Changes in the Hydraulic Properties of Earthen Barrier Materials

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Processes that Alter Hydraulic Properties of Earthen Barrier Materials

- Hydraulic properties of earthen barrier materials change when the network of pores conducting fluid flow changes.
- Pore network can be altered by processes that cause increases in pore size (macropores).
- Pore network can be altered by processes that decrease pore size (pore filling or consolidation).
- For fine-textured soils used to store and block water, increases in pore size are more common.
- For coarse-textured soils used to conduct flow (drainage layers), decreases in pore size are more common.

Macropore Formation in Fine-Textured Soils

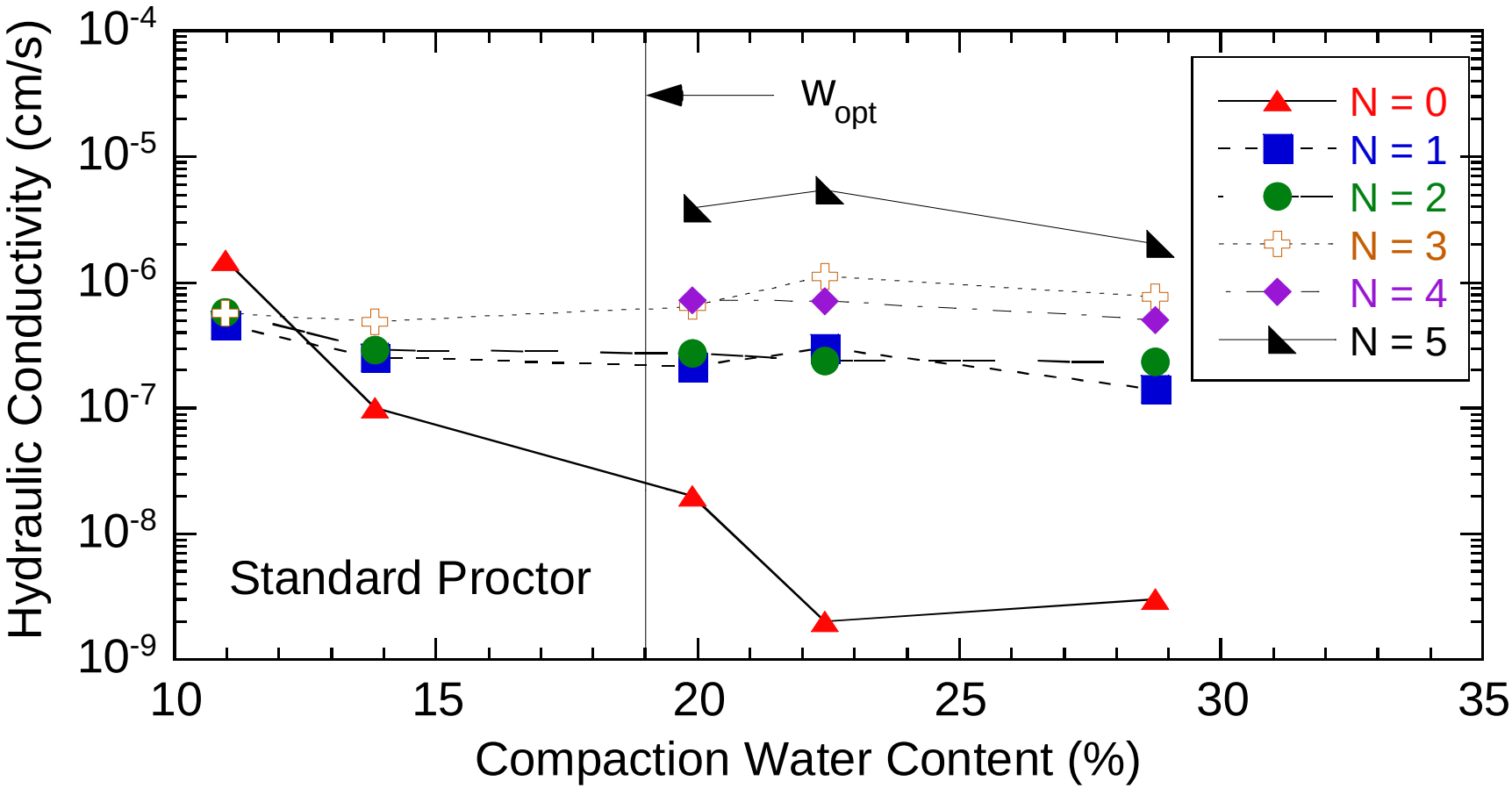
- Macropores form in response to three primary factors:
  - shrinkage cracks that form due to drying
  - tensile cracks that form due to expansion or bending
  - holes that form due to biota intrusion
- Formation of macropores can cause:
  - increase in saturated hydraulic conductivity
  - decrease in water retention capacity
  - larger pores conduct flow more readily
  - larger pores develop smaller capillary stresses
- Impact on hydraulic properties depends on structure of pore network prior to change & volume change that occurs

Example: Pore Network & Hydraulic Conductivity

Compacted Clay – No Macropores
Ks ~ 10^{-9} cm/s

Compacted Clay – Many Macropores
Ks ~ 10^{-5} cm/s

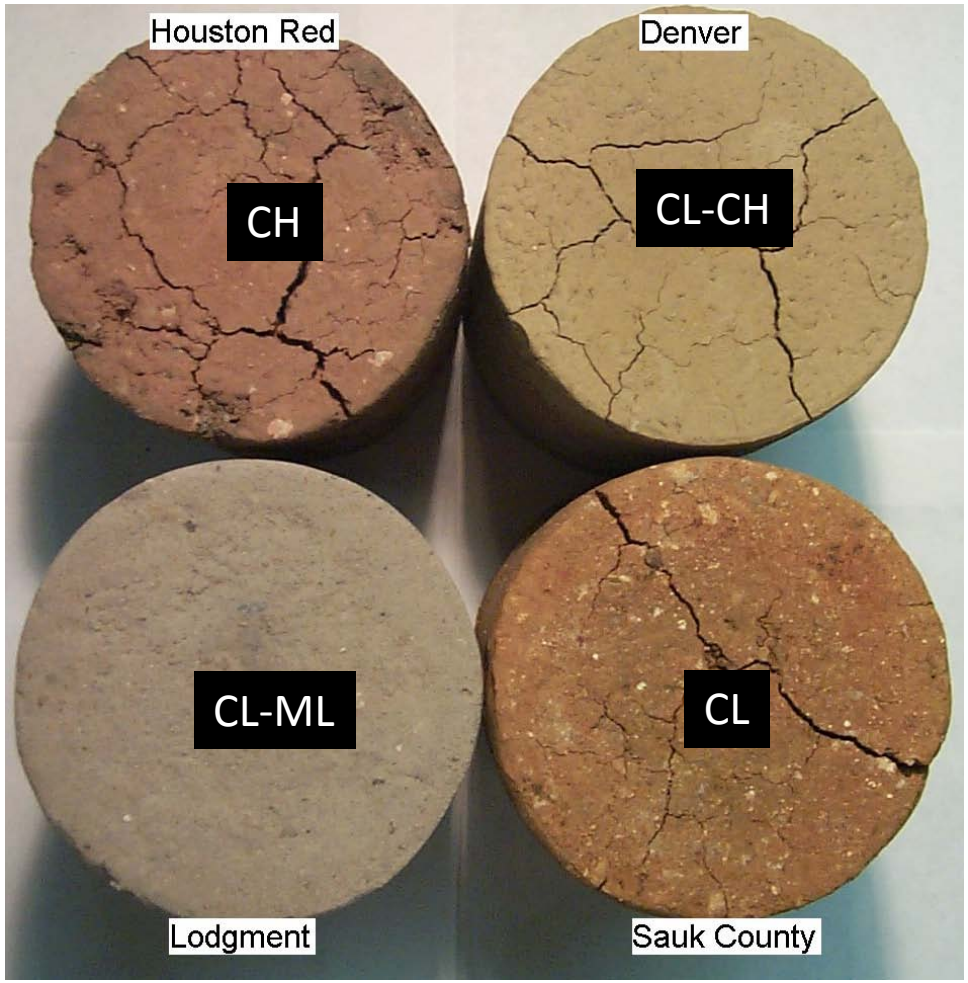
Desiccation, Pore Structure, & Hydraulic Conductivity

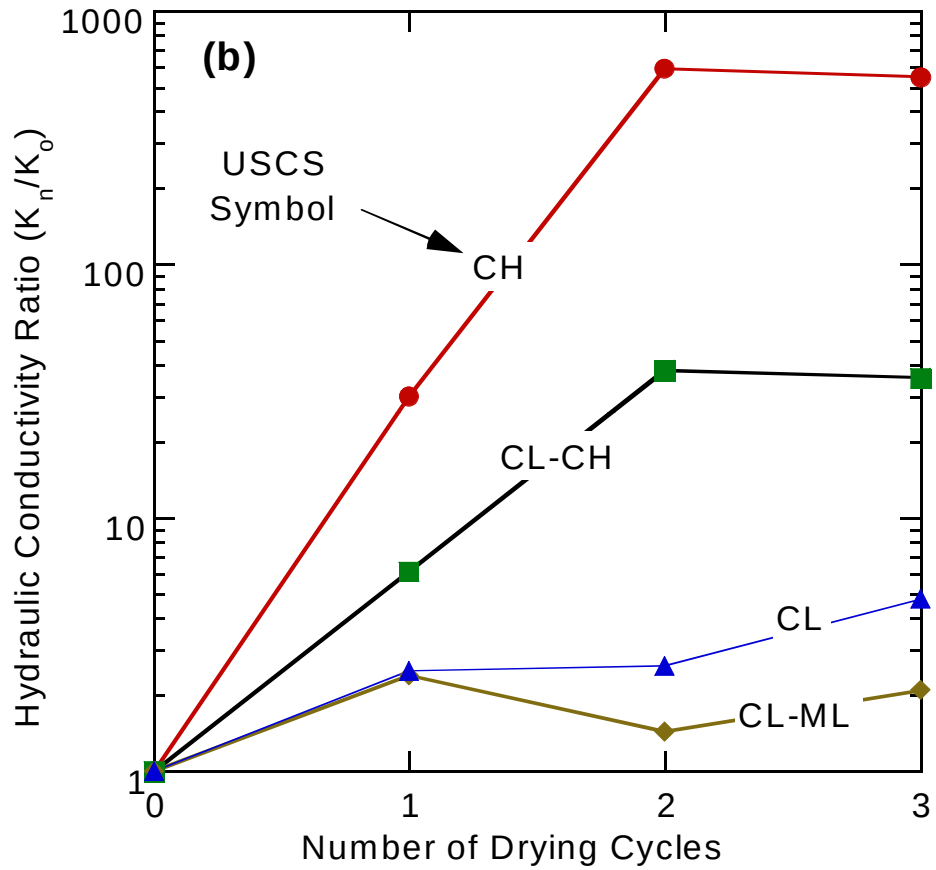


Large changes in Ks occur in soils that are initially devoid of macropores and have low Ks.

Small changes in Ks occur in soils that initially contain macropores and have higher Ks.

