Performance of baseball infield soil mixtures using novel laboratory tests

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The Pennsylvania State University

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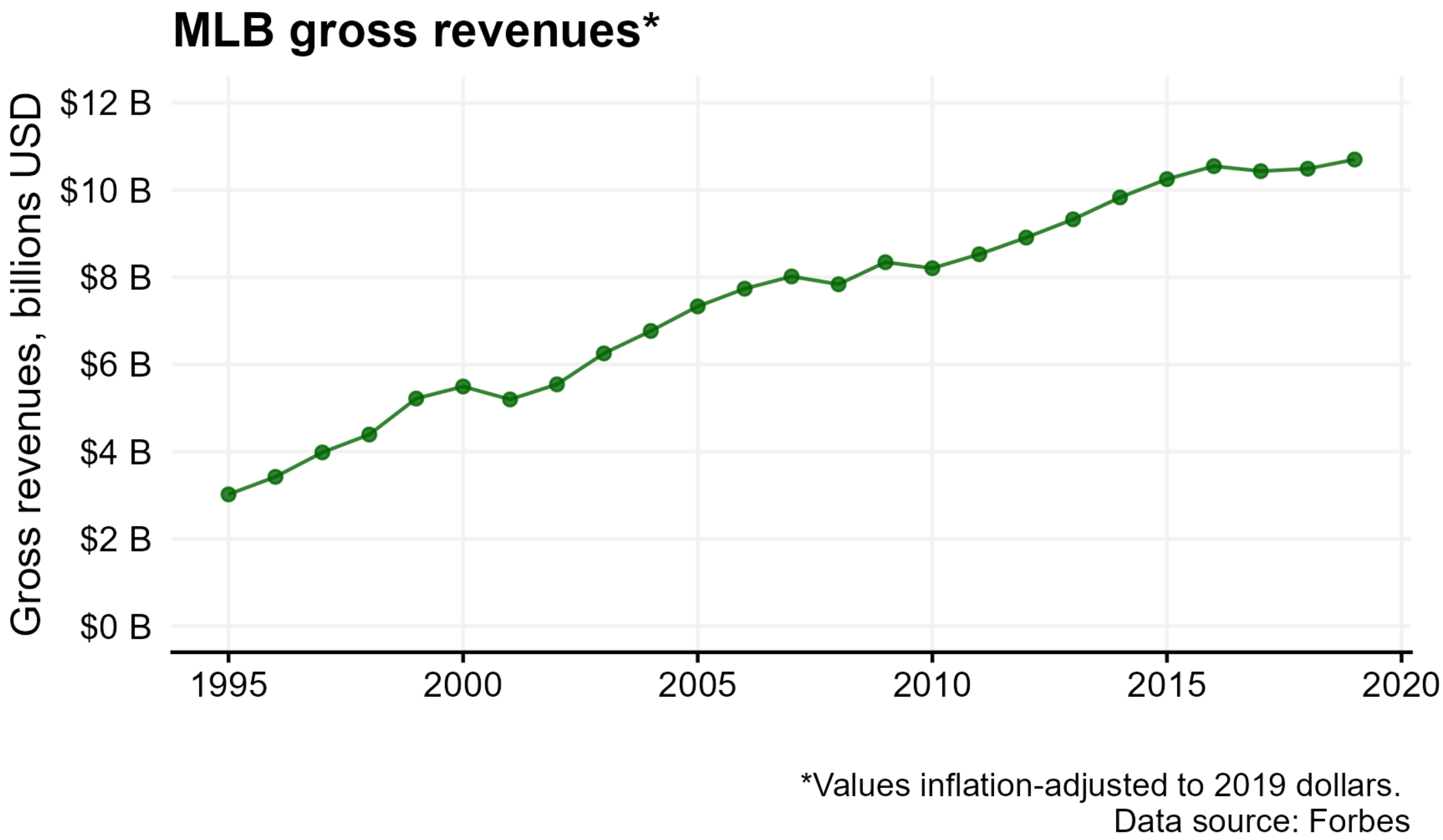
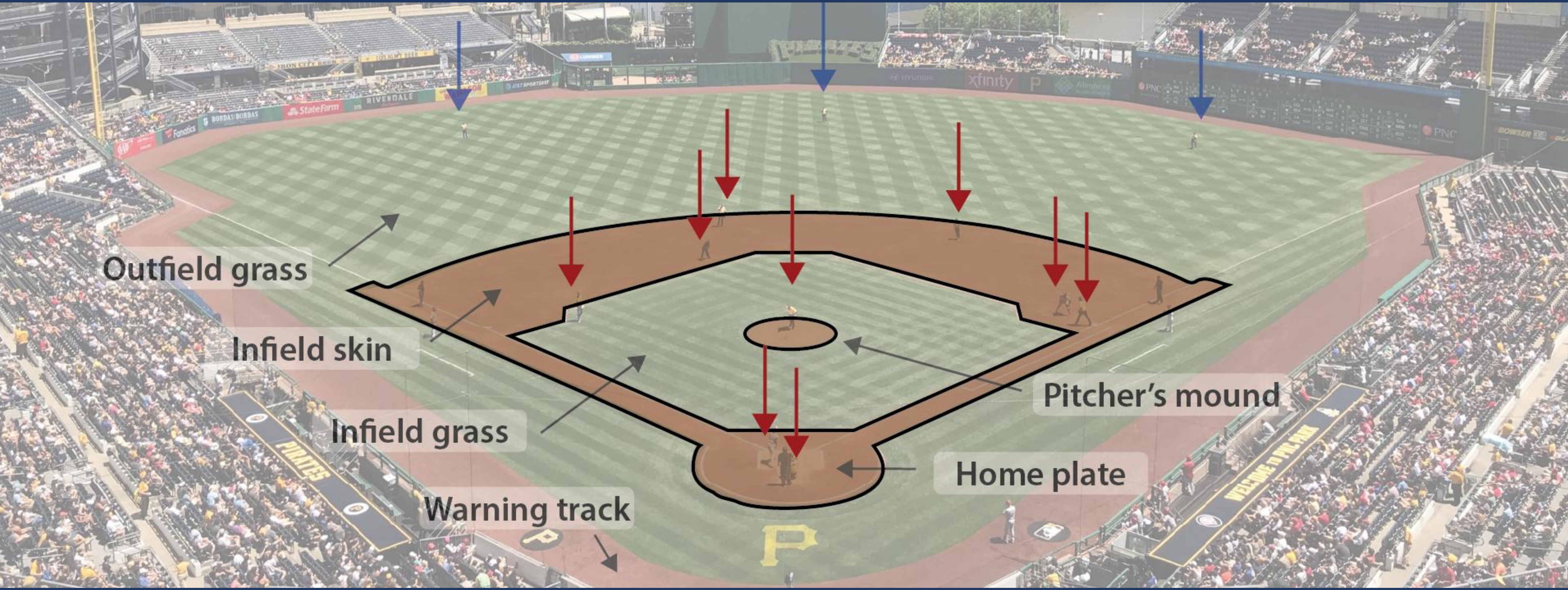
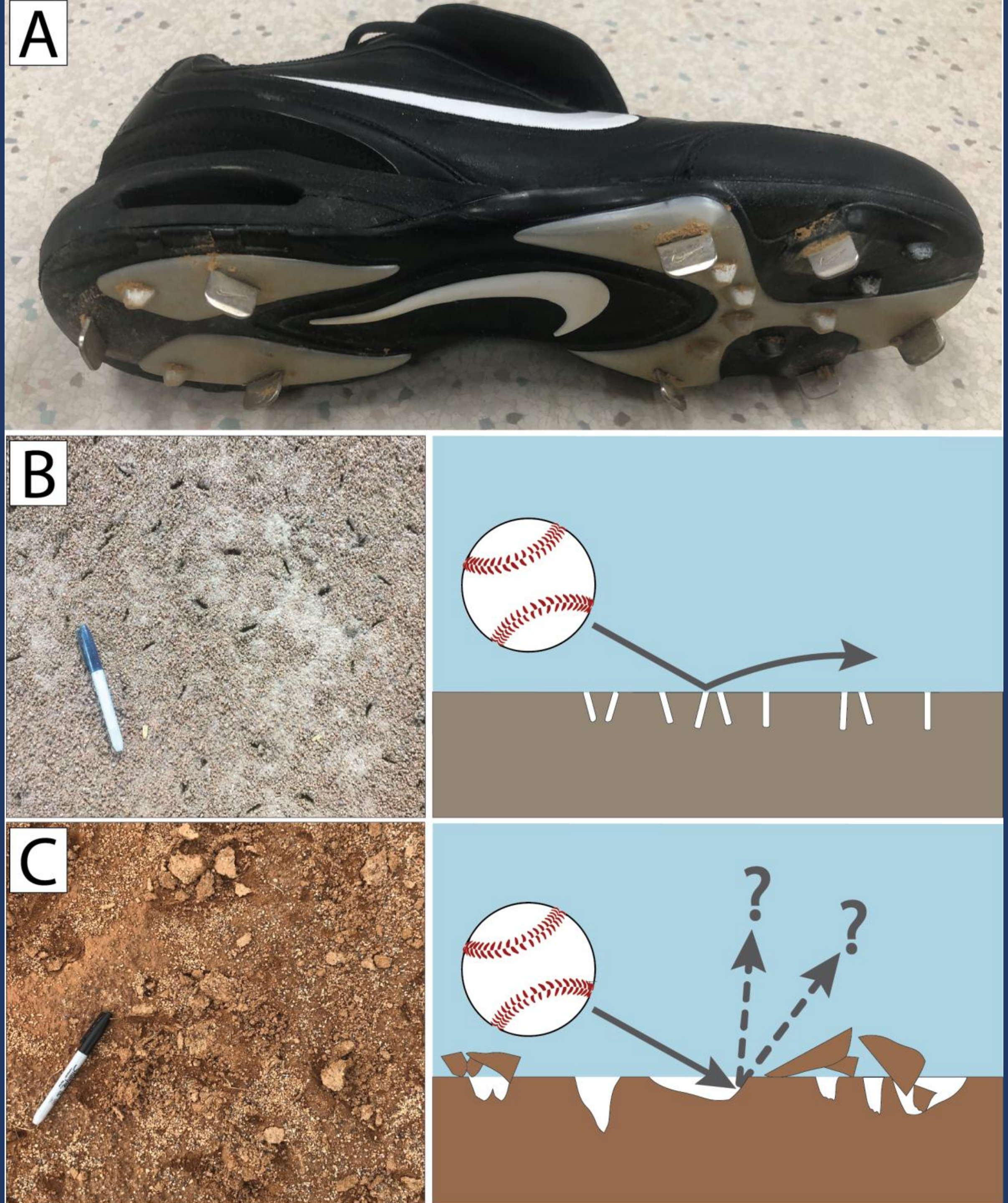
Clearway
Community Energy
Yuengling
LAGER
BUCAROOS
KIDS CLUB
SIGN UP TODAY
AHN
KE'BRYAN HAYES
.295
DAVIES
3 PITCHES
1-2
0
0
1


MLB gross revenues*
Gross revenues, billions USD
$12 B
$10 B
$8 B
$6 B
$4 B
$2 B
$0 B
1995
2000
2005
2010
2015
2020
*Values inflation-adjusted to 2019 dollars.
Data source: Forbes

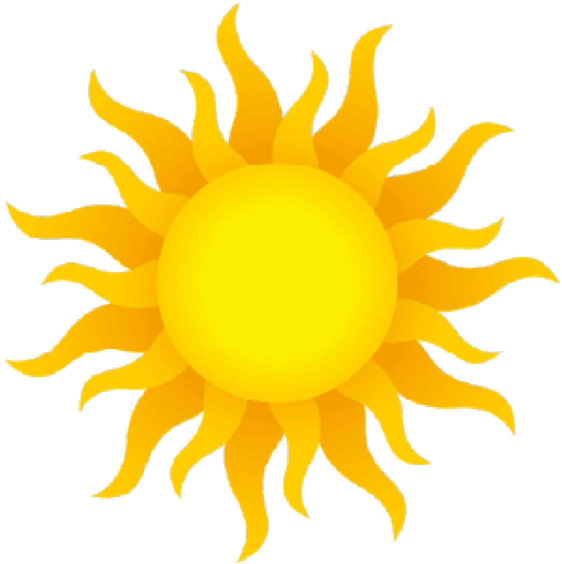

UTLEY
26
ANGELS
27
$37 million


Outfield grass
Infield skin
Infield grass
Warning track
Pitcher's mound
Home plate


A
B
C
?
?


FASTPLAY
IC LIGHT BEER
RIVENDALE
Ice Cream
379
WHO BUT
W.B.MASON
84 LUMBER

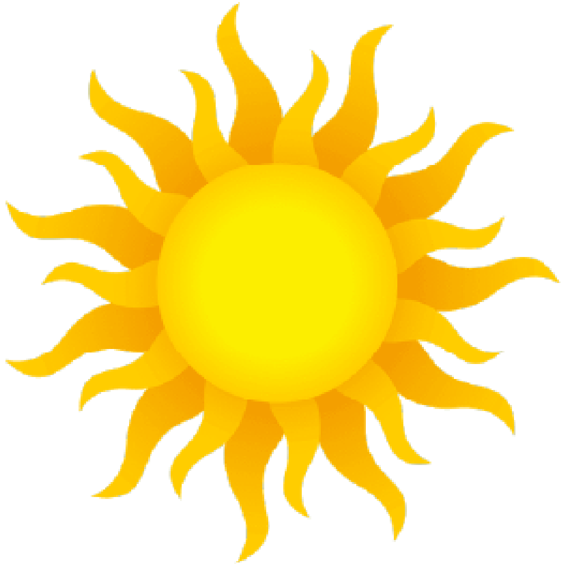
Better soil means easier maintenance



small range | difficult to manage

wider range | easier to manage

Better soil means easier maintenance



small range | difficult to manage

wider range | easier to manage

But where do these thresholds lie??

