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Center for Bio-mediated & Bio-inspired Geotechnics

Introduction to the Center for Bio-mediated and Bio-inspired Geotechnics (CBBG)

by

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Biogeotechnical Engineering

An emerging sub-discipline in geotechnical engineering that includes:

- Bio-mediated Processes: managed and controlled through biological activity (living organisms)
- Bio-inspired Processes: biological principles employed to develop new, abiotic solutions (no living organisms)
    - Includes Nature-inspired abiotic processes

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The Biogeotechnical Premise

Nature has developed many elegant and efficient biogeotechnical processes

- Billions of years of trial and error

These processes can be used to build, maintain, and renew sustainable and resilient geotechnical systems

→ We want to Learn from Nature

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The Biogeotechnical Challenge

Accelerate beneficial processes to occur in a time frame of interest

and/or

Induce adverse processes in a context where the effect is beneficial

JennBredemeier.deviantart.com

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NSF Engineering Research Center

Nature-inspired geotechnical solutions for civil infrastructure

Four thrusts

- Hazard Mitigation
- Environmental Protection
- Infrastructure Construction
- Subsurface Exploration /Excavation

Four public Universities

- ASU, UC Davis, Georgia Tech, New Mexico State

Research and Education

Broad Industry partnership program

- Consultants, Designers, Contractors, Owners, Agencies

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CBBG Thrusts and Technologies

Environmental Protection and Restoration

- Soil and Groundwater Remediation
- Microbial Crust Restoration

Infrastructure Construction

- Fugitive Dust Control
- Surface Water Erosion Control

Hazard Mitigation

- Earthquake-Induced Liquefaction Mitigation via Mineral Precipitation and Biogas Generation (Desaturation)

Subsurface Excavation and Exploration

- Self-Boring Probes

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Industry Partner Program

Industry partners provide input on strategic direction, collaborate on research and development

Geosyntec consultants — engineers | scientists | innovators
Chevron
Freeport McMoRan Copper & Gold
Republic Services
Arcadis — Design & Consultancy for natural and built assets
Salt River Landfill — An Enterprise of the Salt River Pima-Maricopa Indian Community
Nicholson
Schnabel Foundation Company
United States Environmental Protection Agency
Geo-Logic Associates
BioCement Technologies
ADOT
Hayward Baker Geotechnical Construction — Keller
ConeTec
Groundwater Technology
City of Phoenix
Golder
Geopier®
Haley Aldrich
Aero Aggregates
ADEQ Arizona Department of Environmental Quality

Environmental Protection and Restoration Research

Traditional subjects

– Remediation of hydrocarbons, chlorinated solvents

CBBG Innovative Techniques

– Microbial metabolic exploration
– Remediation of metals and metalloids
– Precipitation of contaminants
– Metabolic chain elongation
– Microbial crust restoration

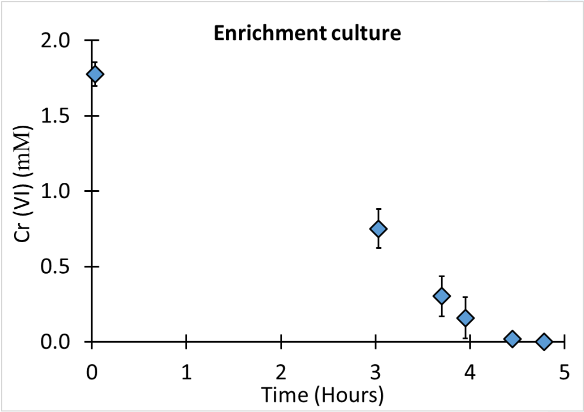
Detoxification and immobilization of Cr(VI) - Krajmalnik-Brown

