Hydraulic & Chemical Properties of Geosynthetic Clay Liners Exhumed from Dry Covers

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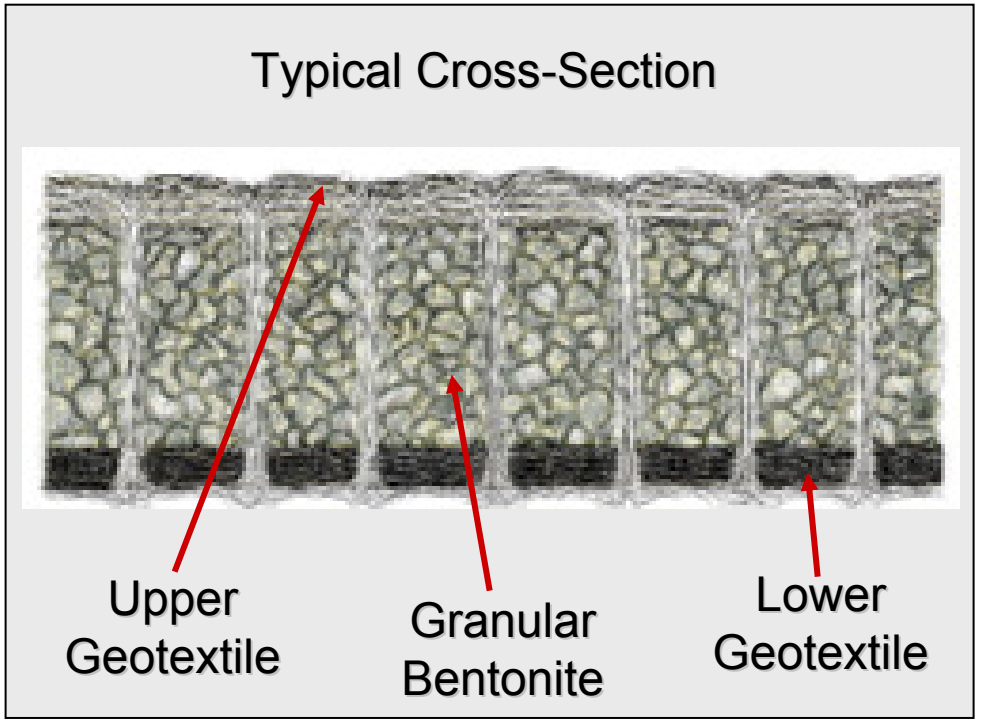
Geosynthetic Clay Liners

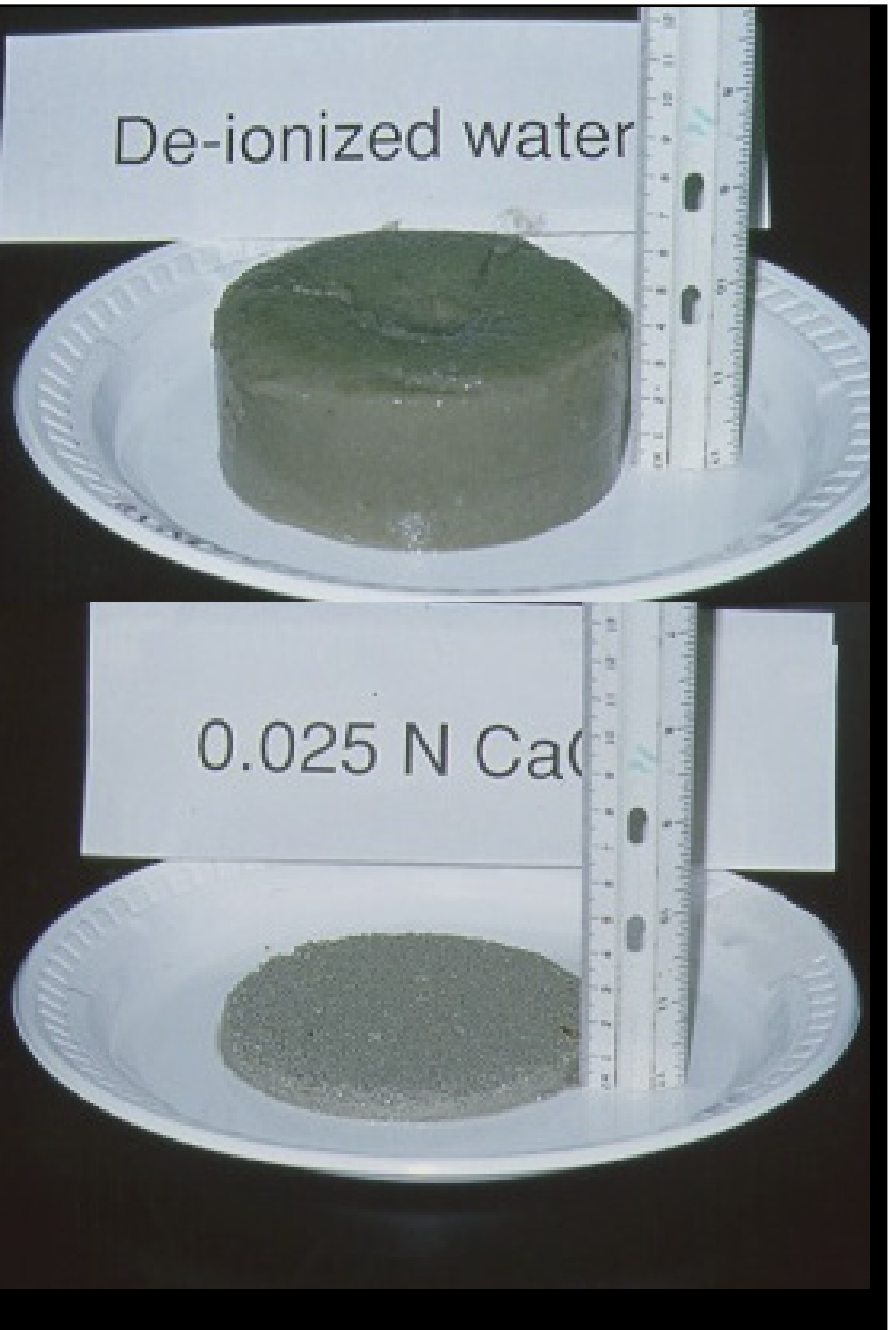
Rapid installation relative to compacted clay barrier

Geosynthetic Clay Liners

- For low hydraulic conductivity, ***Na*** bentonite granules must swell to from a gel (paste).
- Gel must be maintained to retain low hydraulic (~ 10^{-11} m/s) conductivity.
- If granules do not swell and form gel, higher hydraulic conductivity (>10^{-7} m/s).