Current ideas

- Total sand (55-75 %)
- Sand sizes (>2/3 medium + coarser)
- Silt-to-clay ratio (0.5-1)

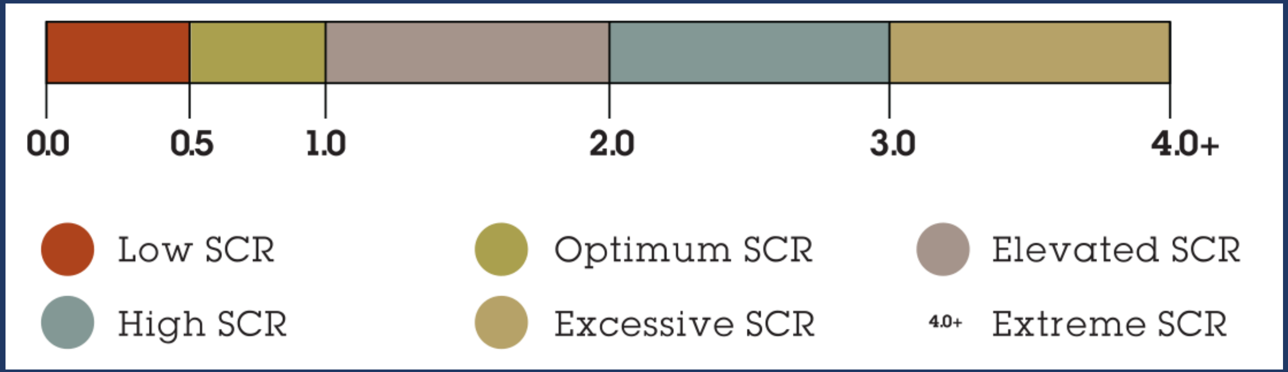


Figure credit: DuraEdge Products

What happens when the soil gets wet?

Problem statement

- Historically, building and maintaining the infield skin has been considered an art form.

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- There is no available research on the cleat-in/cleat-out concept - specifically how it is governed by mixture components AND changes in water content.
- But in order to test the soil, we first need something to measure!

Objectives

- Develop novel laboratory tests which identify:
  1. Lower boundary - water content corresponding to cleat-in/cleat-out threshold
  2. Upper boundary - water content at which the soil can no longer provide adequate shear strength

- Apply new tests to experimental mixtures; evaluate effects of sand content and clay mineralogy on threshold water contents

6 chapters:

- Cleat-mark method development
- Cleat-mark mixtures
- Toughness method development
- Toughness mixtures
- Sand properties effects on Atterberg limits (Parts I and II)

Chapter 1

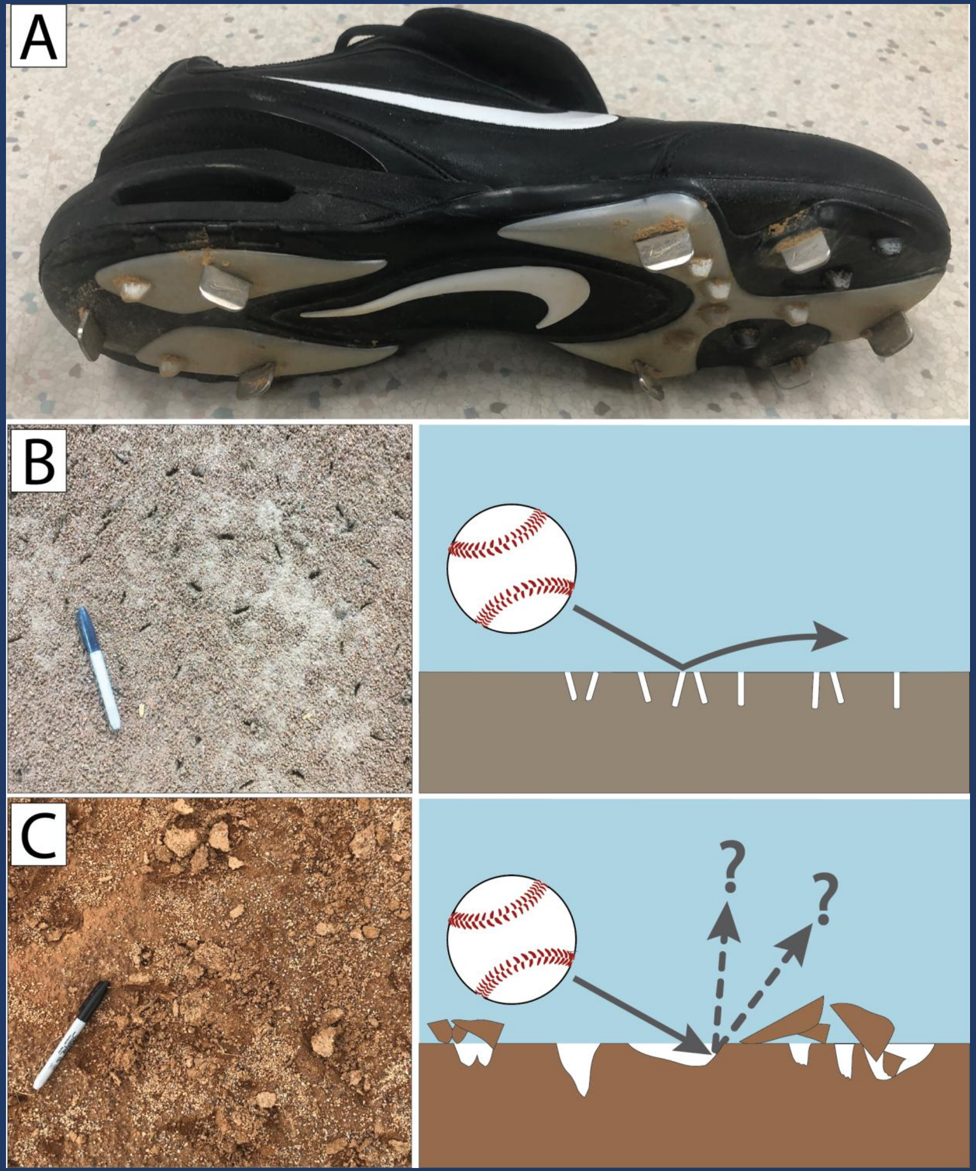
A laboratory method for measuring disturbance of baseball infield soil surfaces by cleated footwear

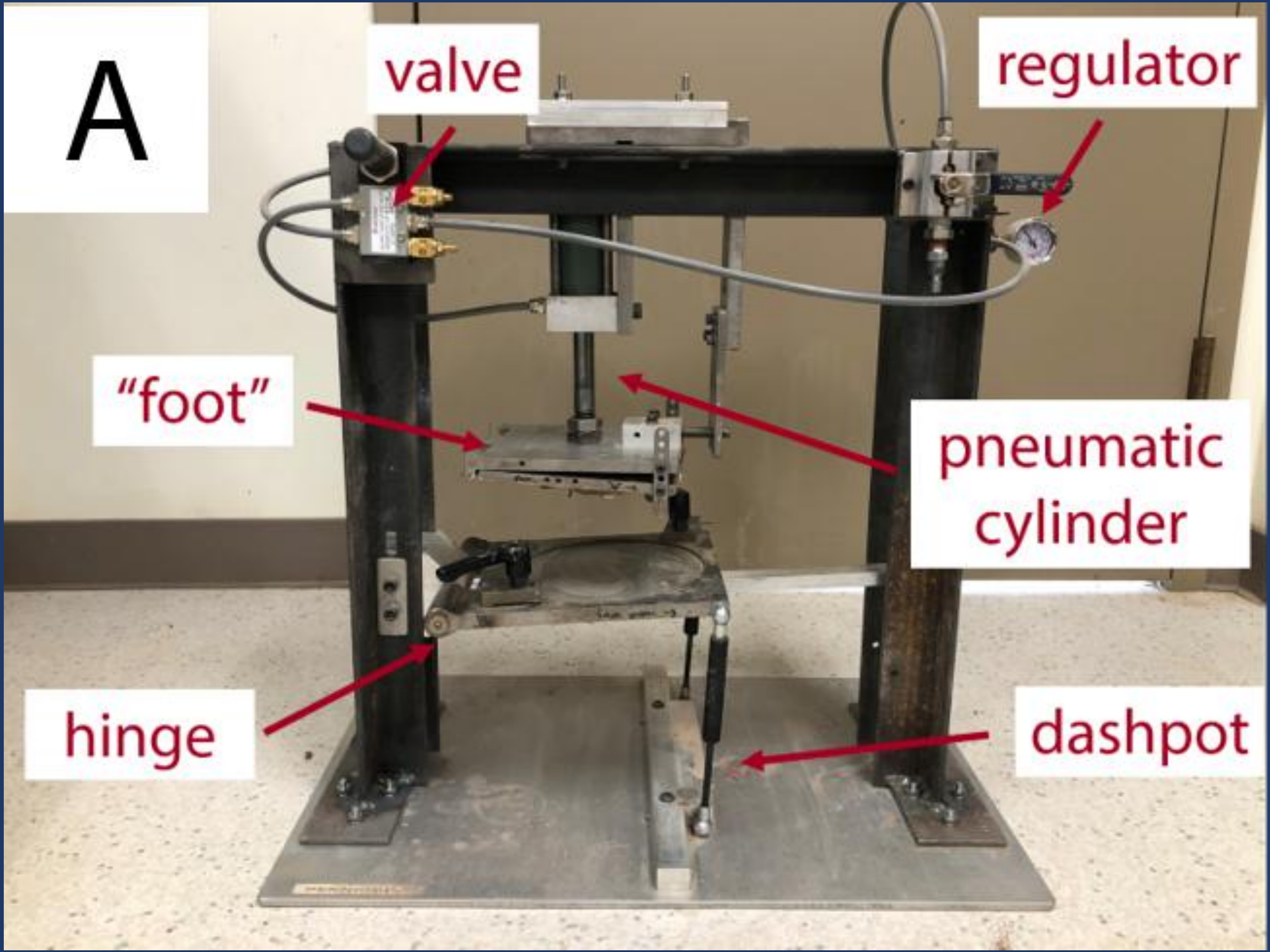
Submitted to *Geotechnical Testing Journal*

*What happens when the soil ~~gets wet~~ **dries out**?*

Objective

- Create a laboratory method to measure *water content corresponding to the cleat-in/cleat-out threshold*




A
valve
regulator
"foot"
pneumatic cylinder
hinge
dashpot


B


C

Desirable (ductile i.e. cleat-in/cleat-out)

Undesirable (brittle i.e. chipping/fracturing)

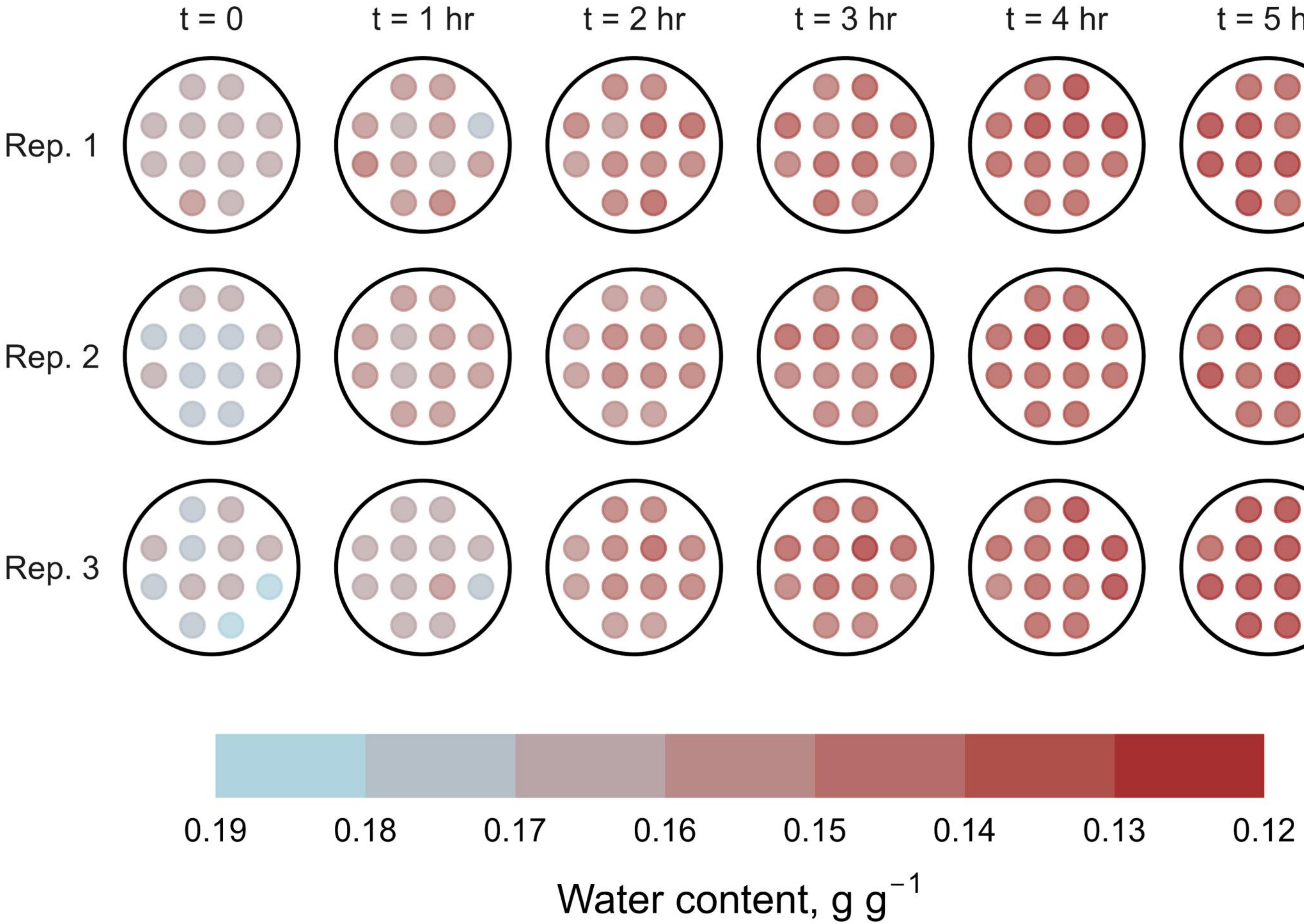
Desirable (ductile i.e. cleat-in/cleat-out)