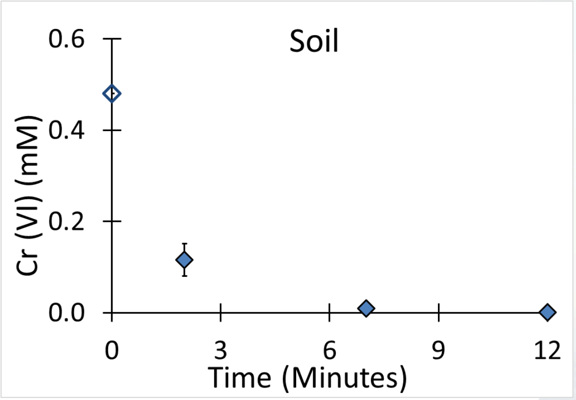
Achieved unprecedented rates for reduction of Cr(VI) to Cr(III)

- Linked to microbial growth: hours
- Not-linked to microbial growth: minutes

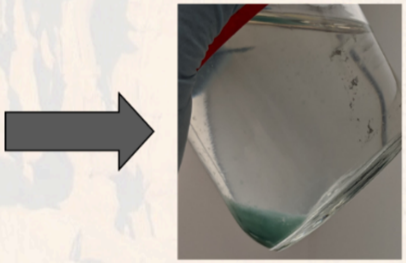
Currently exploring mechanisms

- Some Cr(VI) reducing microbes identified in enrichment culture





Dissolved Cr (VI)



Cr (III) precipitate

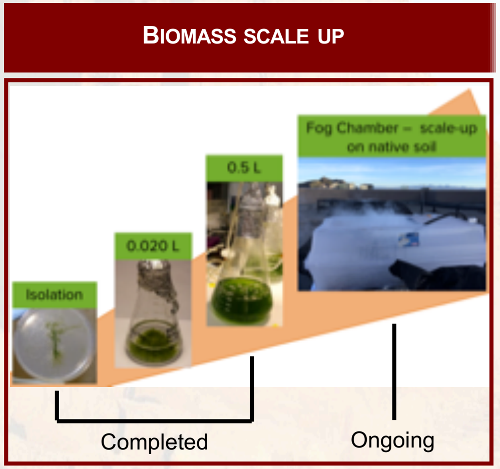
Restoration of degraded soil crust - Garcia-Pichel

Microbial reforestation

- Large-scale restoration of disturbed soil crust in semi and arid lands

Field deployable microbial nursery

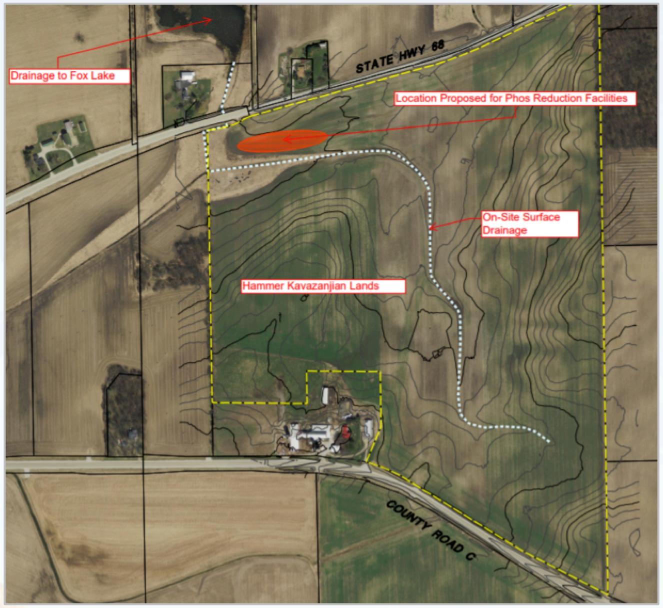
- Restore soil crust cyanobacterial community via location specific inoculum