Importance of Bound Cation Valence

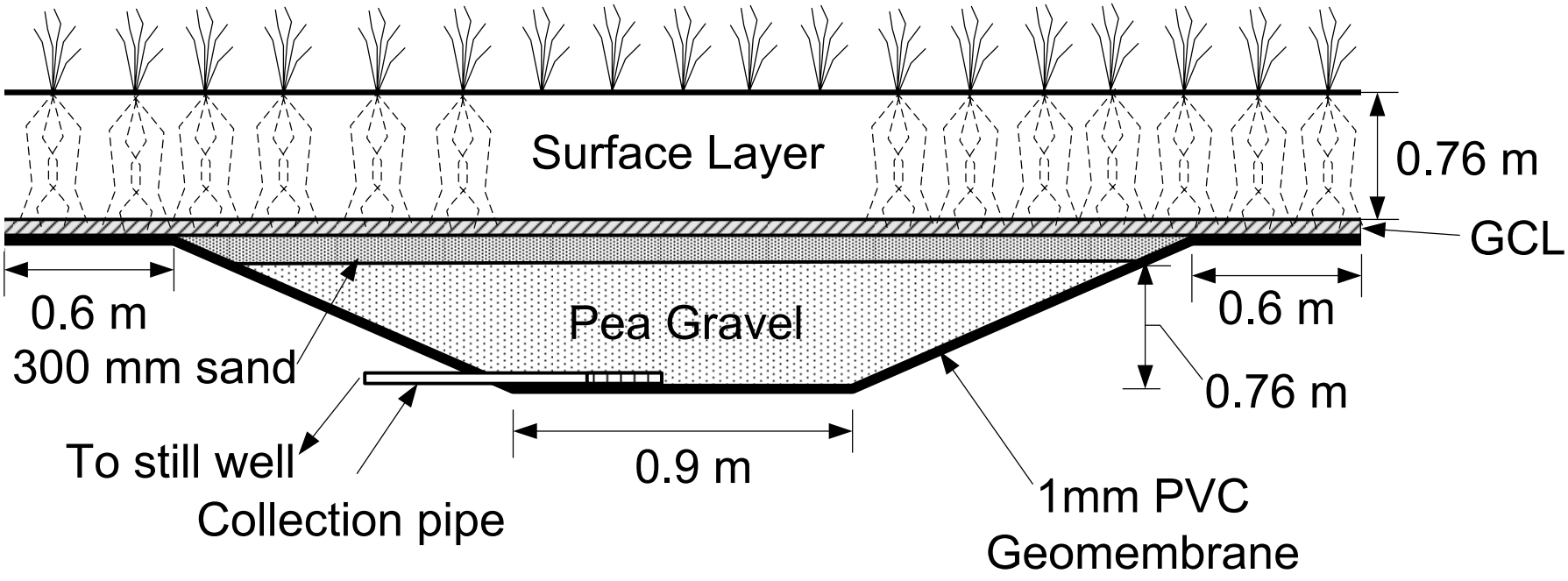


Na-Bentonite in DI Water (monovalent) – crystalline + osmotic hydration

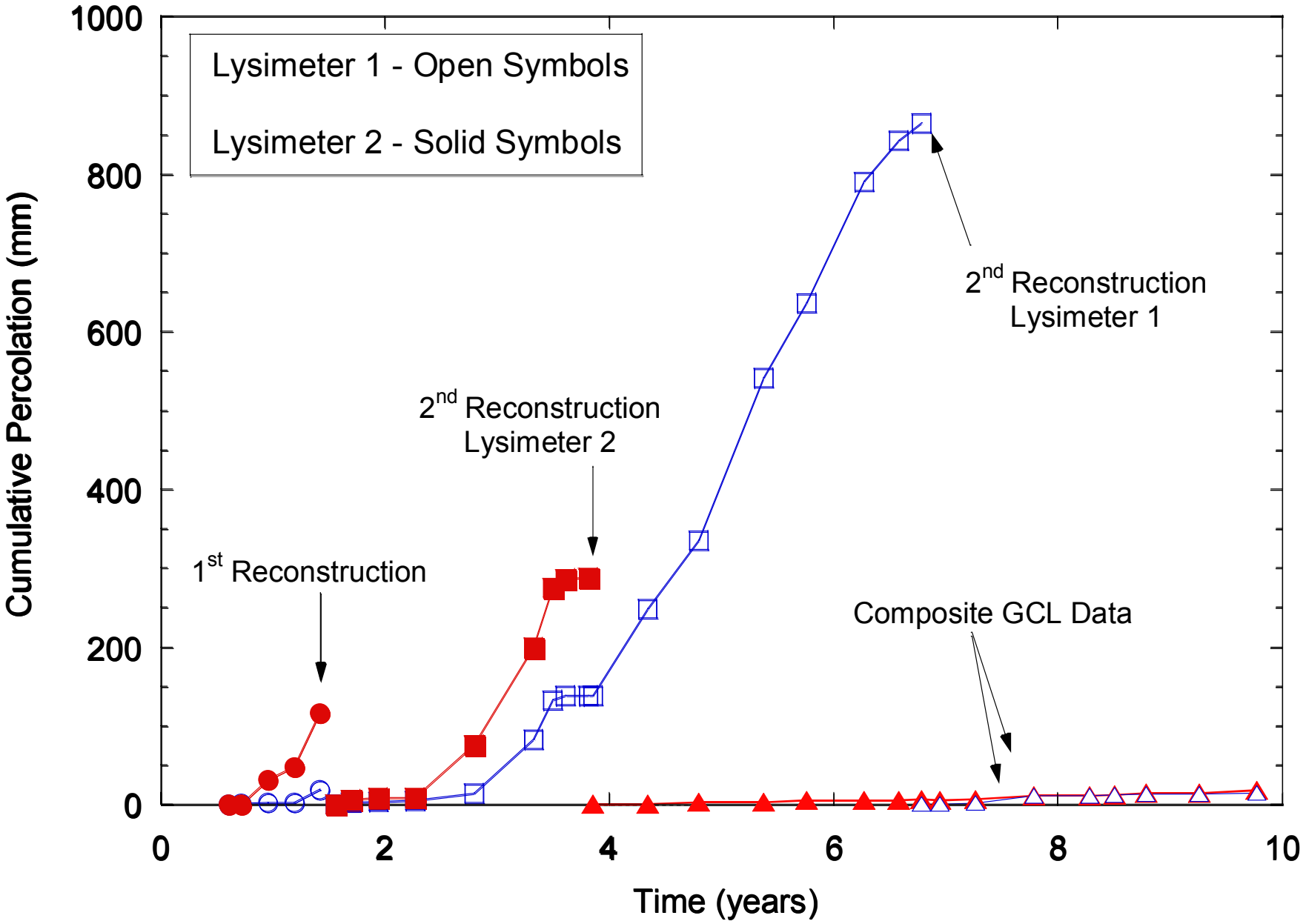
Na-Bentonite in Calcium (Ca^{2+}) Rich Water (divalent) – crystalline hydration only.

Wisconsin GCL Failure

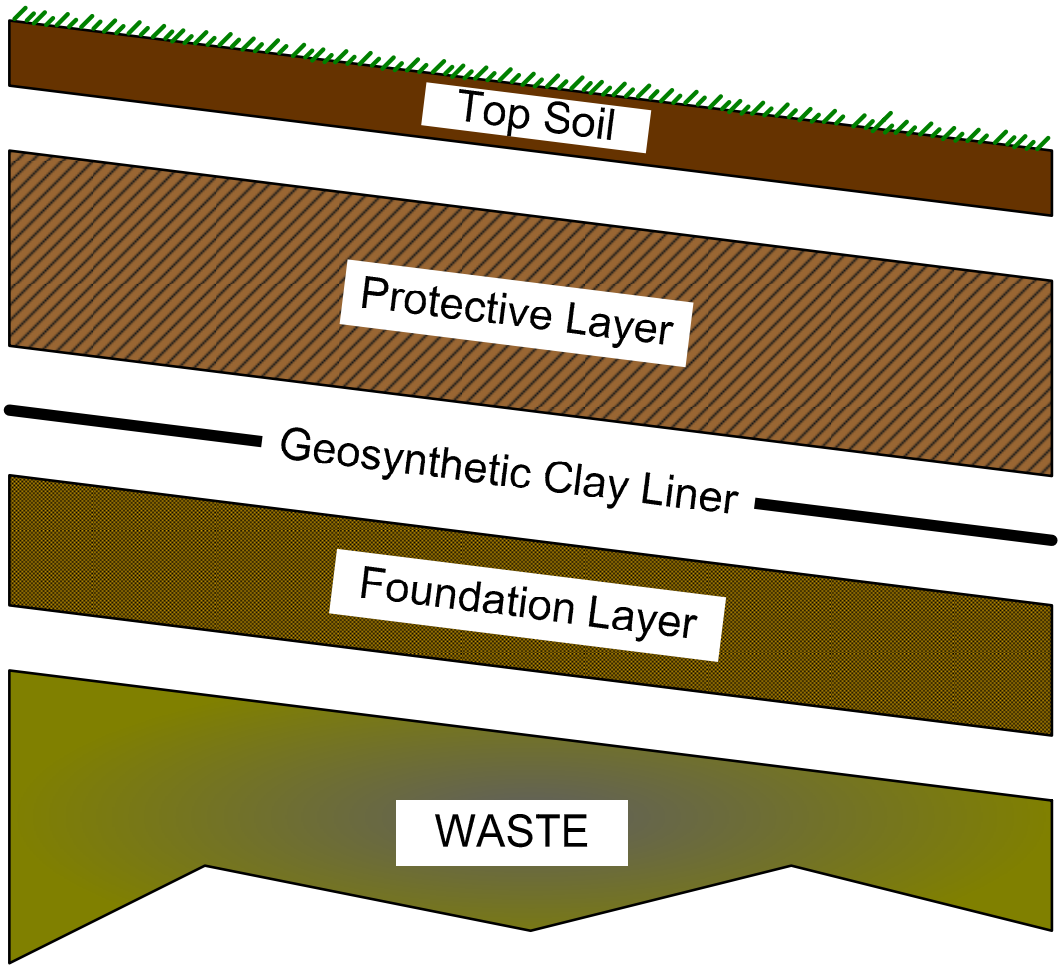
Leakage monitored with lysimeter (collection pan) directly beneath GCL