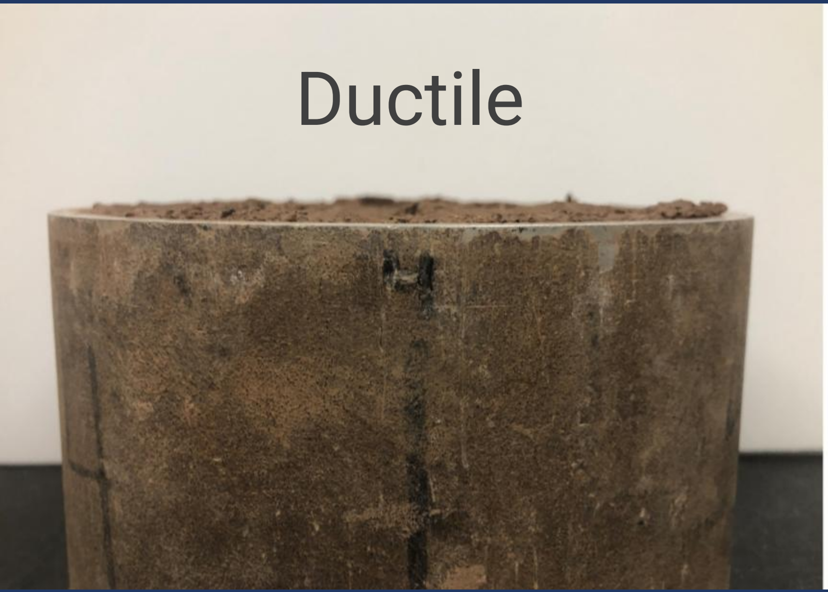
Undesirable (brittle i.e. chipping/fracturing)

The device simulates pro athlete loads

- Peak load ~ 2.5x body weight (Kent et al., 2012)
- Load duration ~ 100 ms (Nigg et al., 1984)
- Loading angle 70-85° (Donatelli et al., 1999)


20
COUNT


t = 0
t = 1 hr
t = 2 hr
t = 3 hr
t = 4 hr
t = 5 hr
Rep. 1
Rep. 2
Rep. 3
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
Water content, g g−1

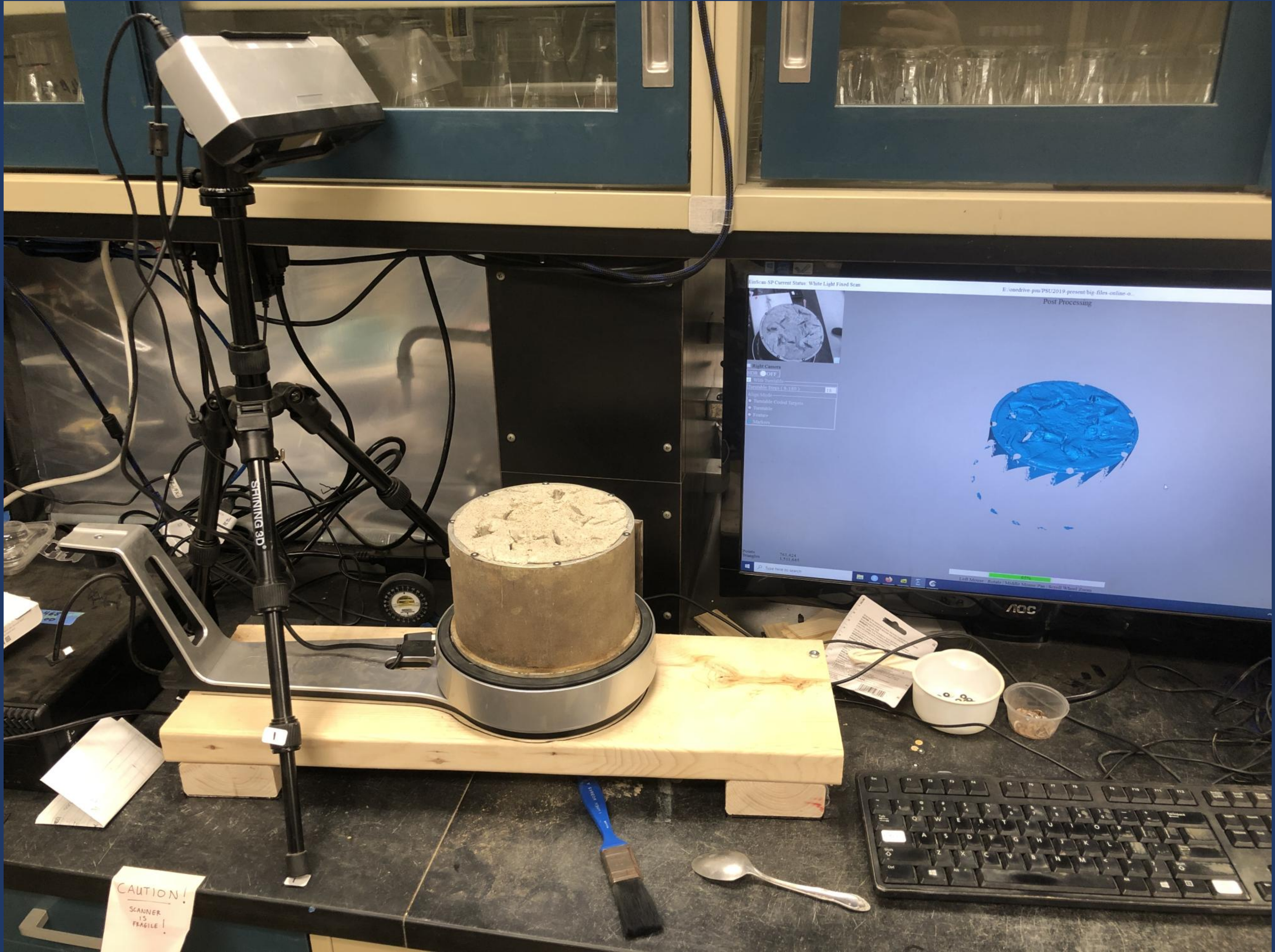

Ductile

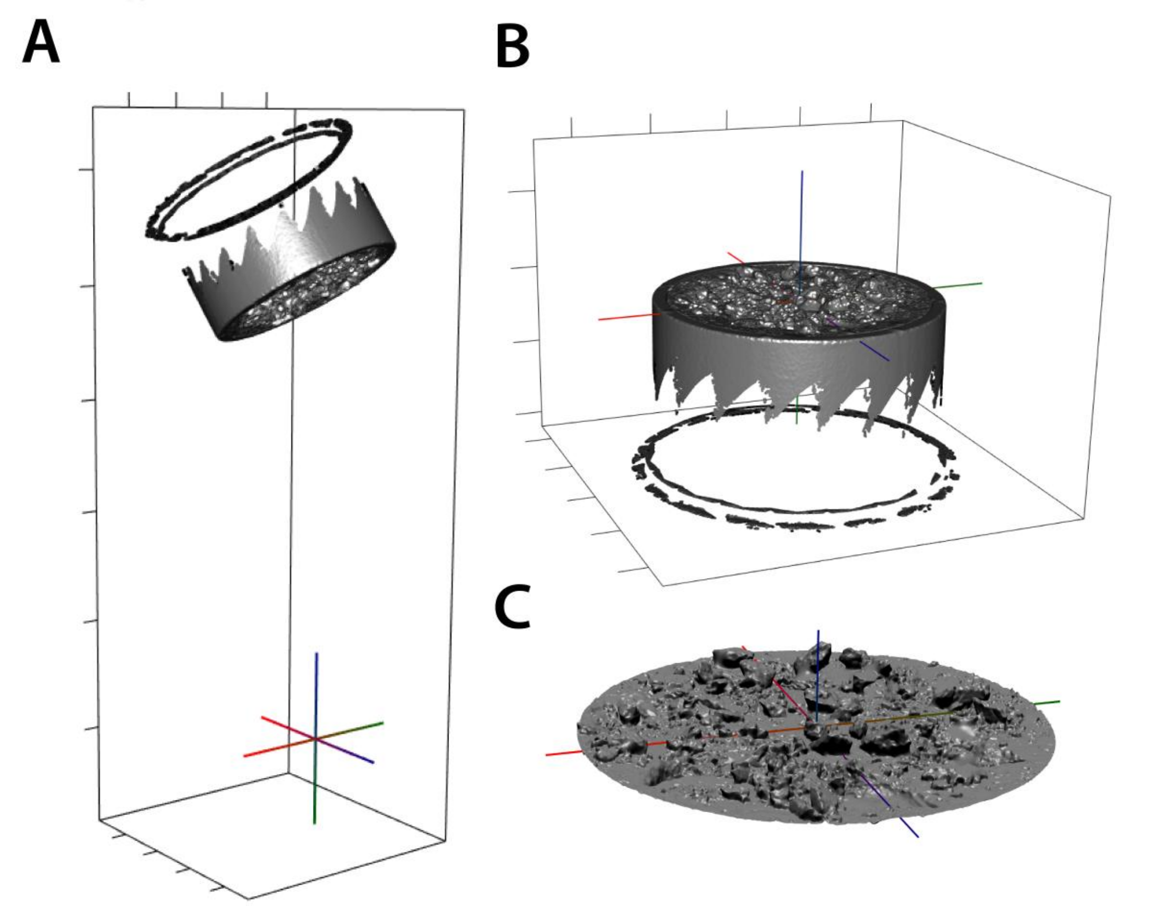

Intermediate

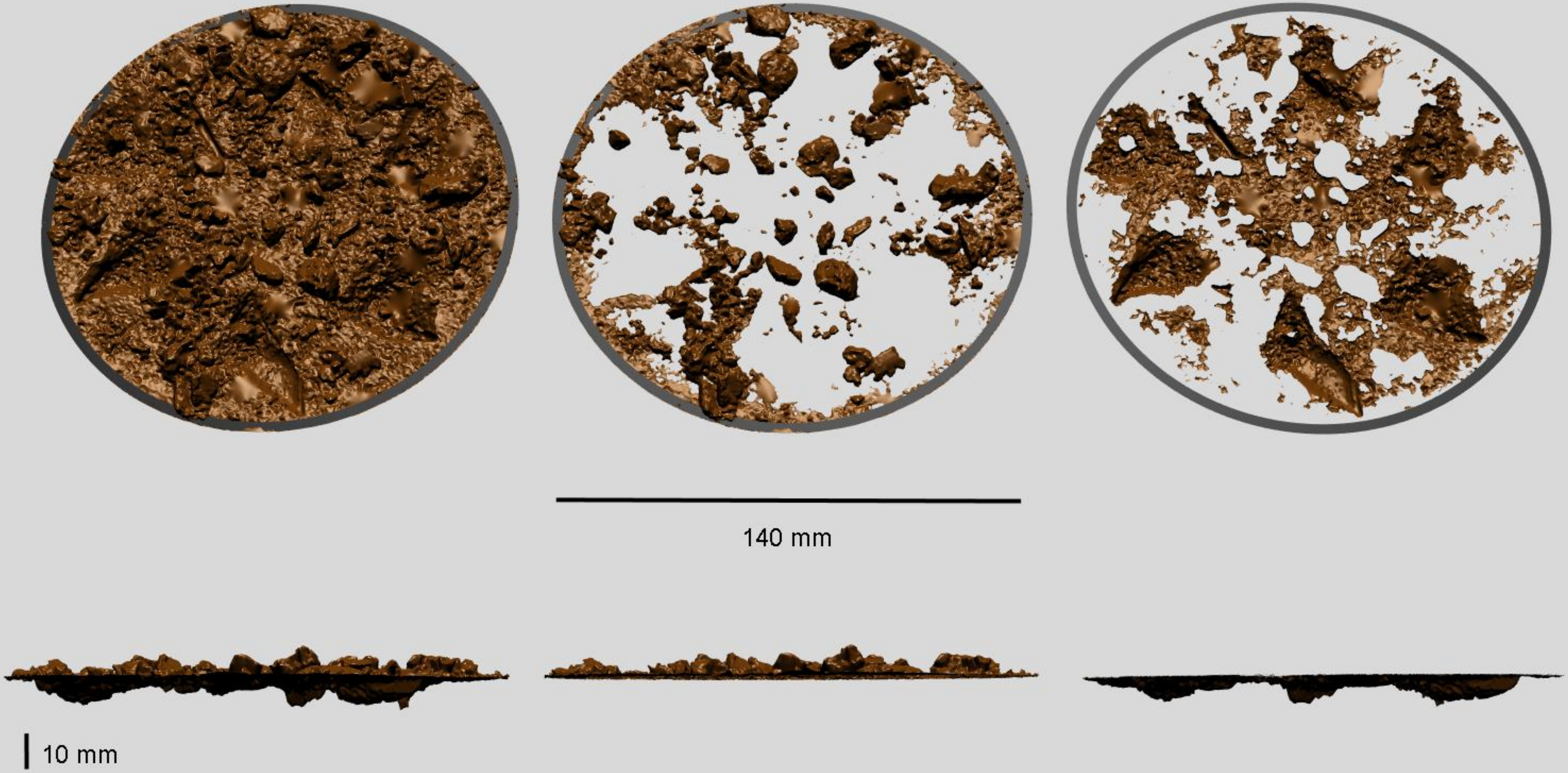

Brittle


FAST ORANGE
Hand Cleaner


LIBERTY

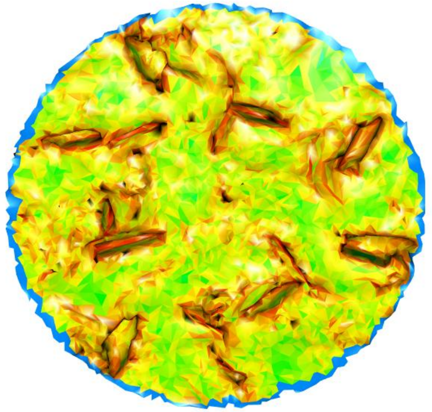

SHINING 3D
Post Processing
AOC
CAUTION!
SCANNER IS FRAGILE!