Desiccation, Volume Change, & Hydraulic Conductivity





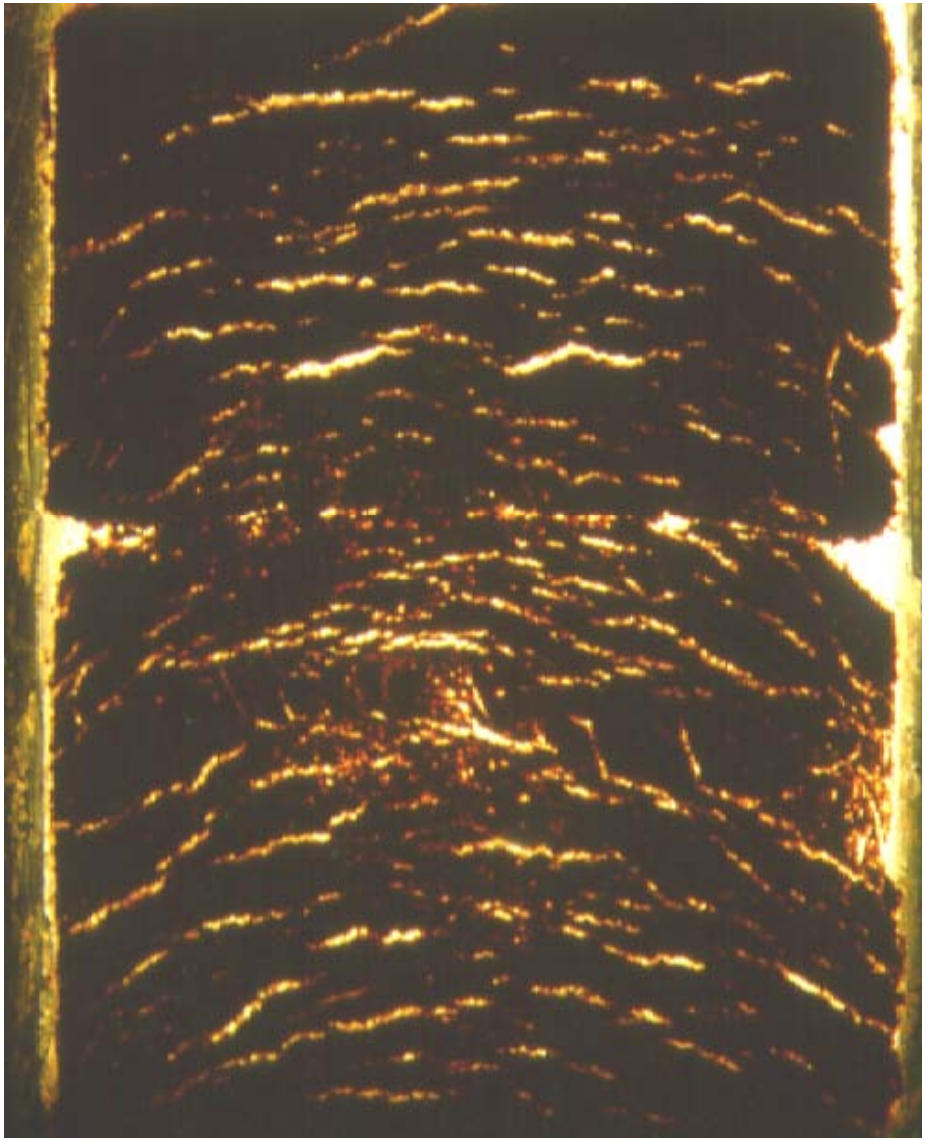
Larger volume change results in more cracking and larger change in Ks.

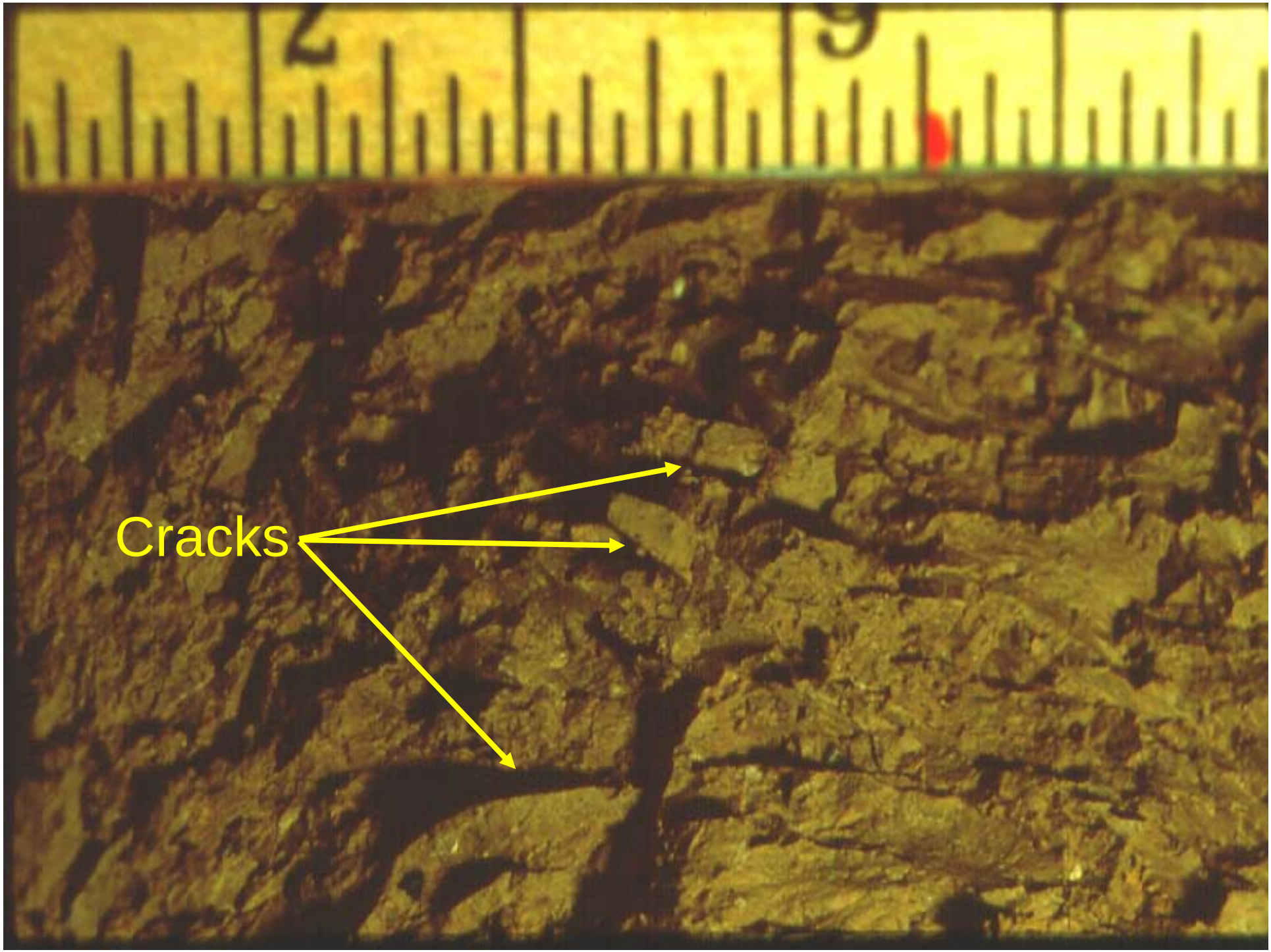
We think of large cracks when we think about desiccation cracking….but

Our field experience illustrates that numerous small cracks/macropores are more common

Structural Changes Caused by Freezing

- formation of ice lenses causes tensile cracks
- water moving to freezing front causes desiccation cracks
- Cracking causes increases in hydraulic conductivity



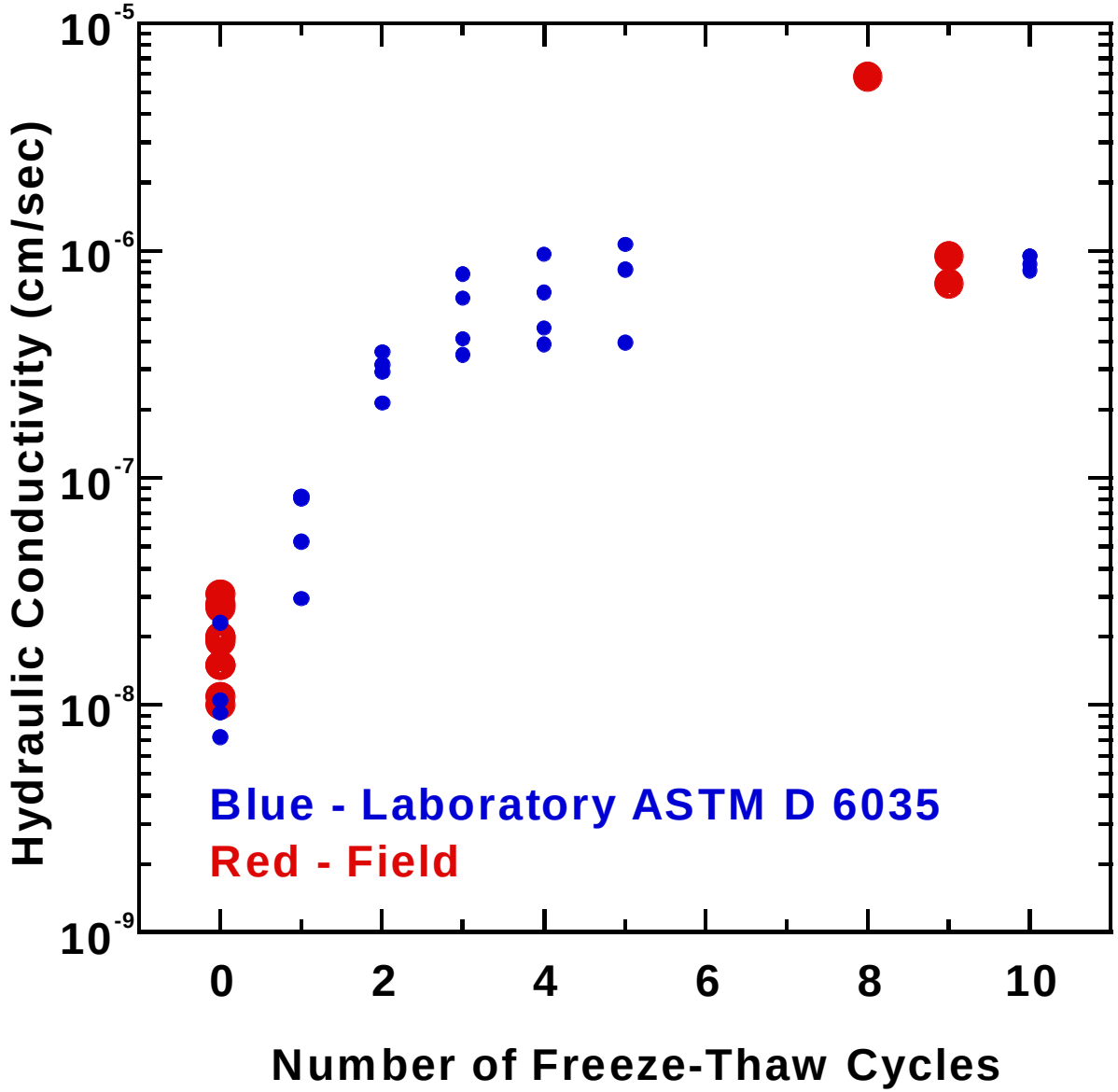

Cracks

How much does the hydraulic conductivity increase?