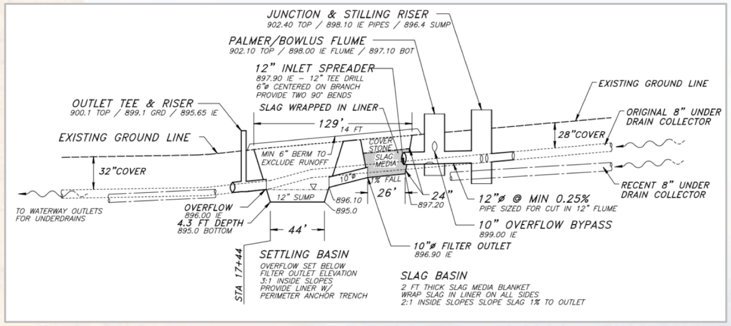


Removal of N and P from ground and surface water-Boyer

Phosphate and nitrogen removal by steel slag and woody mulches

- Phosphate precipitation due to high pH
  - Induced by flow across steel slag in vault
- Nitrate transformation via microbial denitrification
  - Induced in downstream wetlands
  - Shown in lab to occur under elevated pH
- Field test section under construction in Beaver Dam, WI





Steel Slag Vault

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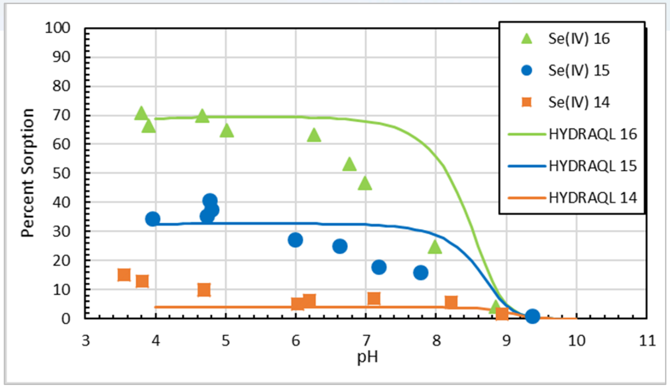
Microbially Enhanced Iron-Modified Zeolite PRB - Papelis

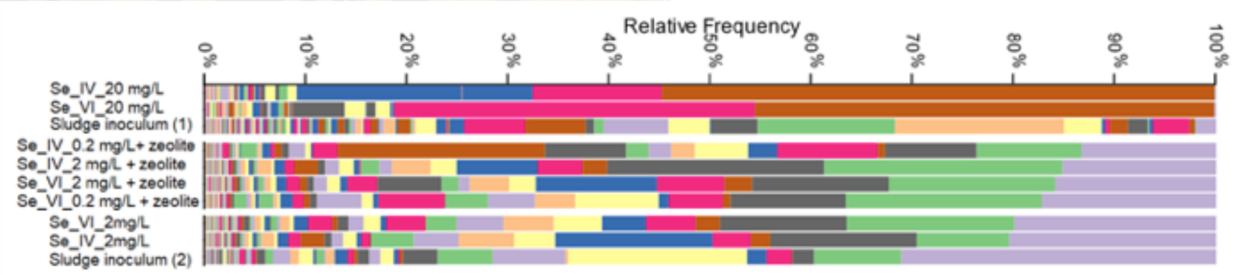
Iron-coated zeolite PRB, enhanced by a biofilm, for remediation of toxic metalloids (e.g., arsenic and selenium)

– Column experiments show microbial transformation of selenium

– Geochemical modeling and microbial ecology analysis underway



Concentration (mM)	Selenate Percent Removal	Selenite Percent Removal
20	54	100
2	53	100
0.2	100	100



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Passive Remediation of Acid Rock Drainage via Coupled Treatment - Delgado

Objective: Identify optimum configuration(s) and operating parameters for bioreduction and metal removal from ARD

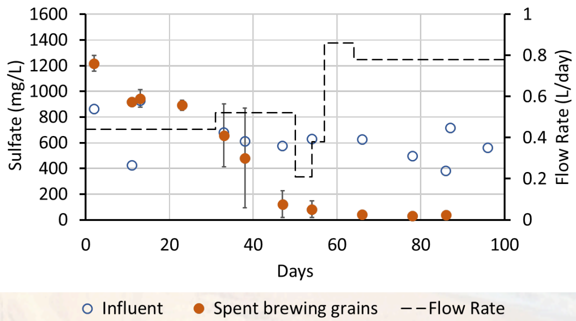
- Evaluate waste organic substrates for passive sulfate bioreduction and heavy metal removal
- Evaluate the effect of BOF slag on ARD chemistry before/after passive bioreduction

