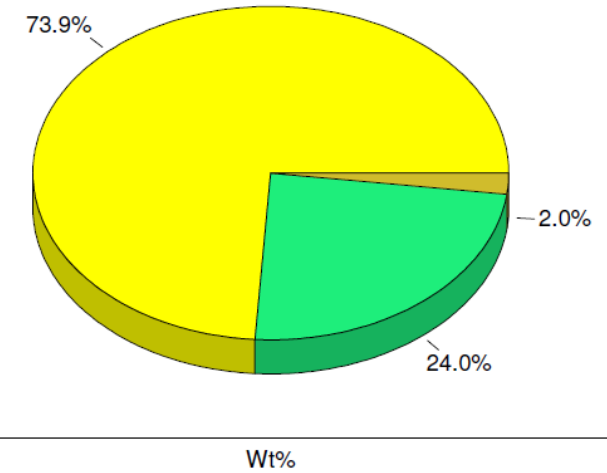
Mineralization Application- Wellbore Integrity



Field Sample Analysis

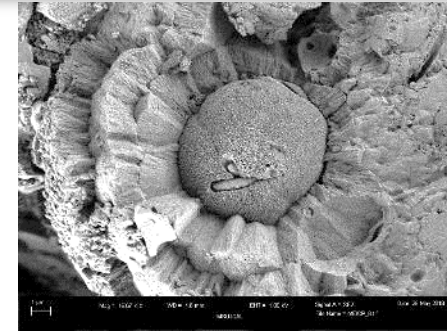
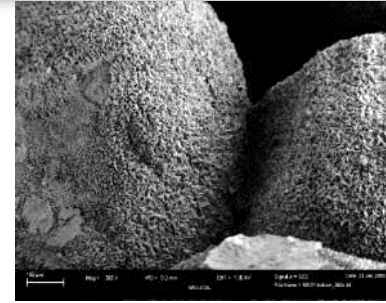
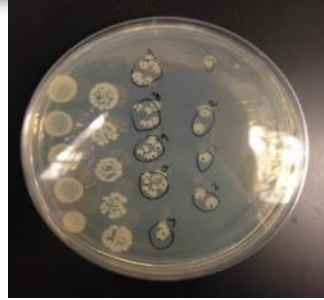


- Calcite - $\text{Ca}(\text{CO}_3)$
- Vaterite - CaCO_3
- Halite - NaCl

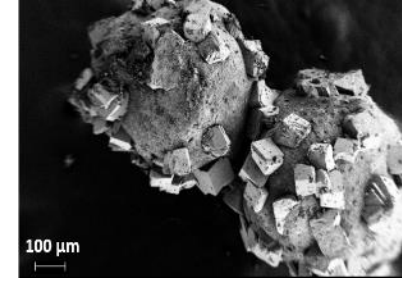
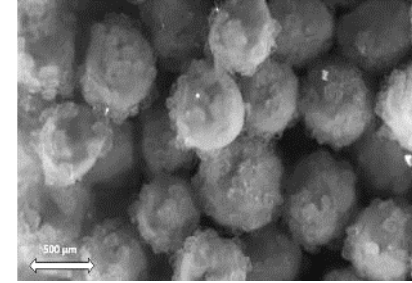