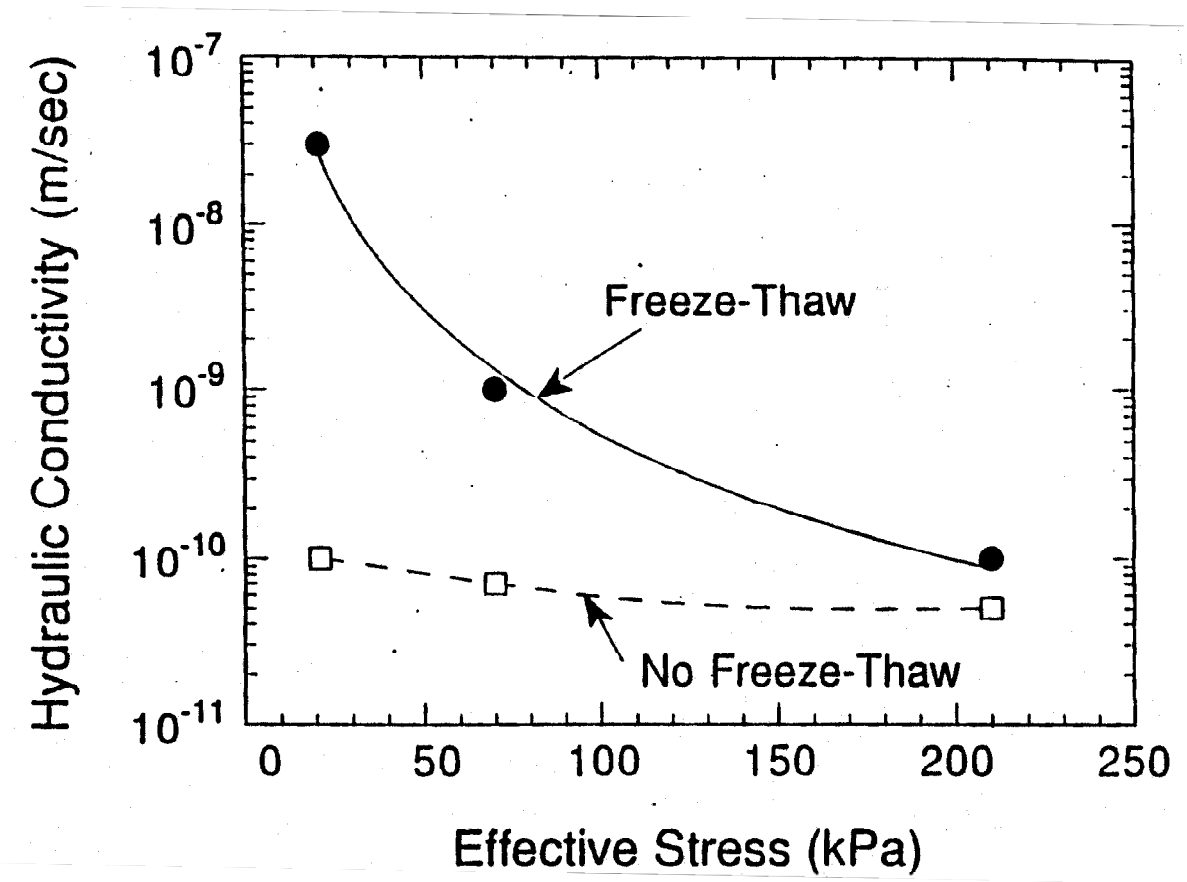
At least 10 X

Typically 100 to 1000 X

Occasionally 10,000 X



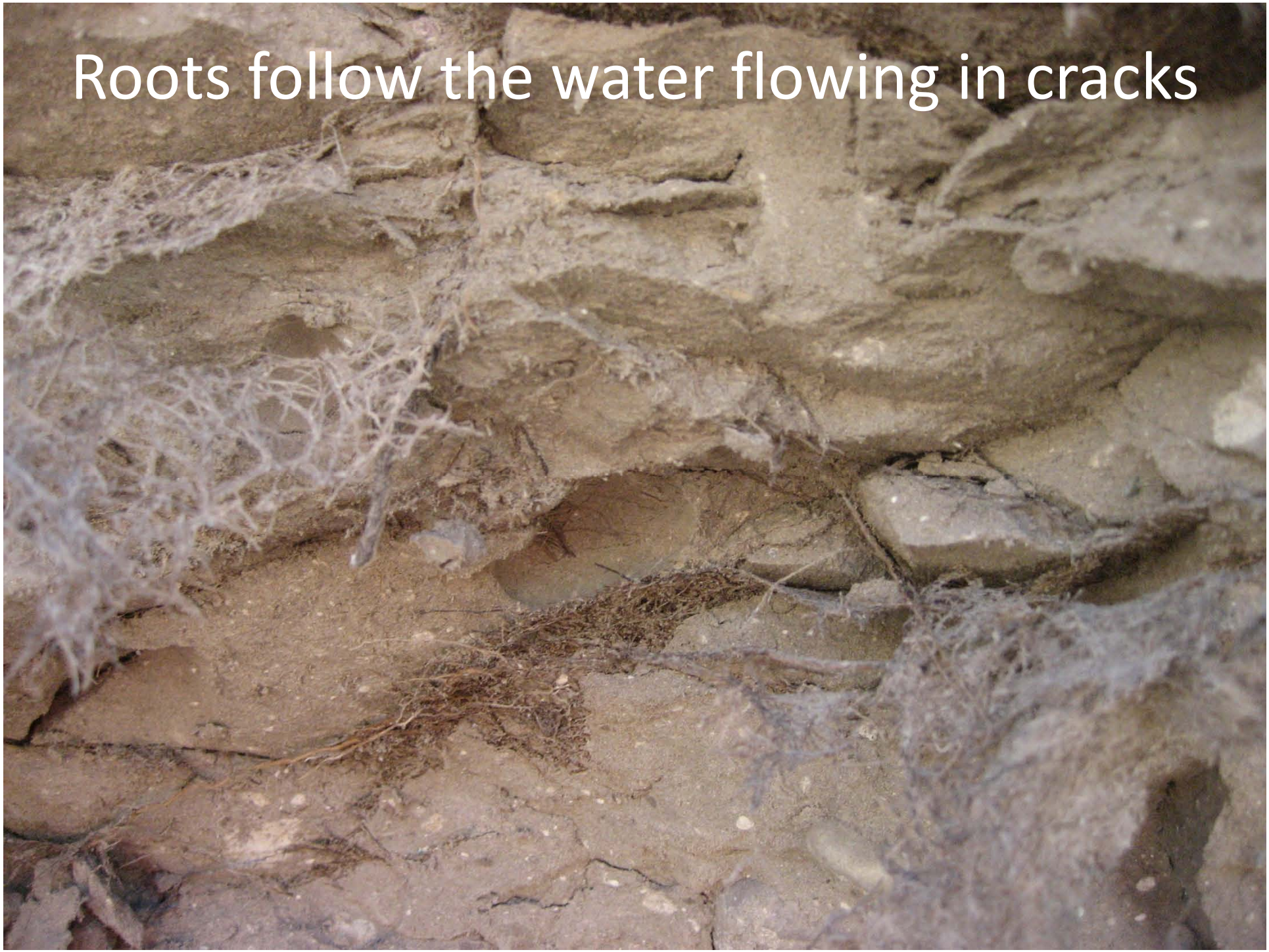
Is the increase permanent?



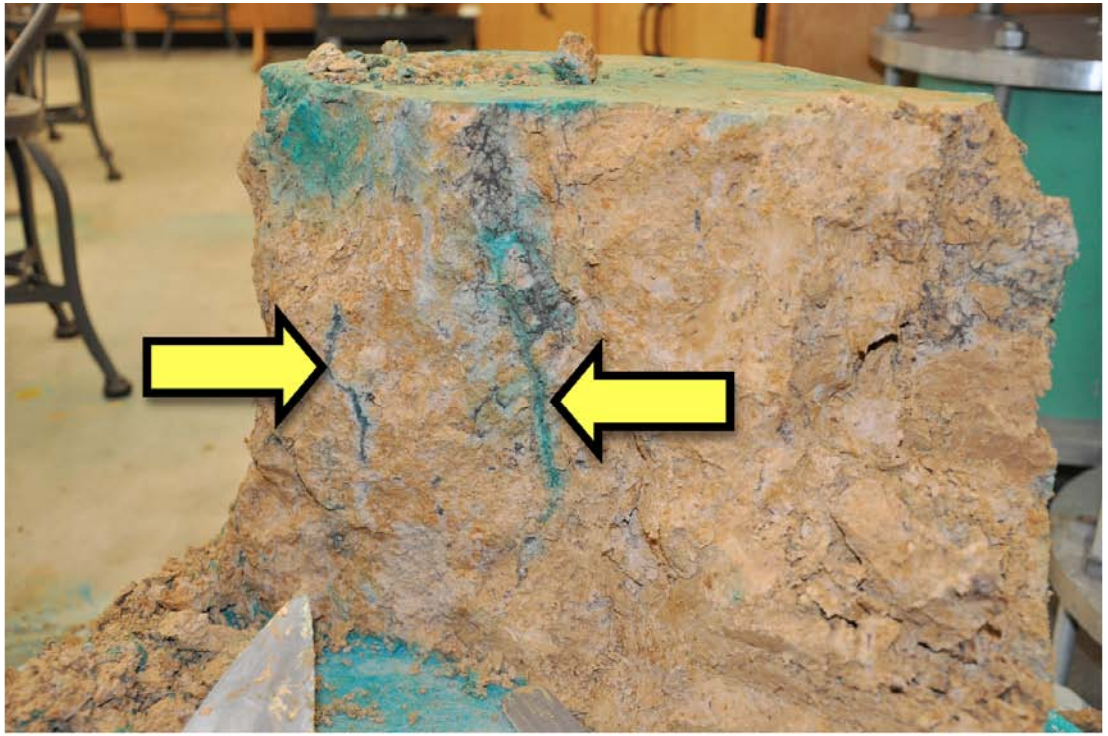
Damage due to frost or desiccation permanent. Does not "heal," but stress will close cracks.

Biota Intrusion Affects Pore Structure

Roots follow the water flowing in cracks



Preferential Flow Through Historic Roots

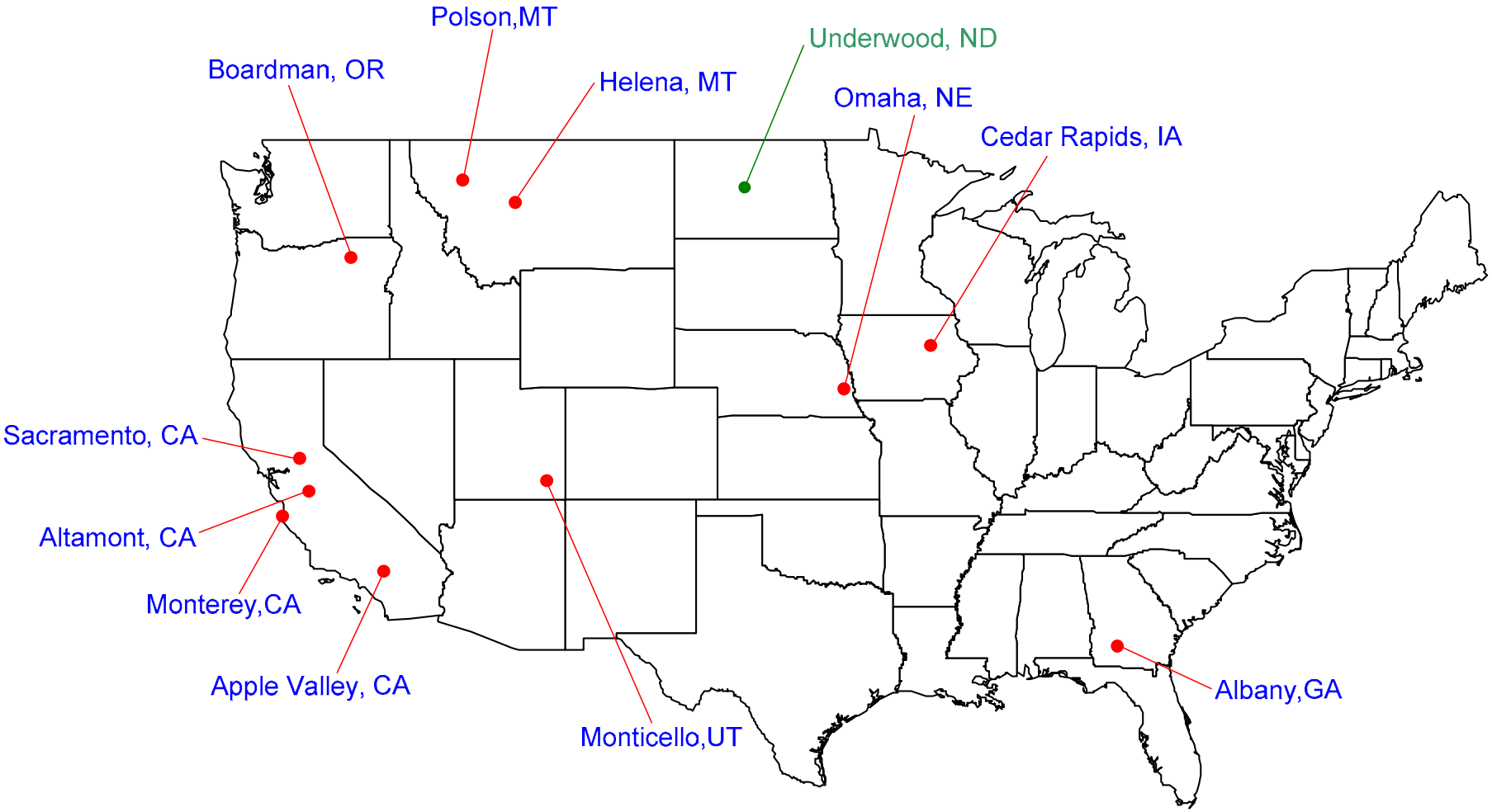


Large (450 mm) block sample from clay layer 10 m bgs.

Dye passed through former root pathways, organic matter still present.