A
B
C

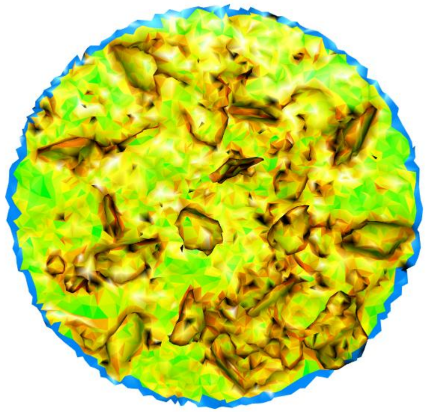

140 mm
10 mm

Dirichlet Normal Energy

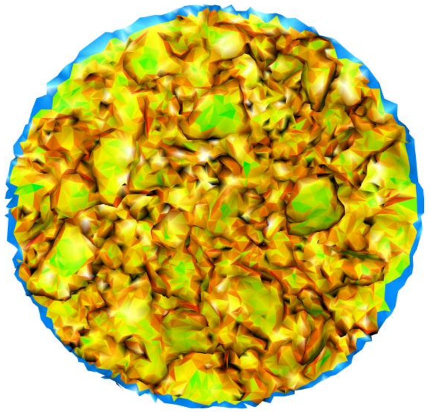
DNE = 1,810

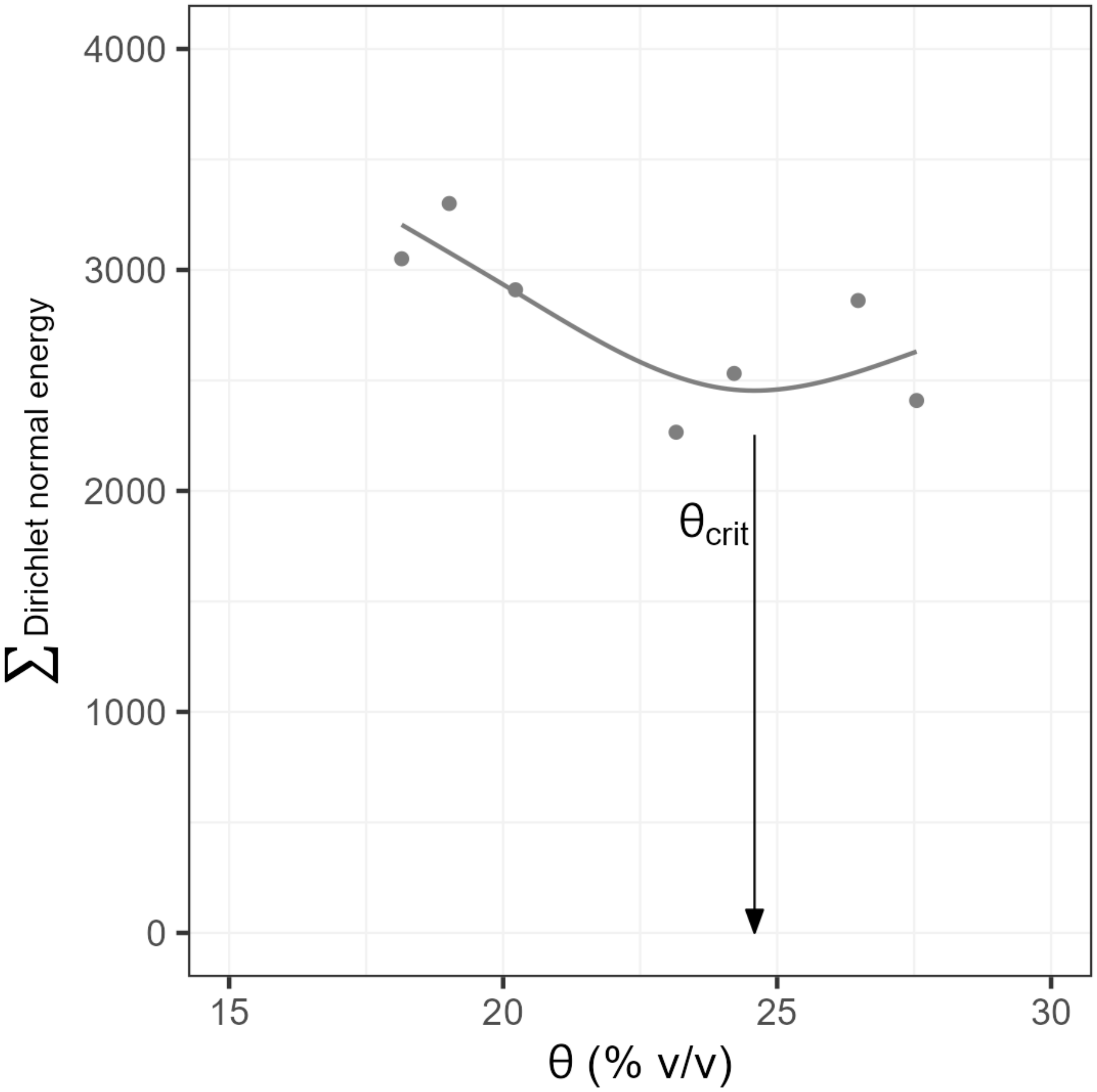


DNE = 2,900

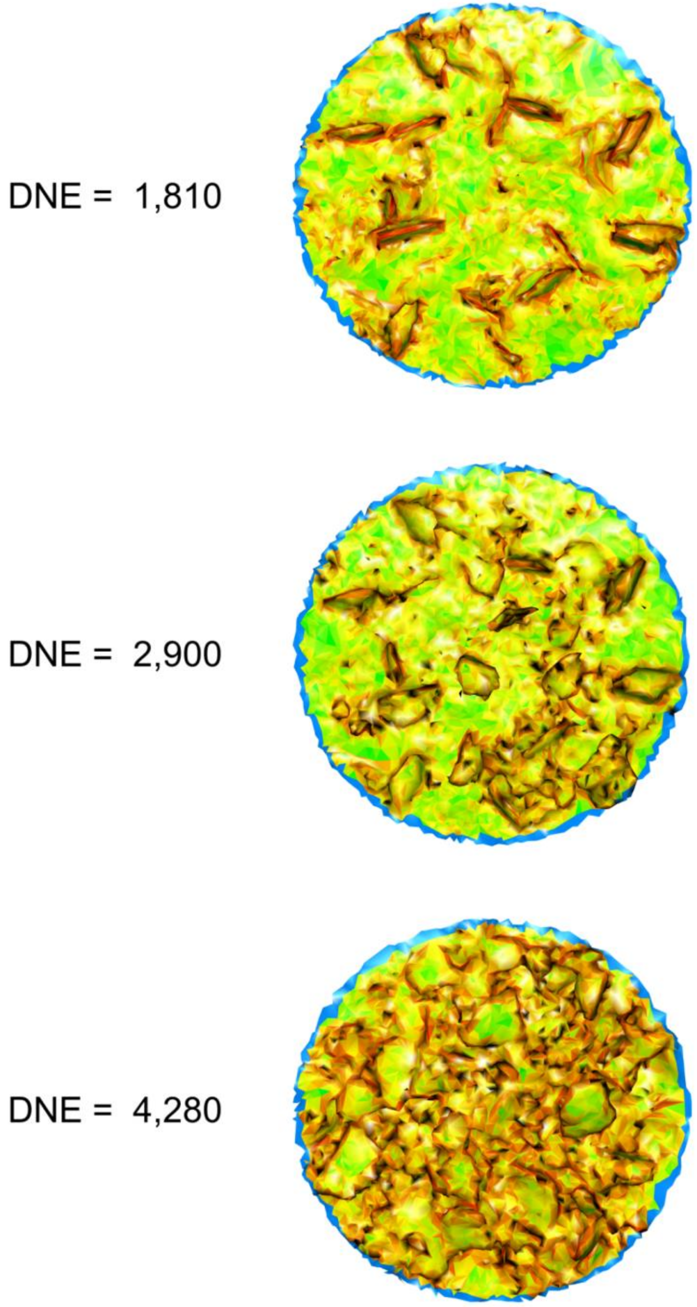


DNE = 4,280

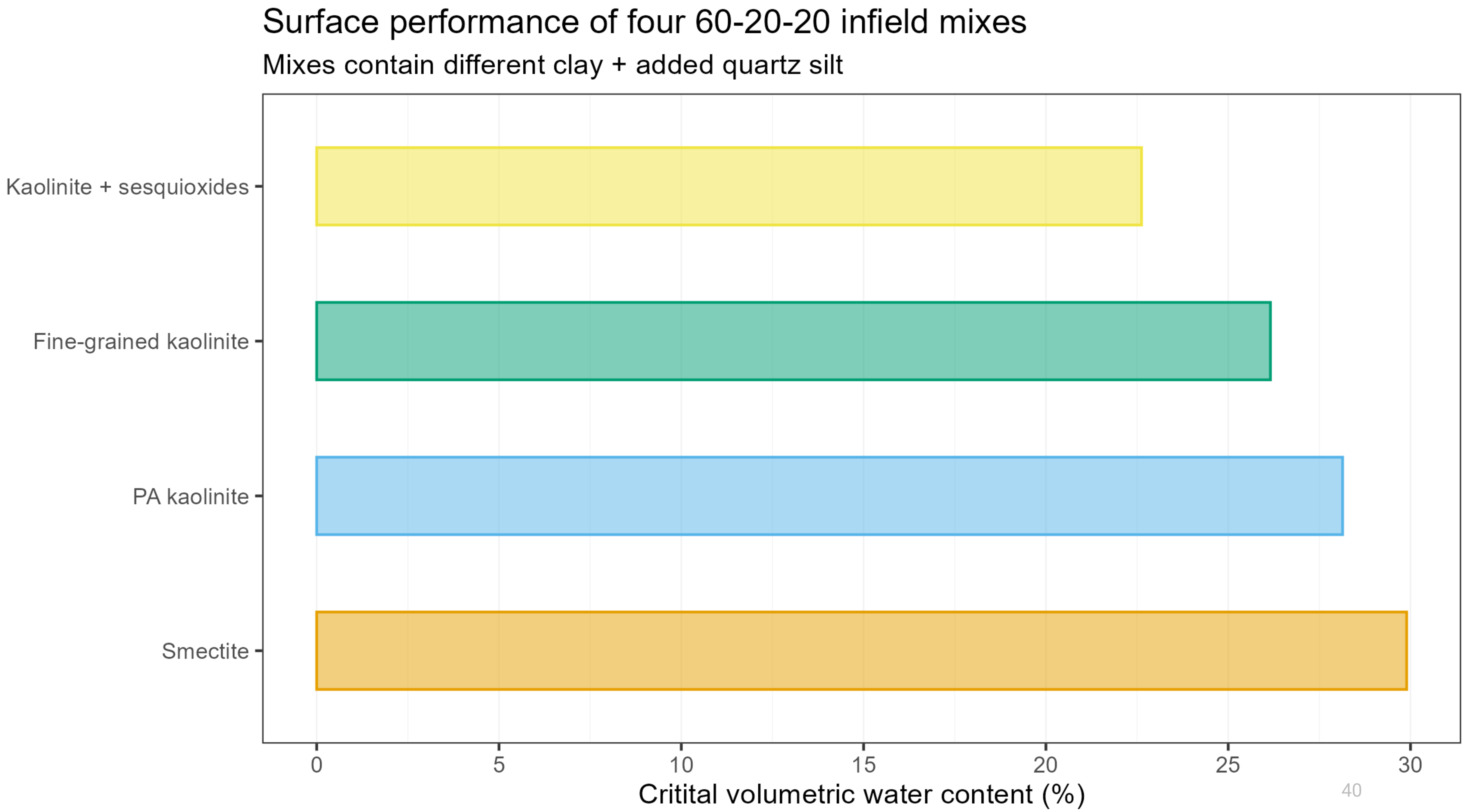




4000
3000
2000
1000
0
15
20
25
30
θ (% v/v)
∑ Dirichlet normal energy
θ_{crit}



DNE = 1,810
DNE = 2,900
DNE = 4,280

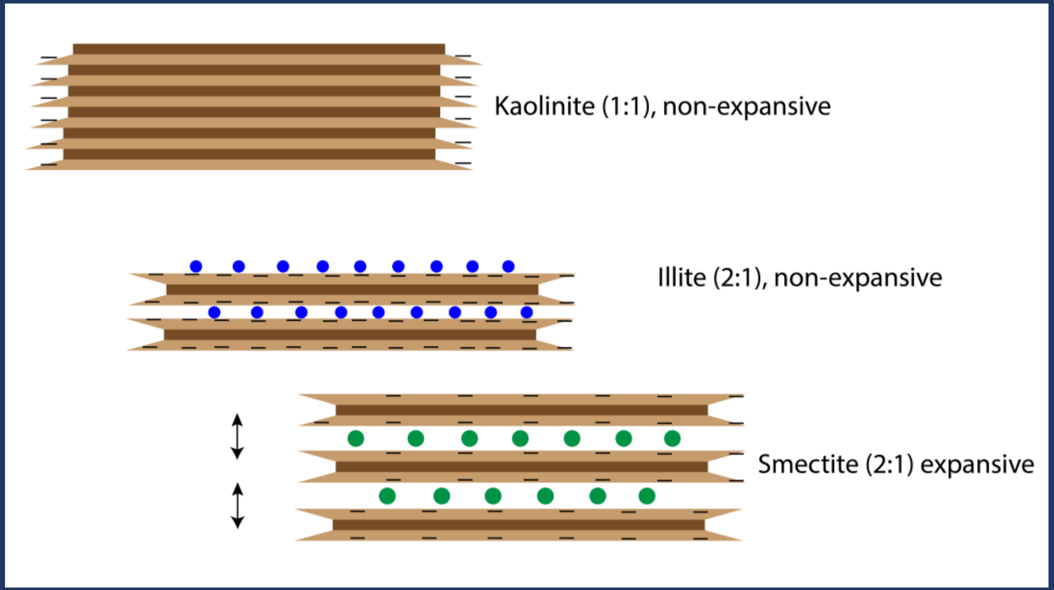

Surface performance of four 60-20-20 infield mixes
Mixes contain different clay + added quartz silt
Kaolinite + sesquioxides
Fine-grained kaolinite
PA kaolinite
Smectite
0
5
10
15
20
25
30
Critital volumetric water content (%)

Chapter 2

Effect of sand content and clay mineralogy on the brittleness of drying baseball infield soils

