# Innovative Remediation for Hydrocarbon- and NaCl-Impacted Sites

*Leveraging synergistic mineral-microbial interactions to develop innovative hybrid bioremediation and desalination technology for soils and groundwater impacted by petroleum hydrocarbons and salt (NaCl)*

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# HYBRID REMEDIATION PROJECT

## Goal

Develop innovative remediation strategies to remove **both petroleum hydrocarbons *and* NaCl** from contaminated soils and groundwater

- Hydrocarbon biodegradation under highly saline conditions is challenging.
- Removal of both hydrocarbons (organic) *and* NaCl (inorganic) is challenging.

# WHY IS IT SO CHALLENGING?

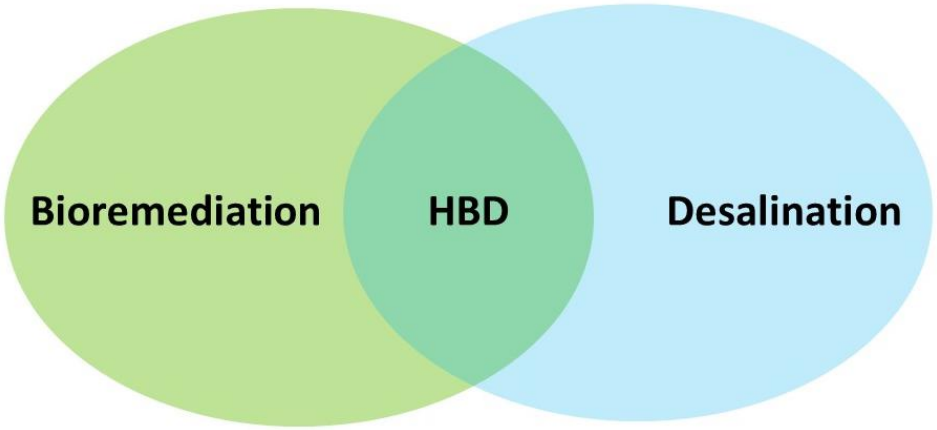
- High NaCl abundance in soil and groundwater inhibits microbial activity and intrinsic hydrocarbon biodegradation (natural attenuation).
- Presence of NaCl in soil pores decreases the aqueous solubility of hydrocarbons, decreasing their bioavailability and therefore bioremediation efficiency.
- High NaCl abundance deteriorates soil structure, flocculating the soils (e.g., sodic and saline soils).

# WHY IS IT SO CHALLENGING?

- NaCl (or other salts) is broadly dispersed or continuously accumulated.
- Conventional desalination technologies are generally cost prohibitive for soil and groundwater remediation, BUT the impacts of salinity and sodicity deteriorate soil health and plant growth, potentially prolonging natural attenuation for hydrocarbon biodegradation in surrounding areas.
- Impacts of hydrocarbons and salinity often independently vary over time.

*Integrated and passive, hybrid bioremediation and desalination adapted to soil and groundwater remediation are lacking.*

# APPROACH




***Leverage and maximize the natural ways:***

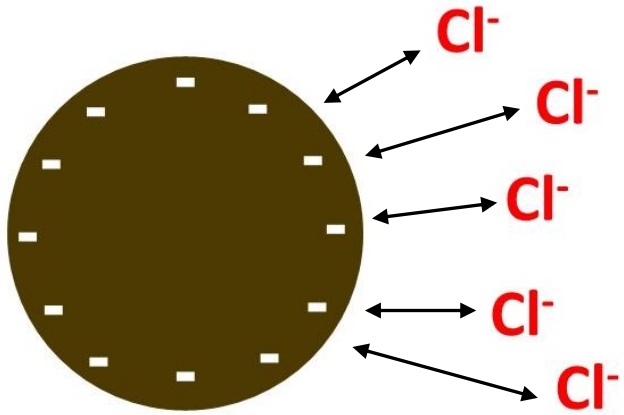
- **Halotolerant hydrocarbon biodegradation**
  - Stimulating indigenous halotolerant hydrocarbon-degrading bacteria is feasible.
  - Active halotolerant hydrocarbon degraders in the presence *and* absence of NaCl.
  - Cold-tolerant bacteria in cold environments often exhibit halotolerance.

- **Natural mineral reaction for salinity mitigation**
  - Anion-fixing minerals with positive charges are rare; however, they exists in nature.
  - Cation-exchange minerals (e.g., zeolite) are abundant in nature.
  - Dual-minerals for $Na^+$ and $Cl^-$ removal have been tested for NaCl removal from potash brine-impacted groundwater.