Accomplishments

- Substantial sulfate reduction, metal removal with spent brewing grains and sugarcane bagasse
- Removal of most metals (some > 90%)
- High flow rates (short HRT)

Select metal removal during continuous operation (%)

	Sugarcane bagasse		Spent Brewing Grains	
Element	Low-flow	Full-flow (3-d HRT)	Low-flow	Full-flow (3-d HRT)
Iron	99.8	98	99.8	99.9
Aluminum	94.9	90.1	86	90.2
Copper	96.6	99.2	93.4	99.3
Cadmium	-	99.1	-	97.8
Nickel	99.9	82.3	65.2	75.3
Chromium	82.4	46.8	67.1	70.9
Zinc	99.9	98	99.9	99.8



FREEPORT McMoRAN COPPER & GOLD

Microbial Chain Elongation (MCE)

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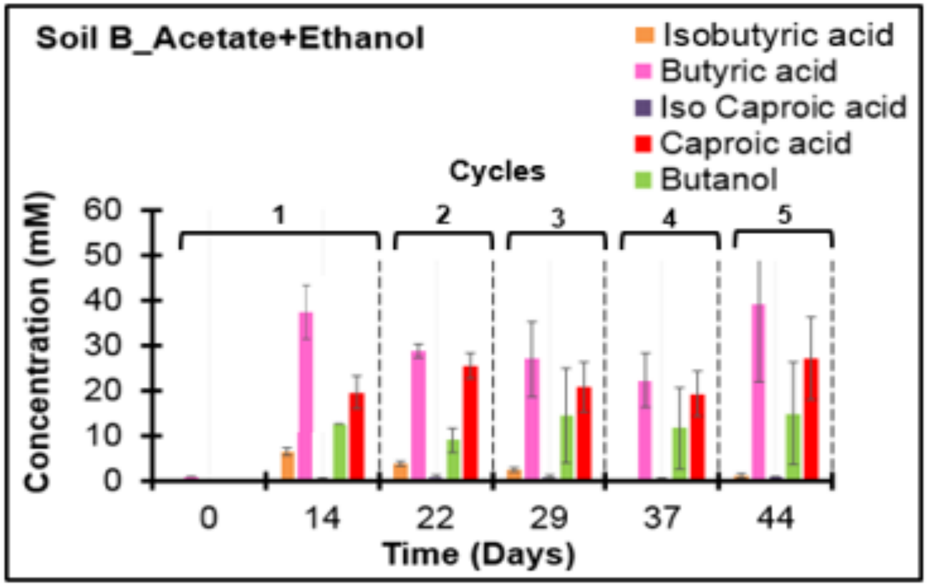
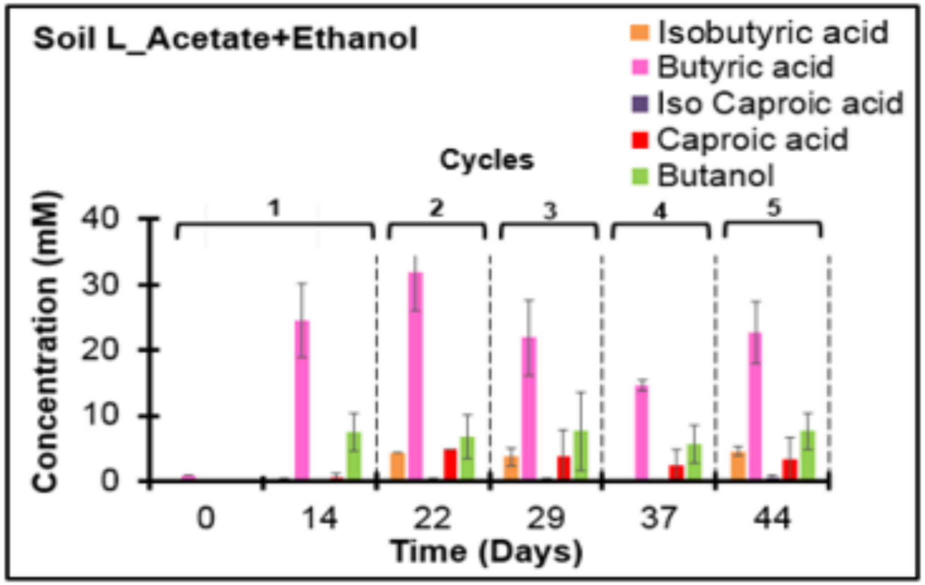
Microorganisms grow in soil anaerobically by building simple substrates into larger, more complex molecules