Subsurface Considerations- Temperature

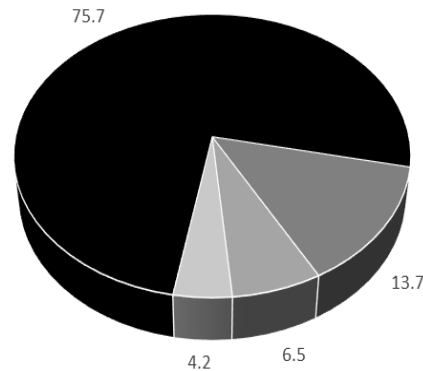
MICP



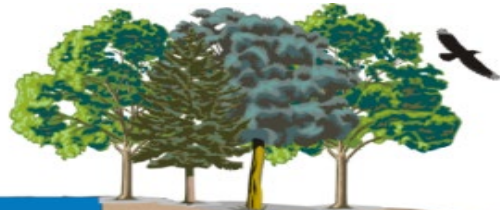
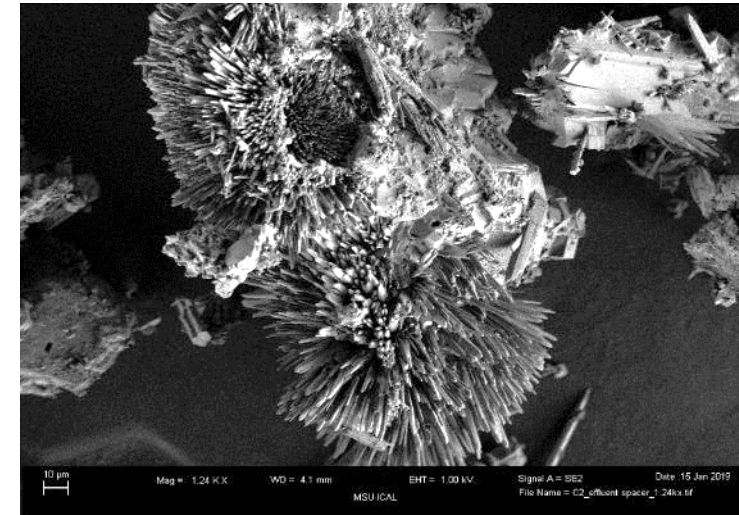
EICP



TICP



■ Aragonite ■ Vaterite ■ Calcite ■ Sodium Chloride



Underground gas storage

H_2S

Oil

Brine

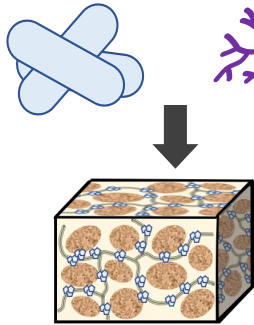
Increasing temperature
and pressure with depth

Living Building Materials

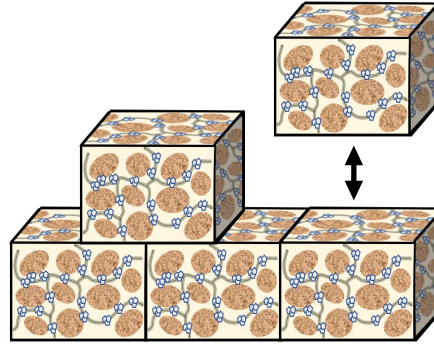
Microbial-manufactured MBMs

Construction

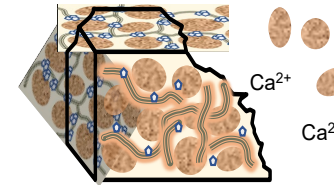
Bacteria and/or fungi



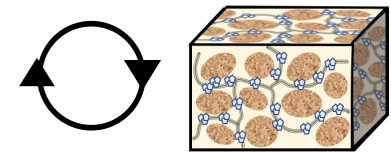
Reversible Interlocking



Breakdown



Recycling



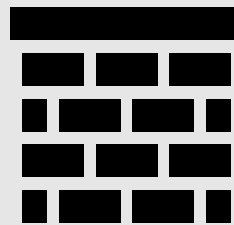
Key innovations over current manufacturing

- Low temperature processing
- Faster time to load-bearing readiness
- Re-use MBMs several times before recycling
- Adaptability of structures
- Biological, as opposed to human, labor
- Materials harvested for next use
- New MBMs use fewer new inputs
- Landfilling avoided