# R&D PROJECT COMPONENTS: HYBRID REMEDIATION


- ✓ Minerals for desalination and salinity mitigation
- ✓ Halotolerant hydrocarbon-degrading bacteria

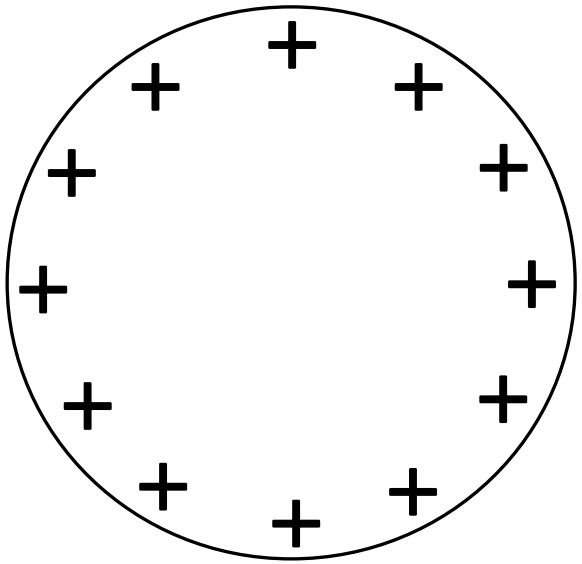
# CHLORIDE




Natural clays

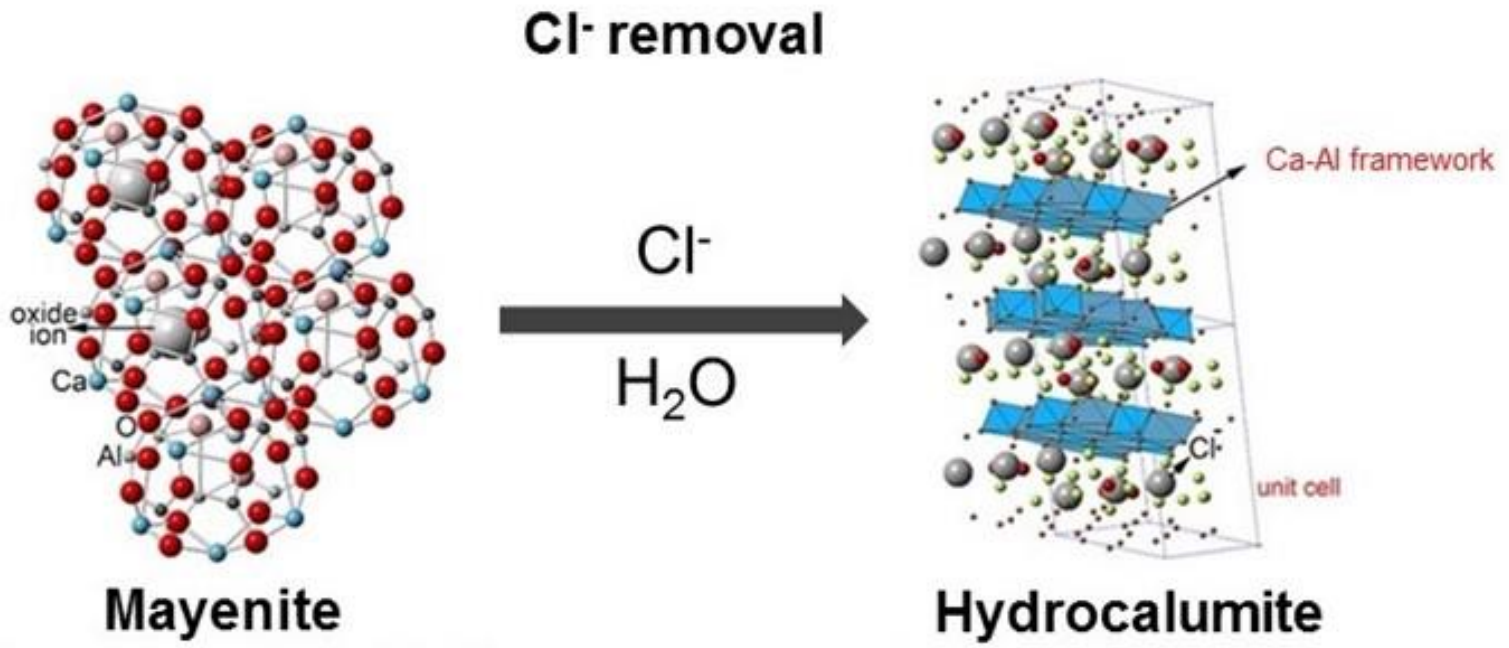
- $Cl^-$ is a salinity- and corrosion-causing ion
- Natural clays are negatively charged
- $Cl^-$ is not sorbed or immobilized
- $Cl^-$ is conservative in soils and groundwater

