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Center for Bio-mediated & Bio-inspired Geotechnics

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

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and

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Biogeotechnical Engineering

An emerging sub-discipline in geotechnical engineering that includes:

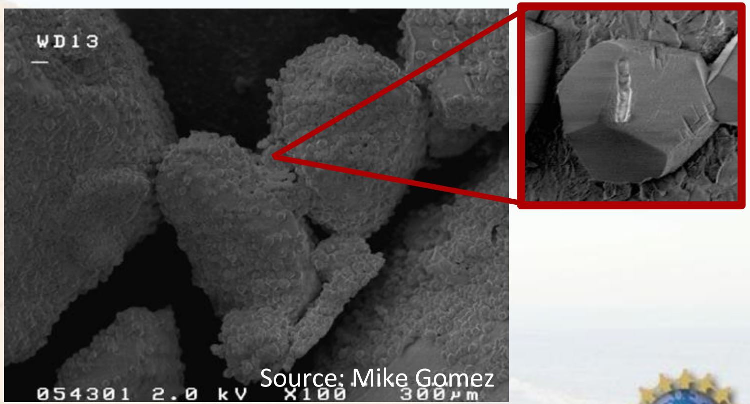
- Bio-mediated Processes: managed and controlled through biological activity (living organisms)
- Bio-inspired Processes: biological principles employed to develop new, abiotic solutions (no living organisms)

Bio-mediated Geotechnics

Modify soil using a biological process (living organism)

Example : Replace Portland cement by using bacteria to precipitate calcite

- soil improvement
- ”bio-bricks”

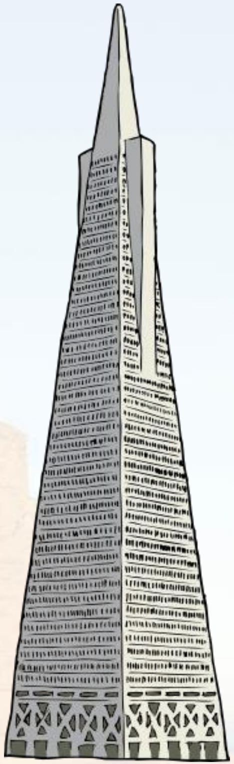


Bio-Inspired Geotechnics

Use natural processes for inspiration

- Mimic biological processes
- Employ biological materials

Example : Can we make this building more stable by studying how this tree relies on its roots?



Source: Swick Co.

Center for Bio-mediated and Bio-Inspired Geotechnics (CBBG)

Seed funding provided by NSF

- Gen-3 ERC
- Research and education
- > $35 million for 10 years

Four leading academic institutions

- ASU (lead), Georgia Tech, New Mexico State, UC Davis

Industrial Partners program

- Consultants, Contractors, Owners, Agencies

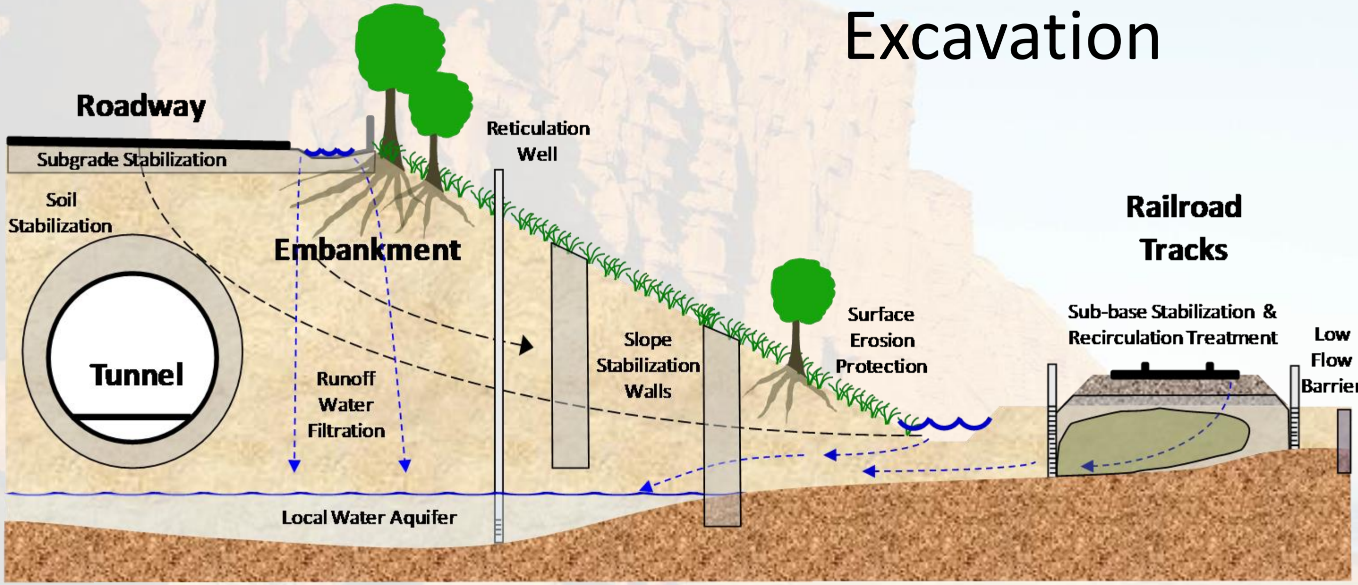
REU and **RET** programs

Center Advantages

- Facilitates interdisciplinary study
  - Bridge knowledge and communication gaps
- Establishes necessary facilities
- Develops necessary workforce
  - Education and outreach programs
- Disseminates information widely
  - Broad geographic distribution
- Accelerates integration into practice