50 kPa: 4.0×10^{-4} cm/s
95 kPa: 1.9×10^{-4} cm/s
116 kPa: 1.8×10^{-4} cm/s

ACAP Network of Final Cover Test Sections



12 Sites, 8 States, 28 Test Sections

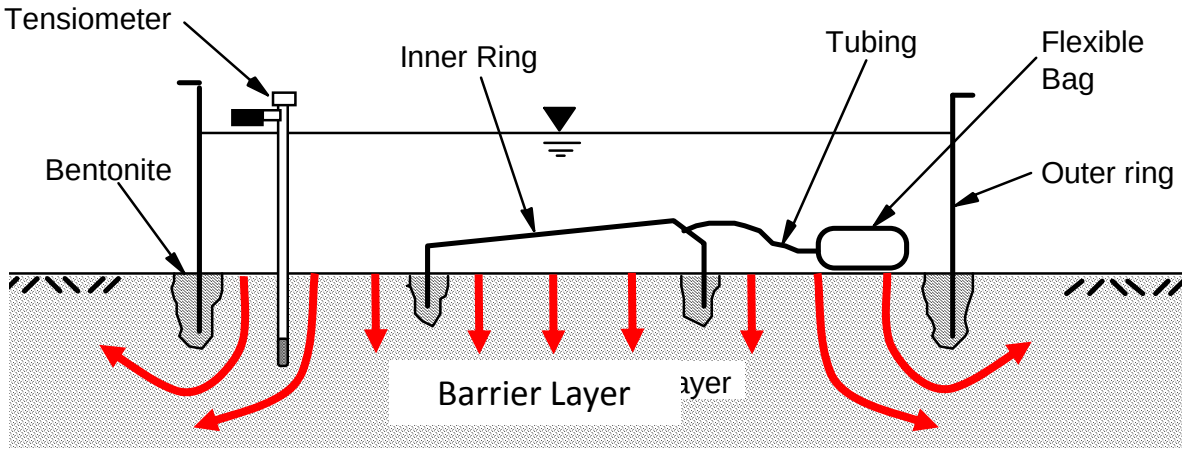
Covers designed to transmit < 3, 10, or 30 mm/yr depending conventional cover required by regulation.

ACAP Exhumation Study

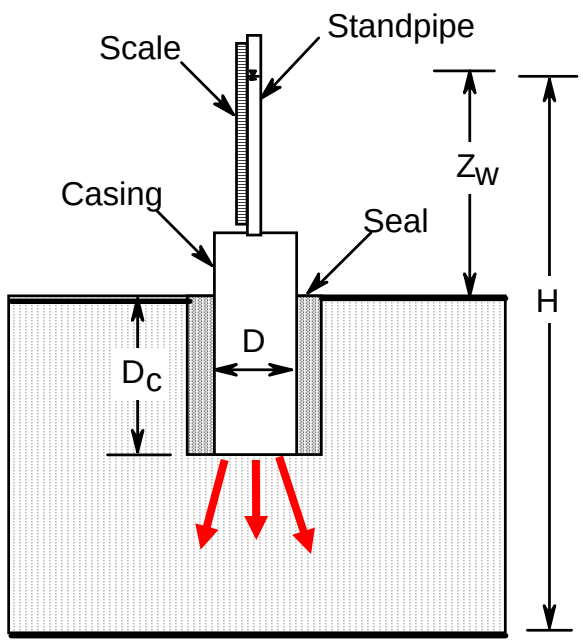
- **Elements**
  - Field testing of hydraulic properties of cover materials
  - Collect large-scale undisturbed samples for lab analysis
  - Collect geosynthetic materials (geomembranes, geocomposite drainage materials, GCLs) for lab analysis
  - Geomorphological surveys

- **Objectives**
  - Identify changes in engineering properties
  - Relate changes in properties to structural development
  - Recommend monitoring strategies to detect changes in performance

Field Tests – Sat. Hydraulic Conductivity



SDRI: large infiltration test with careful control on mass



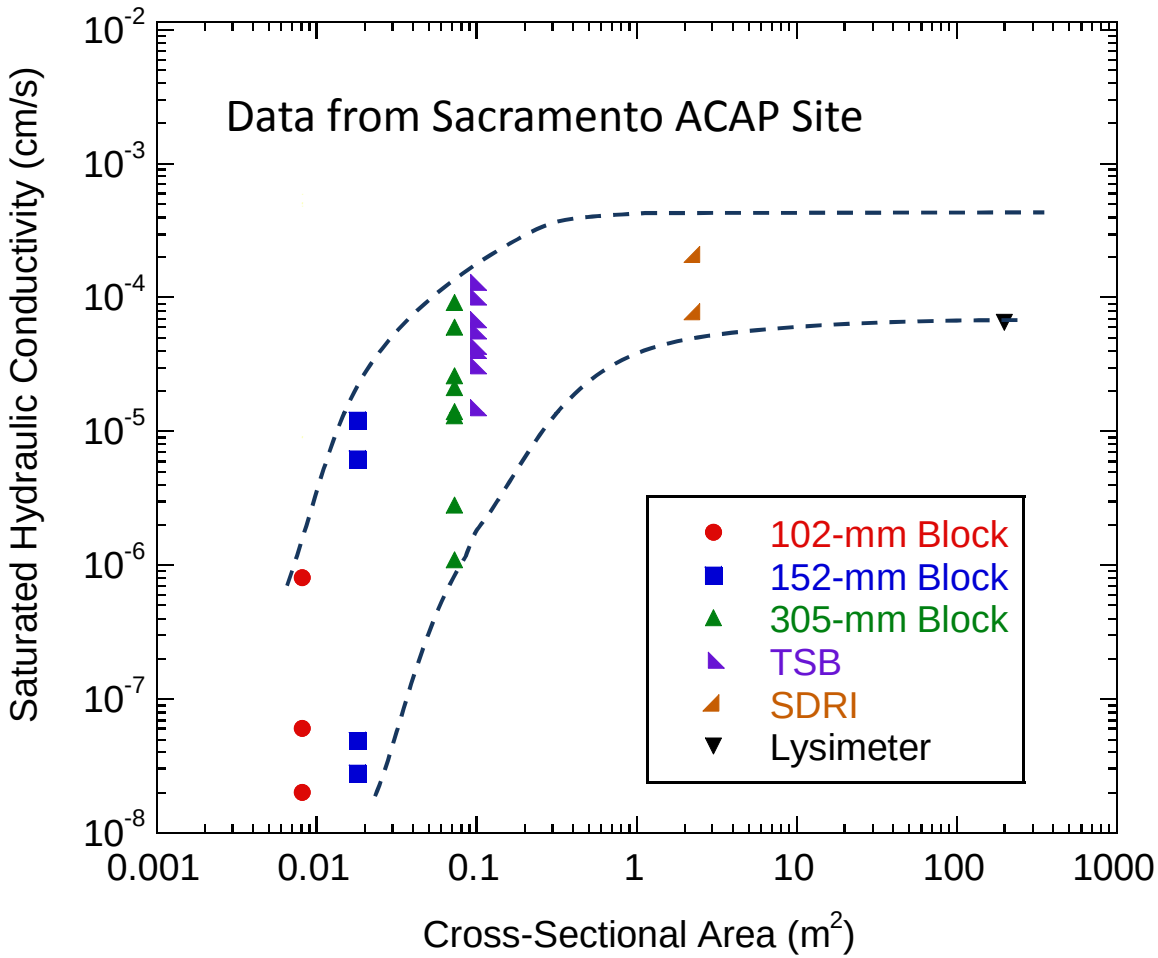
TSB: falling or constant head test in cased borehole

SDRI Being Operated – Iowa Site

TSB Being Installed and Operated – Utah Site

Collecting Block Sample

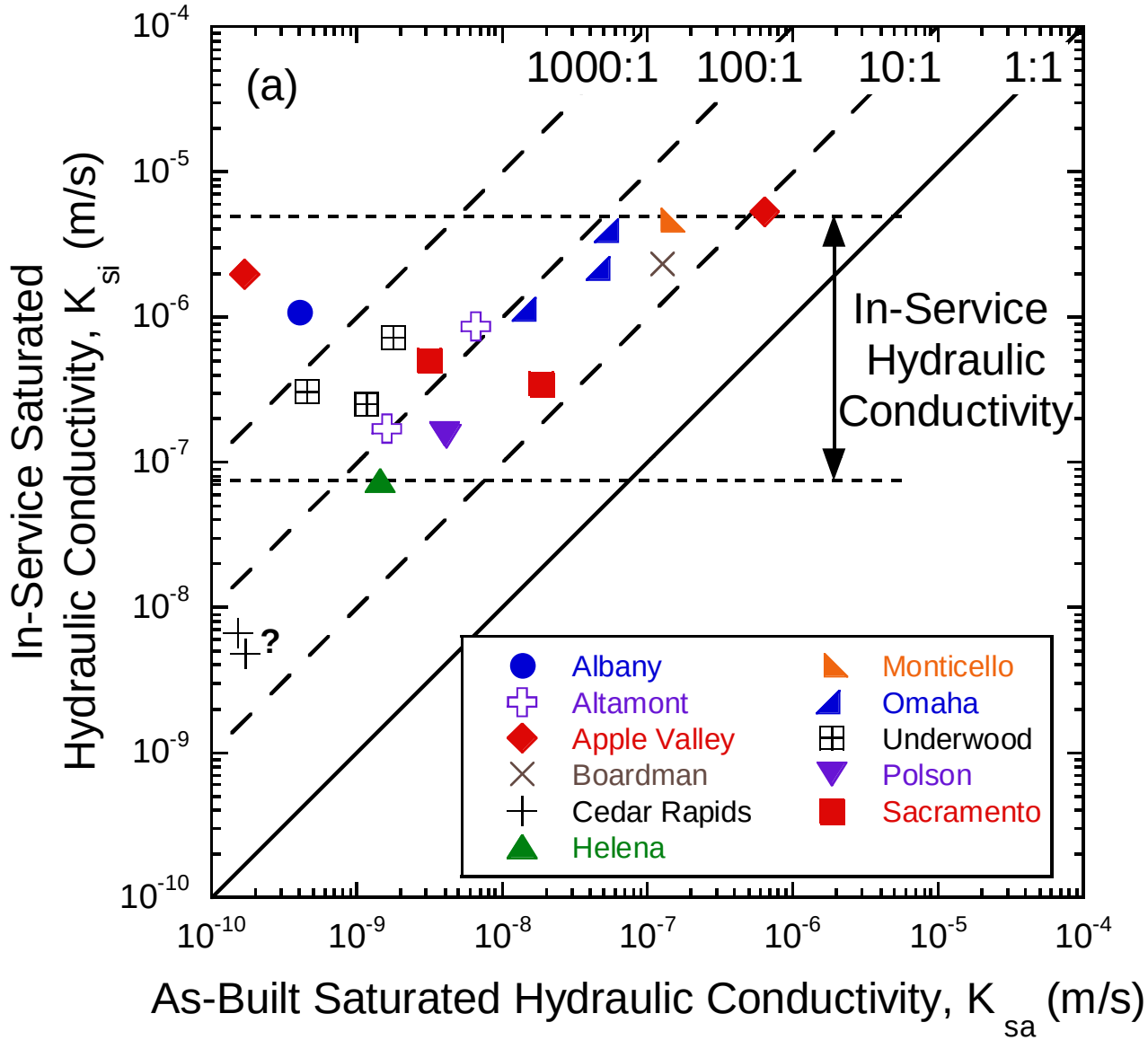
Scale Effect in K_s - Caused by Structure



Hydraulic conductivity increases as more structure incorporated.

At some point, structure adequately represented & field hydraulic conductivity is obtained.