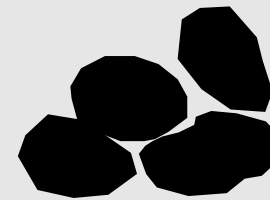
Concrete



Cement manufacturing is CO₂-intensive



Structures are only used once

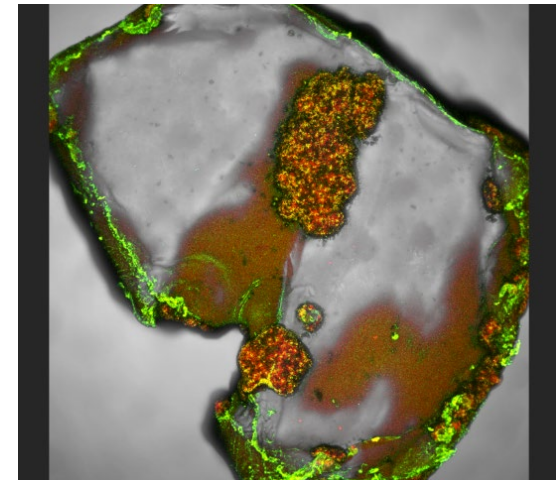
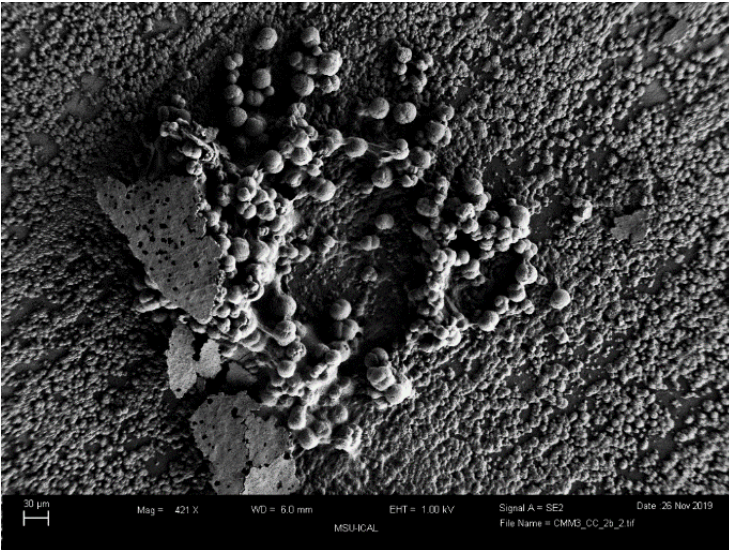
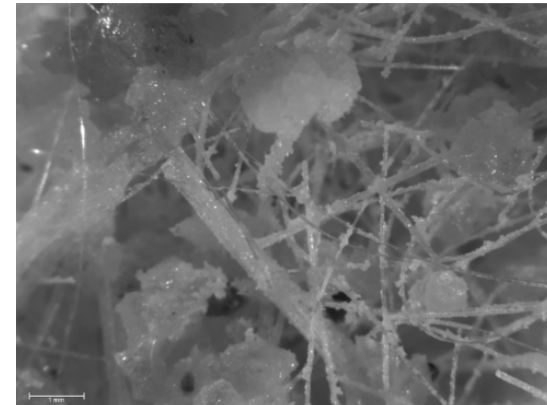
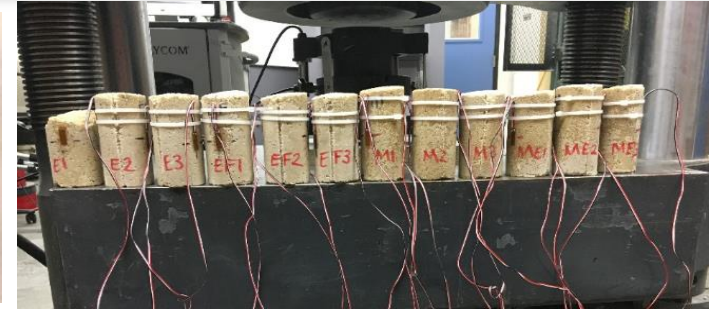
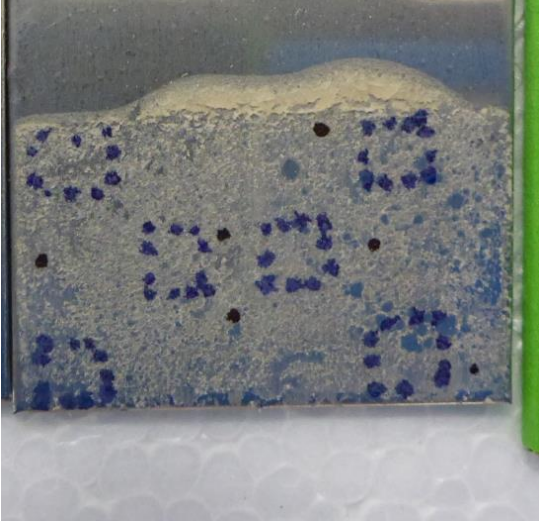