CBBG Thrusts

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



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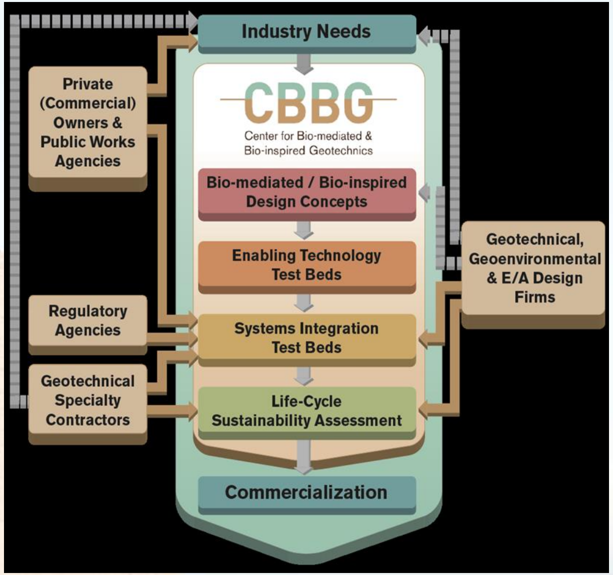
Industry Partner Program

- Broad spectrum of stakeholders
  - Engineers, Contractors, Owners, Agencies
- Input on research priorities
- Collaboration on research
  - Reduced overhead
- Access to students



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CBBG Industry Partners

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

- Freeport McMoRan Copper & Gold
- Salt River Landfill — An Enterprise of the Salt River Pima-Maricopa Indian Community
- Cosanti Foundation
- Geosyntec consultants — engineers | scientists | innovators
- Schnabel Foundation Company
- Republic Services
- Geo-Logic Associates
- NMDOT
- United States Environmental Protection Agency
- ConeTec
- Haley Aldrich
- Keller
- Menard
- Groundwater Technology
- Geopier®
- Golder
- Nicholson
- ADOT
- ADEQ — Arizona Department of Environmental Quality
- City of Phoenix

The Biogeotechnical Premise

- Nature has developed many elegant biogeotechnical processes
  - Billions of years of trial and error
- These processes be used to address geotechnical problems

→ We can Learn from Nature

Learning From Nature

Durable geologic deposits

Resilient foundations

Efficient and safe penetration and tunneling

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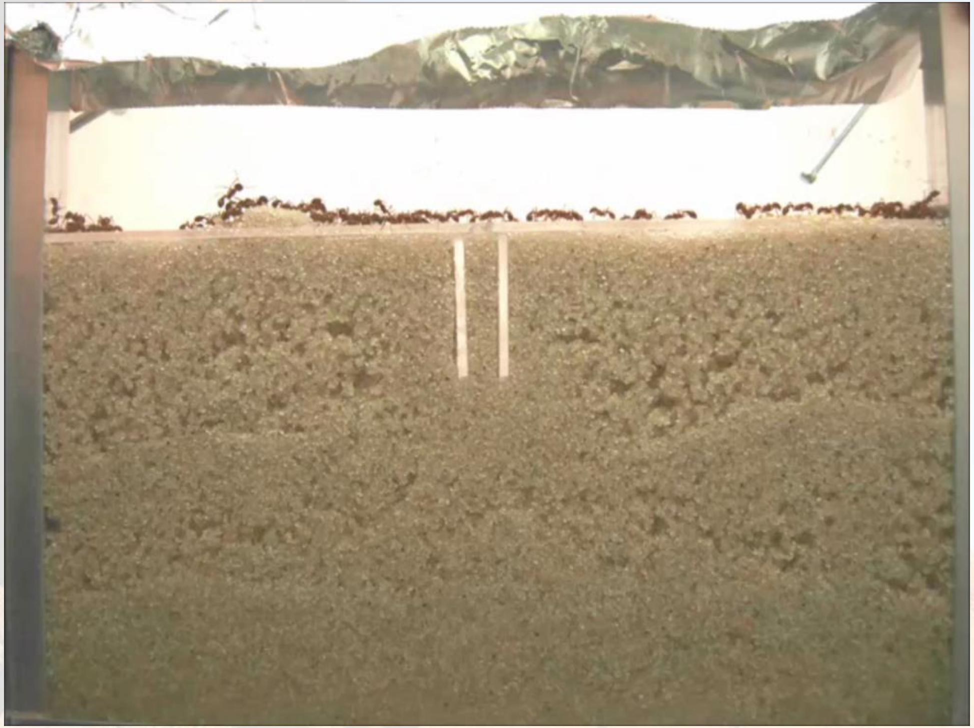
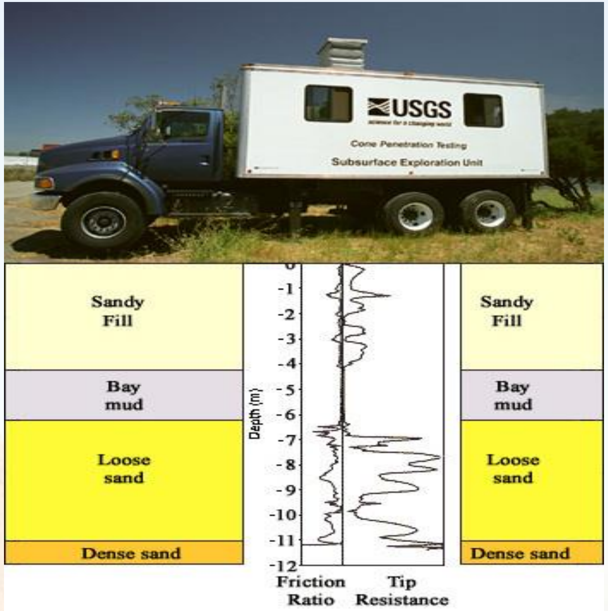
Learning from Nature: Can you dig it!



Video courtesy of Prof. Carlos Santamarina, Georgia Institute of Technology

Learning from Nature - Penetrating Deep!