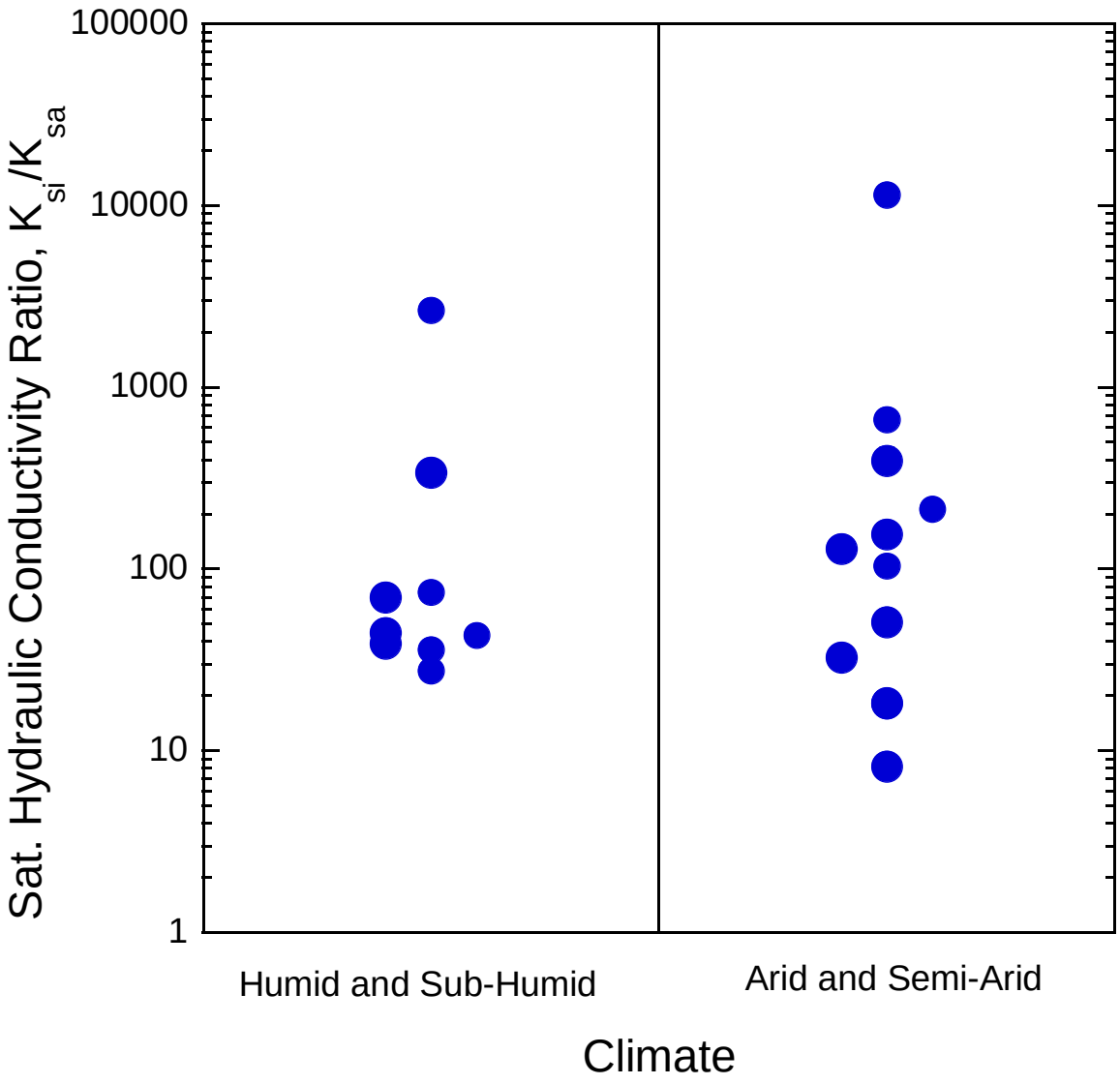
Changes in Sat. Hydraulic Conductivity



If *no* change, data would scatter around 1:1 line

Data coalesce into band with $K_s = 10^{-7} - 10^{-5}$ cm/s independent of initial K_s

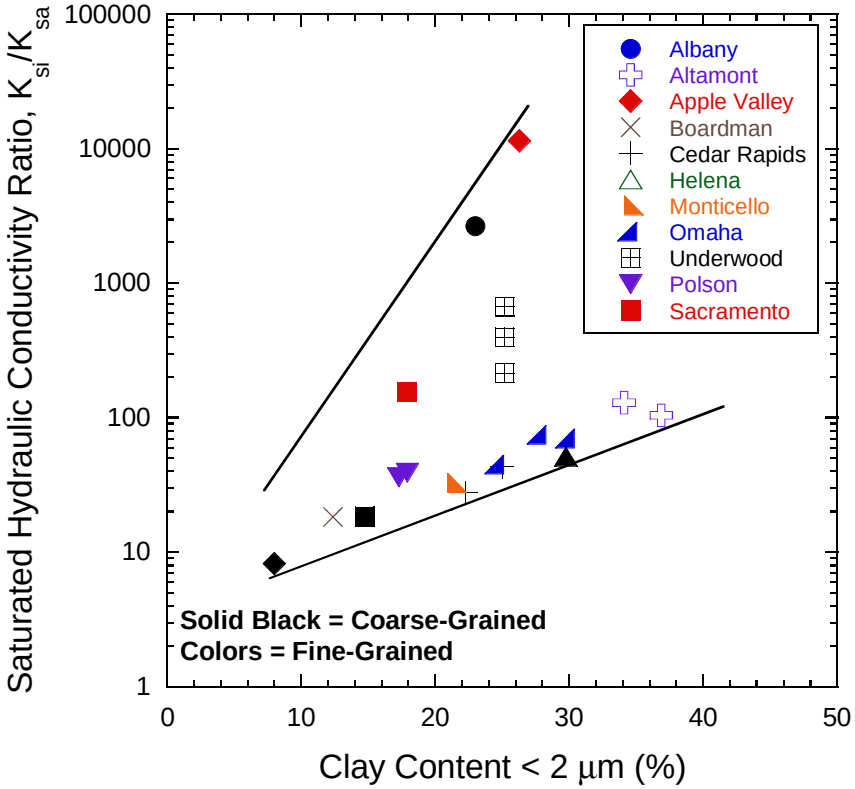
Effect of Climate

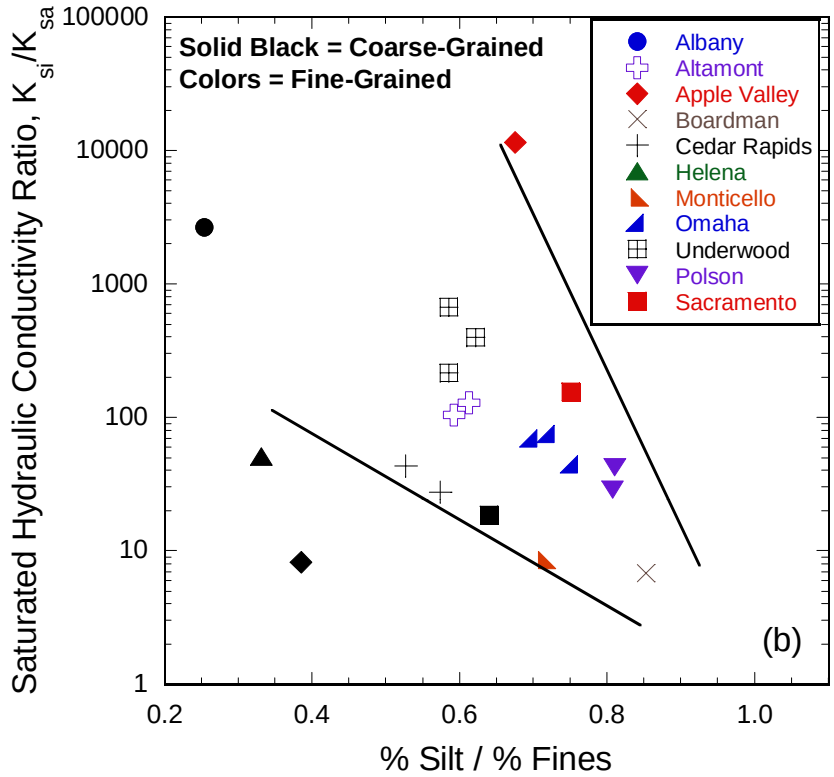


Alterations in Ks often assumed to be unique to drier climates.

Similar increases in Ks for humid and sub-humid climates.

Influence of Soil Composition



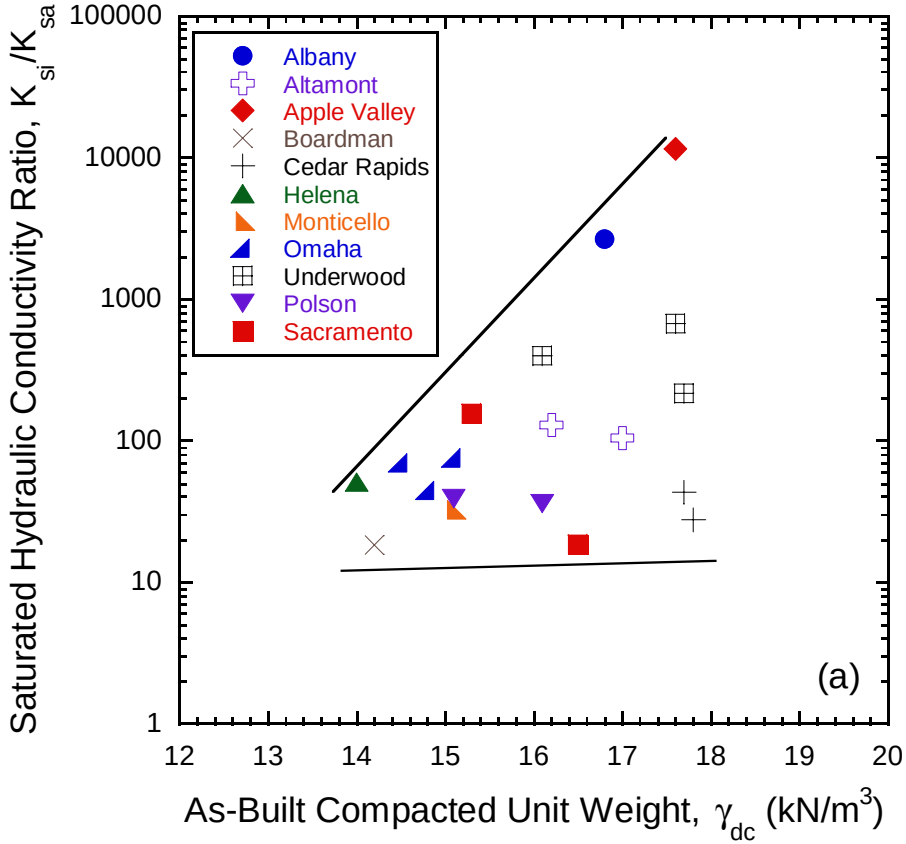


Soils with lower clay fraction more resilient

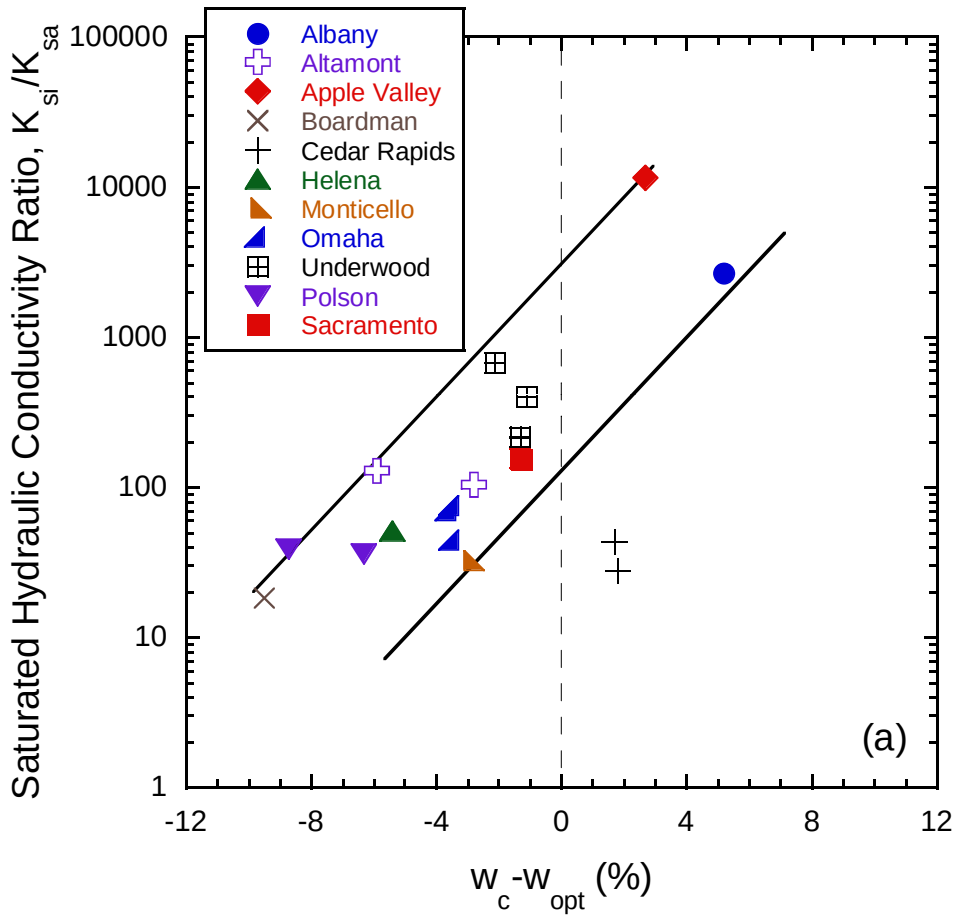
Fine-grained soils with greater silt fraction more resilient