Structures demolished after use

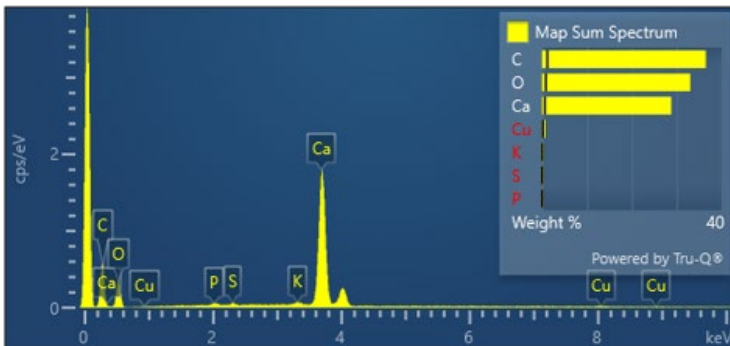
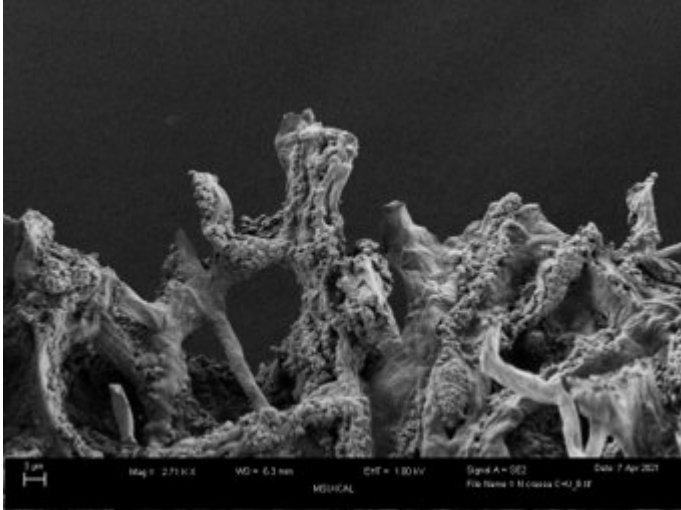


