Microbiological Improvement of the Physical Properties of Soil

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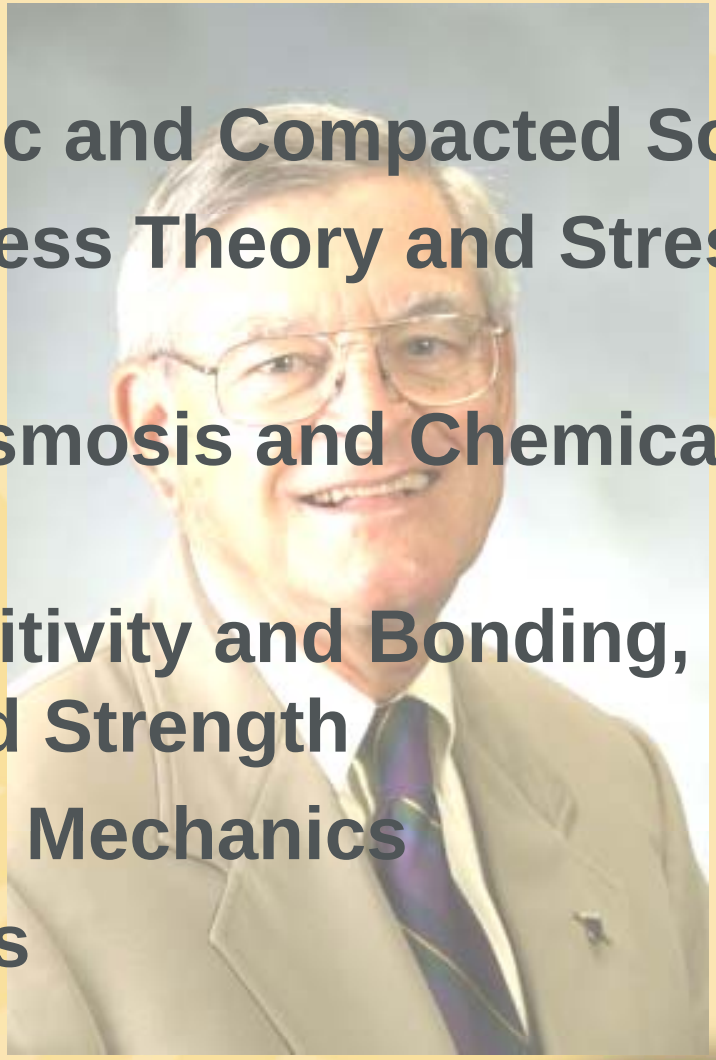
CONTRIBUTIONS OF JAMES K. MITCHELL (1)



- Clay Fabric and Compacted Soil Properties
- Rate Process Theory and Stress-Strain-Time Behavior
- Electro-Osmosis and Chemical Osmotic Effects
- Clay Sensitivity and Bonding, Effective Stress and Strength
- Lunar Soil Mechanics
- Waste Fills

CONTRIBUTIONS OF JAMES K. MITCHELL (2)

- Soil Liquefaction
- Stone Column Performance
- Aging in Clay and Sands
- CPT Interpretation
- Reinforced Soil Systems
- Soil Improvement by Blasting
- Seismic Risk Mitigation

CONTRIBUTIONS OF JAMES K. MITCHELL (3)

- **BioGeotechnical Engineering**

Biological Considerations in Geotechnical Engineering

James K. Mitchell, Hon.M.ASCE,[1] and J. Carlos Santamarina, M.ASCE[2]

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BioGeotechnical Improvement Processes that Operate on a Geological Time Scale

- Cementation of Granular Soils
  - Carbonate Cementation
  - Transformation of Sand to Sandstone
- Mineral Transformations
  - Smectite to Illite at High Temperature and Pressure
- Formation of the Desert “Varnish” (Crust)

BioGeotechnical Processes that Cause Adverse Effects in Engineering Time Frames

- Clogging of Drainage Systems in Dams, Landfills, and Waste Dumps
- Clogging of Water Treatment Plant Filters
- Fouling of Well Screens
- Formation of Mineral Scale on Pipes

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

BioGeotechnical Improvement Processes and Applications

- Mineral Precipitation
  - Bearing Capacity, Settlement Control, Liquefaction Mitigation, Excavation Stability, Tunneling, *Carbon Sequestration(?)*
- Mineral Transformation
  - Soil Expansion Potential, Slope Stability
- Biopolymer and Biofilm Growth
  - Seepage Control, Subsurface Barriers, Corrosion, Erosion Control