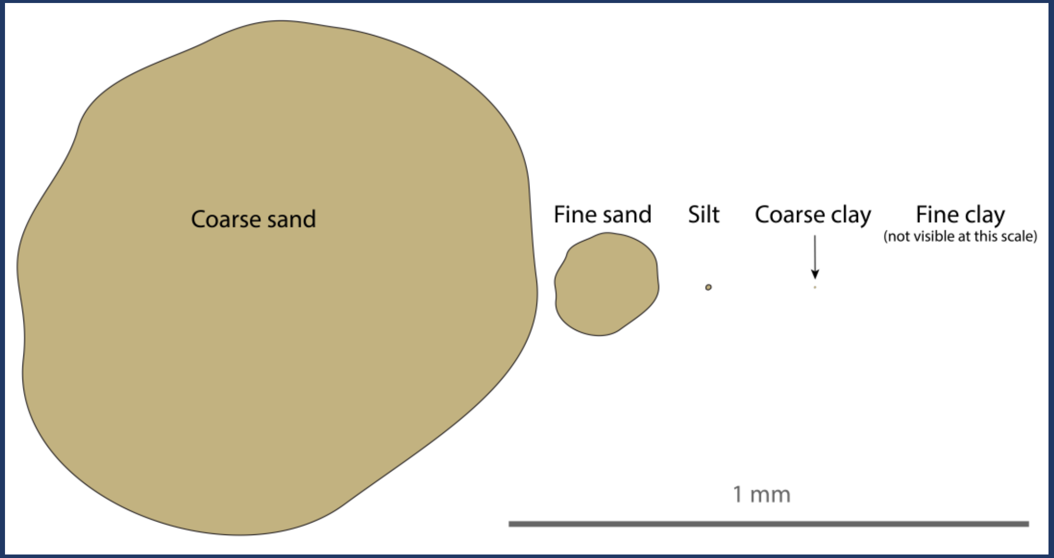
Experiment:

- "Pure" clay minerals mixed w/ 55-80% sand
- Kaolinite, illite, smectite
- 18 total mixtures



Objective:

Determine how clay mineralogy, sand content, and water content interact to govern the cleat-in-cleat-out effect



Methods

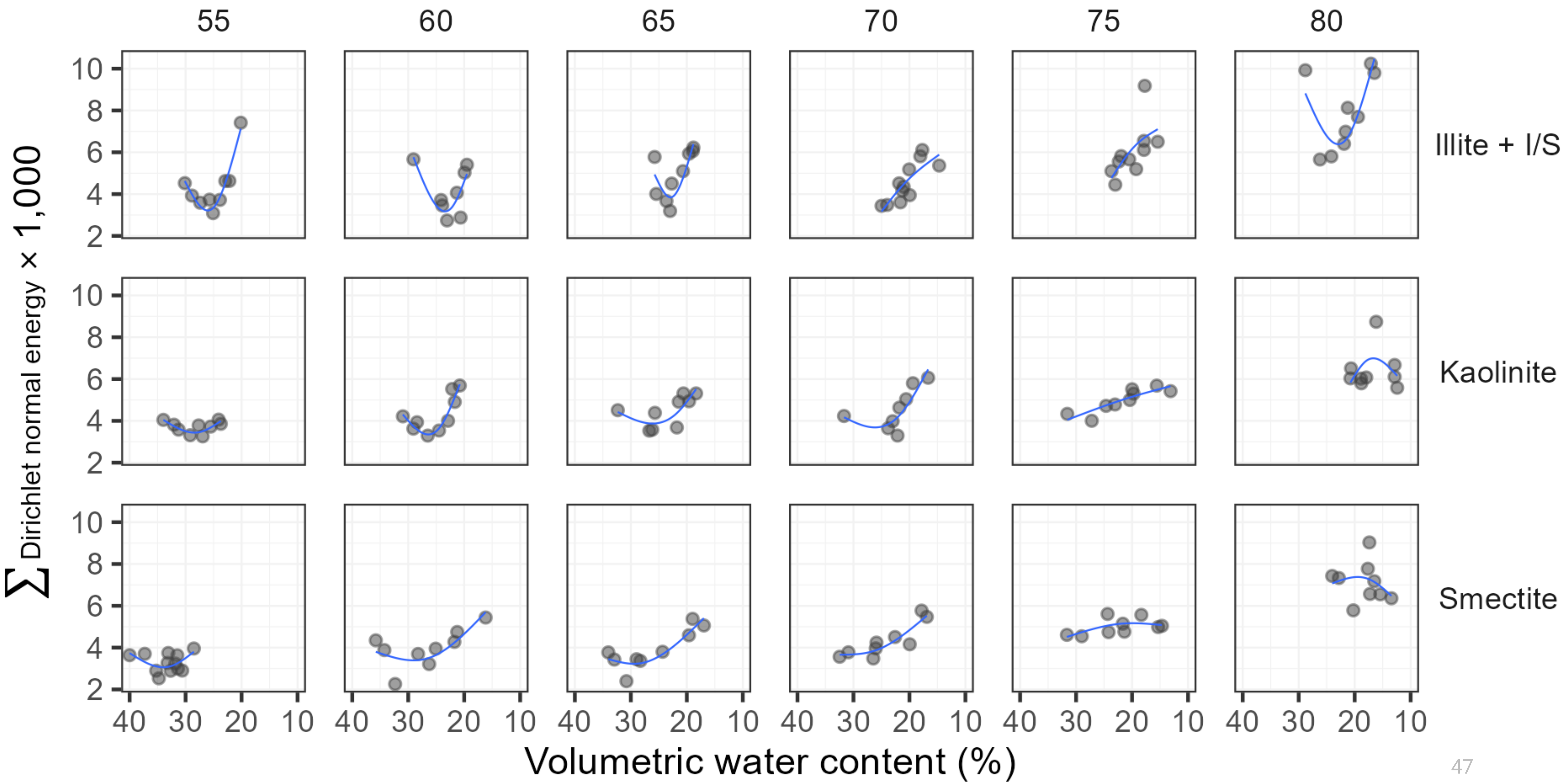
- Cleat mark test performed at ≥9 water contents per soil bracketing $\theta_{critical}$

- $\Theta_{critical}$ chosen from plot of DNE against Θ

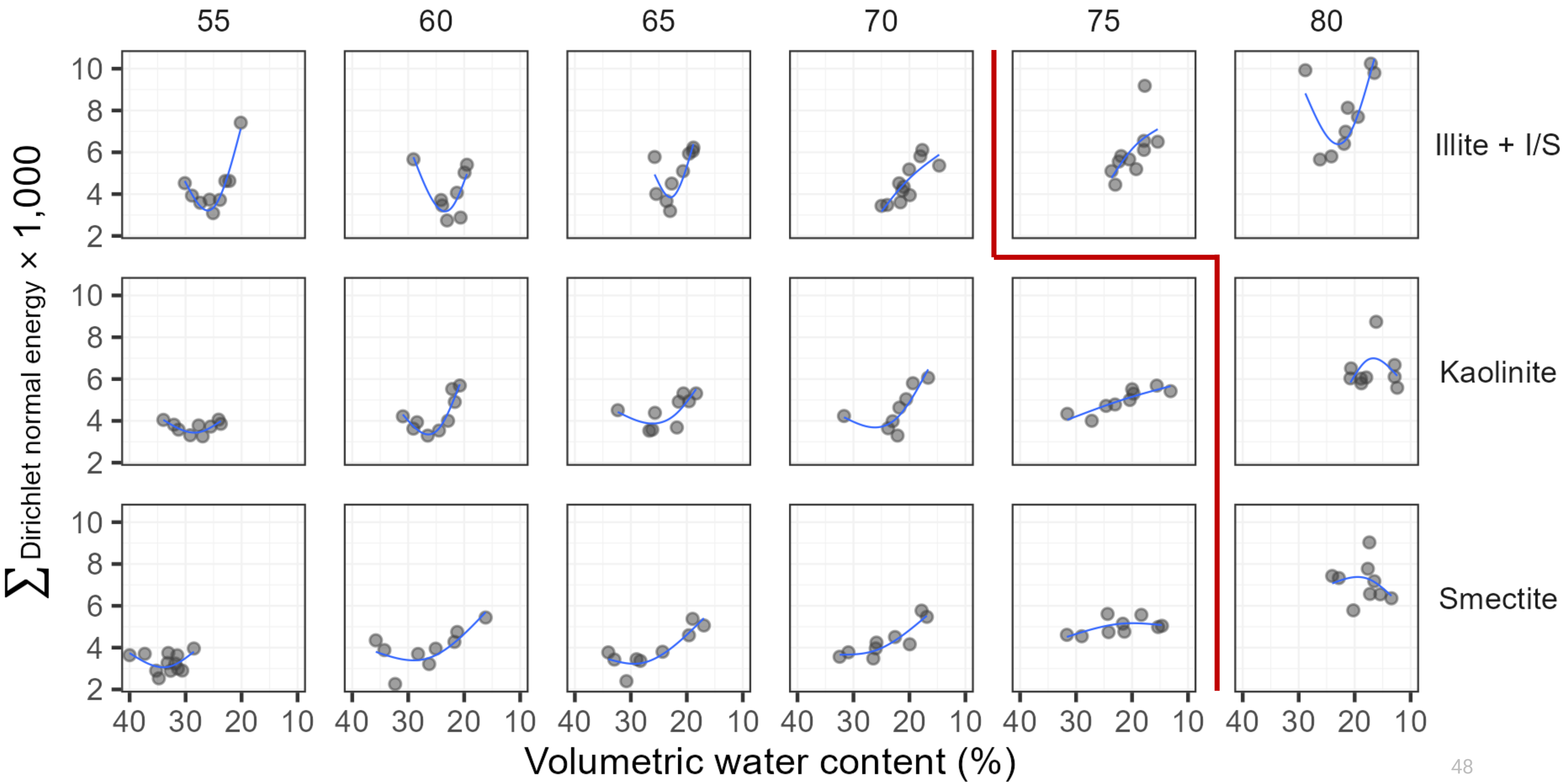
Sand content and clay type interact.

	Sum. Sq.	Deg. Fr.	F-statistic	p-value
Intercept	3.1e+05	1	0.350	0.555
Sand %	4.3e+07	1	47.851	<0.001
Clay type	1.0e+07	2	5.741	0.004
VWC (cubic spline term)	3.8e+07	3	14.228	<0.001
Sand % x clay type	1.1e+07	2	6.248	0.002
Residual	1.5e+08	166	-	-

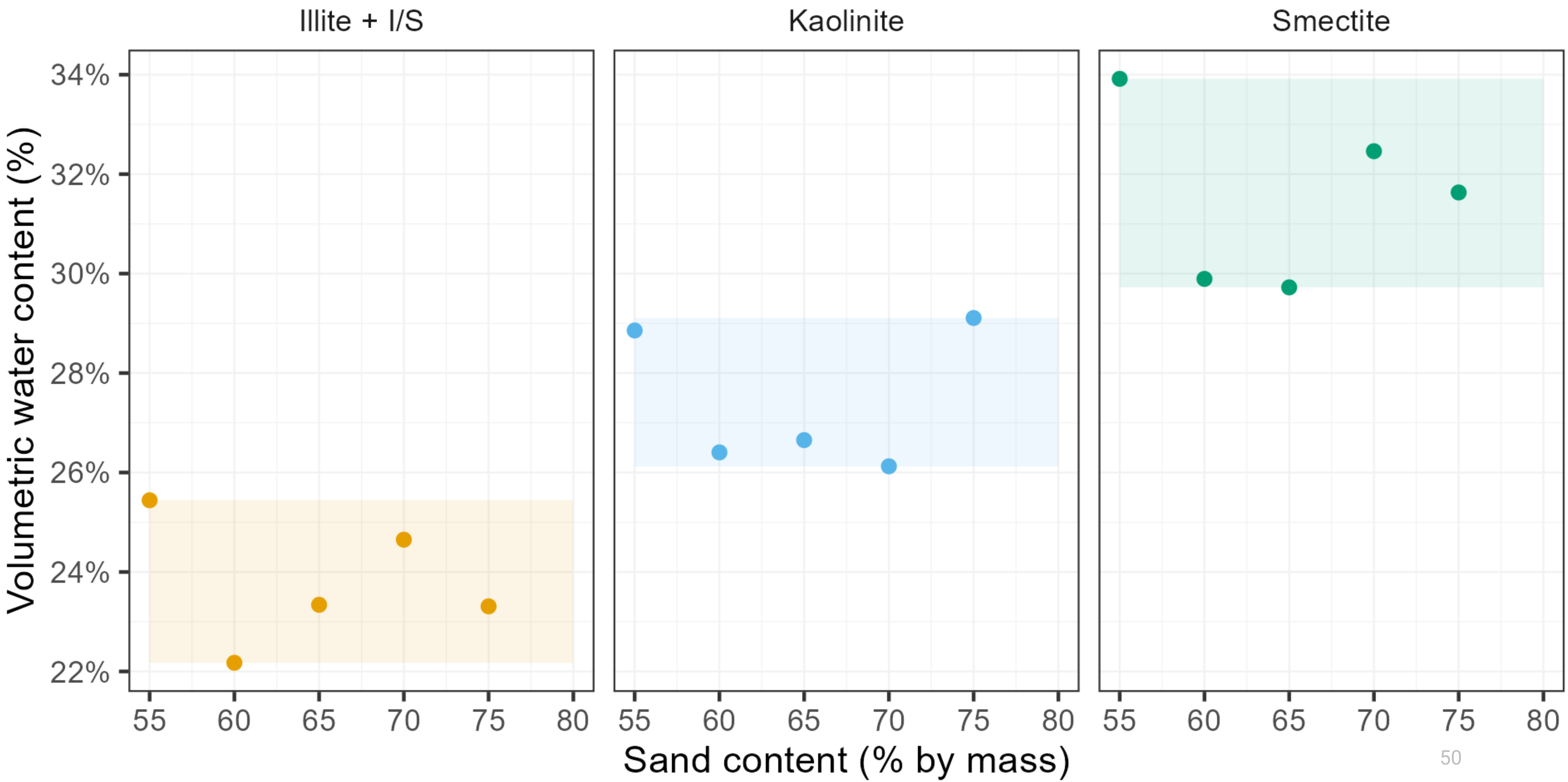
Clay mineralogy and sand content interact to determine $\theta_{critical}$