Demolished concrete waste goes to landfill

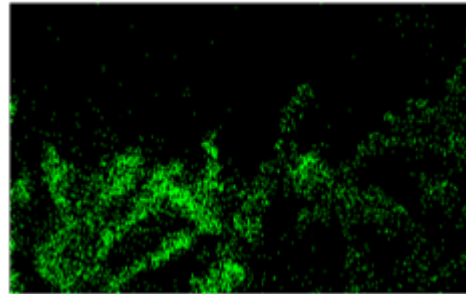
Building Materials and Adhesives



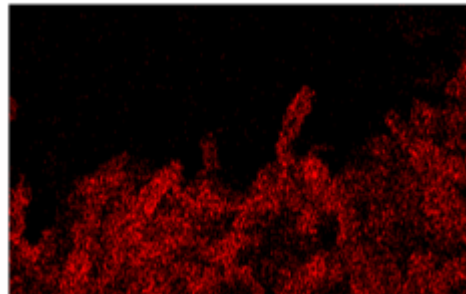
Fungal Mineralization Studies



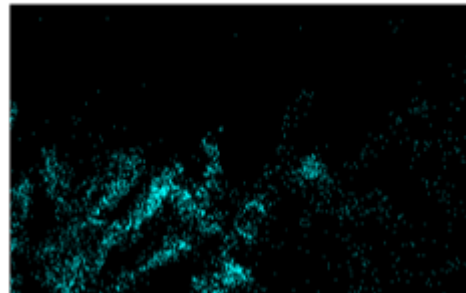