Video courtesy of Prof. Carlos Santamarina, Georgia Institute of Technology

CBBG Vision

Transform geotechnical engineering practice by:

- Developing nature-compatible, sustainable solutions
  - Solutions of first resort
- Integrate geoenvironmental engineering into the mainstream

Inspire a new generation of geotechnical professionals

Bio-Geo-Chemo-Mechanical Processes

Mineral precipitation

Chemical transformation

Biopolymer generation

Self-motile organisms

Root support/reinforcement systems

Biogeotechnical challenge: Mobilize these processes for beneficial use

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Biogeotechnical Ground Improvement Technologies

- Mineral (carbonate) precipitation
- Biofilms
- Biopolymers
- Root-inspired reinforcement and foundations
- Motile ("self-tunneling") probes
- Desaturation

Key Biogeotechnology: Carbonate Precipitation

One of the most common mineral precipitation phenomenon in nature
- Calcium carbonate ($CaCO_3$) most common

Most studied biogeotechnical mechanism
- Increases strength, stiffness

Many $CaCO_3$ precipitation mechanisms
- Some anthropogenic

Many potential applications

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Carbonate Precipitation Processes that Operate on a Geologic Time Scale

Cemented sand

Carbonate sediments

Gypsum nodules

Stalactites, stalagmites

https://upload.wikimedia.org/wikipedia/commons/5/59/Cliff_House_from_Ocean_Beach.jpg

Carbonate Precipitation Processes that Operate on an Engineering Time Scale

(Often adverse)

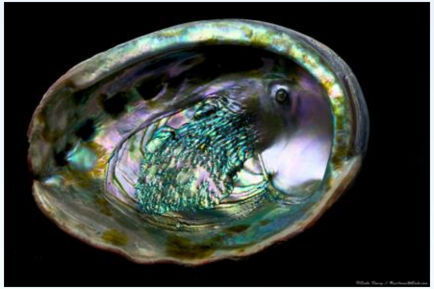
Mollusk shells

Clogging of water treatment plant filters

Mineral scale on pipes

Fouling of well screens

Clogging of drainage systems



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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

Potential Applications

Justanothercinemanic.tumbl.com

- Foundation support
- Erosion control
- Slope stabilization
- Liquefaction mitigation
- Stabilization of underground openings
- “Bio-bricks”

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Engineered $CaCO_3$ Precipitation: "Biogeo Alchemy"

Turning sand into sandstone

- Precipitation of calcium carbonate (Calcite)
  - Microbially
  - Using an enzyme

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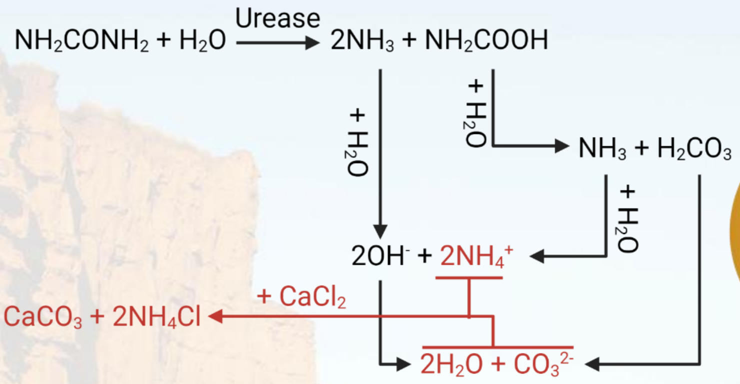
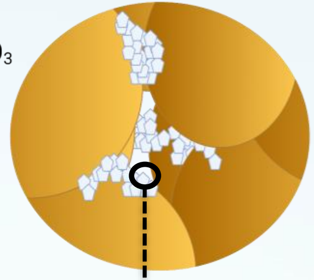
Carbonate Precipitation Mechanisms: Urea Hydrolysis

Several geochemical mechanisms

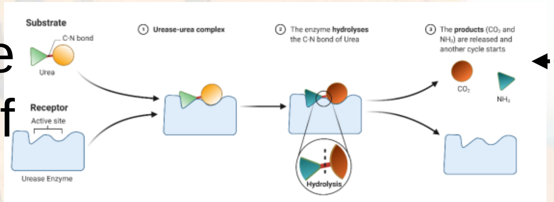
- Urea hydrolysis is the most studied mechanism

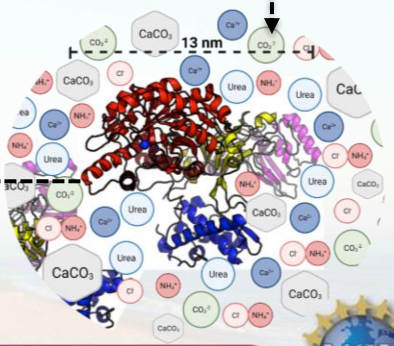




Urea hydrolysis reaction catalyzed by urease enzyme (10^{14} times faster)

- Generating alkalinity and CO_3^{-2}
- Precipitation of carbonate minerals in presence of divalent cations (e.g. Ca2+)





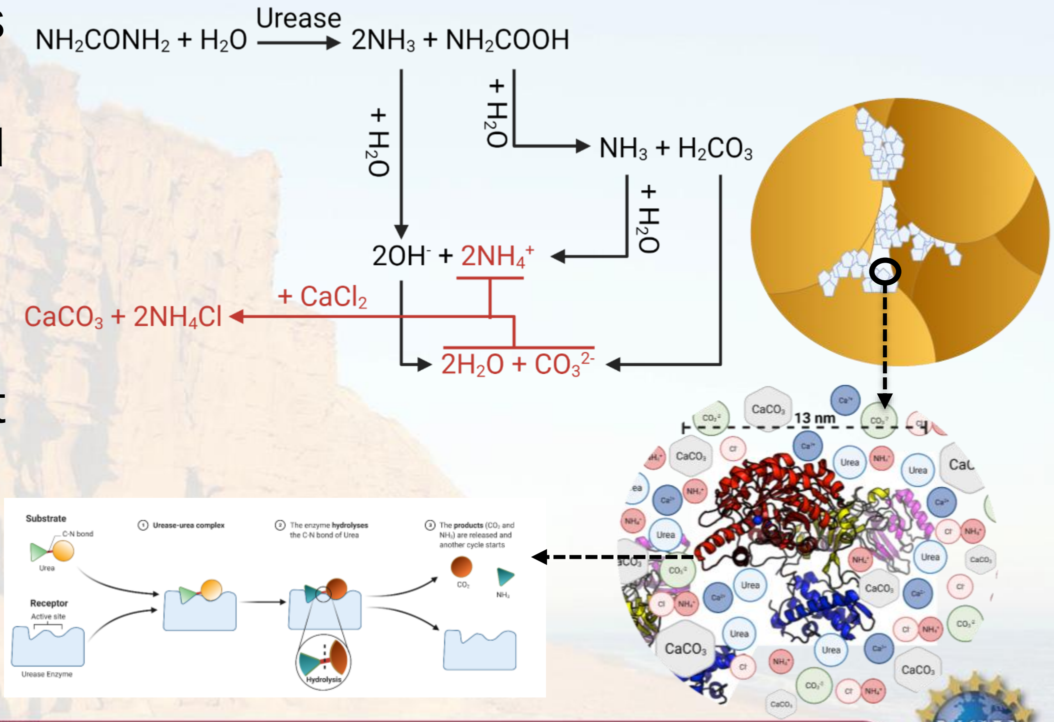
Carbonate Precipitation Mechanisms: Urea Hydrolysis