Application of Microbiological Mineral Precipitation Processes to Engineering

- Advantages
  - Non-destructive, Non-Disruptive
  - Sustainable
  - Cost Effective
- Challenges
  - Understanding the Complex Processes

    Geo….., Chem……, Micro…., Hydro….
  - May Need to Develop Site Specific Approaches

Precipitation Mechanisms

- Carbonate Precipitation
  - Hydrolysis of urea
  - Oxidation of organic compounds by sulfate-reducing bacteria
  - Oxidation of organic compounds by denitrifying bacteria
  - Oxidation of organic compounds consisting of carbon and nitrogen in a well-buffered media
  - Oxidation of nitrogen-rich organic compounds in unbuffered media
  - Microbial fermentation of volatile fatty acids
  - Removal of CO_2 from bicarbonate-containing solutions

ASU Denitrification Experiments

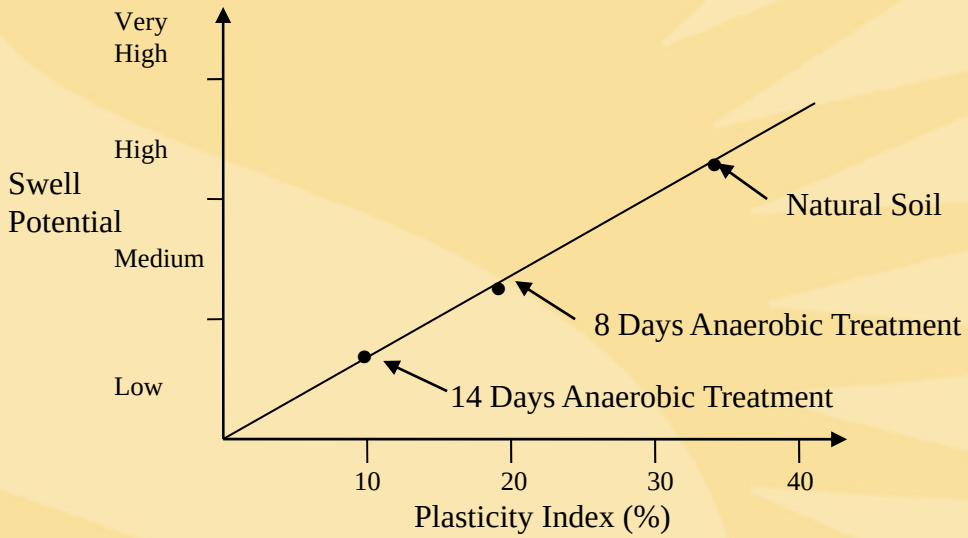
- First-stage experiments (complete)
  - Proof of Concept and Basis for Biogeochemical Models for Optimization Studies
  - *Pseudomonas denitrificans* (ATCC 13867)
  - 150 ml and 2.0 L Batch Reactors with Liquid Media
  - Periodic Sampling to Monitor pH, alkalinity, [NO_3^-], [NO_2^-], [Ca^{2+}], and Headspace Gas Composition (O_2 and CO_2)
  - Studies on Effect of Electron Donor Type, Nutrient Limitations, Salt concentration.

ASU Denitrification Experiments

- Second-stage experiments (in progress)
  - Soil Column Experiments with ASTM 20/30 Ottawa sand
  - Steady-state Flow through Sand Column
  - Periodic Sampling to Monitor pH, alkalinity, [NO_3^-], [NO_2^-], and [Ca^{2+}]
  - Continuous Monitoring of Shear Wave Velocity using Bender Elements

Mineral Transformation

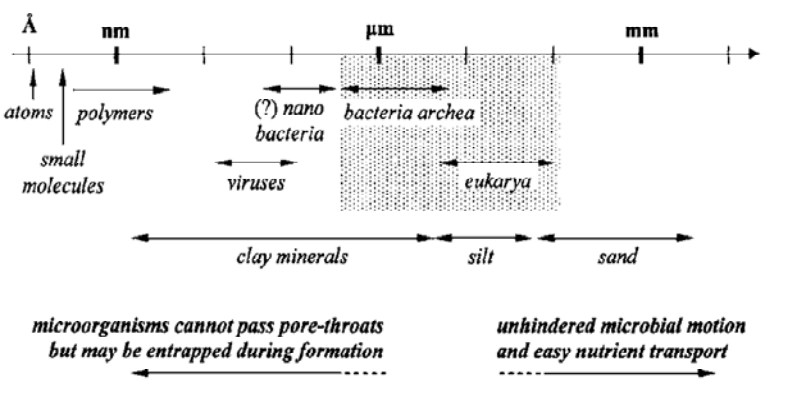
- Smectite (Montmorillonite) to Illite (Kim et al., 2004)
  - May Just be Reduction of Fe^{3+} to Fe^{2+} in Iron-Rich Clays (e.g. Nontronite)