Clay mineralogy and sand content interact to determine $\theta_{critical}$

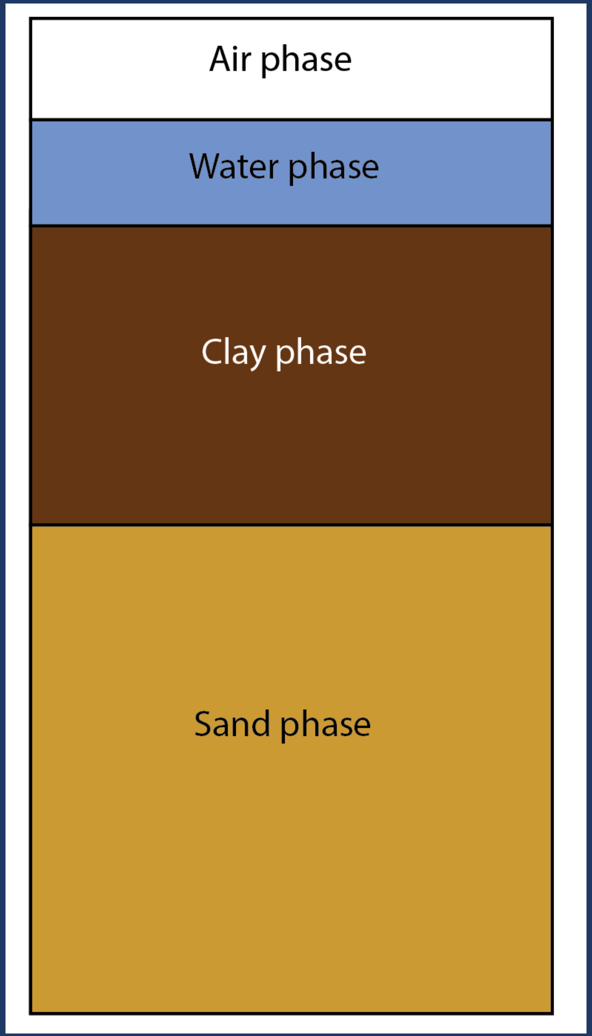


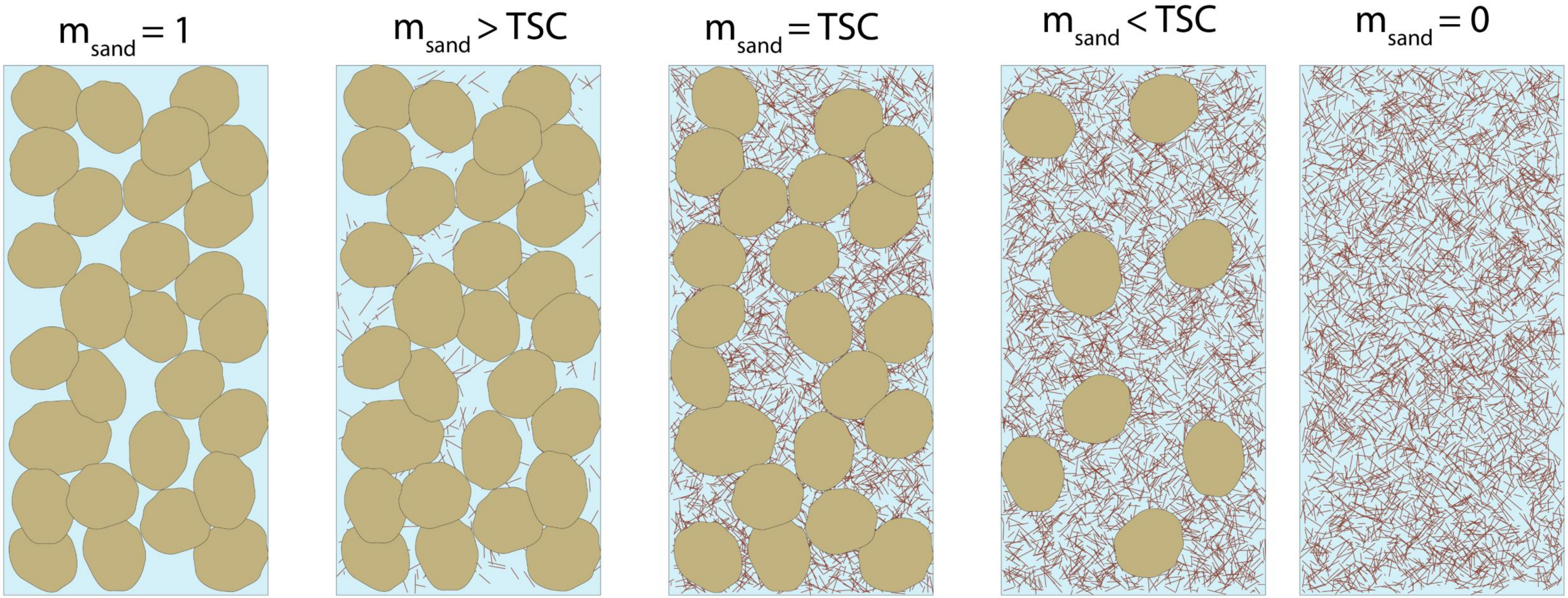
$\theta_{critical}$ varies by clay mineralogy and sand content.



Is there a fundamental basis to the cleat-in/cleat-out effect?

An infield mix is a 4-phase system



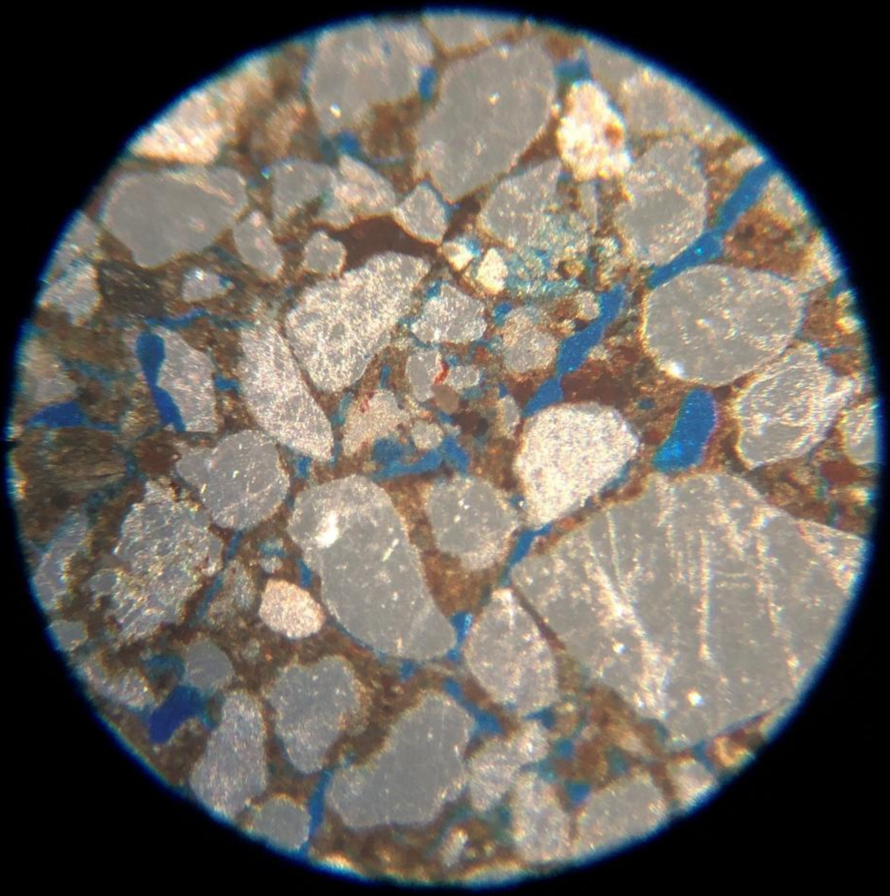

$m_{sand} = 1$
$m_{sand} > TSC$
$m_{sand} = TSC$
$m_{sand} < TSC$
$m_{sand} = 0$

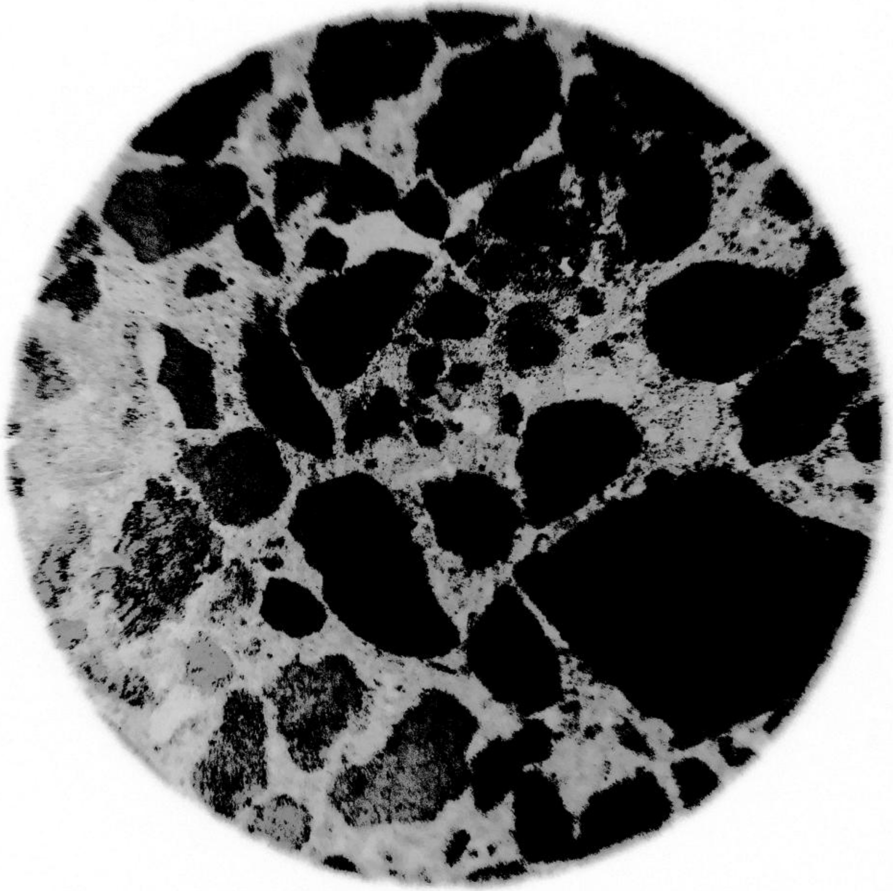
Transitional sand content

$$m_{sa} = \frac{1+\left(\frac{\frac{wG_c}{G_w}}{S_e}\right)}{1+\frac{e_{sa}G_c}{G_{sa}}}$$

Transitional sand content

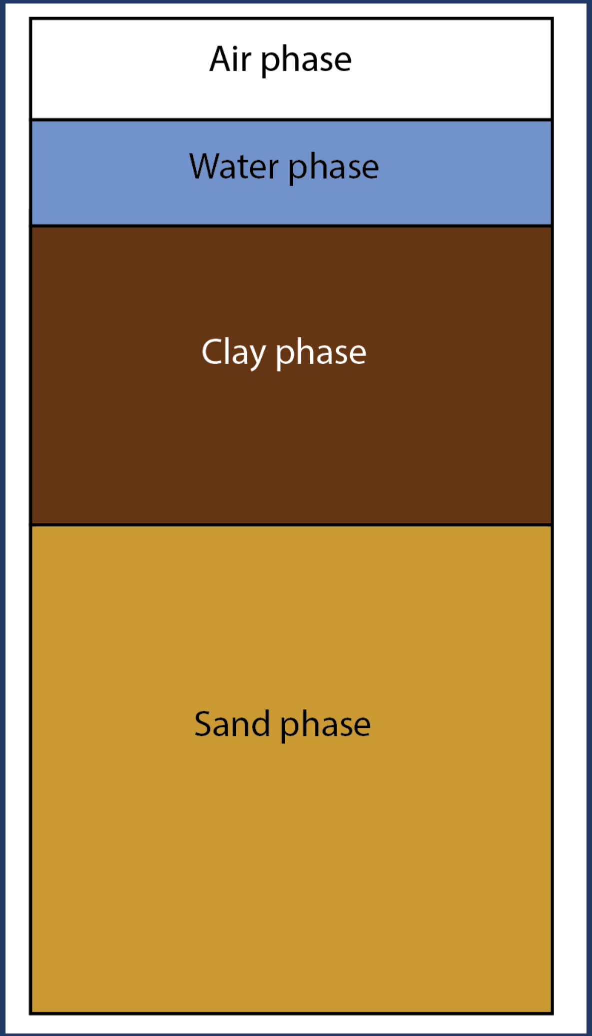
Clay mineral	Calculated sand content from equation	Maximum sand content to provide cleat-in/cleat-out
Illite/I-S	72.2	70-75
Kaolinite	75.3	75-80
Smectite	78.2	75-80