# MAYENITE COMPOSITE



- Positively charged minerals
- Leverage natural mineral phase change
- Comparable with commercial anion exchangers
- Simple synthesis, cost-effective and recyclable
- Porous materials

# MAYENITE COMPOSITE: HOW IT WORKS




*$Cl^-$ is removed from the aqueous phase and trapped in the mineral phase through the mayenite-to-hydrocalumite mineral phase change*

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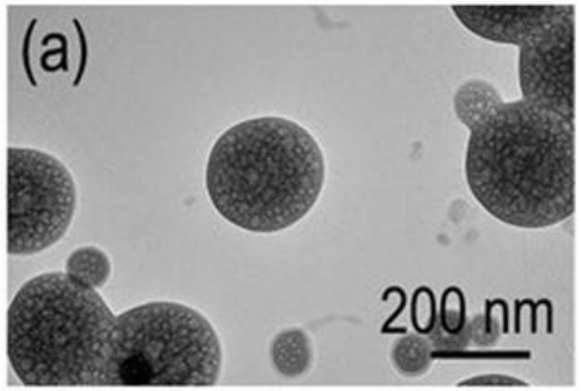
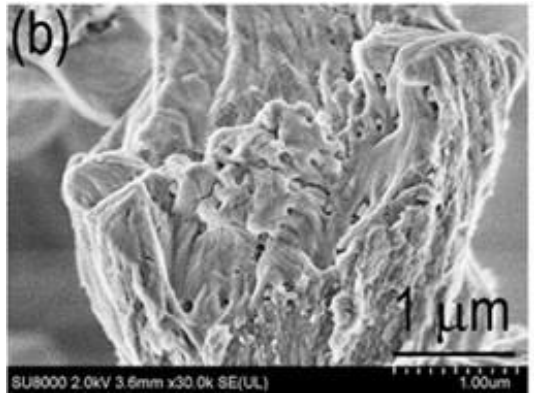
# MINERAL PHASE CHANGE: WHAT DOES IT LOOK LIKE?