Influence of Placement Condition

Dry Unit Weight



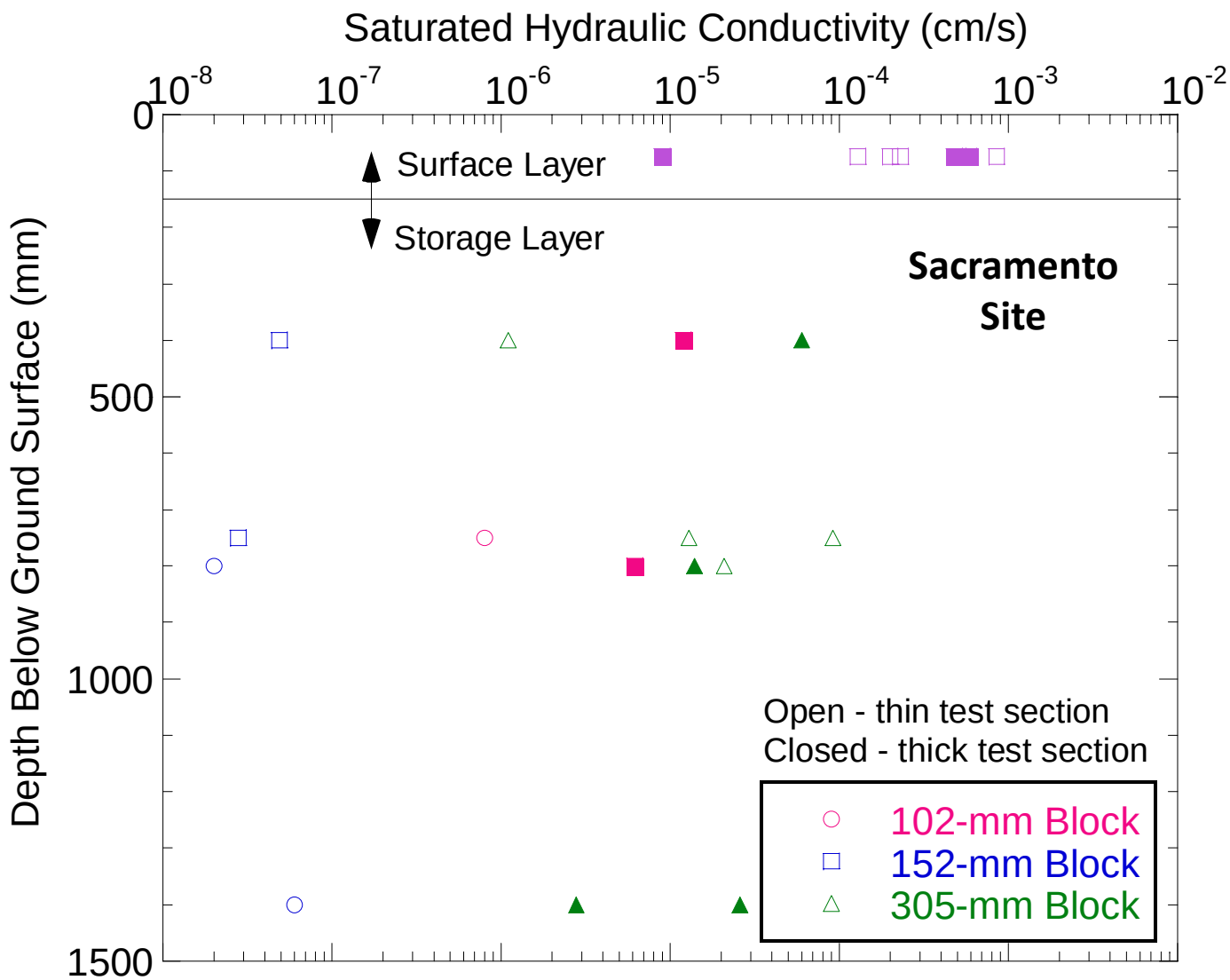
Water Content



Denser soils less resilient … nature loosens dense soils.

Wetter soils are less resilient … nature adds structure.

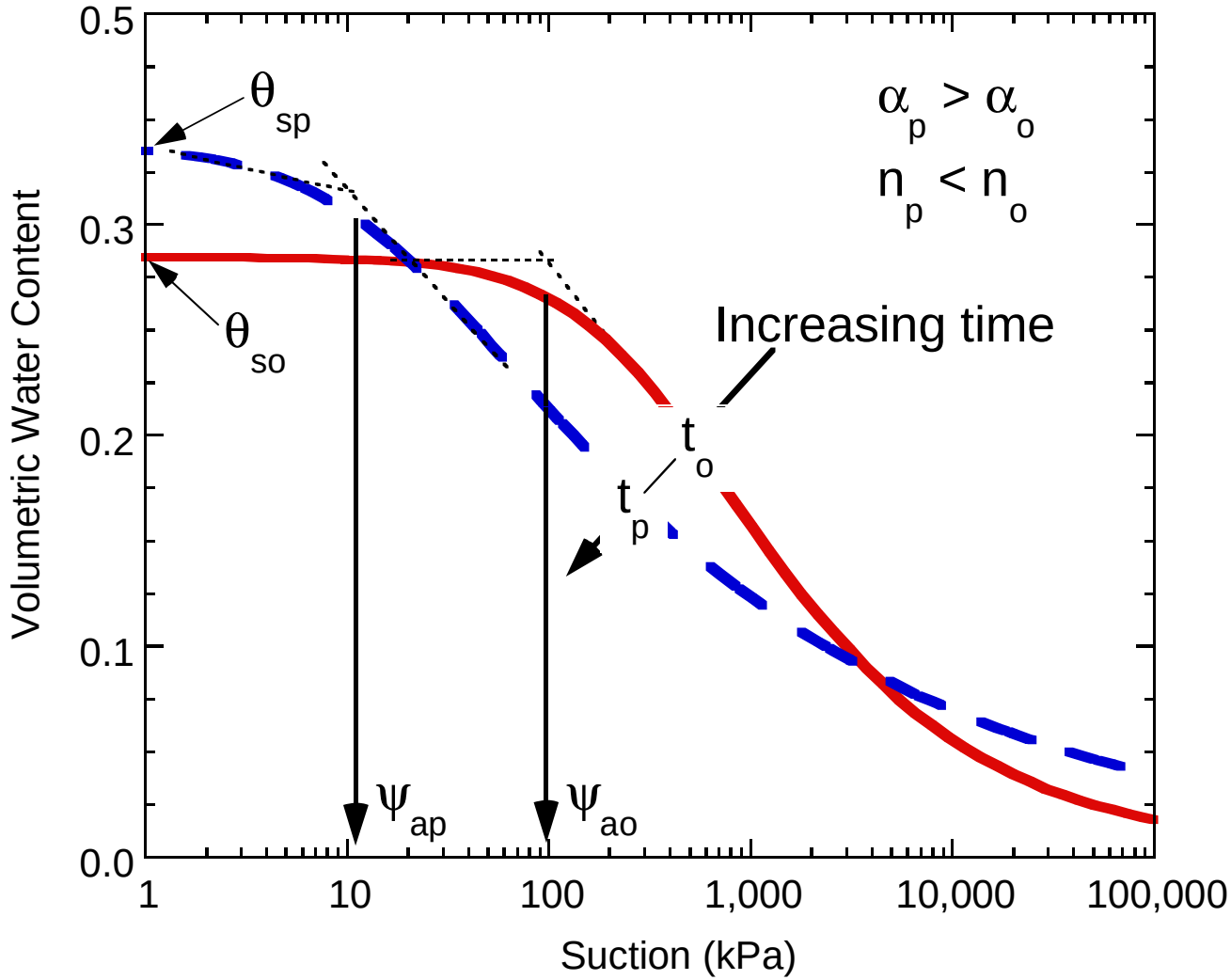
Effect of Depth and Scale on Saturated Hydraulic Conductivity



Radon Barrier – Monticello, UT

Roots seek out water in wet fine-grained soils, e.g., clay radon barriers, even at 1.6-1.9 m depth