- Not to Scale -

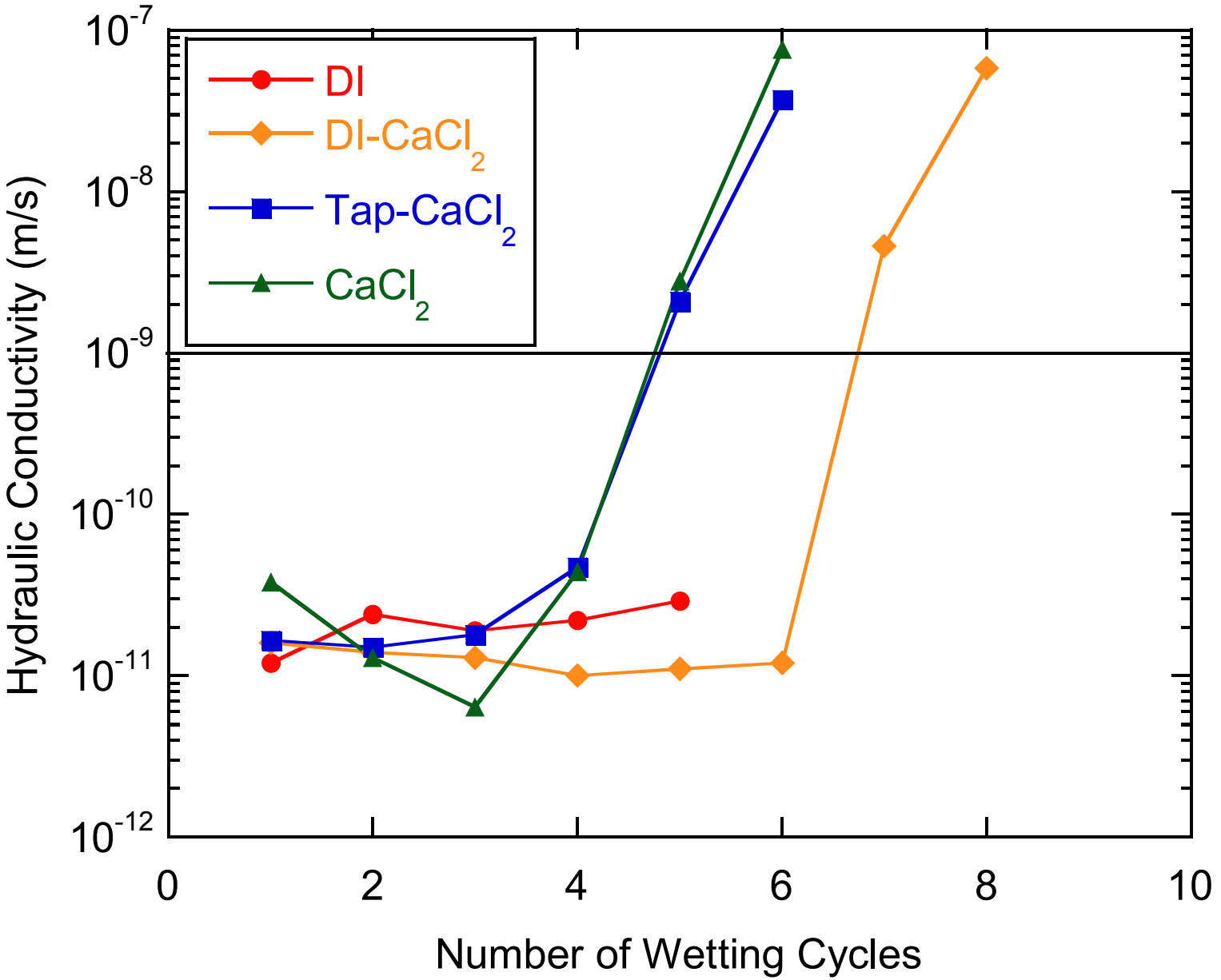

Lysimeter 1 - Open Symbols
Lysimeter 2 - Solid Symbols
1st Reconstruction
2nd Reconstruction Lysimeter 2
2nd Reconstruction Lysimeter 1
Composite GCL Data
Cumulative Percolation (mm)
Time (years)
0
200
400
600
800
1000
0
2
4
6
8
10

Dry Cover with GCL Barrier Only

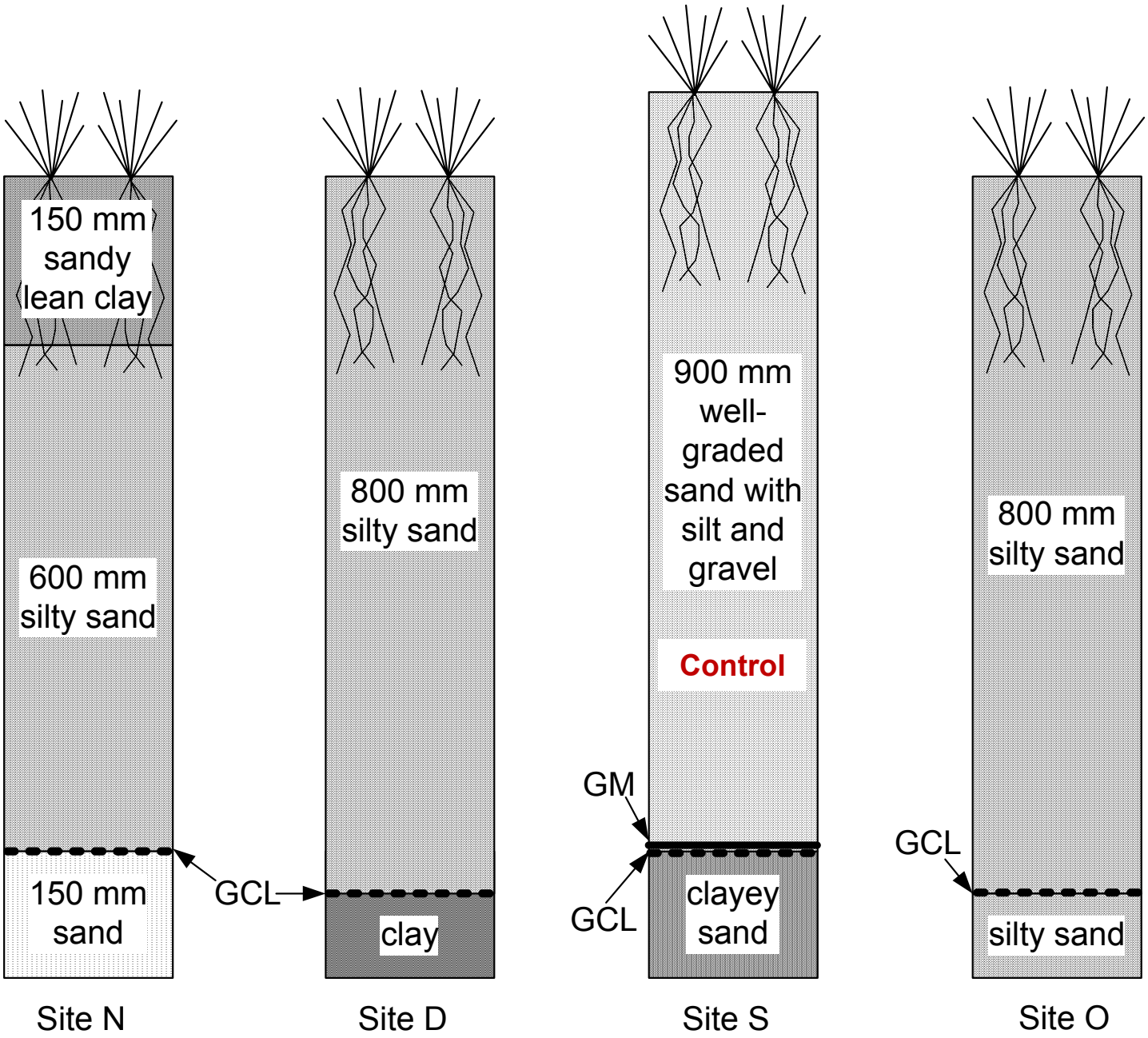


- GCL exposed to wet-dry cycling with seasonal changes in meteorology.
- Bentonite interacts with pore waters in adjacent soils, potentially replacing Na with divalent cations like Ca and Mg.

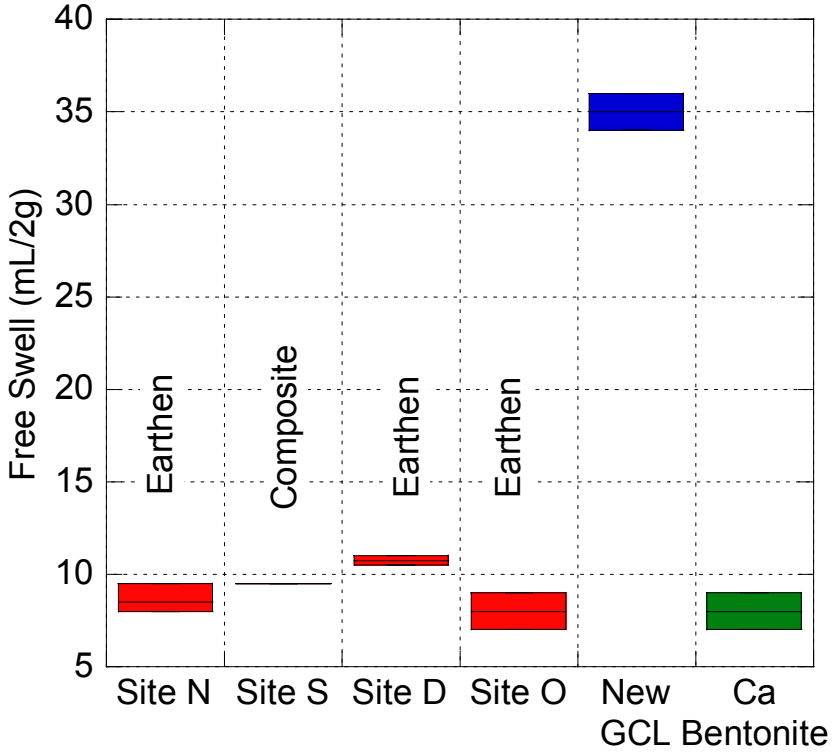
Wet-Dry Cycling & Hydraulic Conductivity