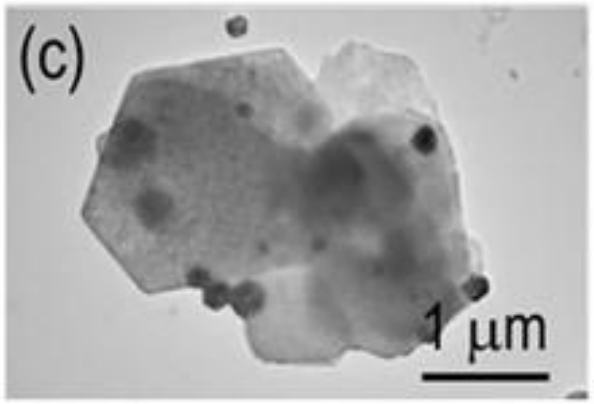
Mayenite composite

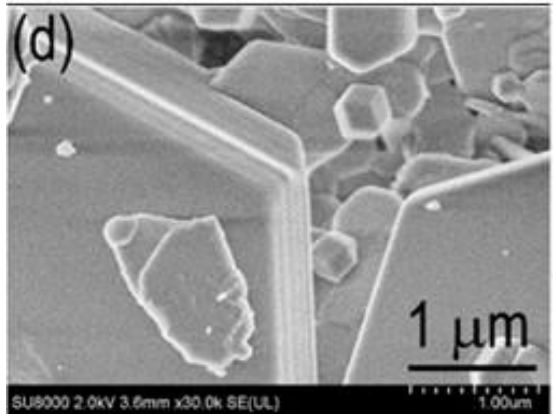



$Cl^-$ removal

Hydrocalumite

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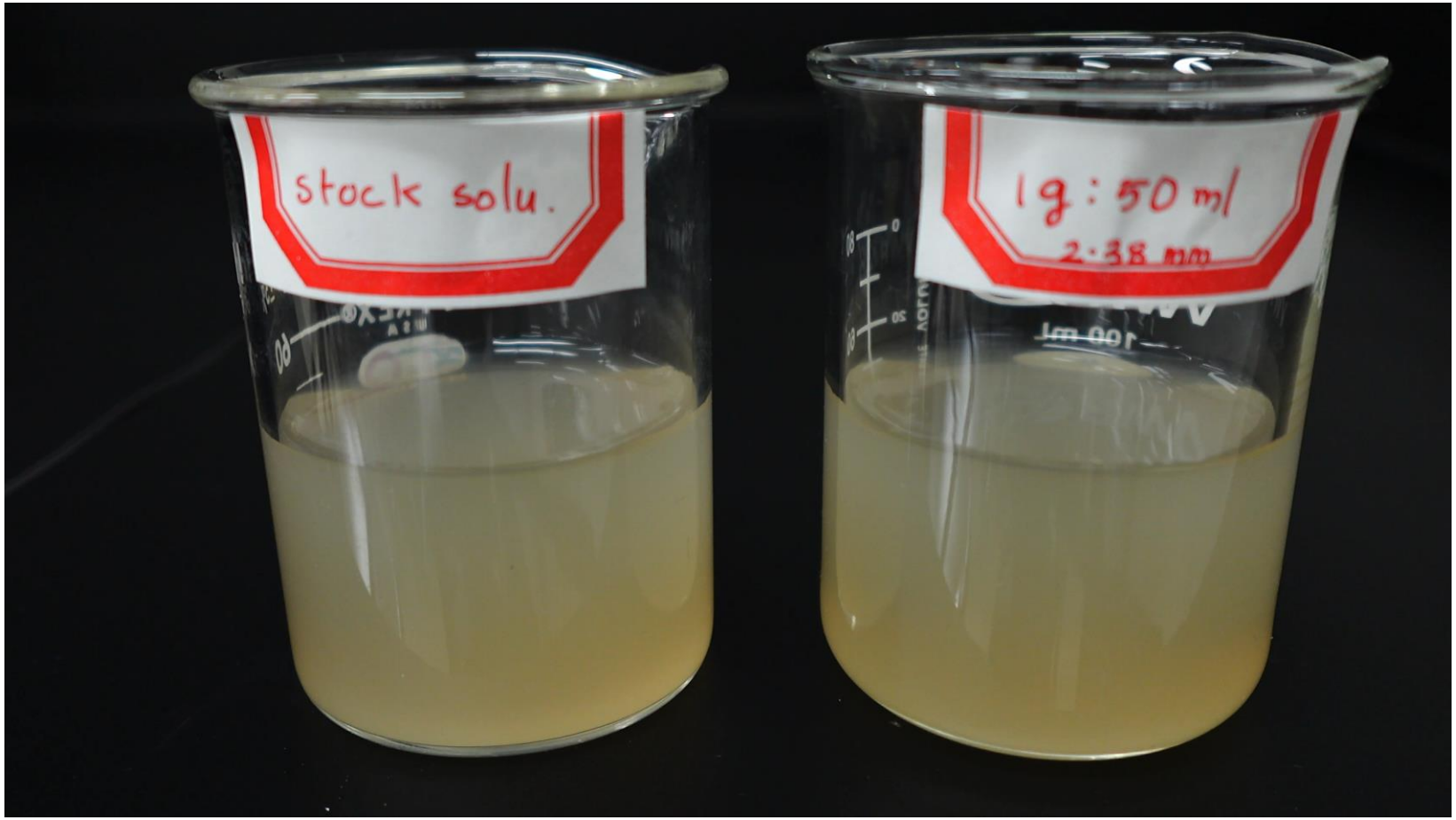
# POSSIBILITY OF PASSIVE TREATMENT (NO MIXING)