- Facilitates bioremediation via biostimulation (addition of organic and inorganic carbon
- Occurred in all soil microcosms tested
- End products differed by soil type
- Products included C4-C6 fatty acids, C4 alcohol, **H_2 (in high concentrations)**





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Mineral Precipitation

Mineral precipitation phenomenon very common in nature

- $CaCO_3$ most common

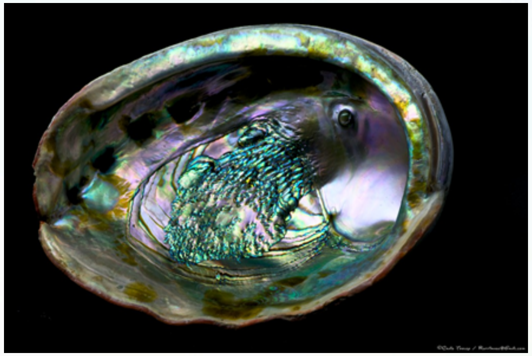
$CaCO_3$ precipitation most studied biogeotechnical mechanism

- Increases strength, stiffness, dilatancy
- Reduces permeability
- Can co-precipitate some contaminants

Many $CaCO_3$ precipitation mechanisms

- Some anthropogenic
- Some generate biogas (→ desaturation)

http://top10for.com/top-10-most-iconic-british-landmarks/



www.mendonomasightings.com/

Potential Applications

Justanothercinemanic.tumbl.com

Liquefaction mitigation

Fugitive dust / erosion control

Subsurface barriers

Co-precipitation of contaminants

Slope stabilization

“Bio-bricks”

Foundation support

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Microbially and Enzyme Induced Carbonate Precipitation (MICP, EICP)