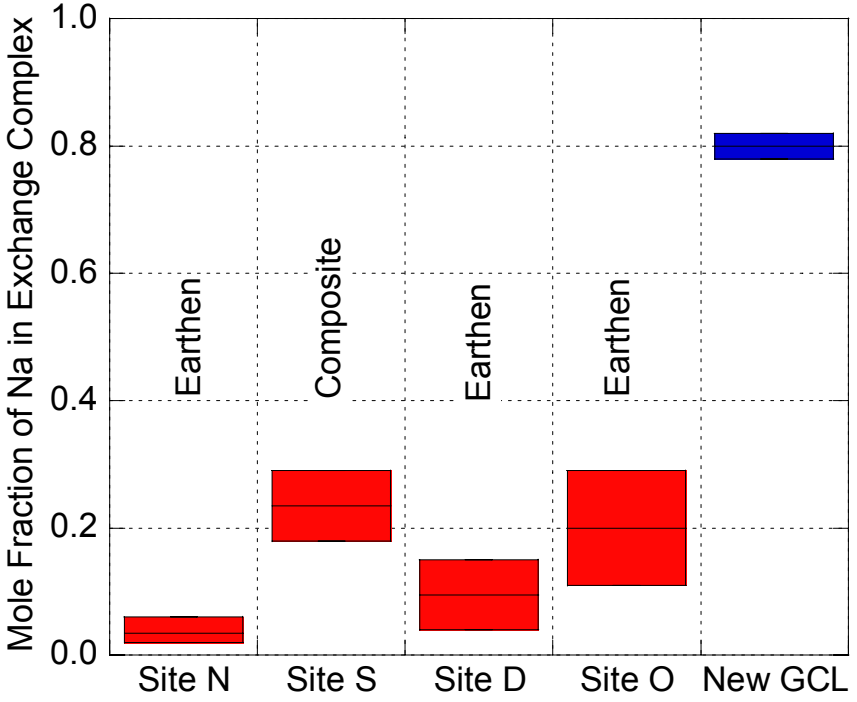


Cover Profiles – GCLs in Soil Covers

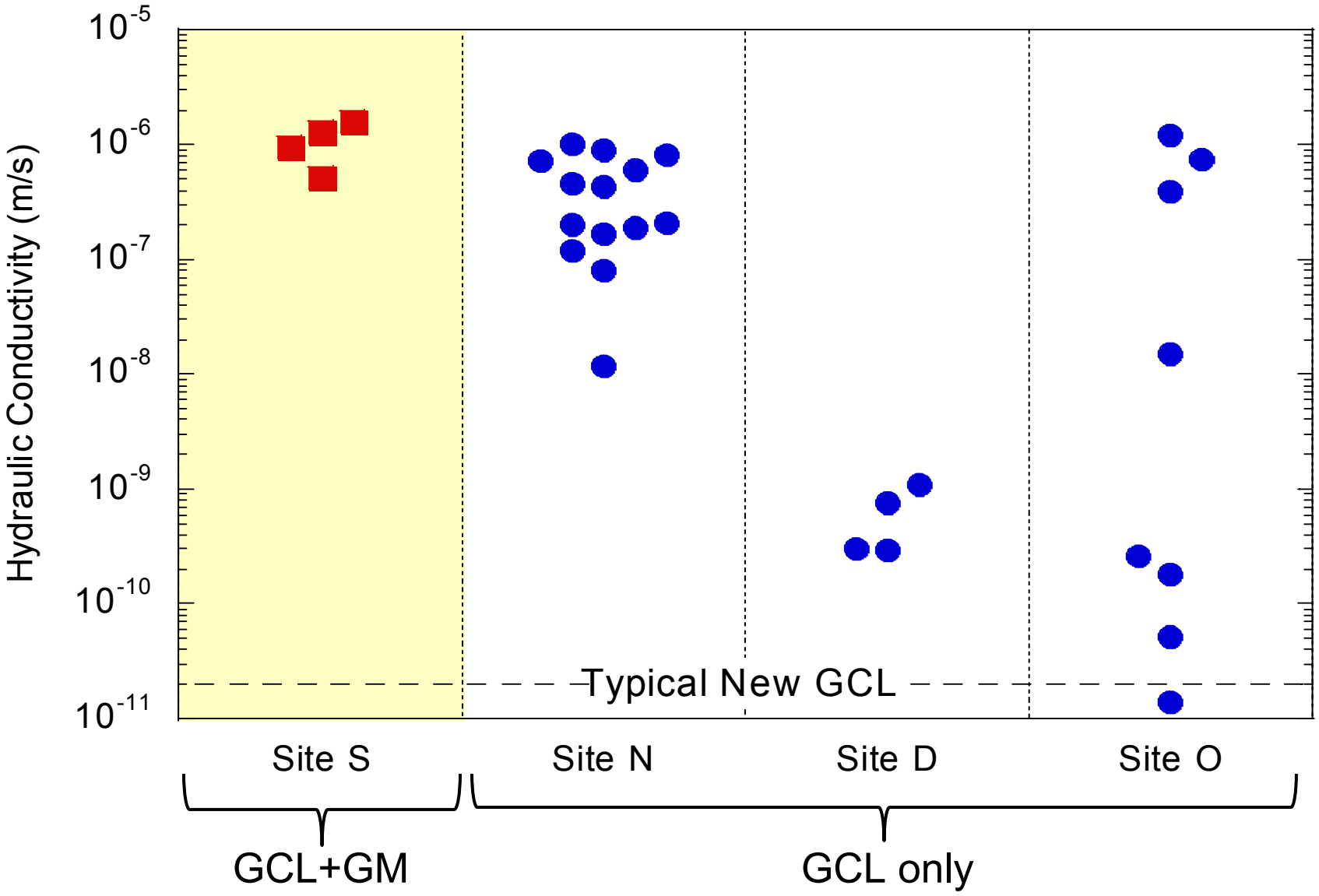


Free Swell and Exchange Complex

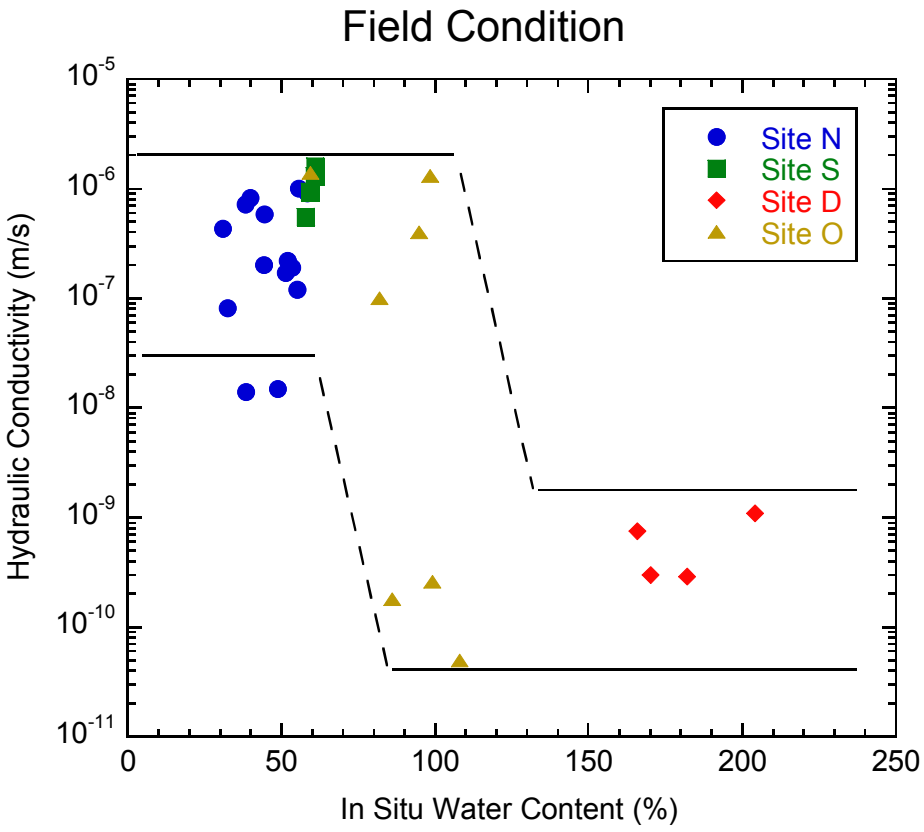


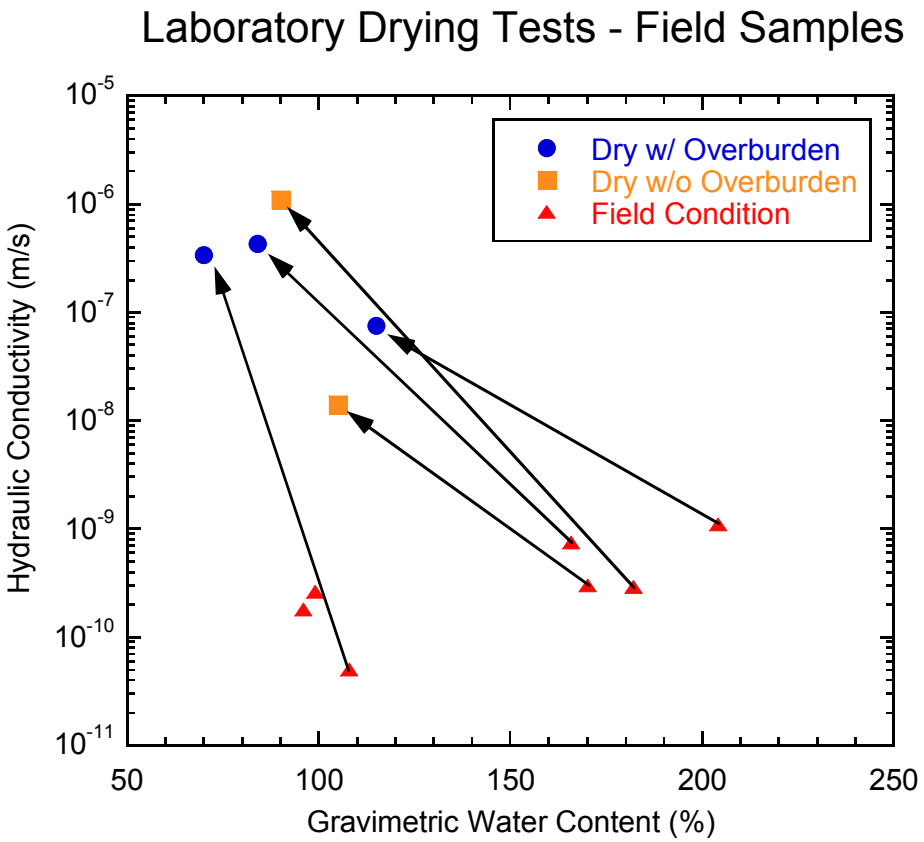


- Bentonites transformed from Na to Ca-Mg bentonite
- Even GCL overlain by geomembrane has Ca-Mg bentonite (diffusion of Ca & Mg from underlying subgrade?)