C K α 1,2



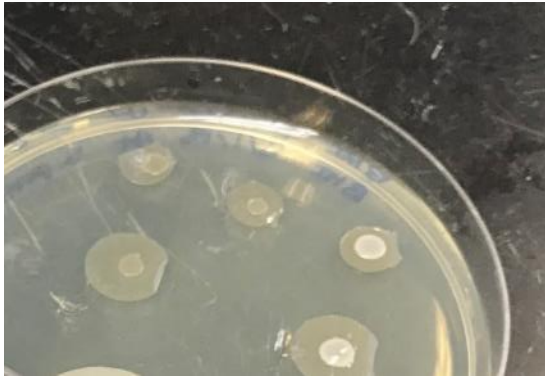
Ca K α 1



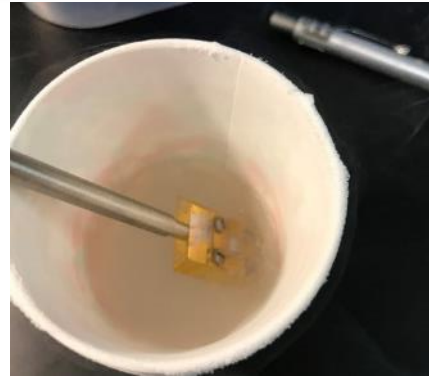
O K α 1



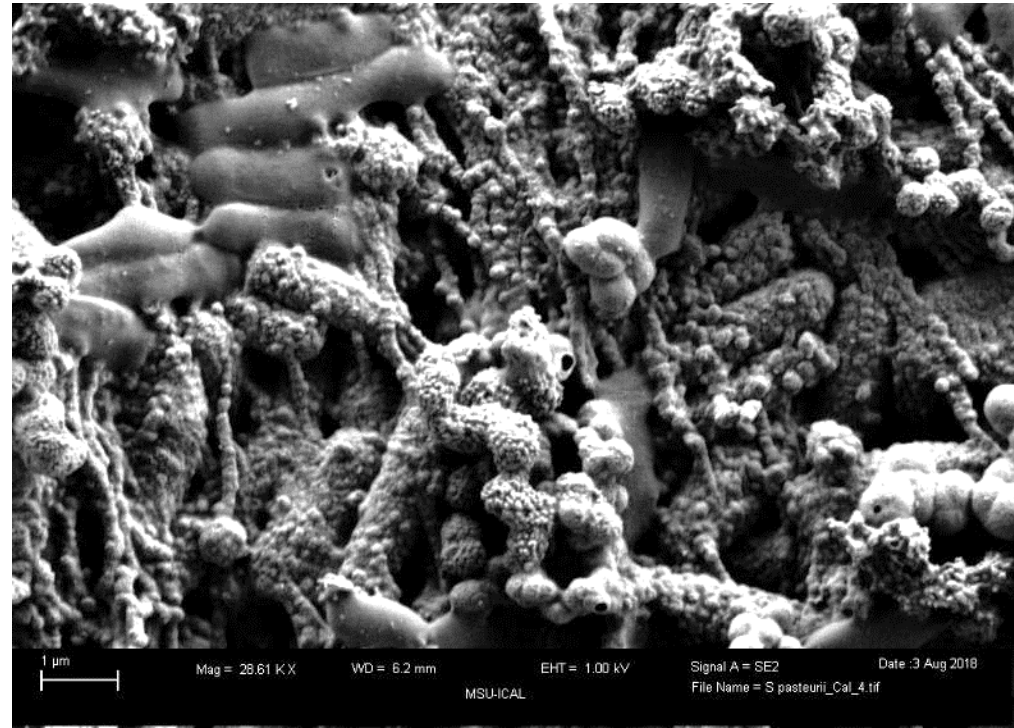
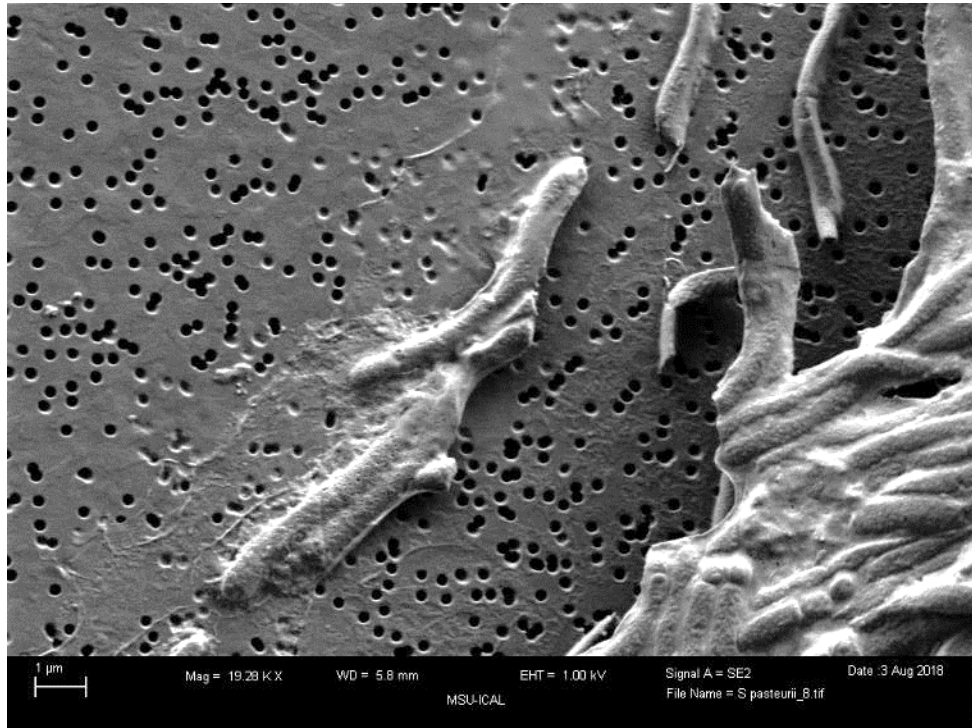
Biofilm Investigation Cryo- Zeiss FE-SEM