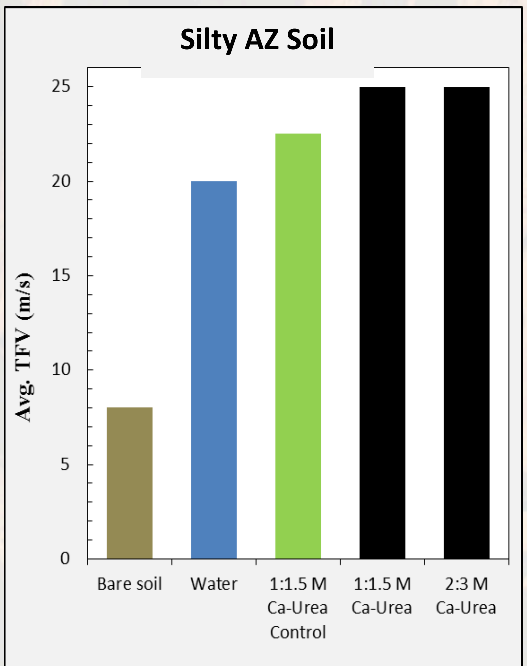
Biocementation via hydrolysis of urea

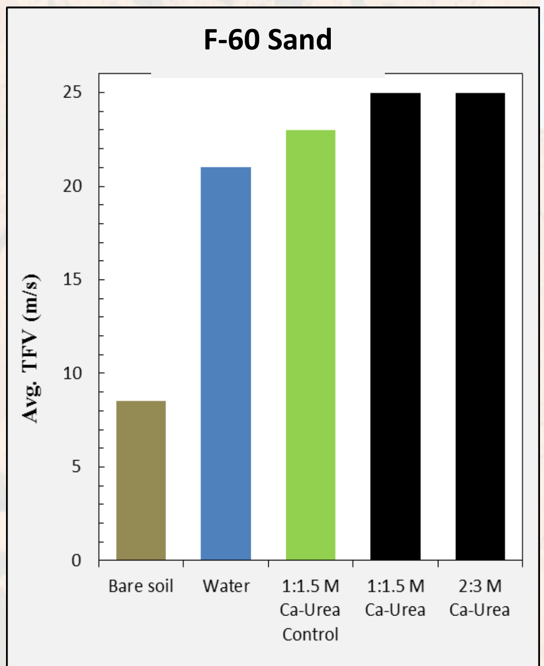
- Catalyzed by the enzyme urease
  - Urease supplied by microbes (MICP) or from agricultural sources (EICP)
  - Must provide urea & calcium source ($CaCl_2$)
- An alternative to Portland cement

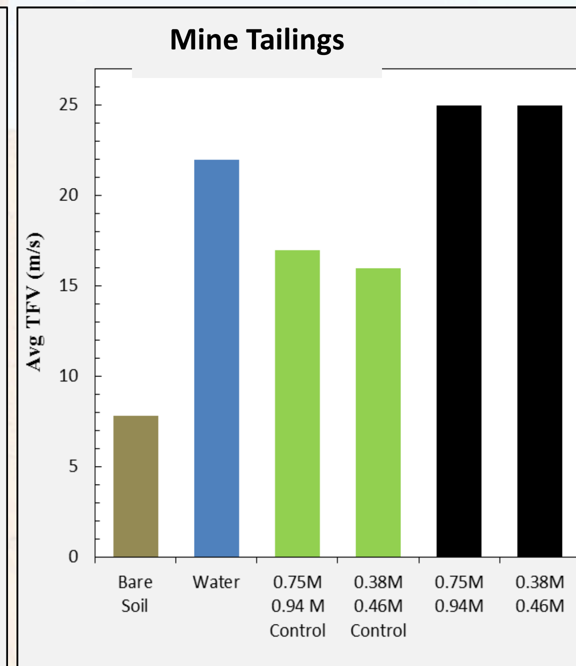
Fugitive Dust Mitigation

Create a calcium carbonate ($CaCO_3$) crust via Enzyme Induced Carbonate Precipitation (EICP)

- A “one and done” solution
- Field trials this month (w/ FMI, RSI, SRL)







Sequestration of Radionuclides, Metals via MICP

Sequester by co-precipitation with $CaCO_3$

- Fujita et al.

Suitable for divalent radionuclides, metals

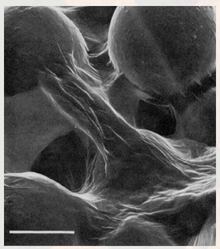
- Strontium, Cadmium

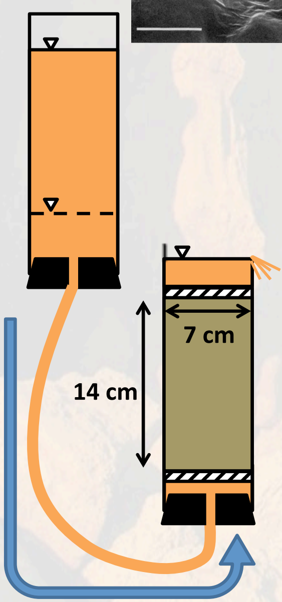
$$Sr^{2+} HCO^{3-} + OH^{-} = SrCO_3(s) + H_2O$$