Hydraulic Conductivity (m/s)
10-5
10-6
10-7
10-8
10-9
10-10
10-11
Typical New GCL
Site S
Site N
Site D
Site O
GCL+GM
GCL only

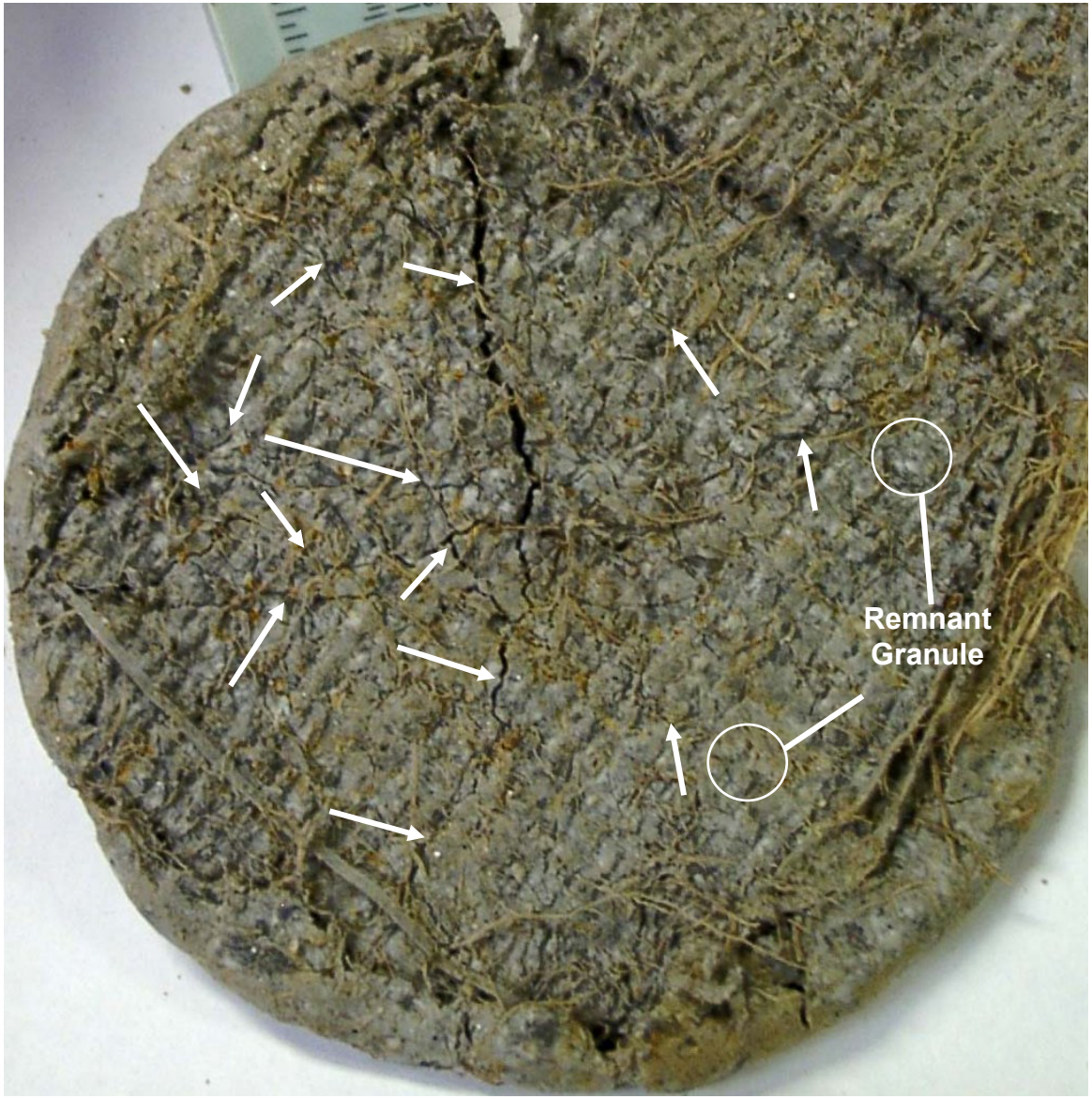
Importance of Water Content





- Hydraulic conductivity tied to water content of GCL, even though complete exchange of Mg/Ca for Na.

- Drying wetter specimens resulted in large increase in hydraulic conductivity.



Exhumed GCL where Na has been replaced by Ca and Mg.

Loss of swell precludes healing of desiccation cracks.

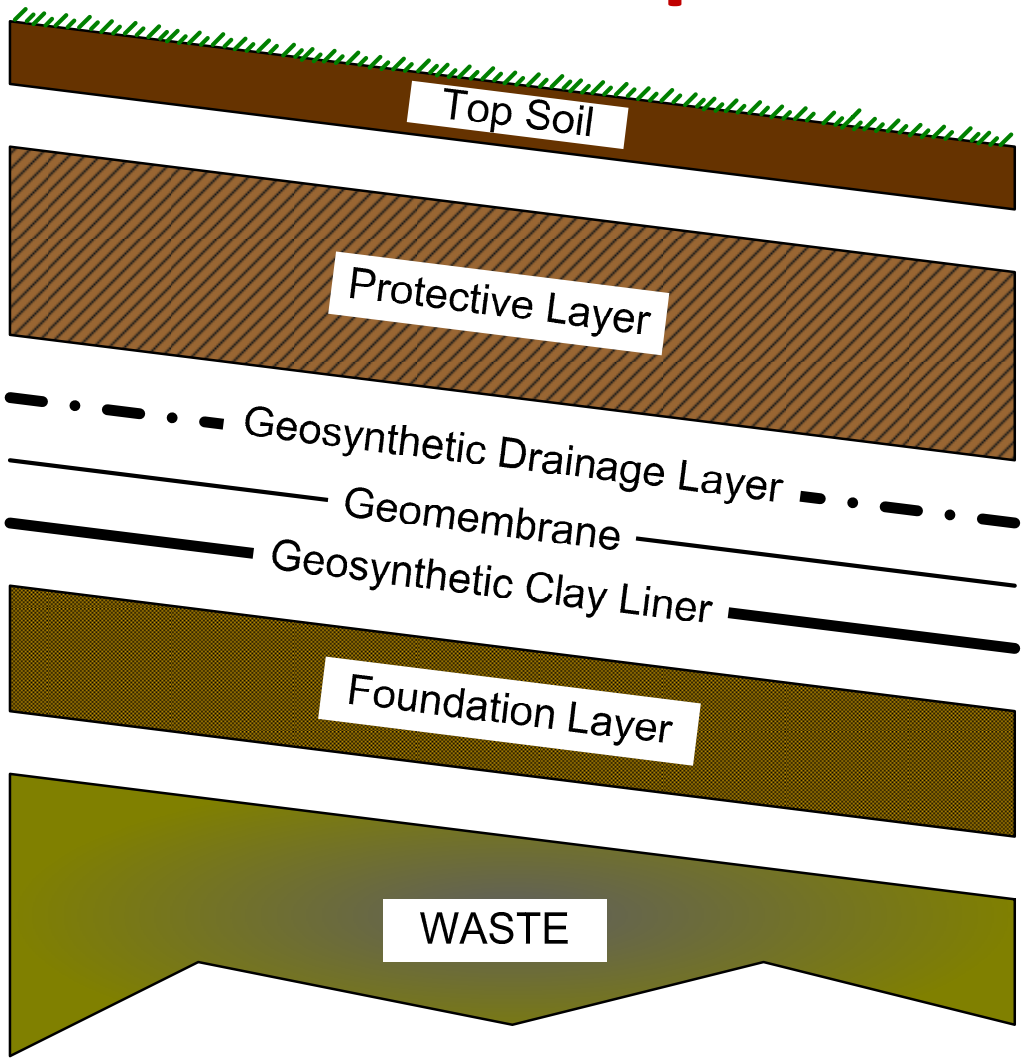
Some granules visible.

Exhumed GCL showing cracks and remnant granules.