Not mineralized

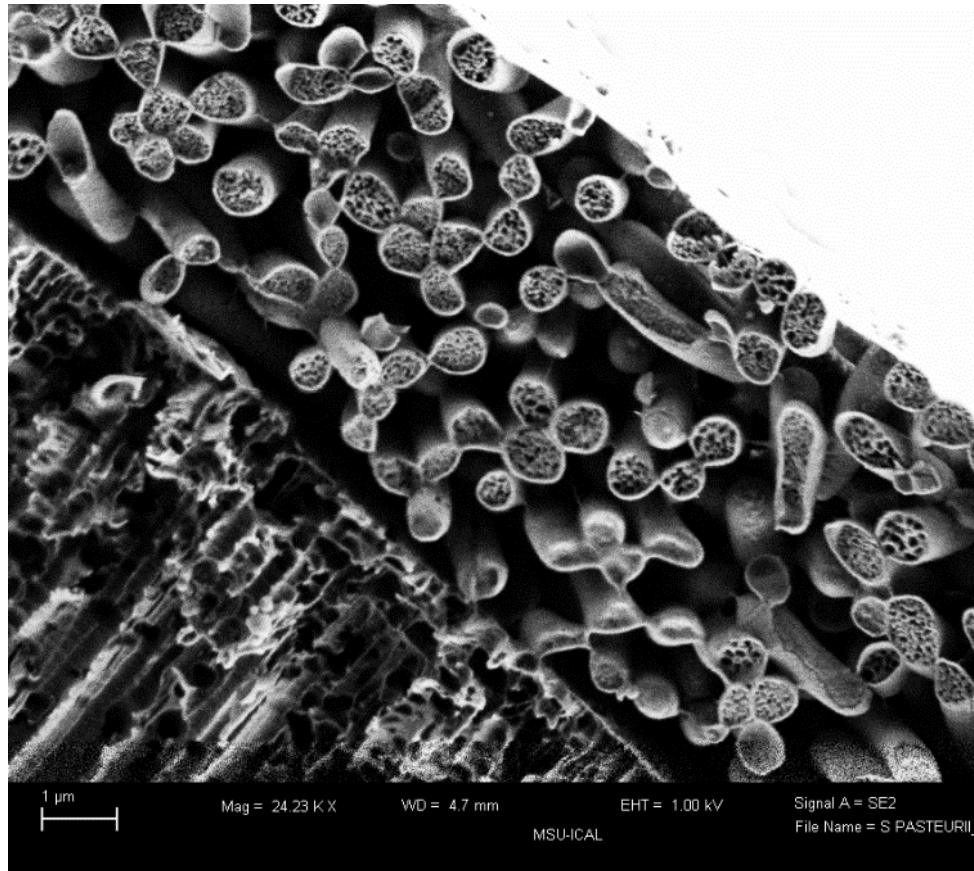


Mineralized

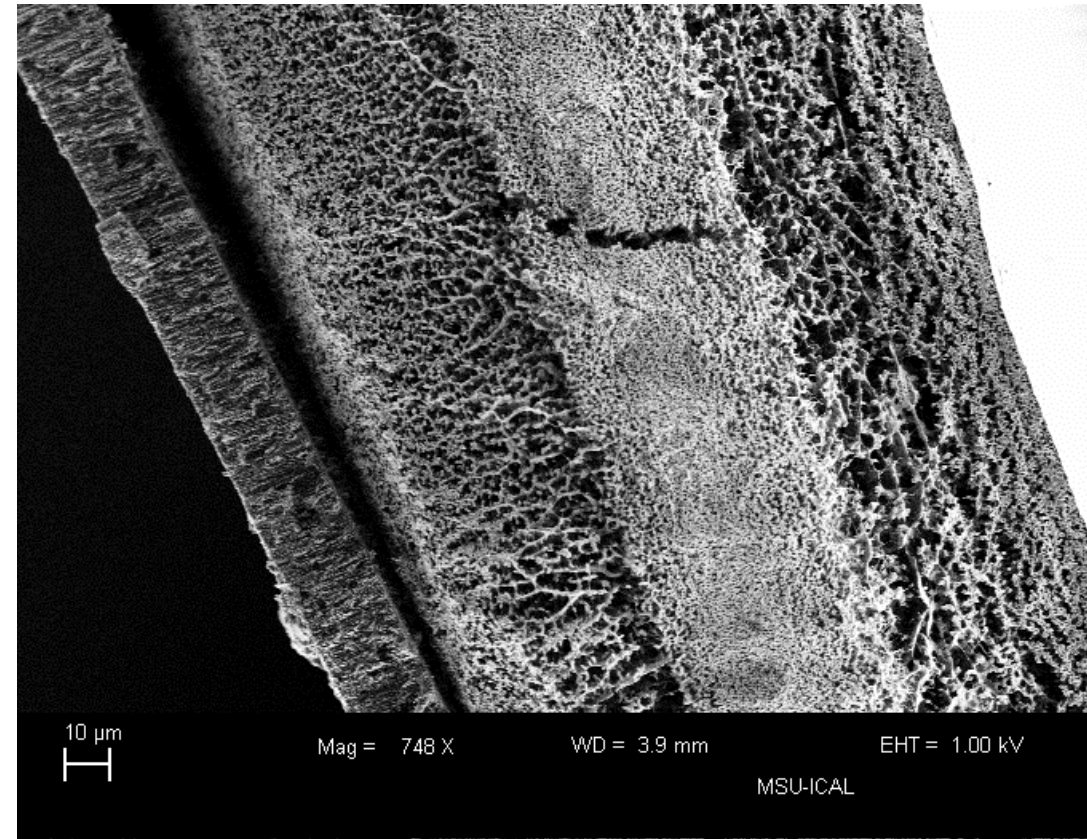


Biofilm Investigation Cryo- Zeiss FE-SEM

Not mineralized



Mineralized



Acknowledgements



MONTANA



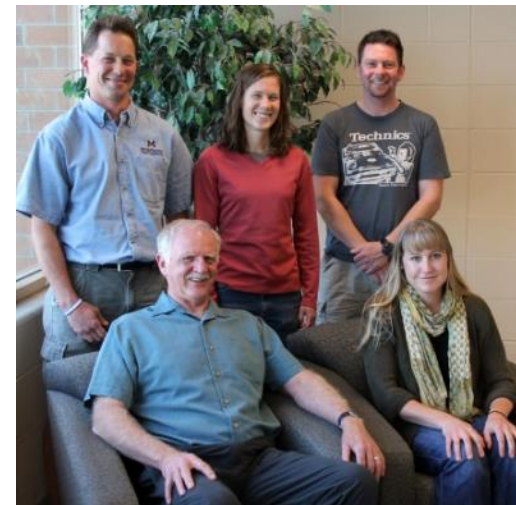
UAB THE UNIVERSITY OF ALABAMA AT BIRMINGHAM