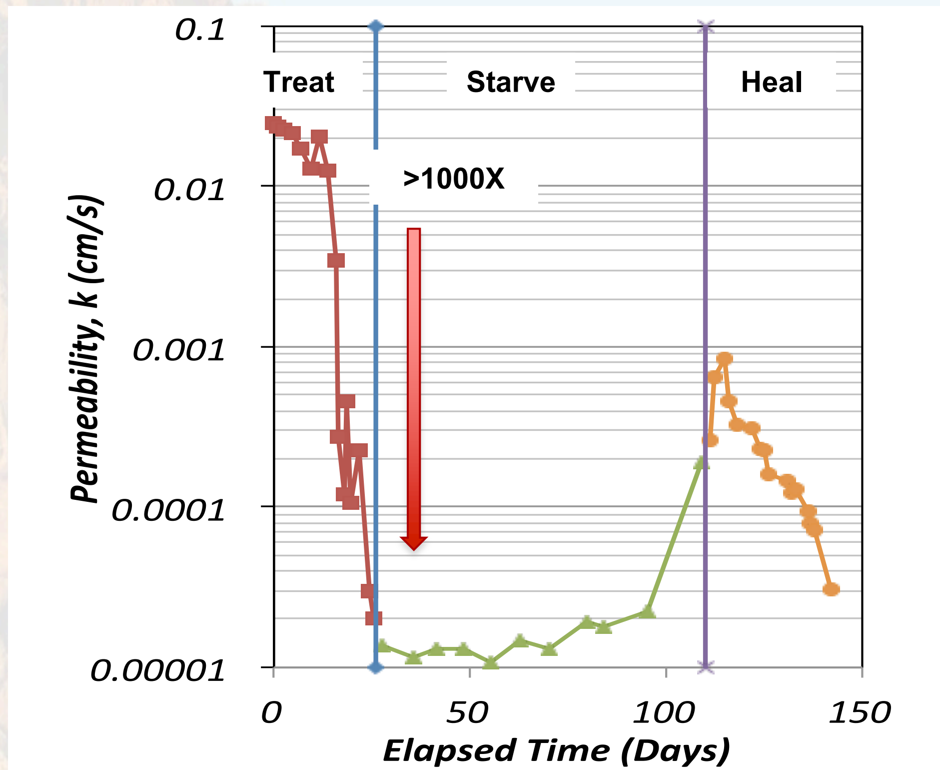
Biofilms for Seepage Control - DeJong

Reduction is temporary – can reverse & heal as needed

Self-equilibrating seepage paths deliver biofilm to critical locations







DeJong et al. (2016)

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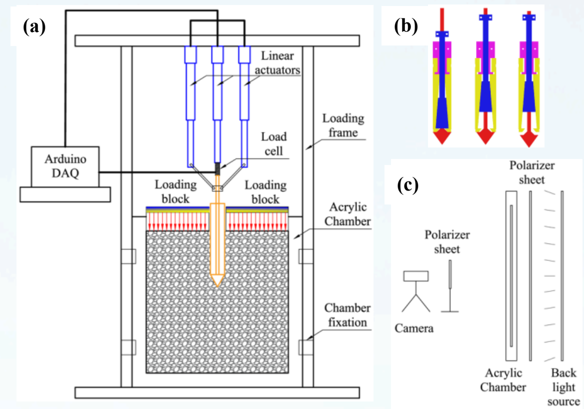
Bio-inspired Self-burrowing Robots – Cortes, Frost, Tao

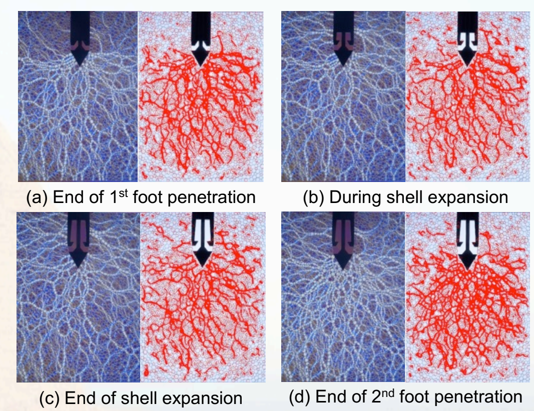
MOTIVATION/GOALS

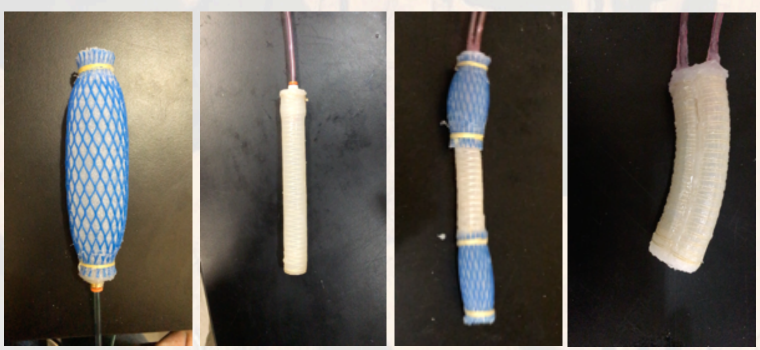
- Develop self-advancing probe using razor-clam inspiration