Soil-Water Characteristic Curves

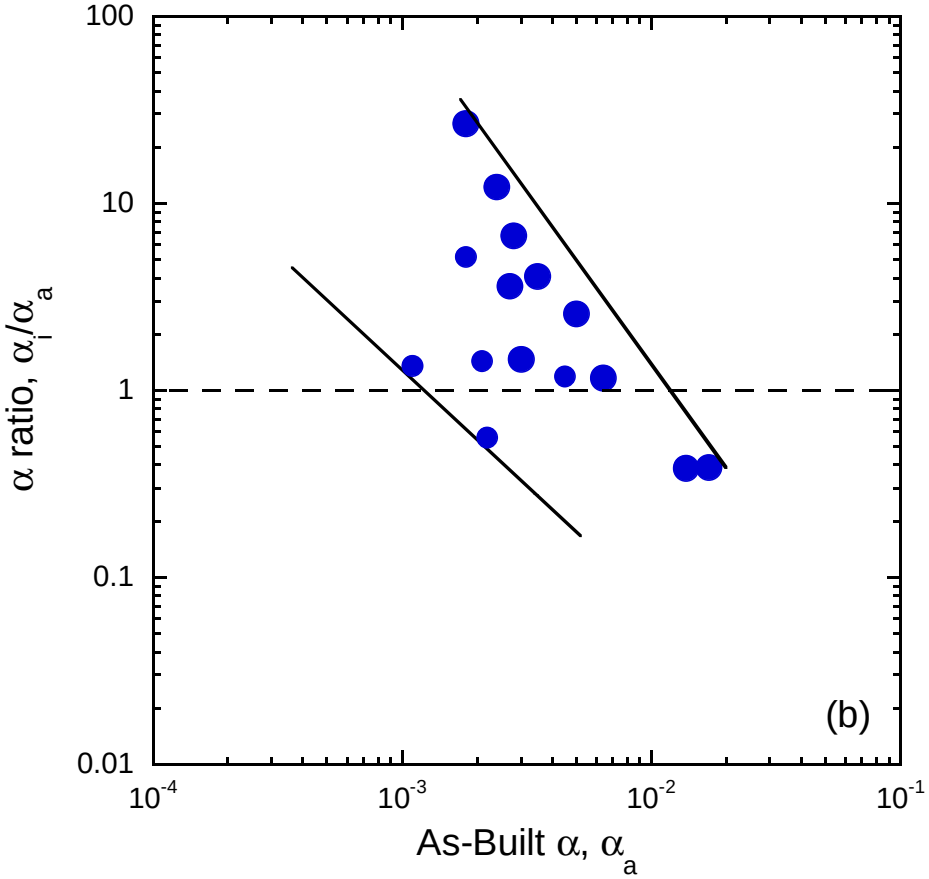


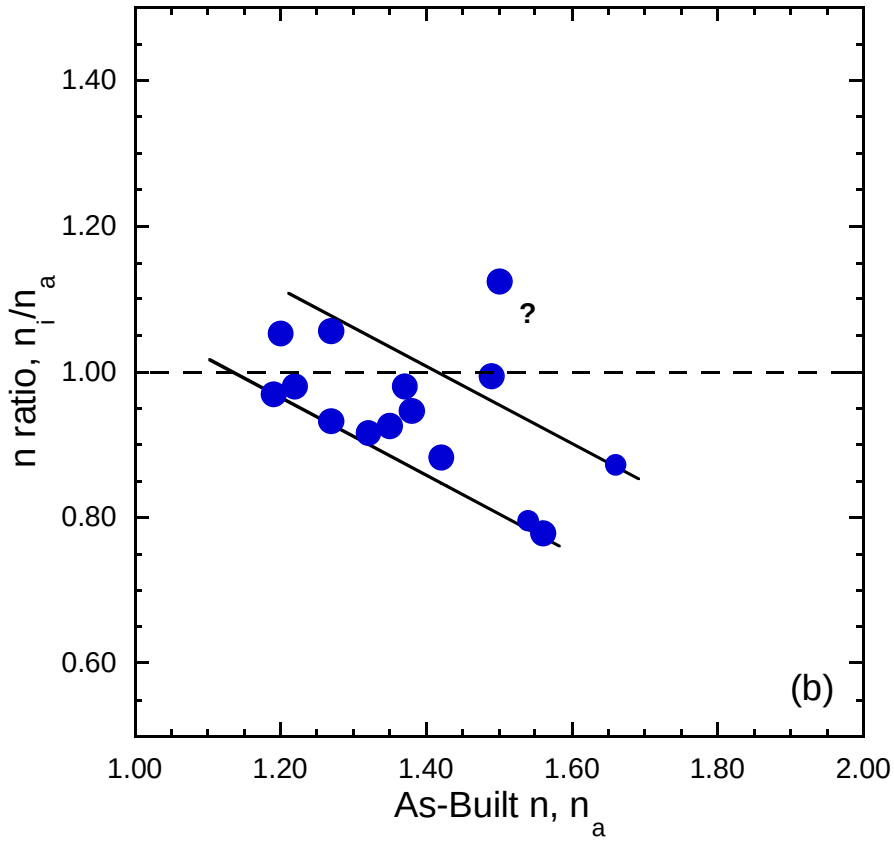
t_o: initial condition

t_p: after pedogenesis

Structure formed by pedogenesis expected to increase ❑$_s$, increase ♋ (lower ⊼$_a$), & decrease n.

Changes to the SWCC Due to Structure

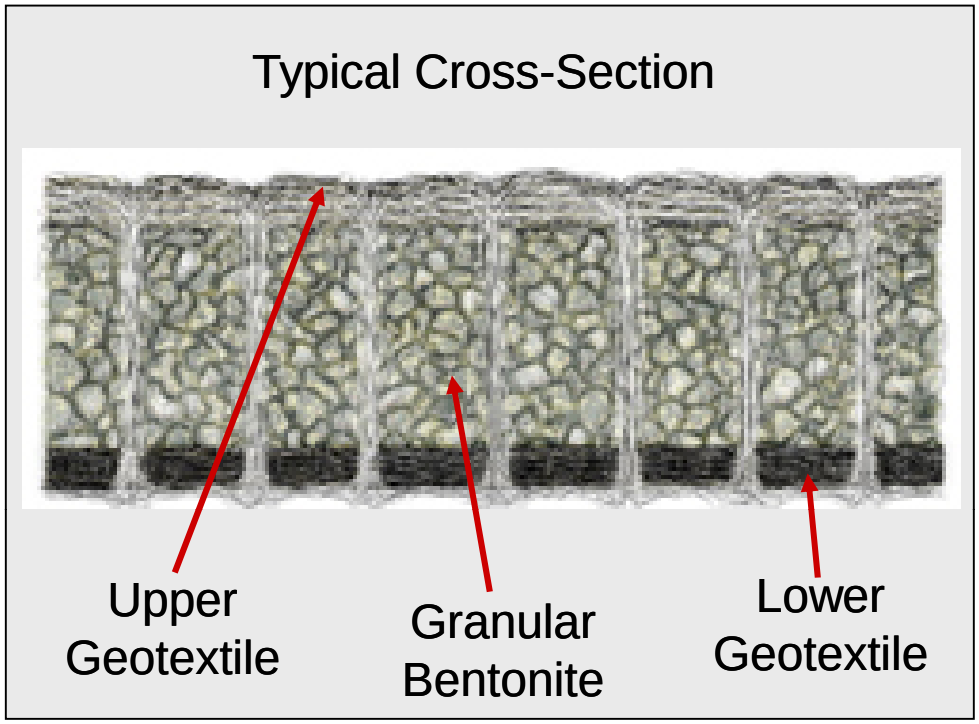




Formation of larger pores in soil structure results in lower air entry pressure (higher ♋) and broader pore size distribution (lower n) … net result is lower water retention. Looser soils (higher initial a and lower initial n) resilient.

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).

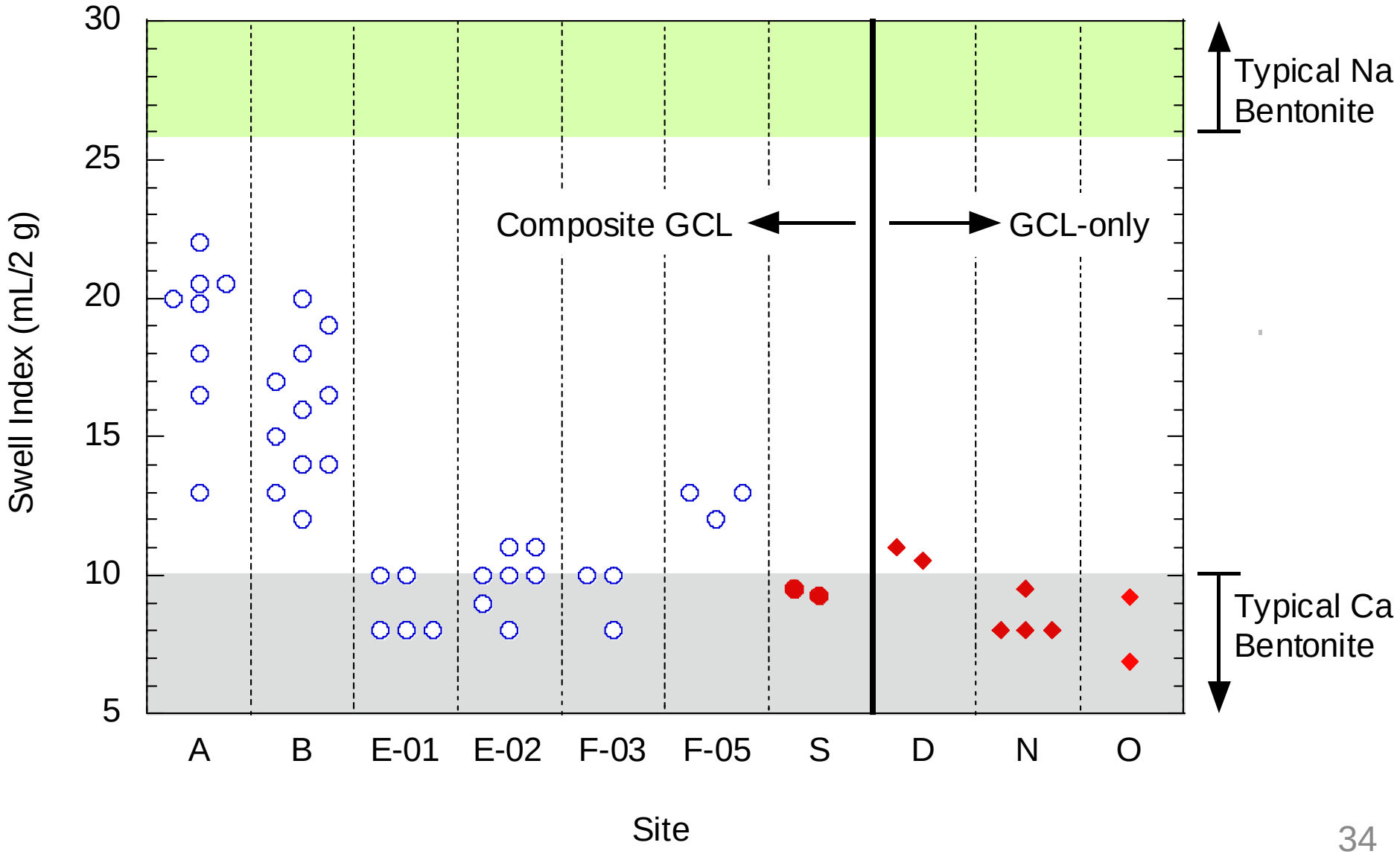


Importance of Bound Cation Valence

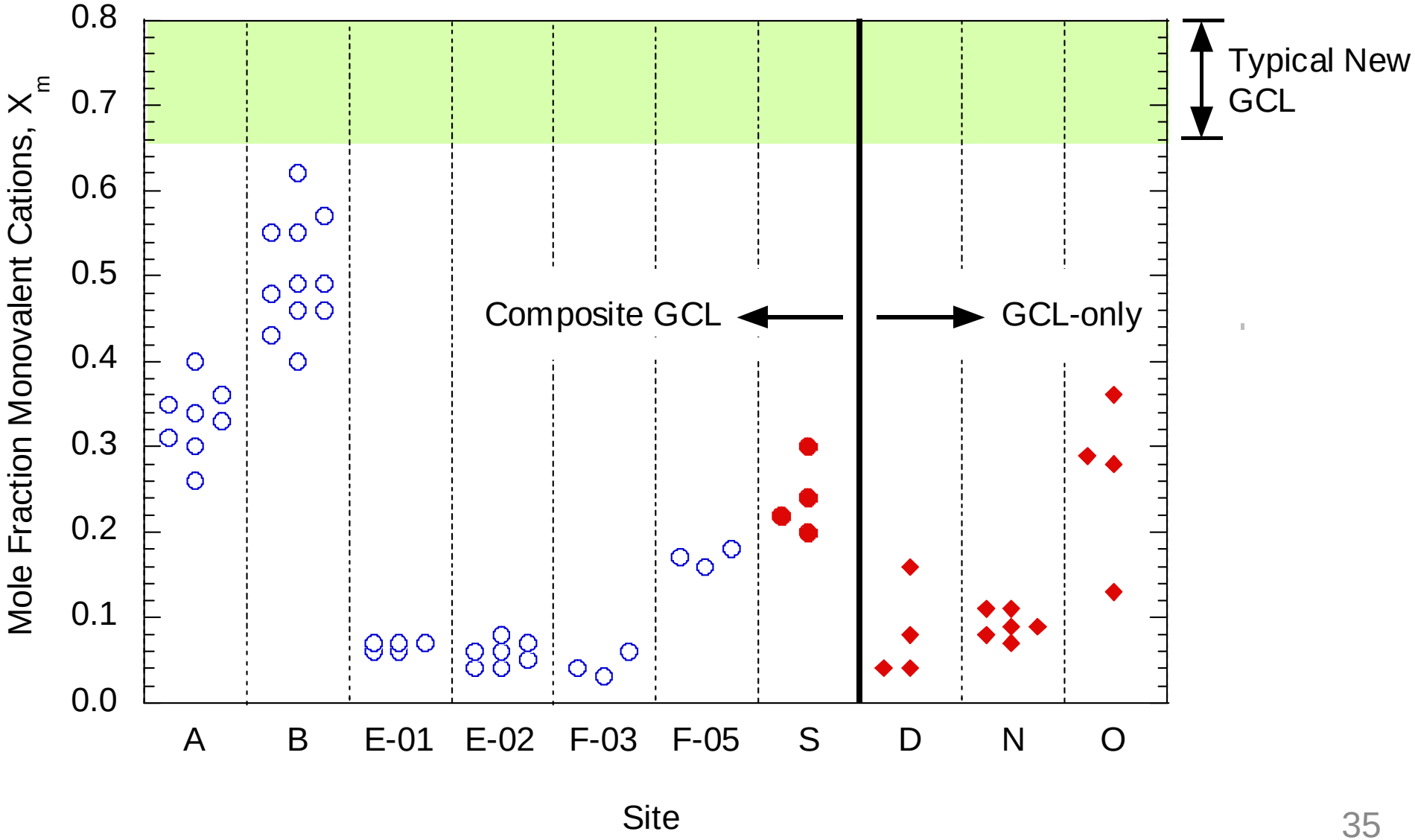
Na-Bentonite in DI Water (monovalent) – crystalline + osmotic hydration