Video file

**(In-person presentation only)**

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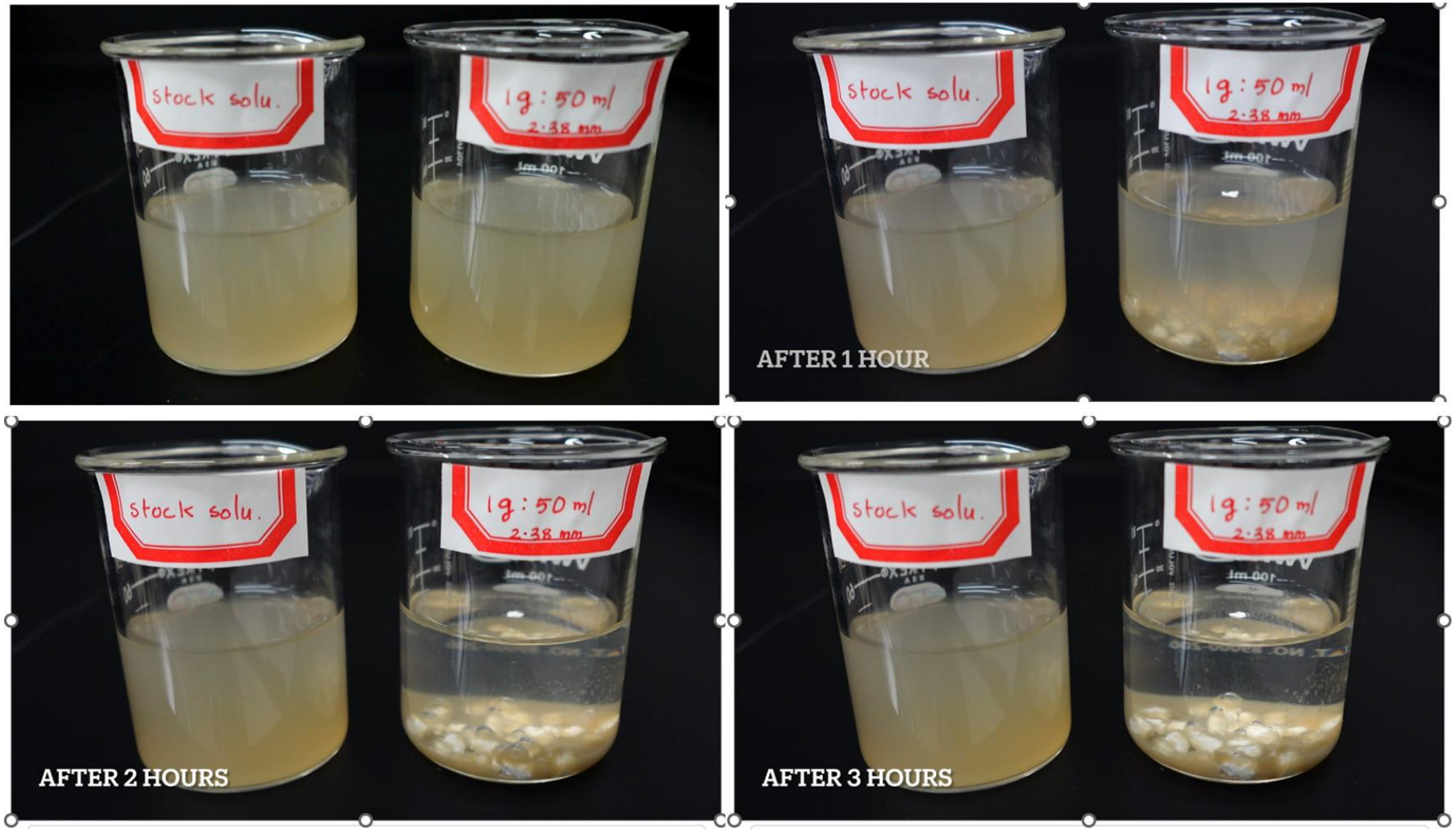
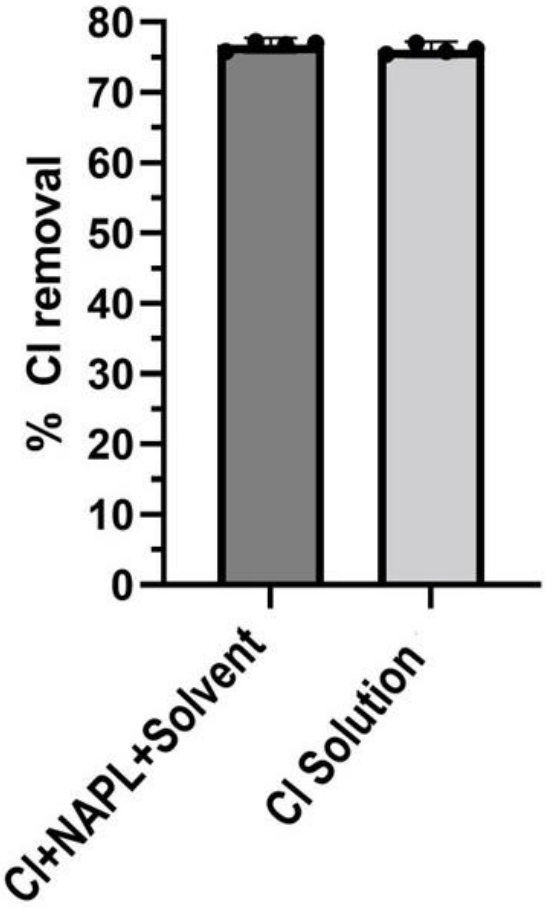