Source of urease enzyme:

- Urease producing microbes (MICP)
- Free urease enzyme extracted from plants or microbes (EICP)

Ammonium chloride by-product

- Toxic to soil and groundwater at high concentration
- Needs to be managed
  - Extracted and recycled
  - Converted in-situ



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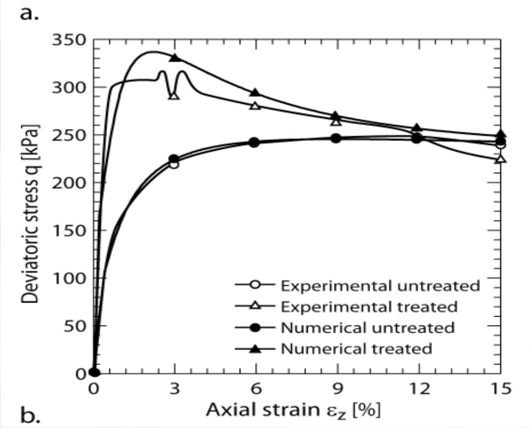
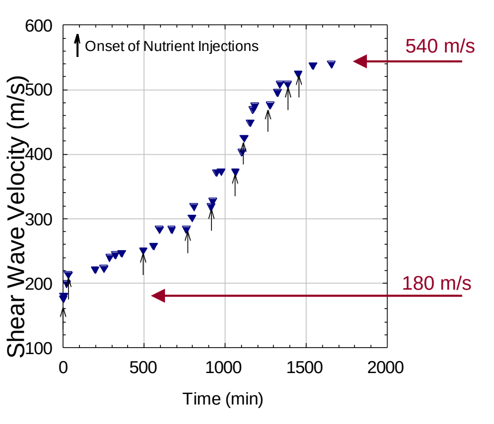
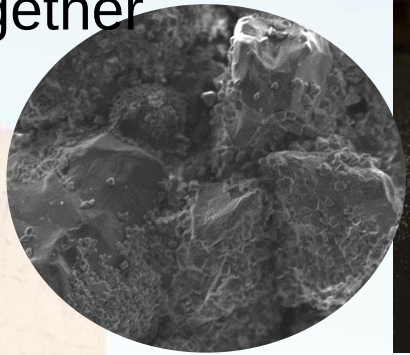
Soil Improvement through Biocementation

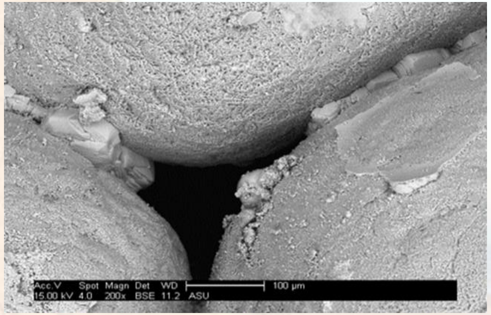
Precipitation of calcium carbonate in soil pores

- Binds (cements) soil particles together (called biocementation)
- Improves strength and stiffness







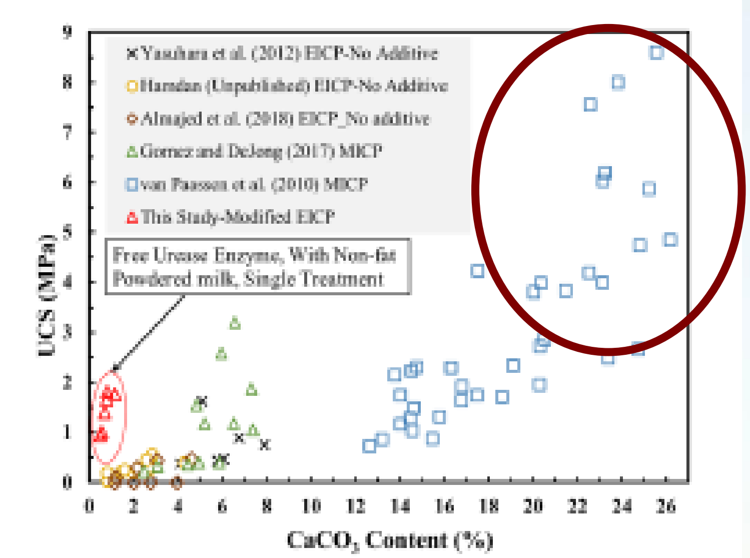


Graphics courtesy of Jason DeJong, UC Davis

MICP via Urea Hydrolysis

Highest reported strength gain

- Up to 1500 psi with multiple treatment cycles



Challenges:

- Microbial culture and activity
- Treatment uniformity: penetration of bacteria is limited to soils with pore size bigger than bacterial cells