Key Points

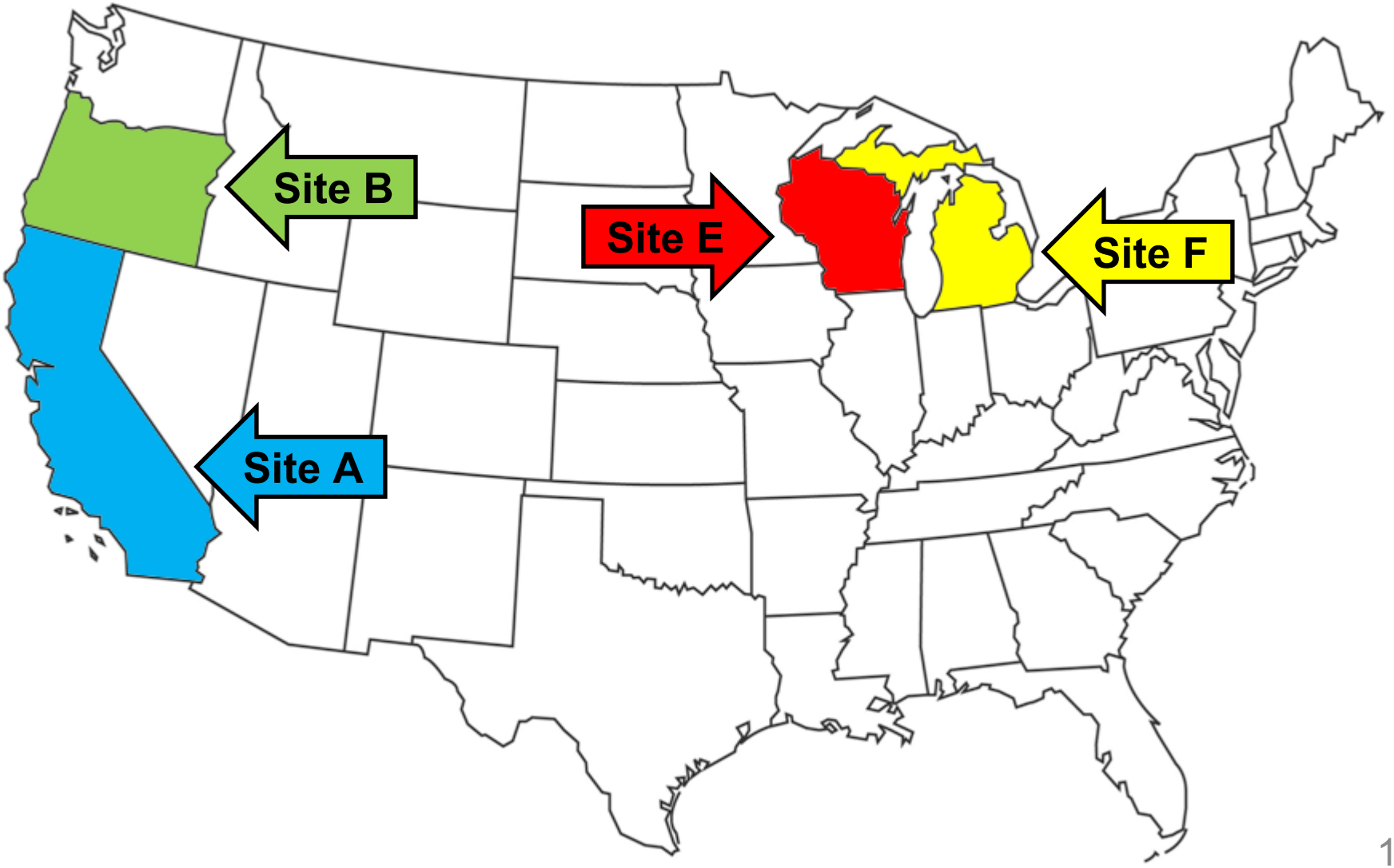
- Cation exchange (Ca/Mg for Na) occurred in ALL GCLs (with and without overlying geomembrane). Na bentonite in all GCLs converted to Ca/Mg bentonite.
- GCLs with low water content had high hydraulic conductivity (with and without geomembrane). Desiccation *or* lack of hydration. Preferential flow thru cracks or around remnant granules.
- GCLs that retained higher water content had low hydraulic conductivity.

Landfill Final Cover – GCL-GM Composite Barriers

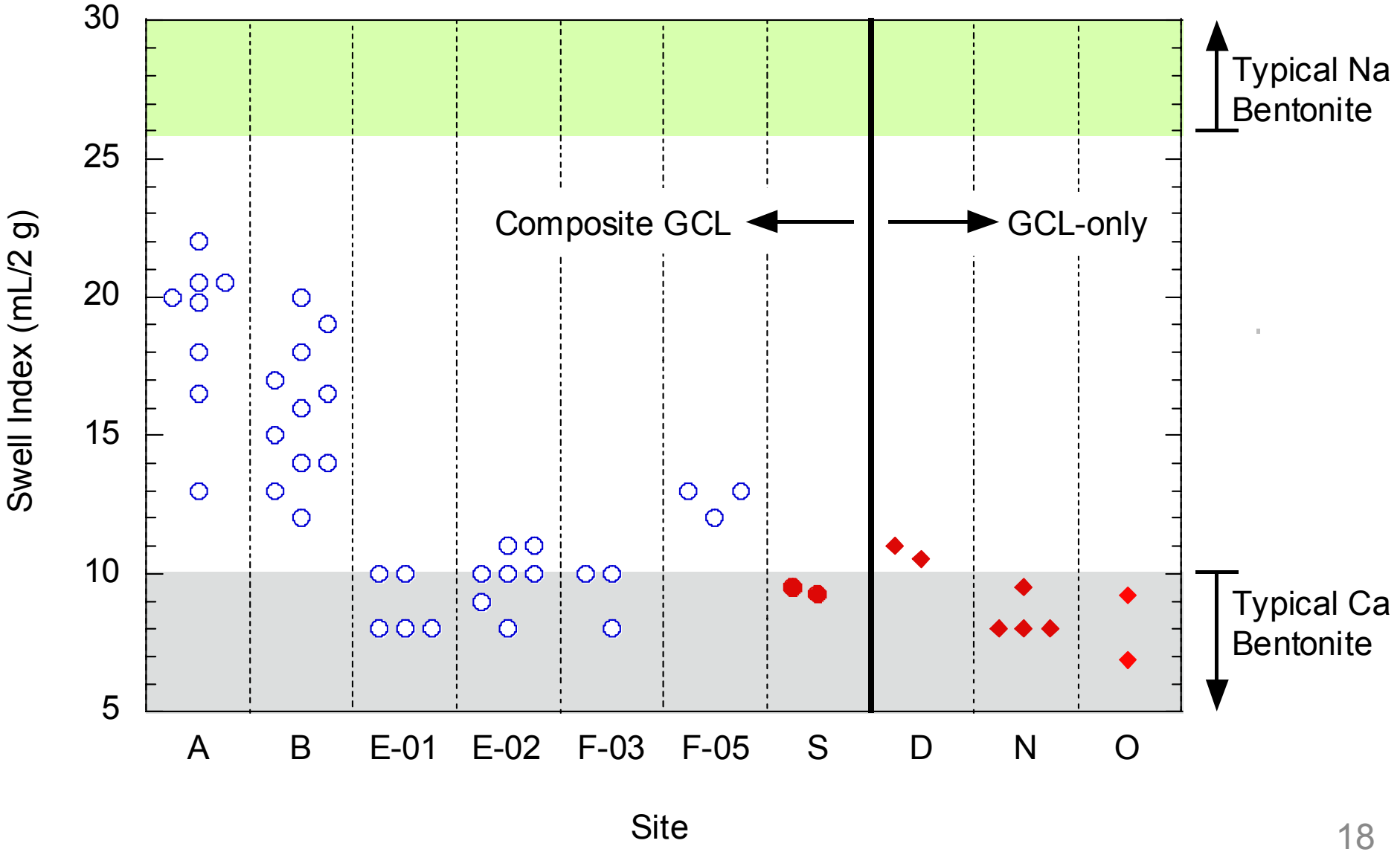


- Is Site S an anomaly?
- Does GM protect the GCL?
- Does cation exchange still occur?
- Do GCLs in composites retain low hydraulic conductivity?