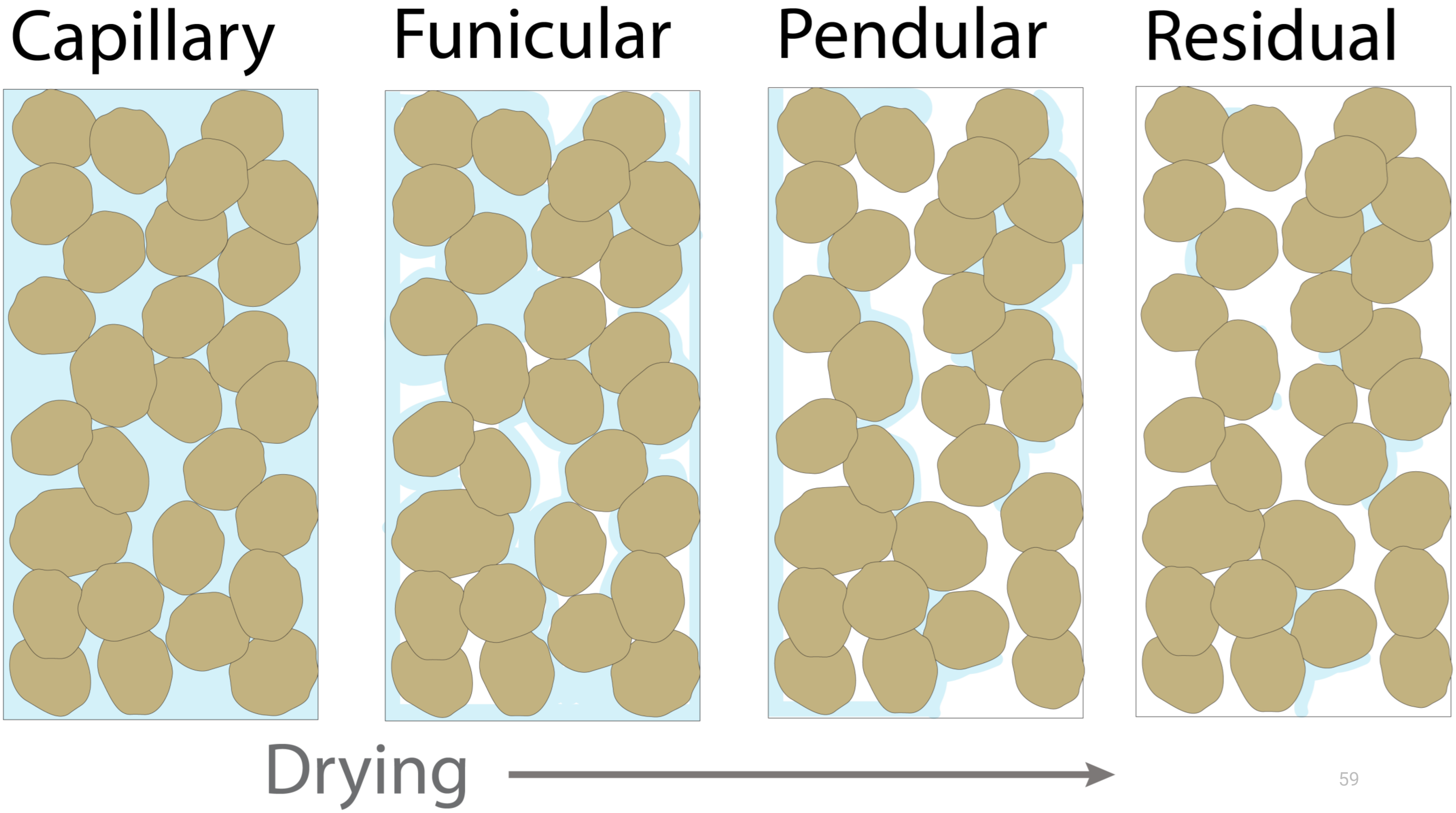


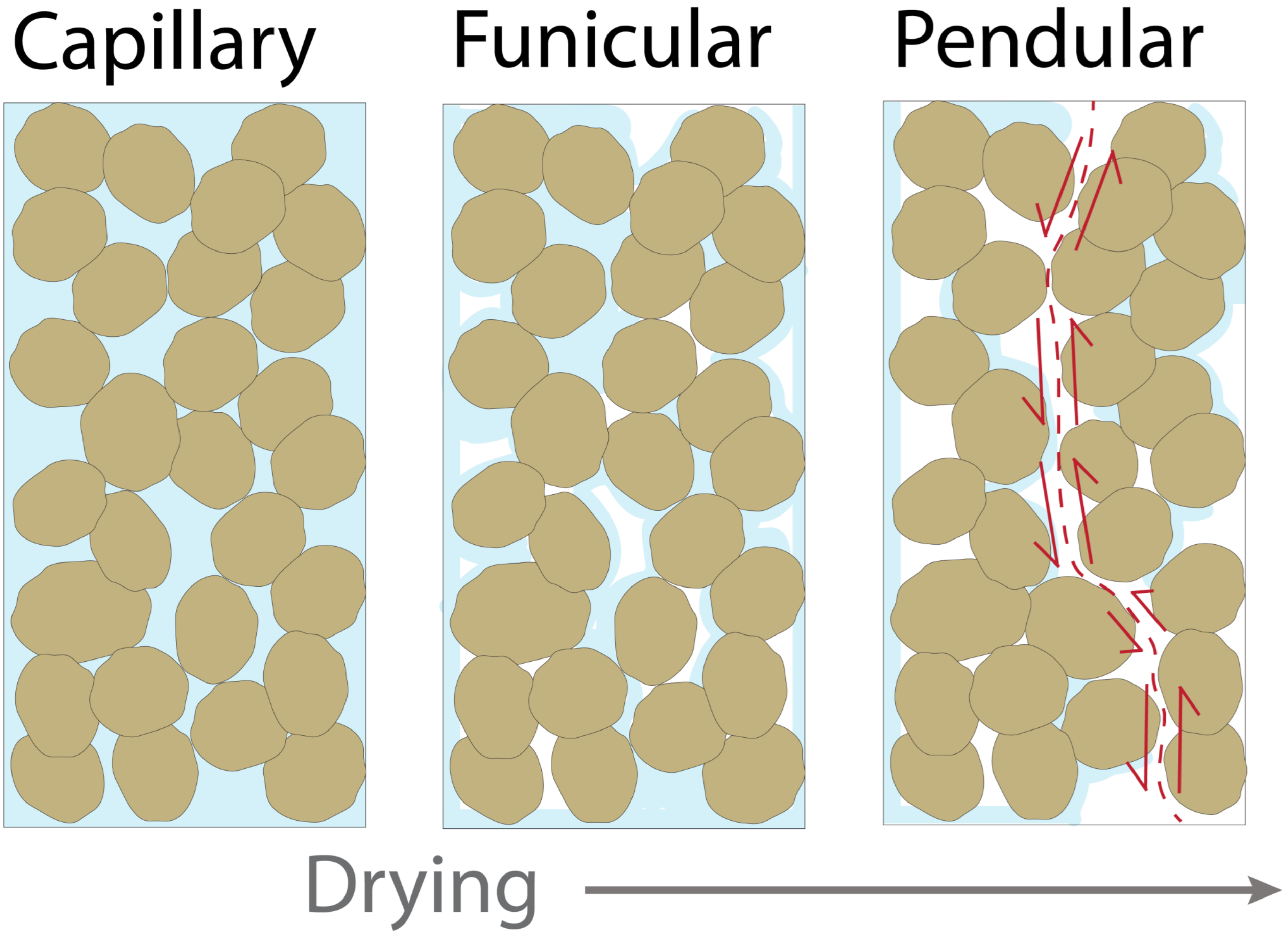


Illite, 75% sand

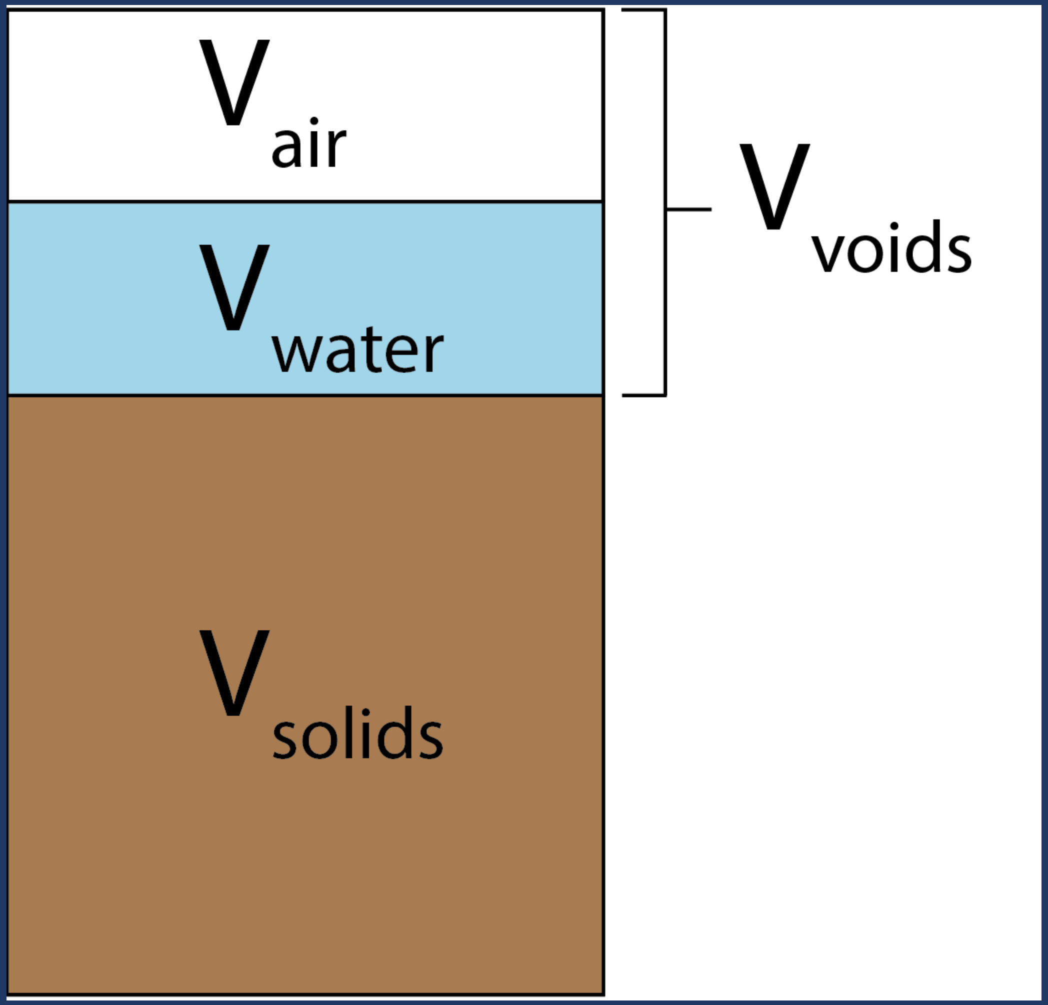
An infield mix is a 4-phase system




Capillary
Funicular
Pendular
Residual
Drying


Capillary
Funicular
Pendular
Residual
Drying

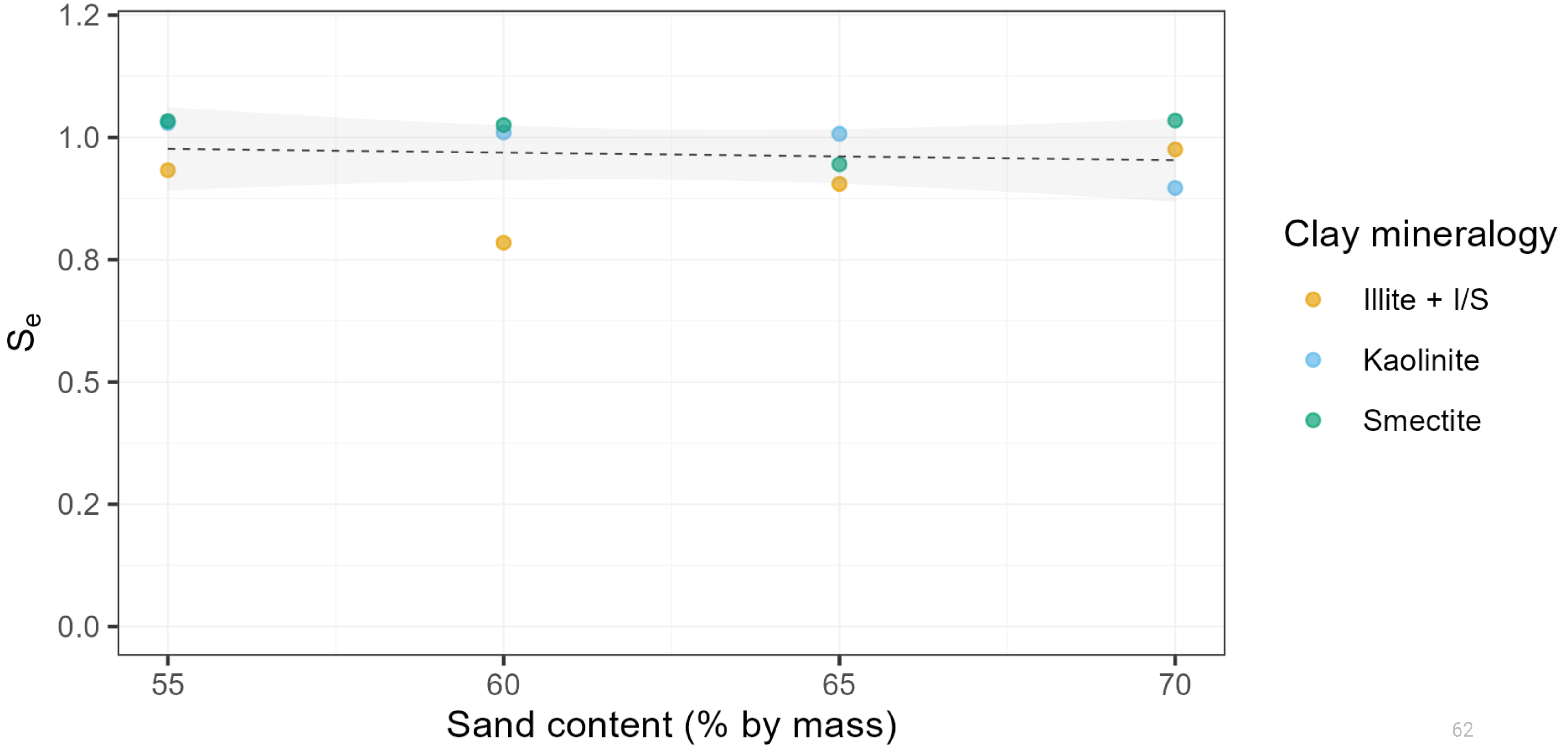
Effective saturation



$$S_e = \frac{V_w}{V_v} = \frac{\theta}{n}$$

$\theta_{critical}$ occurs at $S_e \approx 1$.

Relationship holds regardless of sand content or clay mineralogy.