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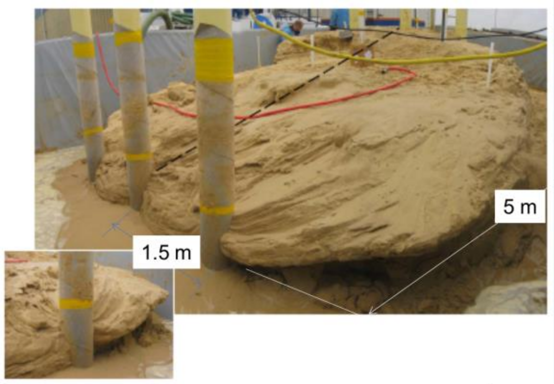
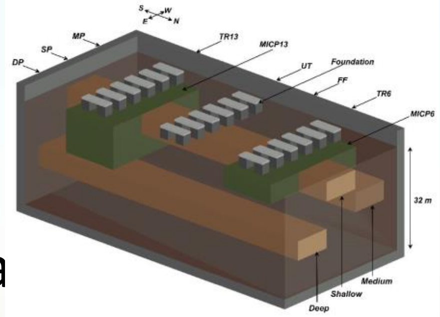
Application: MICP for Mass Stabilization

- Large tank tests at TU Delft .
- Stabilization of degraded MSE backfill by Soletanch in Europe
- Field testing by ASU in Toronto
- Centrifuge model tests at UC Davis
- ASU field tests pending in British Columbia
  - Stabilization of Fraser River embankment founda





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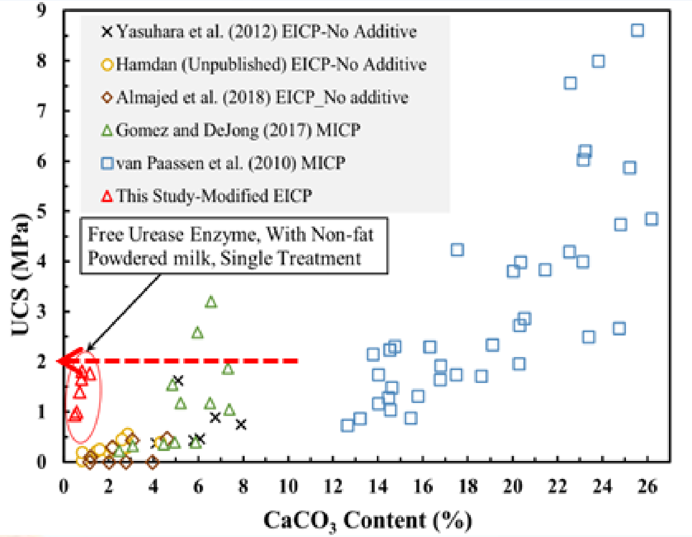
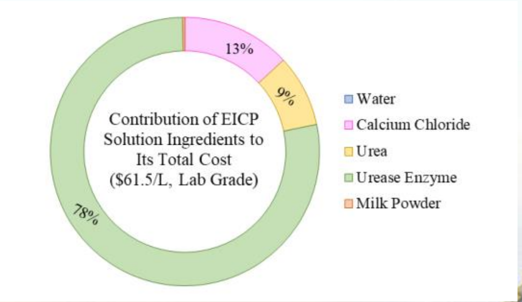
EICP via Urea Hydrolysis

- No bacteria involved
- Penetrates finer-grained soils (e.g., silt)
- High strength at low $CaCO_3$ content

<u>Challenge:</u>

- Cost of urease enzyme
  - Enzymes available in the market are mainly designed for sensitive applications (e.g. medical, food industry,…)
    - Usually highly purified and very expensive





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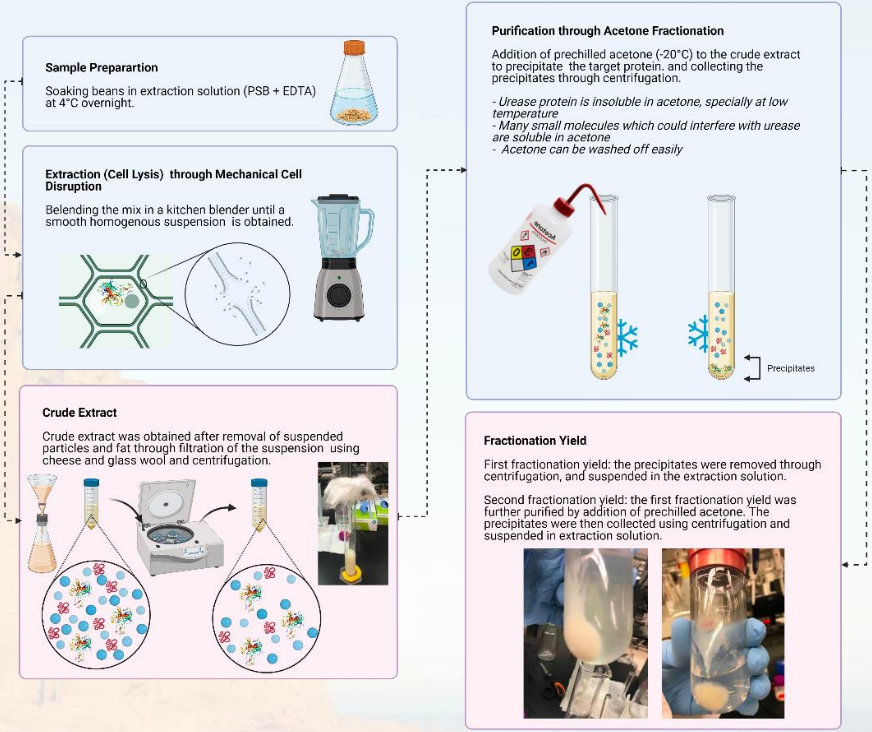
Cost Challenge: Crude Enzyme Extraction

Four urease-rich plant were investigated:

- Jack bean (dehusked), jack bean meal, soybean, watermelon seed (dehusked)