University of Stuttgart
Germany

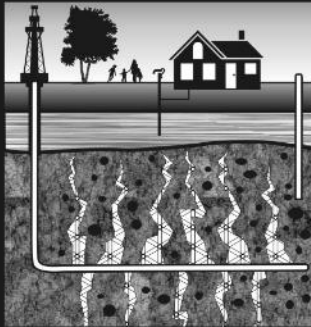
SOUTHERN
COMPANY

Schlumberger

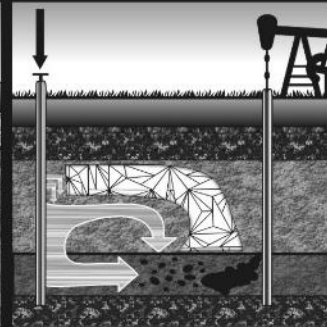


Engineering Applications- Mineralization

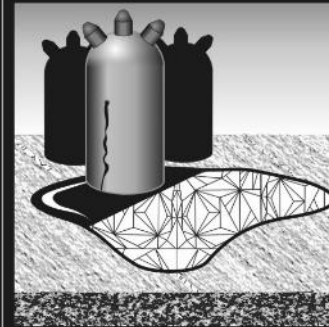
Engineered Applications of Ureolytic Biomineralization



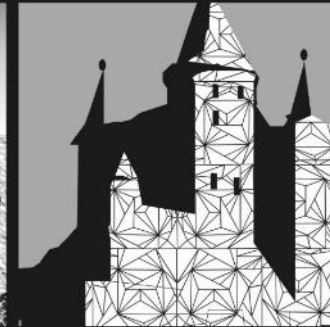
a) Hydraulic Fracturing



b) Enhanced Oil Recovery



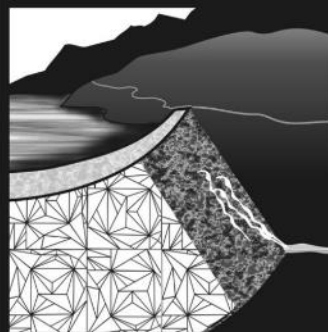
f) PCB Remediation



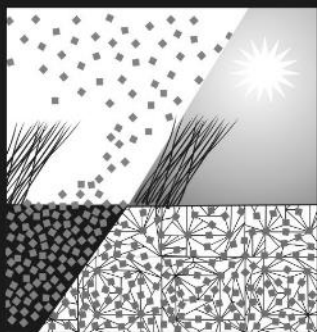
g) Limestone Remediation



h) Pond/Reservoir Sealing



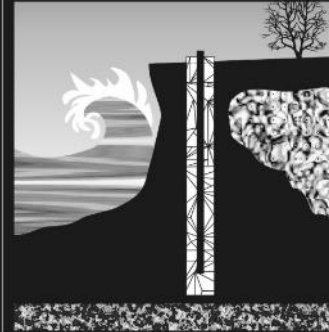
c) Soil Stabilization



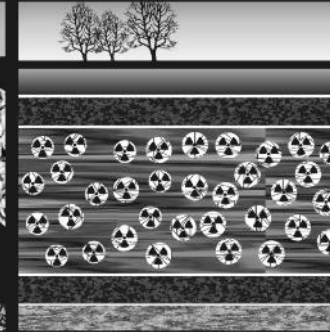
d) Dust Suppression



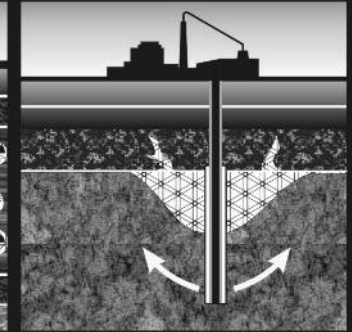
e) Concrete Remediation



i) Subsurface Barriers



j) Groundwater Remediation



k) Carbon Dioxide Sequestration

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

Biocement to make art



Eric Troyer

Eric Troyer,
Ashley Berninghaus,
Cody West, and
John Joyce

MSU NACOE