Effect of ex-situ treatment with *Shewanella oneidensis* on swelling clay (Fowler, 2008)

In situ Improvement by Mineral Transformation

- Potential Pore Size Constraints



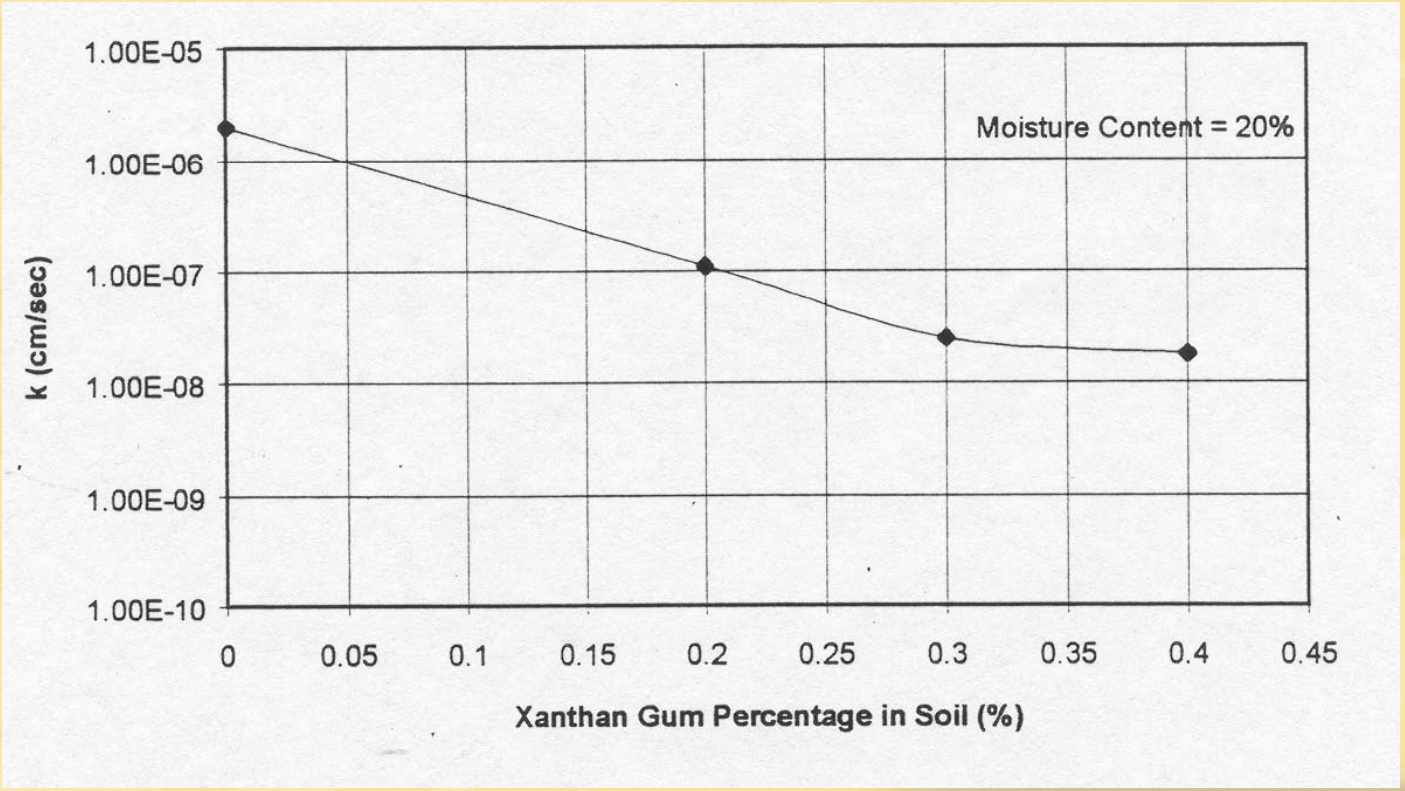
Comparative sizes of microorganisms and soil particles (Mitchell and Santamarina, 2005)