No advanced/costly extraction and purification techniques



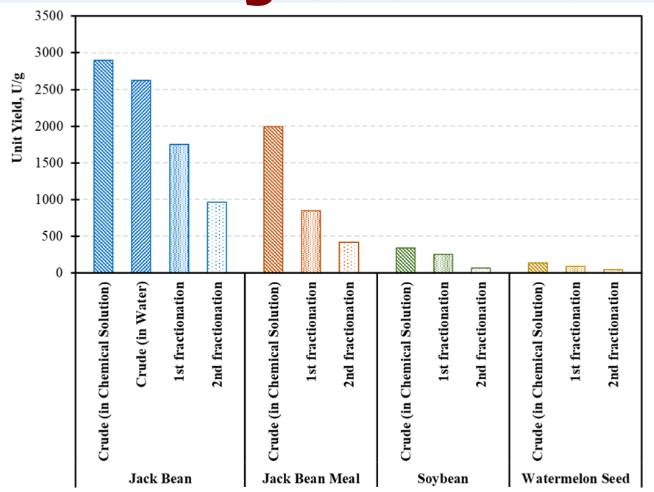



Cost Challenge: Crude Enzyme Extraction

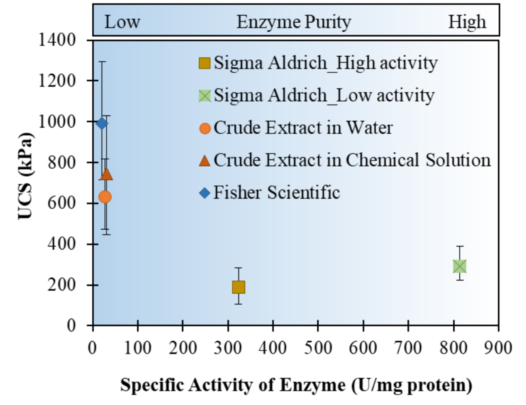
Extracts from jack beans showed the highest:

- urease content
- Highest unit yield

  (amount of enzyme per initial mass of bean)



Crude jack beans extract resulted in a comparable (and some cases a better) strength than commercial enzymes



Cost Challenge: Crude Enzyme Extraction

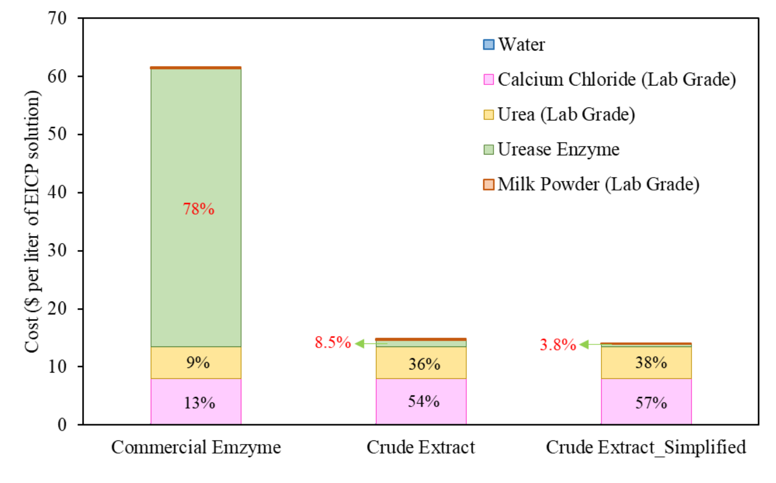
A significant reduction in cost.

A simple extraction process that can be conducted in the field.

Commercial urease in EICP solution was replaced with crude jack bean extract.

Enabled performing meso-scale experiments:

- Biocemented columns
- Fugitive dust control



Biocemented Columns via EICP

Concept: Create columns of cemented sand for ground improvement

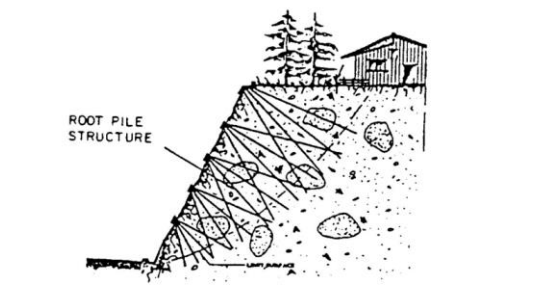
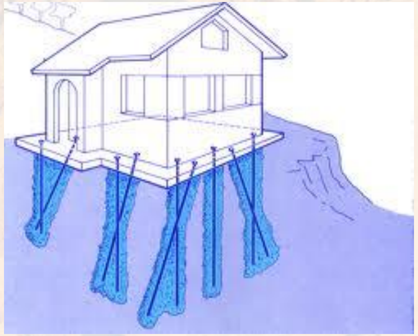
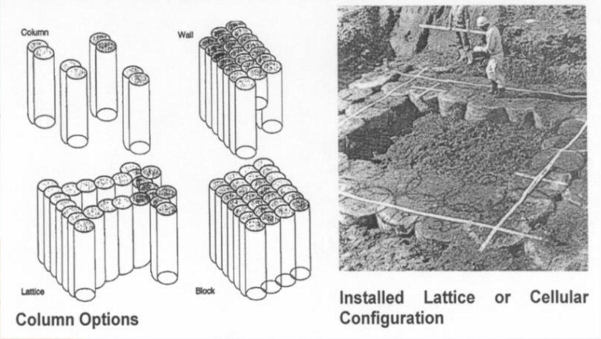
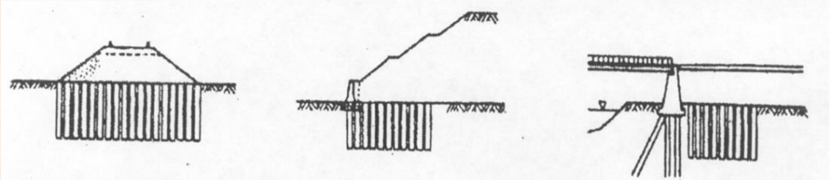


Figure 5-5 Landslide stabilization. (From Mitchell and Villet, 1987.)