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

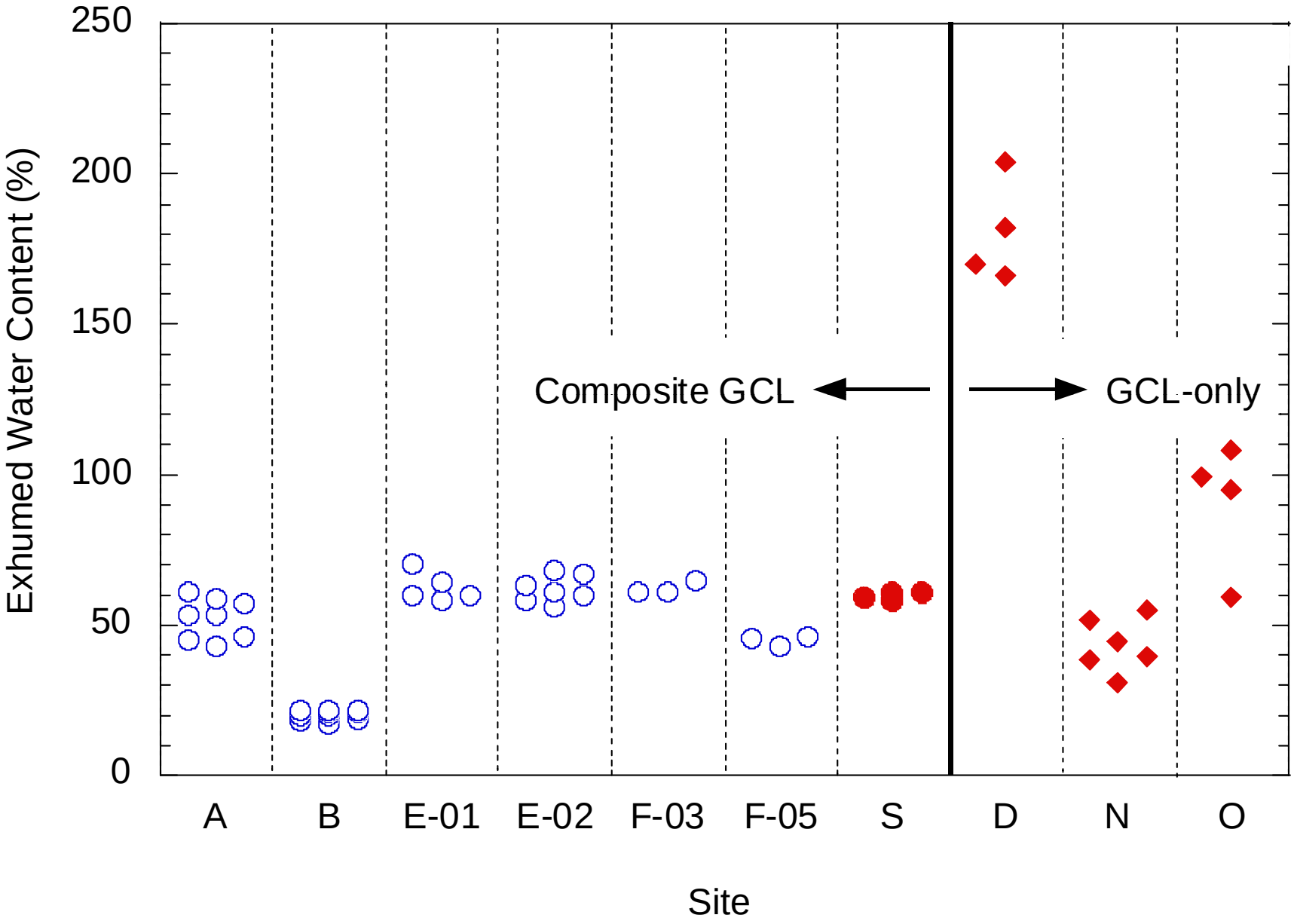
Swell Index (ASTM D 5890)



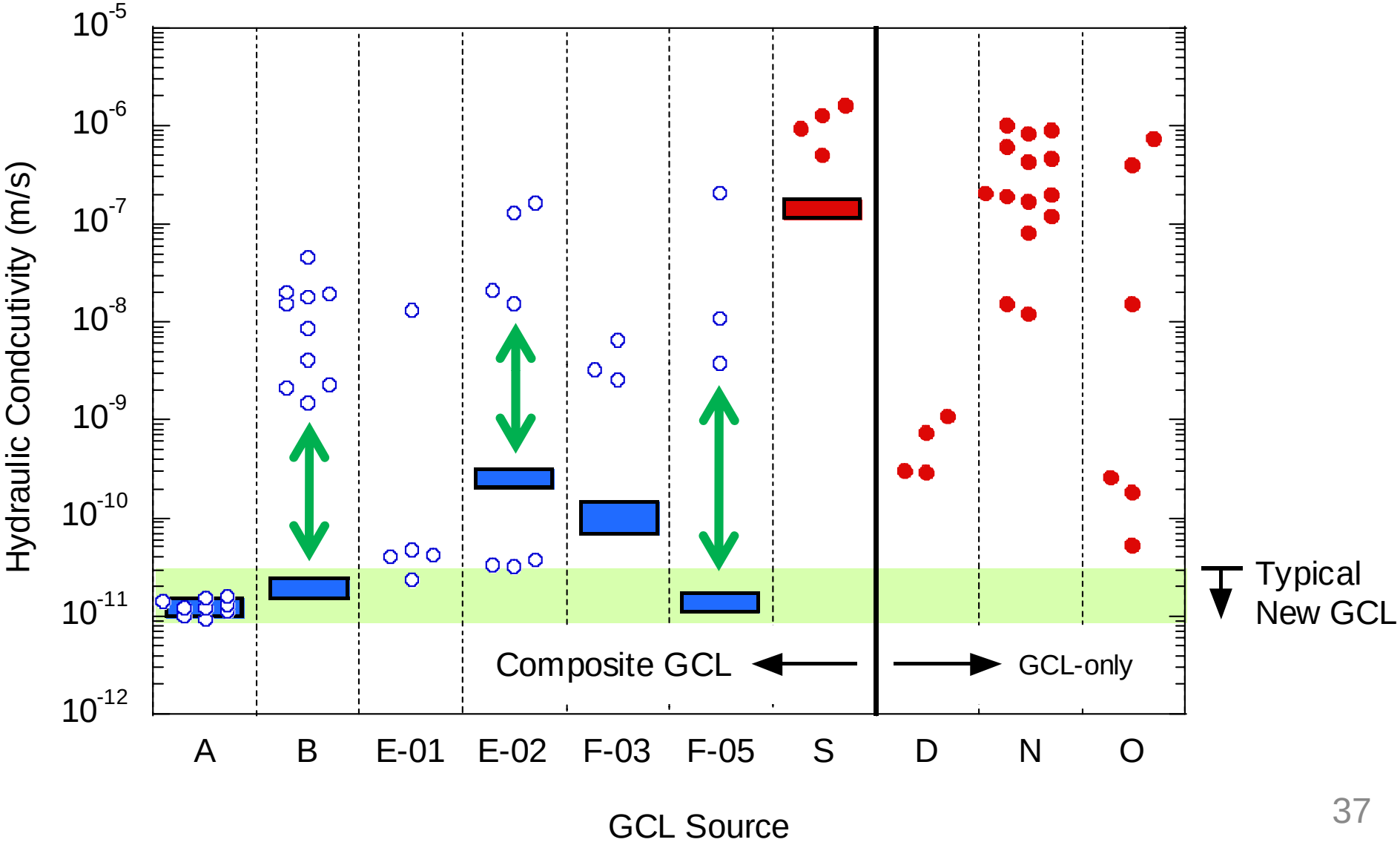
Bound Monovalent Cation Fraction



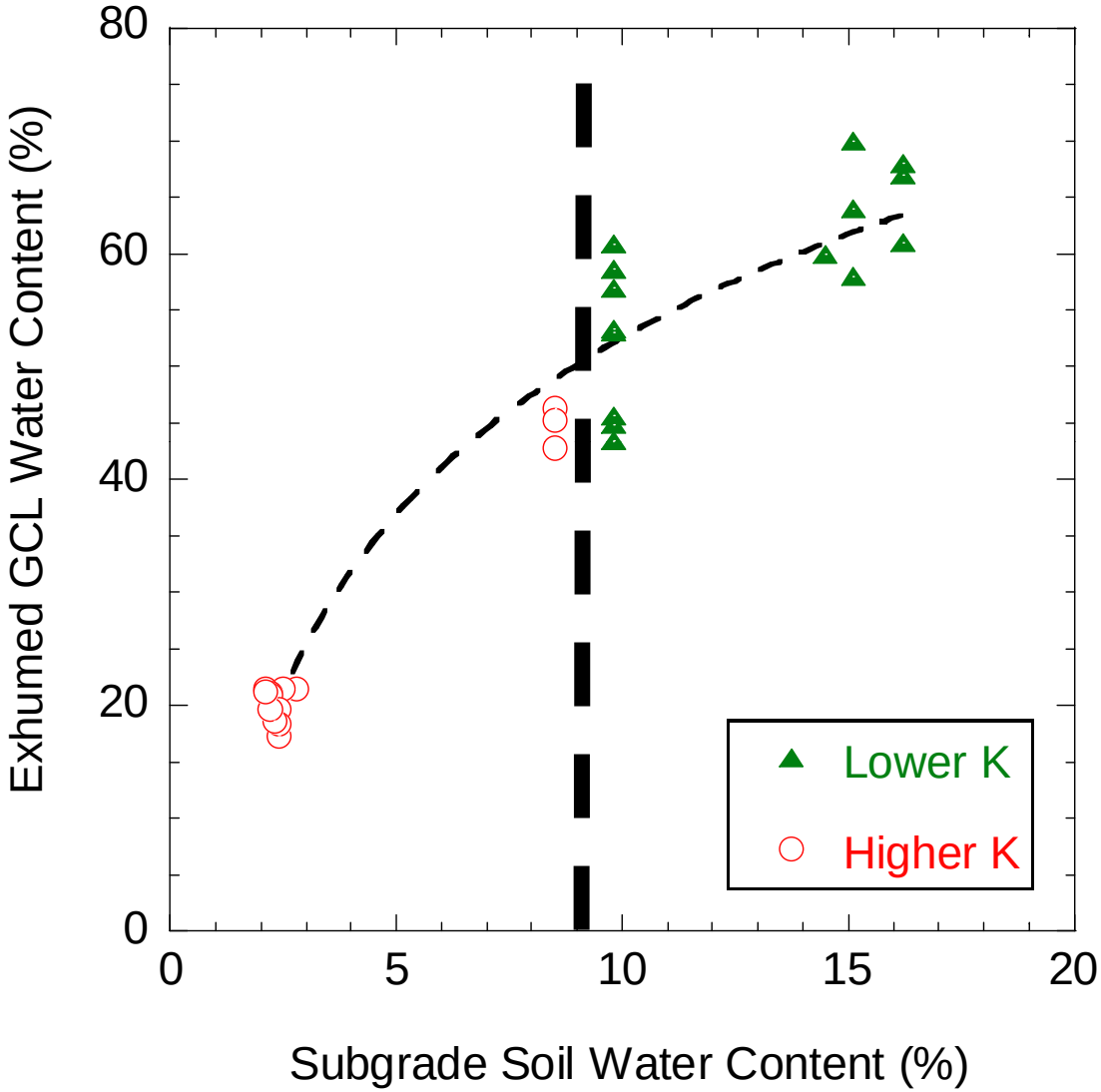
Exhumed Water Content



Hydraulic Conductivity



Importance of Subgrade Water Content



GCL water content increases with subgrade water content.

Recent work has shown that threshold for lower/higher Ks corresponds to subgrades compacted wet vs. dry of optimum.

Lessons Learned – Earthen Barriers

- Nature alters engineered condition in short period: dense soils become looser and unstructured soils gain structure.
- Hydraulic properties of engineered fine-textured soils become similar over time, regardless of initial condition or climate. Use these longer term properties for design and modeling.
- Recognize that soil properties will change and construct covers to mimic the longer term condition.
- Chose soils with lower clay content if possible to ensure greater resiliency.

Lessons Learned – GCLs

- GCLs can become very permeable if they undergo wet-dry cycling concurrently with cation exchange.
- Geomembranes can protect GCLs from alterations in hydraulic conductivity. However, GCL must be hydrated rapidly and then protected from desiccation.
- Adequate hydration requires subgrade compacted wet of optimum water content.