RESEARCH ACCOMPLISHMENTS

- Achieved upward burrowing with robot
- Performed penetration tests in 2-D photoelastic chamber

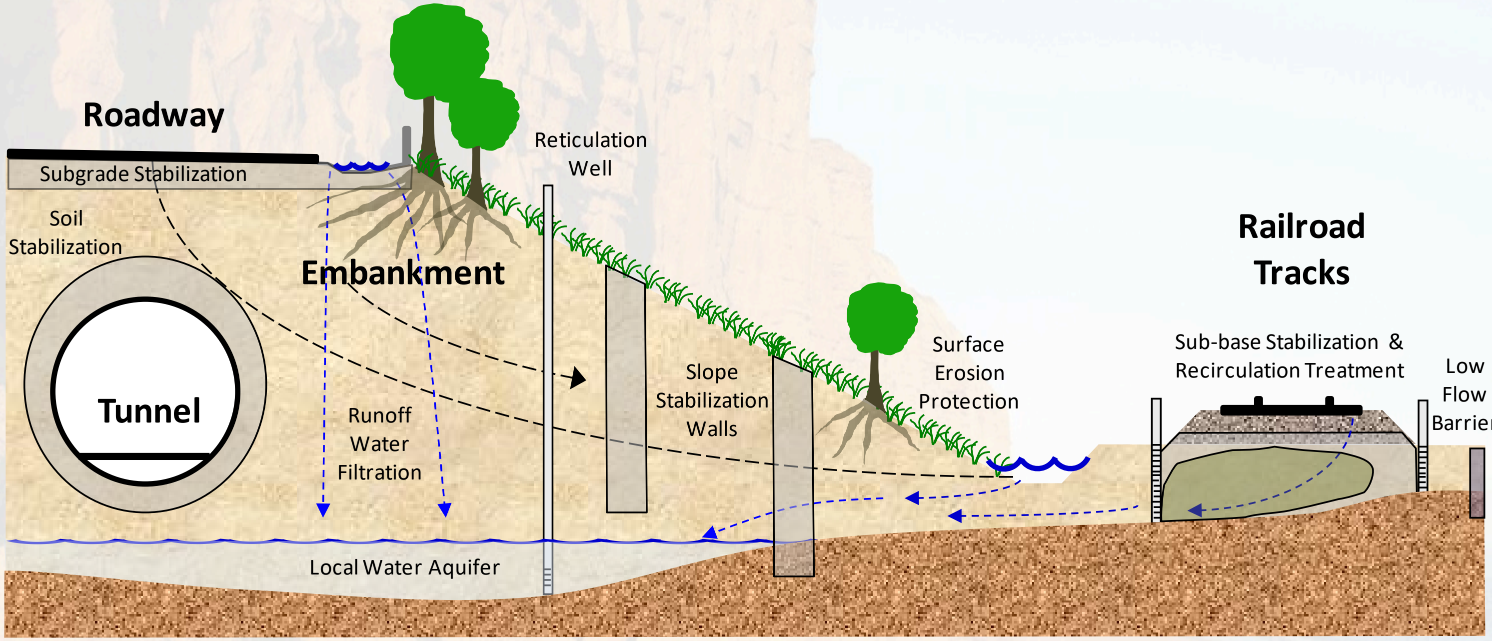



(a) End of 1st foot penetration
(b) During shell expansion
(c) End of shell expansion
(d) End of 2nd foot penetration



The Biogeotechnical Future

- Many potential biogeotechnical applications for environmental protection
- Some under investigation, many more waiting to be explored



DeJong et al. (2011)

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Thank you for your attention!

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