FHWA Report no. FHWA-NHI-11-032

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Biocemented Columns via EICP

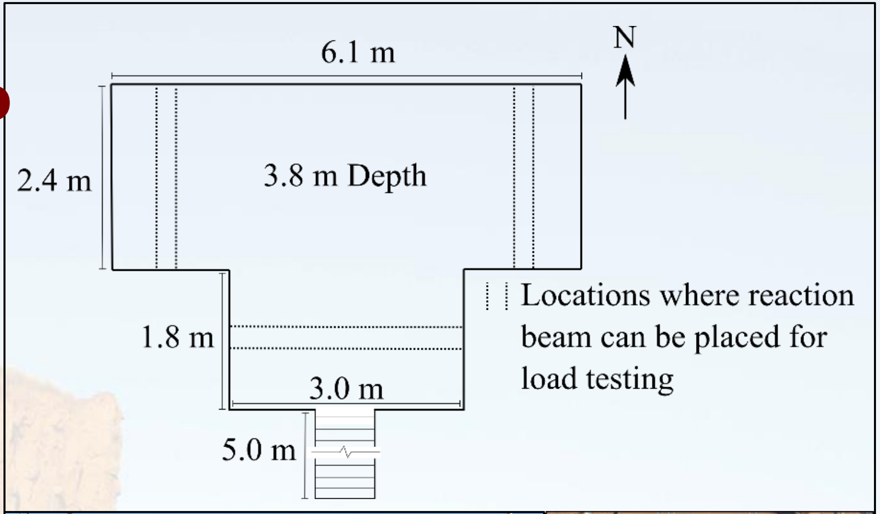
ASU Poly Campus test pit

Seven field-scale columns

- 1 – 3 ft diameter

Conventional grouting approach

Enzyme extracted on site



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Biocemented Columns via EICP: Exhumation

EICP for Fugitive Dust Control

Worldwide air quality problem
- Due primarily to wind-blown soil
  - Not industrial emissions

Plagues many arid/semi arid areas
- Southwest US
- Eastern China
- North Africa

Causes serious health problems

EICP for Fugitive Dust Control

<u>Traditional Dust Control</u>

Water
- Short-lived
- Limited effectiveness

Salt solutions
- Environmentally unfriendly

Synthetic polymers
- Expensive

EICP for Fugitive Dust Control

Concept: Create a wind-erosion resistant carbonate crust using a sprayed-on EICP solution

Advantages:

- “One and done” (but for how long?)

Disadvantages

- Initial cost
- Potential environmental impact

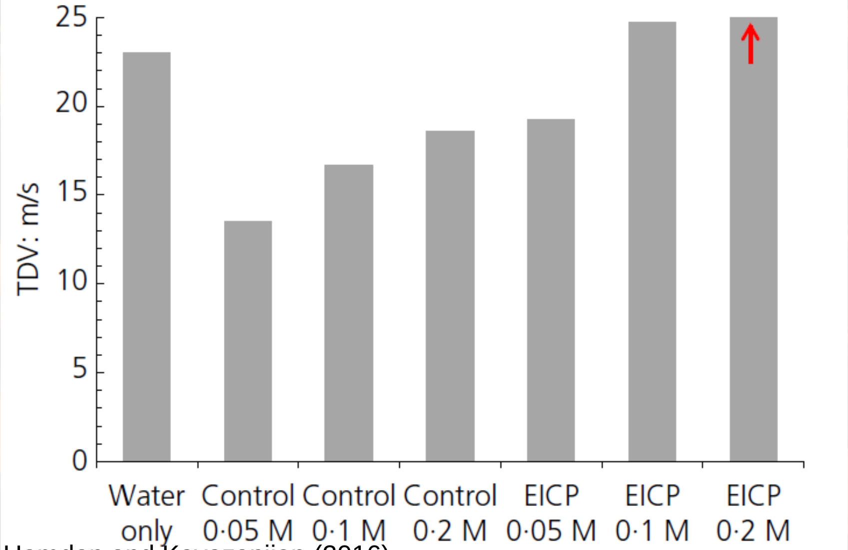
EICP for Fugitive Dust Control: Lab Results

9" pan test

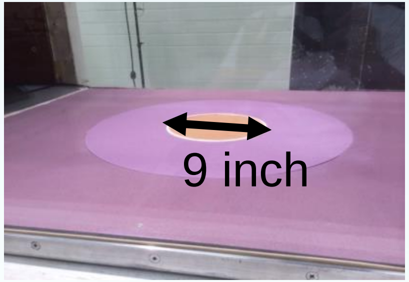
ASU/NASA Planetary Wind Tunnel Testing

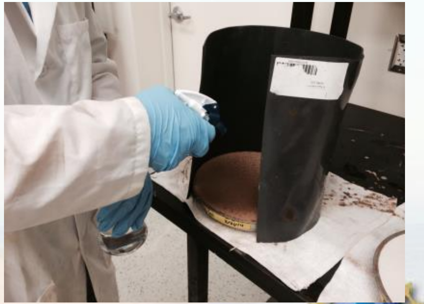
EICP-treated pan maxed out the capacity of the wind tunnel.