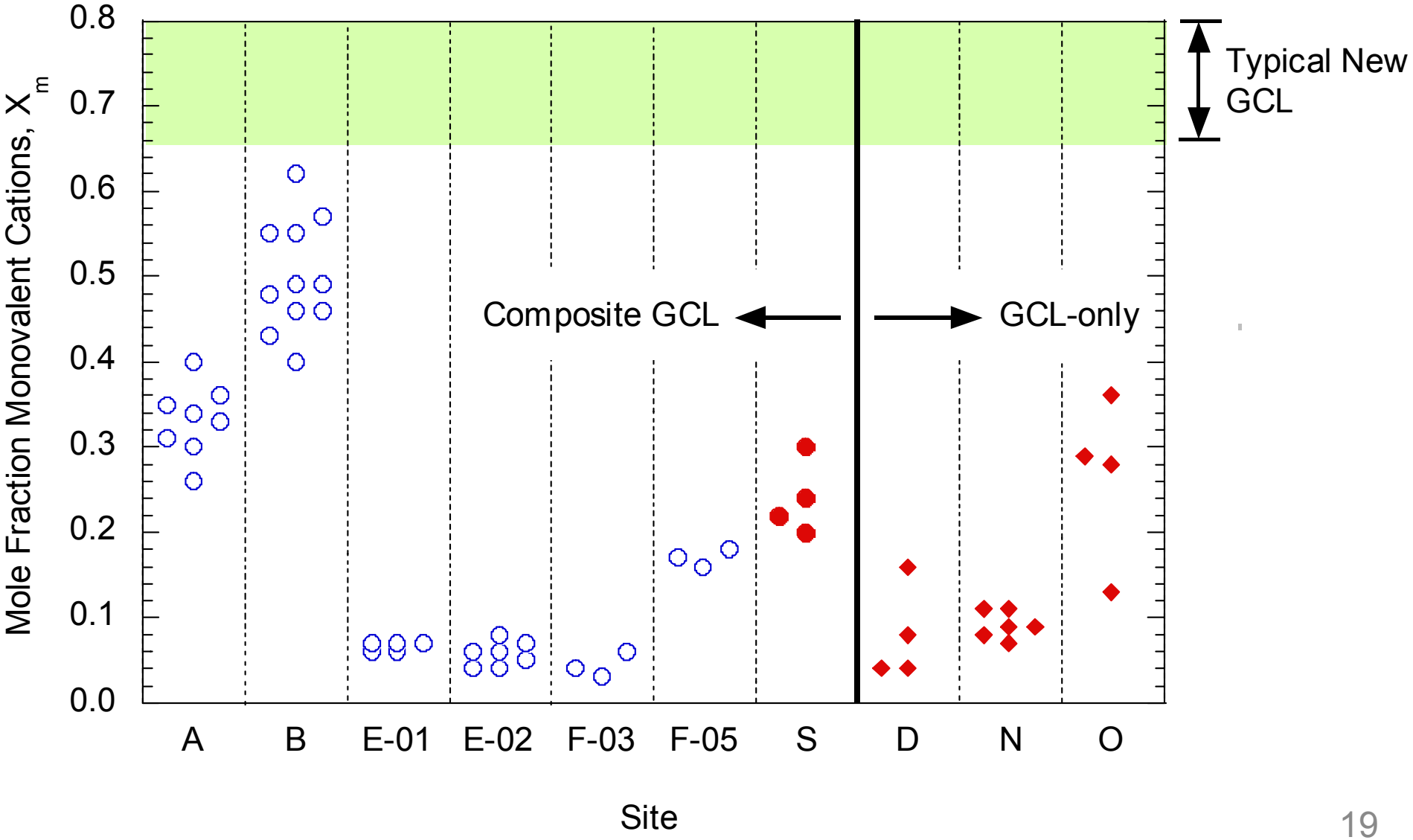
Sites for Exhumations



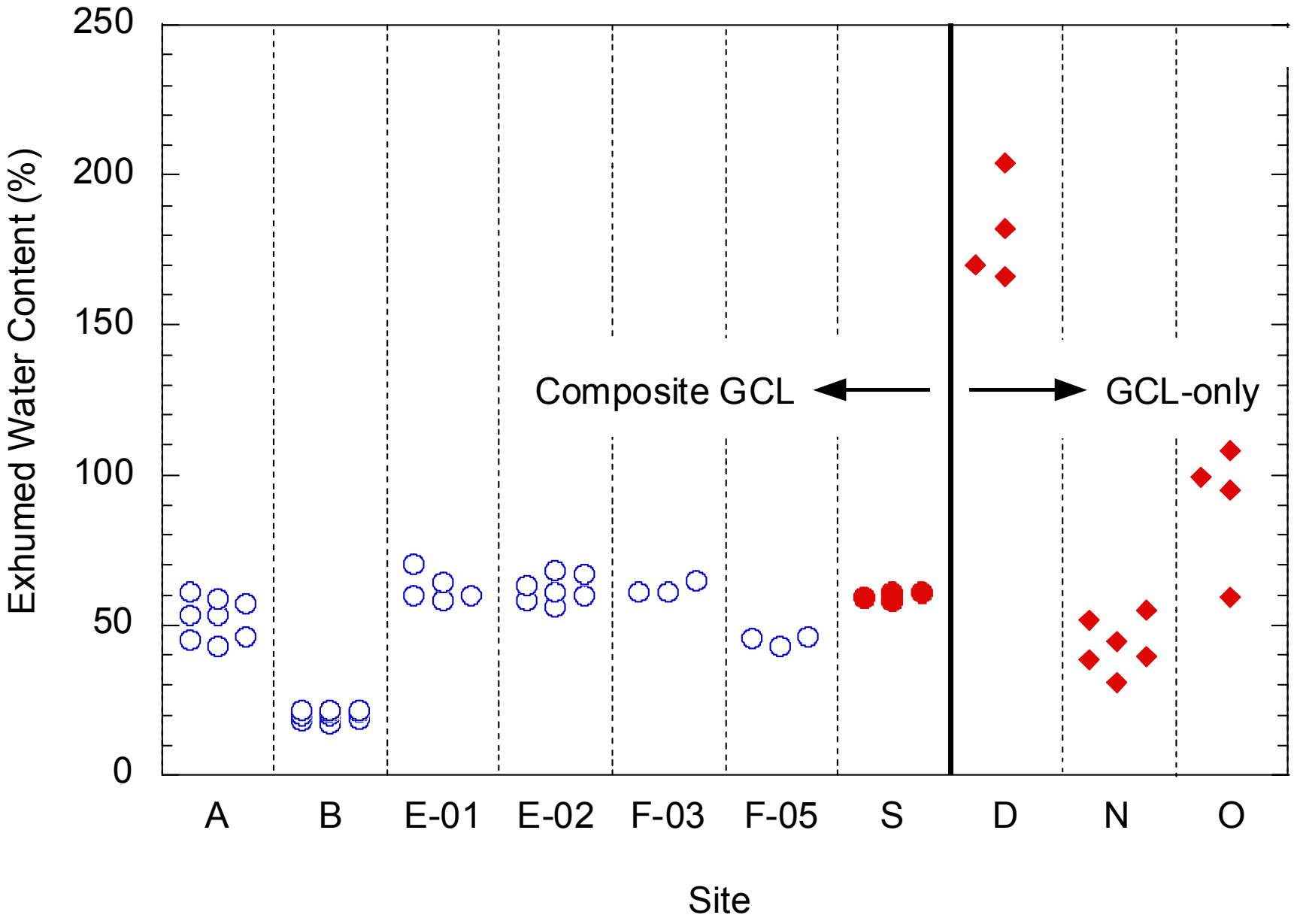
Swell Index (ASTM D 5890)