Considerations:

- Pore Size at the Wetting Front in Expansive Clays
- Use of Starved Bacteria and Nano Bacteria

Biopolymer Improvement

- Permeability Reduction – Bonnie Silt Compacted with Xanthan Gum (Karimi et al., 1998)



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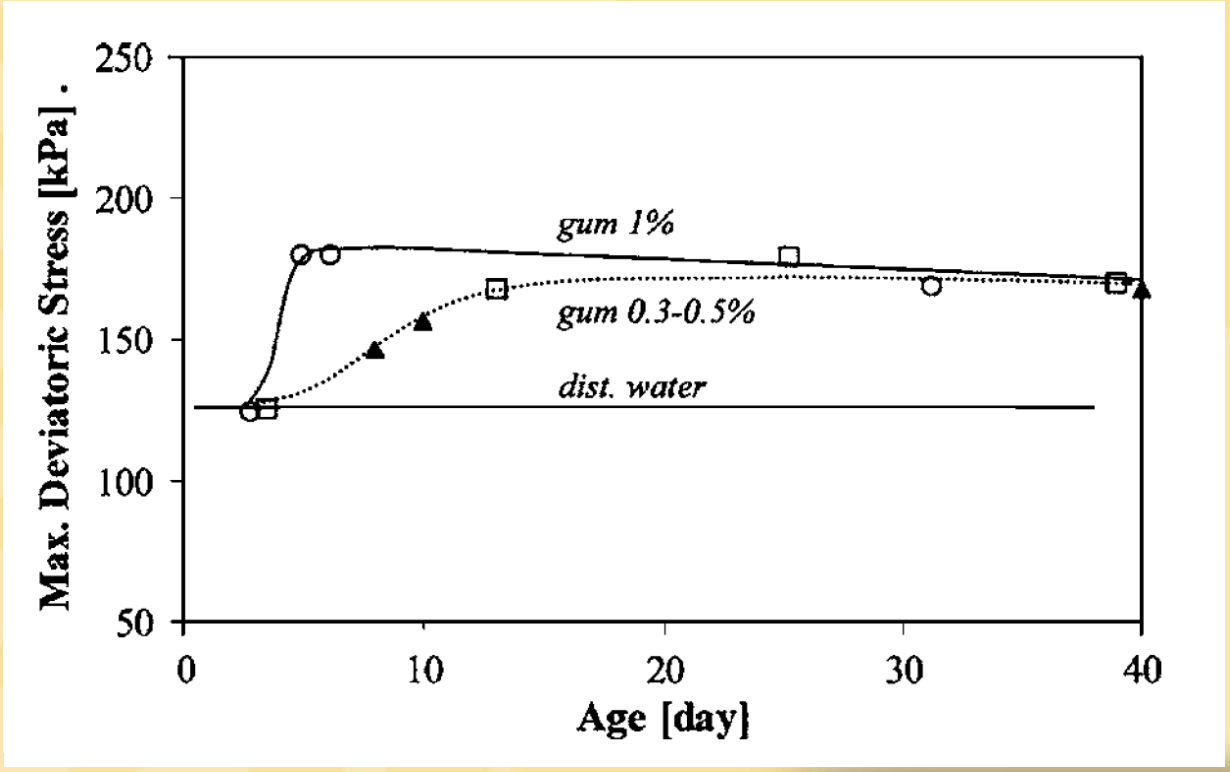
Biopolymer Improvement

- Martin et al. (1996): Bonnie Silt Compacted with Xanthan Gum in Triaxial Compression



Biopolymer Improvement

- Corrosion Protection
  - Significant increase in corrosion of steel and aluminum when protective biofilm was suppressed (Ruo et al., 2004)
- Erosion Control
  - Desert crusts develop due to photosynthetic biopolymer growth (Garcia-Pichel, 2002)

Important Issues to Consider

- Permanence/Reversability of Microbial Processes
  - Reversability may be Beneficial
- Stimulating Microbes In Situ vs. Introducing Microbes to the Environment
- The Need to Add Nutrients and Source Minerals
- Delivery of Necessary Microbes and Nutrients
- Energy Consumption
- Environmental Impacts / Unanticipated Side Effects
- Public Acceptance

Conclusions

- Many Potential Applications of BioGeotechnical Processes for Soil Improvement
- Much Work to be Done to Realize this Potential

THANK YOU

- To the Audience
  – for Your Attention

- To Jim Mitchell
  - for Being Jim