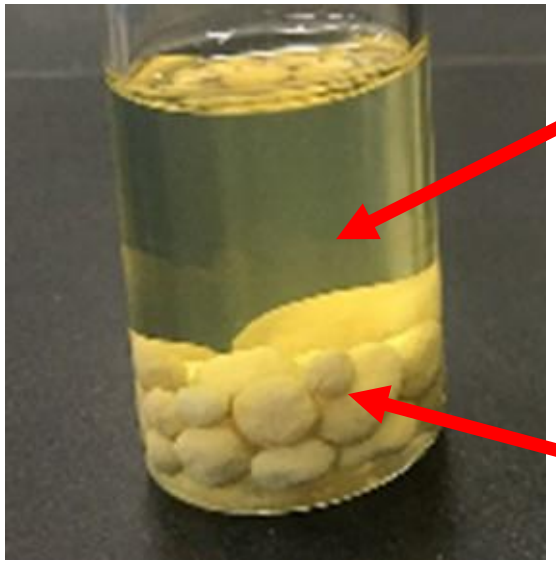
# VERSATILITY OF MAYENITE COMPOSITES

- Chloride removal in presence of hydrocarbons (0-13% reduction)
- Excess oxyanions: sulfate, nitrate, phosphate, etc.
- Remove suspended solids (clays, colloidal particles)
- Improve of water turbidity
- Hydrocarbon removal potential (porous material)



# INTERACTION WITH HYDROCARBONS

## Stability

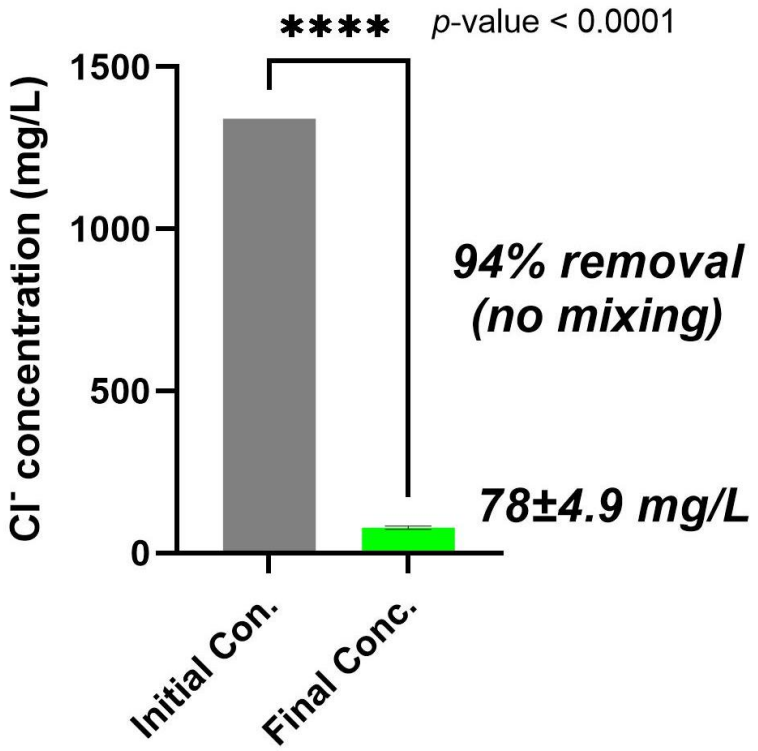


Nonaqueous Phase Liquid (free phase diesel)