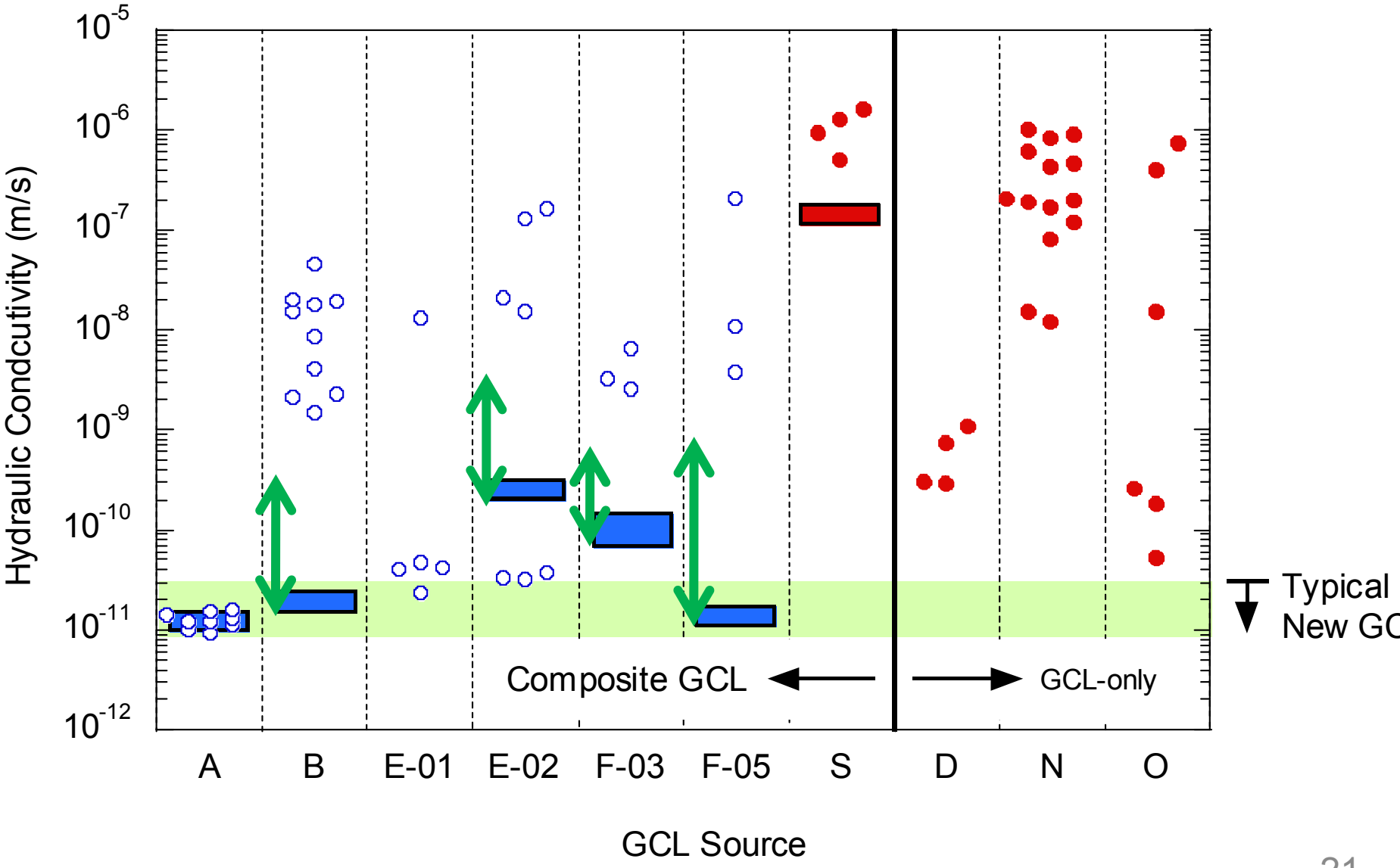
Bound Monovalent Cation Fraction



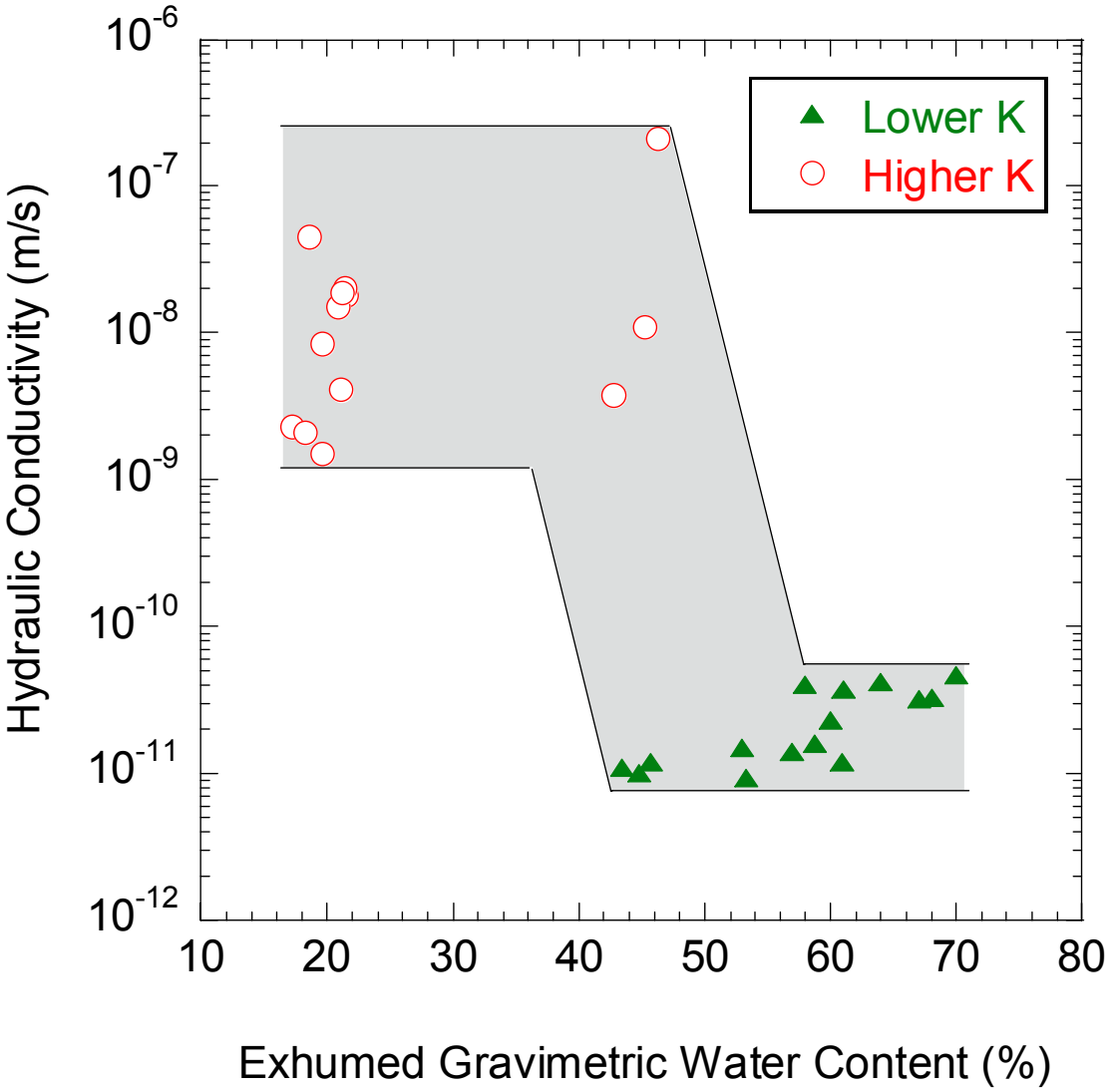
Exhumed Water Content



Hydraulic Conductivity (ASTM D 5084)

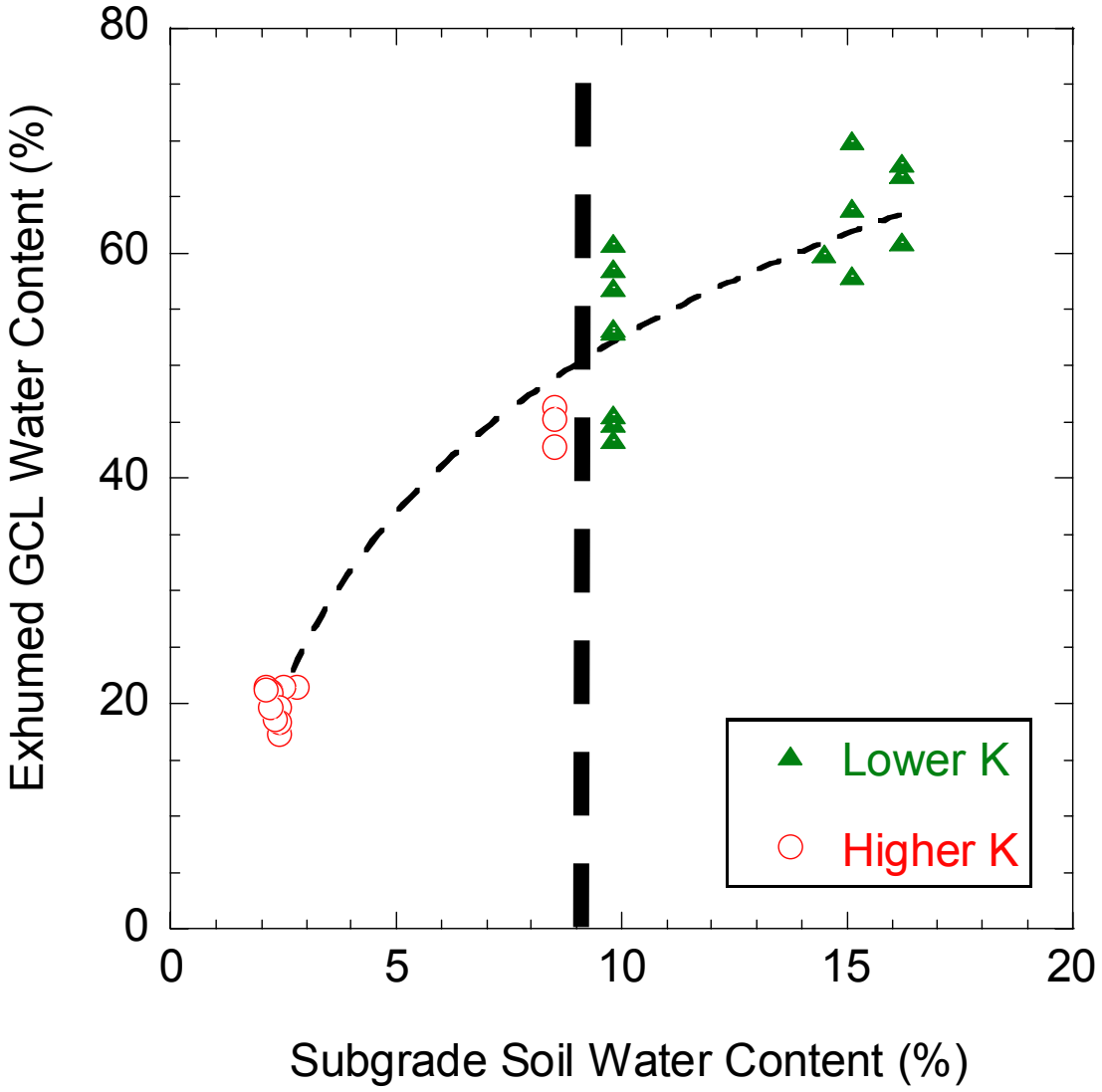


SW Hydraulic Conductivity & Exhumed Water Content



GCLs with higher water content had low hydraulic conductivity, even if Ca/Mg replaced Na.

Importance of Subgrade Water Content



GCL water content increases with subgrade water content.

9% is threshold for hydraulic conductivity corresponding to crystalline vs. osmotic hydration.

Lessons Learned

- GCLs beneath geomembranes undergo cation exchange due to Ca and Mg in subgrade and from dissolution of calcite in the bentonite. Become Ca-Mg bentonites.
- Hydraulic conductivity of GCLs in composite barriers varies significantly with hydration condition. Adequate subgrade water content (>9%) required to ensure osmotic swell and low hydraulic conductivity of the bentonite.
- Low hydraulic conductivity even if cation exchange occurs provided bentonite undergoes osmotic swell prior to exchange.
- Simple message – get the GCL wet and keep the GCL wet

Practical Implication

Percolation Rates from Covers with Geomembrane-GCL Composite Barrier

Location of Study	Duration of Study (yr)	Average Annual Precipitation (mm/yr)	Average Percolation Rate (mm/yr)
Apple Valley, CA	4.1	119	0.0
Boardman, OR	4.5	224	0.0
Cassville, WI	6.0	892	2.5

Geomembrane-GCL barriers are very effective hydraulic barriers in dry covers.

Questions?