F-60 Ottawa Silica Sand: mean grain size 0.18 mm , Cu = 1.7

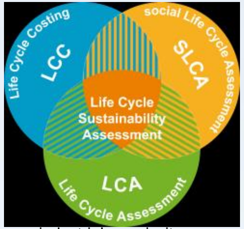


Hamdan and Kavazanjian (2016)





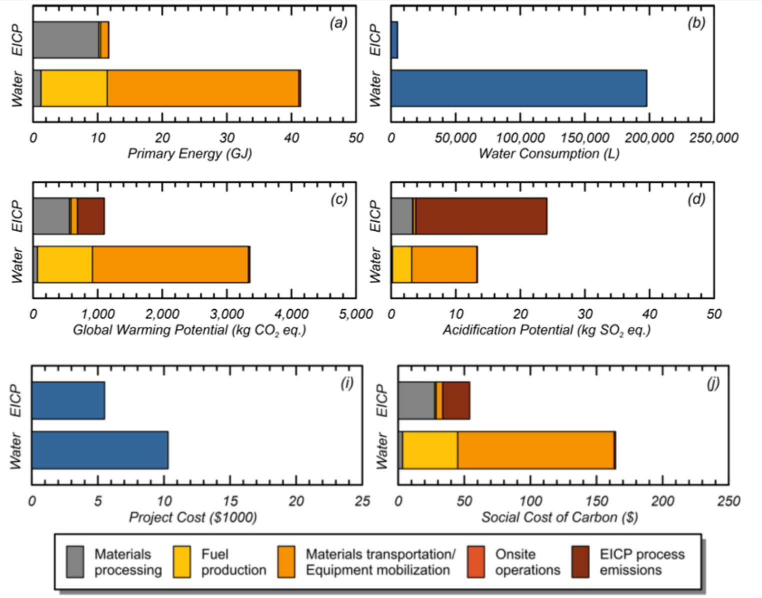
EICP for Fugitive Dust Control: LCSA



industrialece.wixsite.com

Compare EICP and water for dust control using Life Cycle Sustainability Assessment (LCSA)

- Cost
- Permanence/reversibility
  - Reversibility may be beneficial
- Energy consumption
- Environmental impacts



EICP for Fugitive Dust Control: Test Sections

Maricopa County landfills
- w/ SLR, FMI, Republic
- Spray on EICP solution
- First trial 2021 (refined techniques)
- Second trial 2022

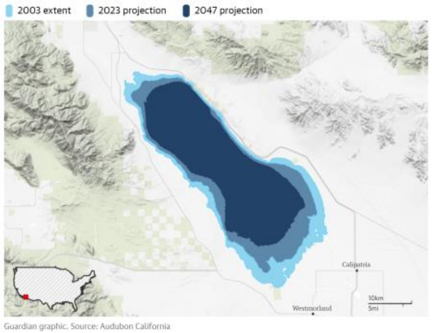

Deployment of first trial plot

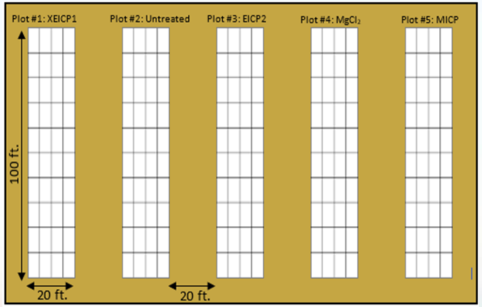

Dust Generation

Salton Sea
- w/Bureau of Reclamation

Fallow agricultural land
- Board of Regents TRIF funds

Abandoned mine site
- ADEQ





Layout of plots for second field trial

Other Biogeotechnical Applications

Tunnel and excavation stability

Contaminated soil and groundwater remediation

Subsurface barriers for contaminant

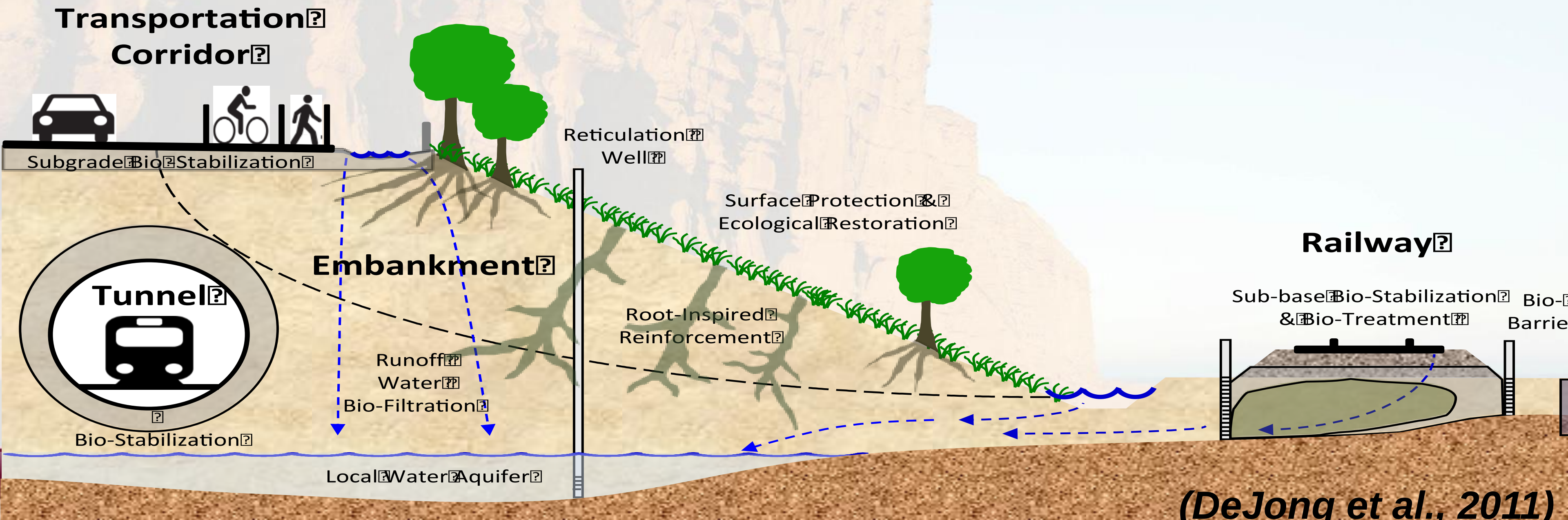
Root-inspired foundations and reinforcement

Self-motile probes and sensors

Bio-leaching metals (e.g., copper)

The Biogeotechnical Future

- Just beginning to explore opportunities
- Only a few to date, **opportunities for much more**



(DeJong et al., 2011)

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Thank you!

Questions?