Stable Mayenite Composite

NAPL-Mayenite System

## Removal



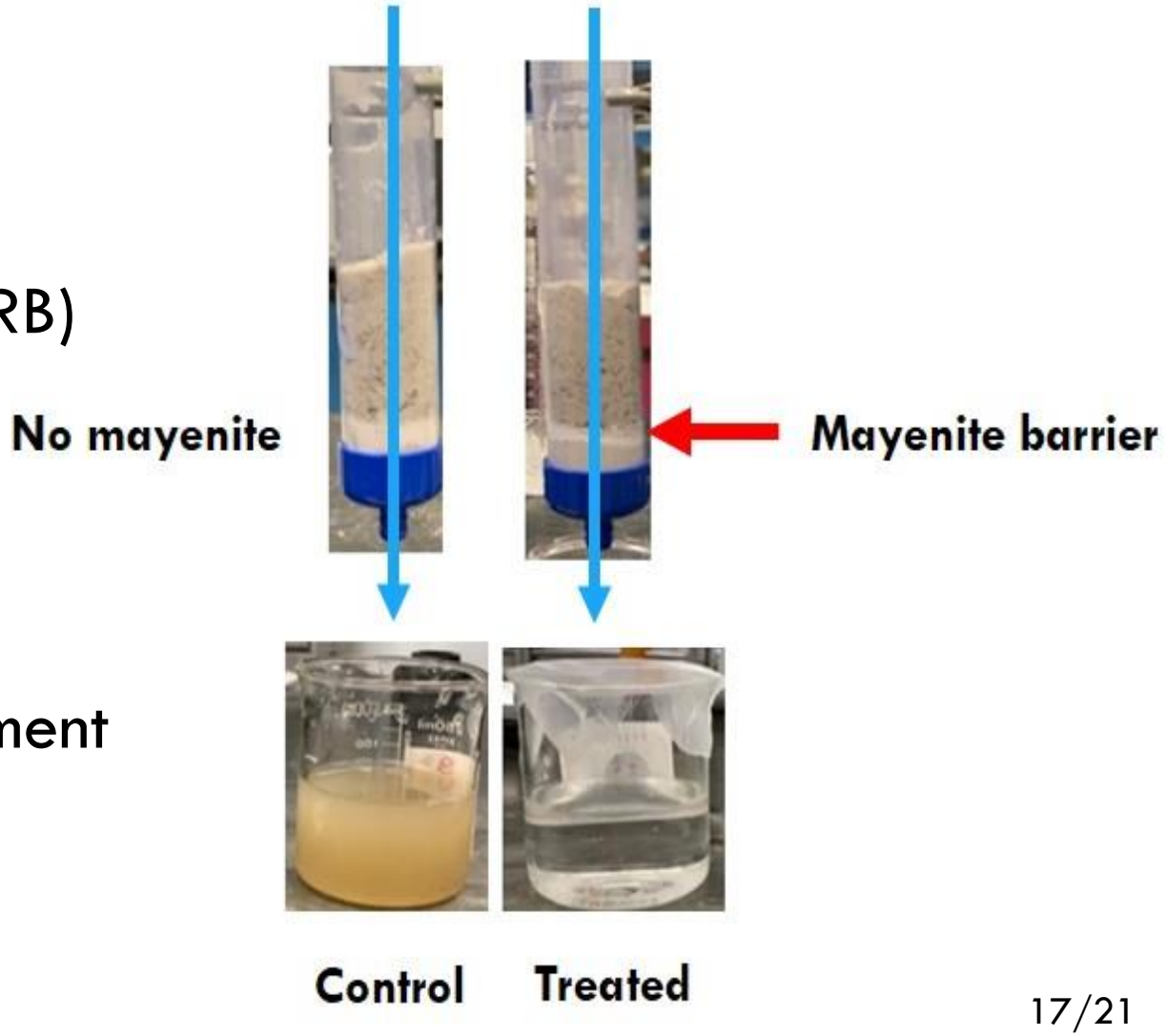

Site groundwater (toluene detected)

# VARIOUS MAYENITE COMPOSITES: CHLORIDE FIXER

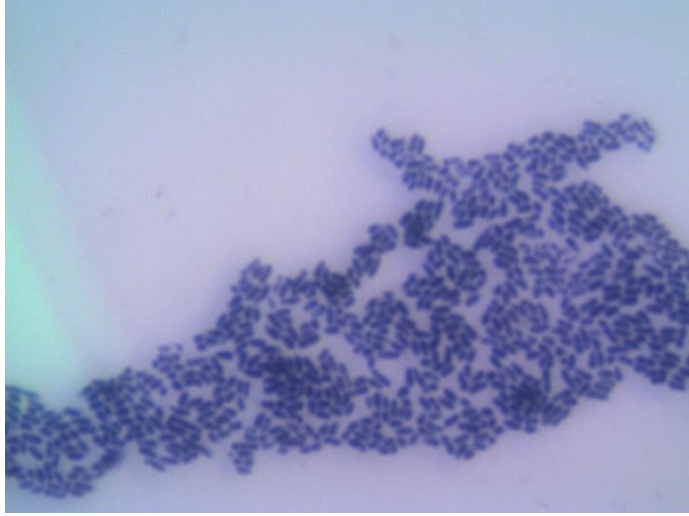
- Mayenite Powder
- Mayenite Tablets
- Mayenite Bricks
- Mayenite Pellets
- Mayenite Slurry
- Mayenite-Clay for $Cl^-$ and $Na^+$

# BARRIER & FILTER MATERIALS

- On-site groundwater treatment
  - Permeable Reactive Barrier (PRB)
  - Leachate control
  - Filtration (plus Biofiltration)
- Oilfield waste/wastewater treatment
- Tailings management



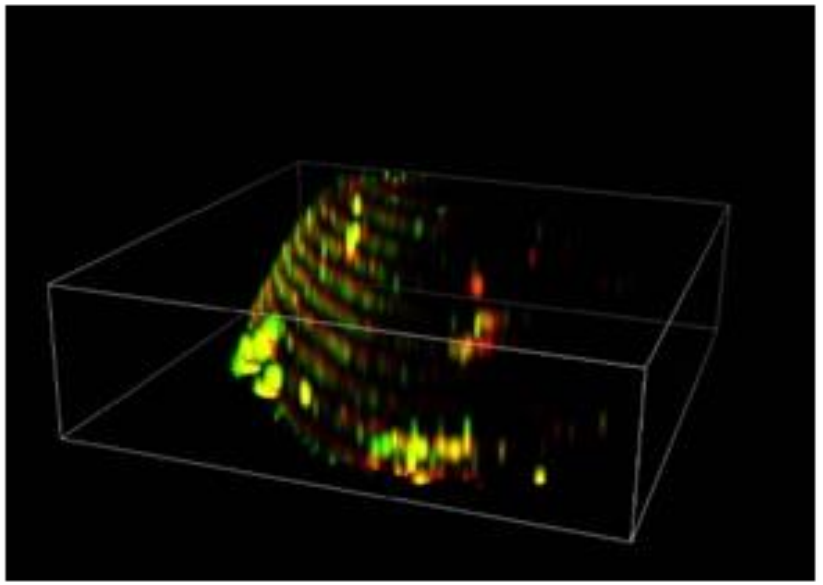
# MINERAL-BACTERIA SYNERGY



- Halotolerant hydrocarbon-degrading microbial cultures from site soil
  - Tentatively called G6 (Generation Six)
  - Key genera: *Devosia*, *Rhodococcus*, *Pseudomonas*
- Growth under various NaCl concentrations (<1, 3 & 5%)
- Tolerant to alkaline conditions (pH 10)
- Powder and liquid forms of G6 cultures available
- Functional genes for alkane and PAH biodegradation detected
- Compatible with mayenite-treated water and soil for $Cl^-$ removal
- Growth on $Na^+$-exchanging clay for $Na^+$ and hydrocarbon removal
- Involved in sodium removal during hydrocarbon biodegradation

# HYDROCARBON-DEGRADING BIOFILM FORMATION

- Halotolerant hydrocarbon-degrading G6 culture biofilms were produced.
- Biofilm formation expands this hybrid remediation for site groundwater (≤1% NaCl).
- PRB-Biobarrier, constructed wetland, on-site groundwater treatment, and oilfield wastewater treatment.



# SUMMARY AND FUTURE WORK

- Various forms of mayenite composites are produced.
- $Cl^-$ removal is feasible for groundwater with mayenite composites.
- Mayenite composites improves suspended solid removal.
- Halotolerant hydrocarbon-degrading microbial consortia (G6) were cultured in the forms of liquid, powder and biofilm on filter media.
- On-site groundwater treatments (e.g., PRB and filtration) are promising options for applying the hybrid remediation strategy.
- Current work: halotolerant biostimulation for soil treatment is feasible during $Cl^-$ and $Na^+$ treatment
- Future work: scale-up productions of HBD agents and field experiments (e.g., soil treatment) for the options will be focused on in future work.

# ACKNOWLEDGEMENT





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