Summary: Part I

- Lower water content boundary: brittle failure

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- Direct measurement of behavior change w/ water content

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- Lower water content boundary: brittle failure
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- To achieve CICOE, m_{SA} < TSC and S_e approaching 1

Chapters 3-4

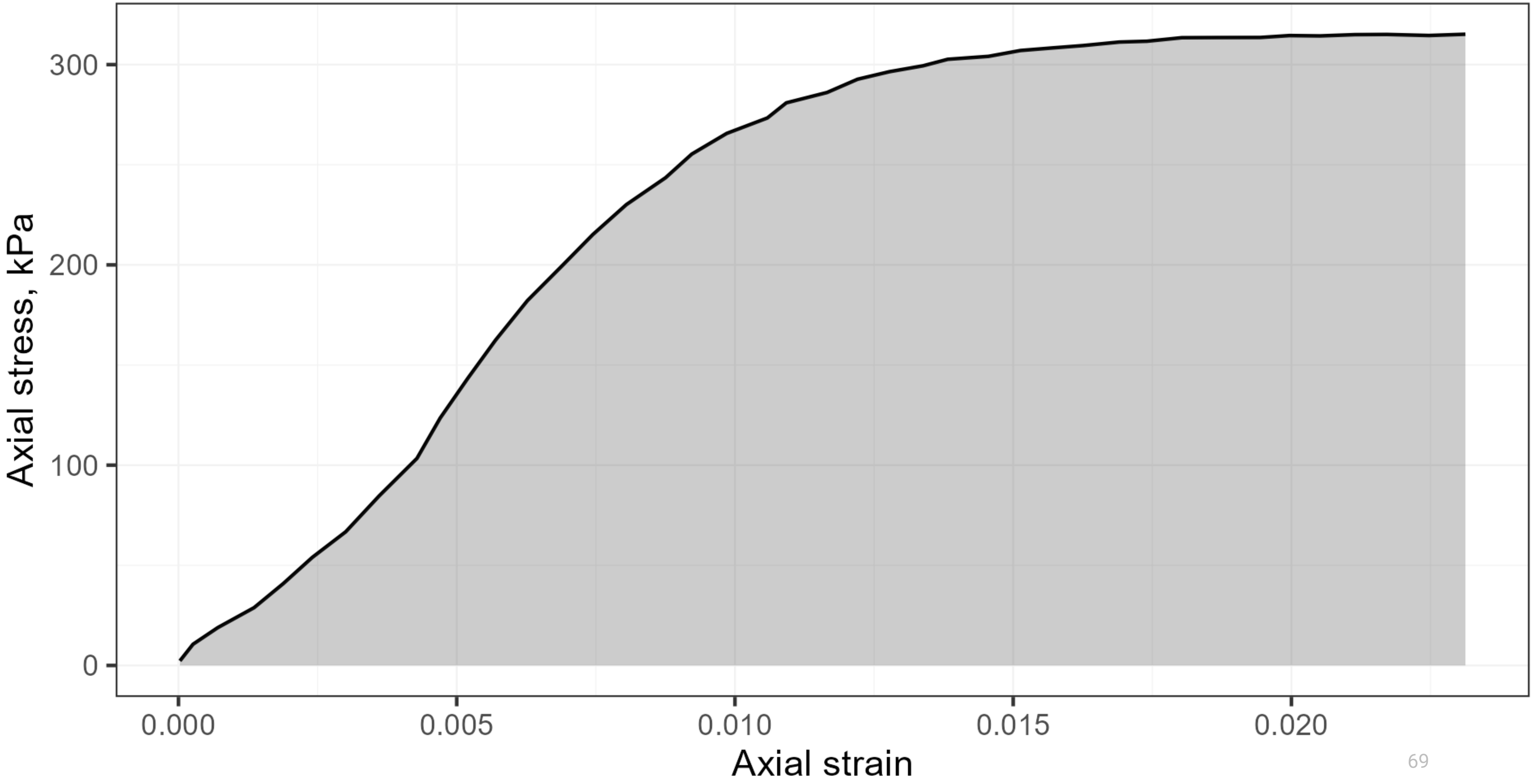
Toughness-water content relations using unconfined compression tests

Toughness = energy needed to deform soil to failure

- governs the amount of damage done to the soil when @ high water content

- Important for stable footing when soil is in ductile/plastic condition

Computing toughness for one sample



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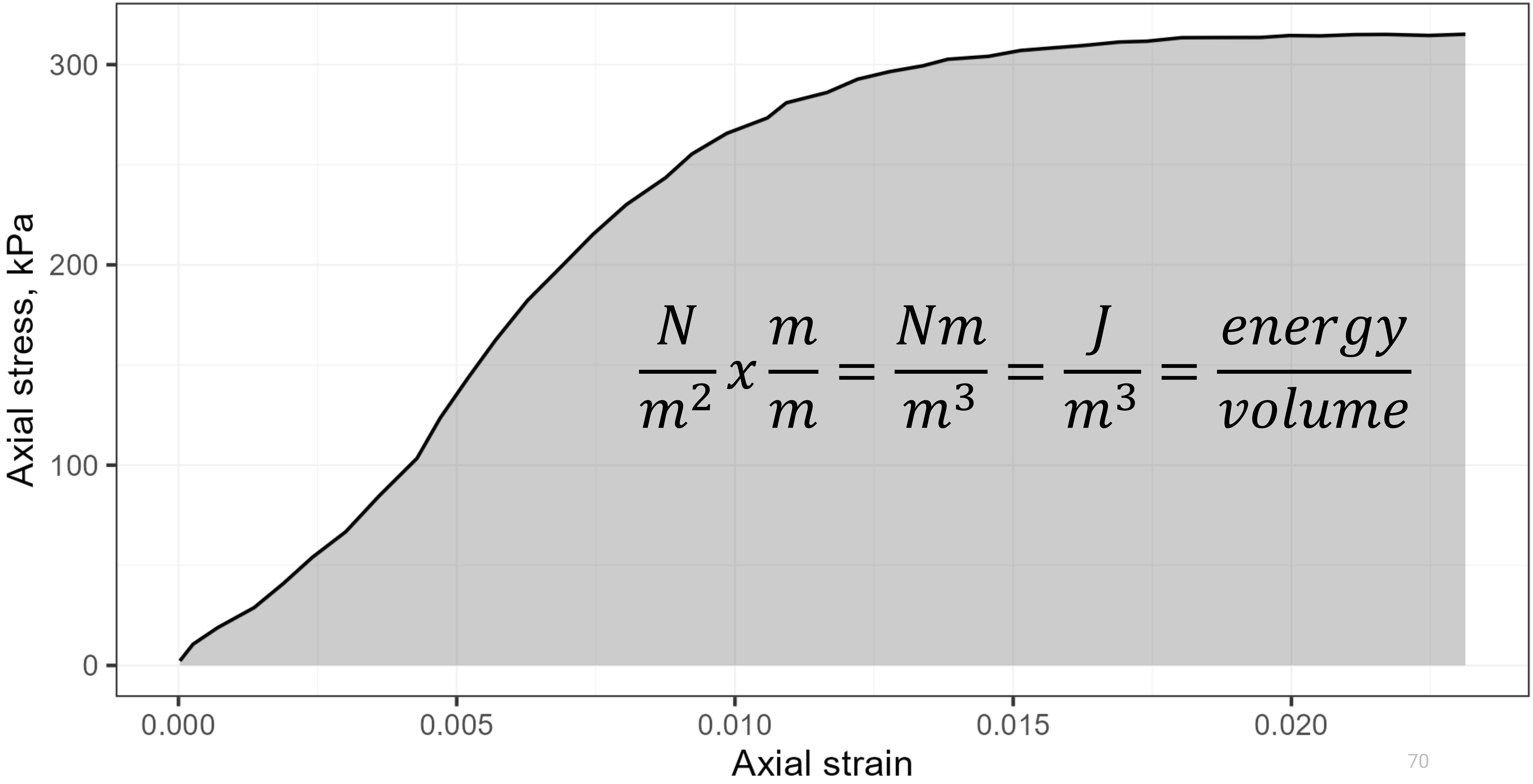
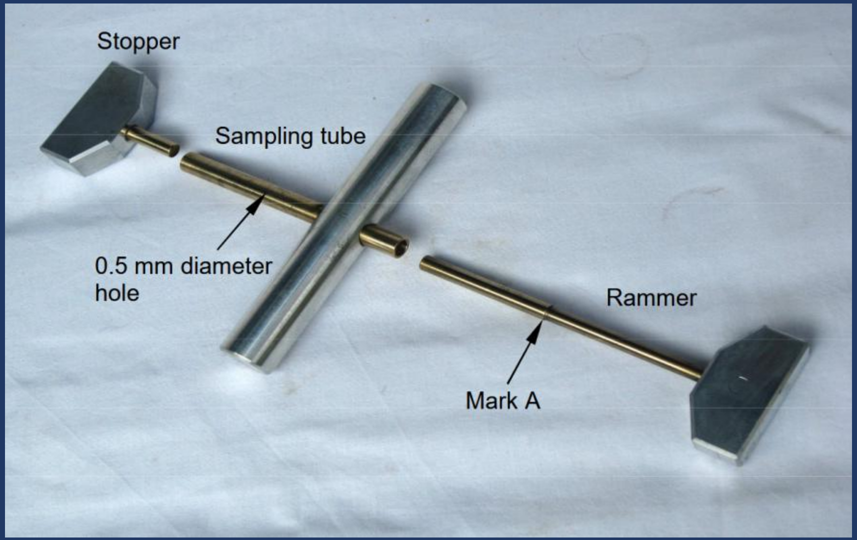
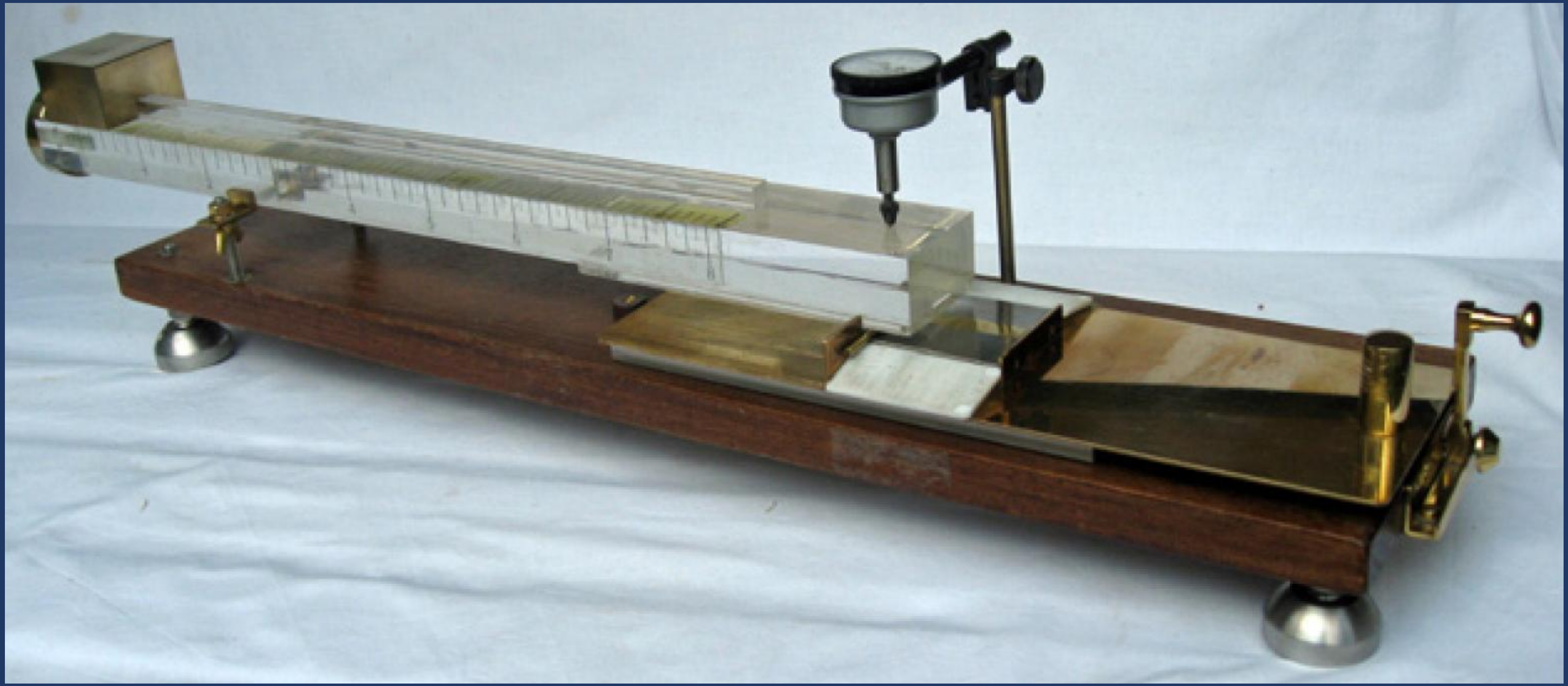


Barnes toughness method



Thread maker

Rolling apparatus



Plastic limit

“In order to classify clays according to their toughness it would be necessary to determine the shearing resistance at the plastic limit by means of a direct shearing test or an unconfined compression test.“

-Casagrande (1932)

ASTM D2166 provides little help re: specimen preparation

"Specimens shall be prepared to the predetermined water content and density prescribed by the individual assigning the test."

Research goals

- Develop a method to prepare specimens for unconfined compression testing

- Test a suite of sand-clay mixtures to determine the how clay mineralogy and sand content interact with soil water to determine toughness

Specimen preparation

- No standard method for remolded samples

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Specimen preparation

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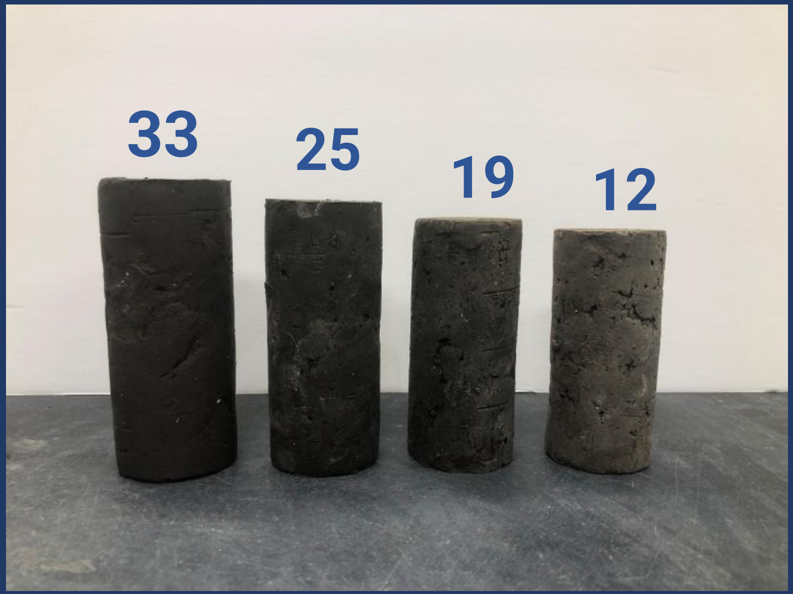
- Ideal method – optimum density; wet-dry cycle; re-wet……impractical
- Pack wet-of-optimum
- Beginning penetrometer resistance of ~0.5 kg cm^2
- Extrude from steel sleeve
- Dry series of samples to pre-computed masses
  - Ensures adequate spread of data points

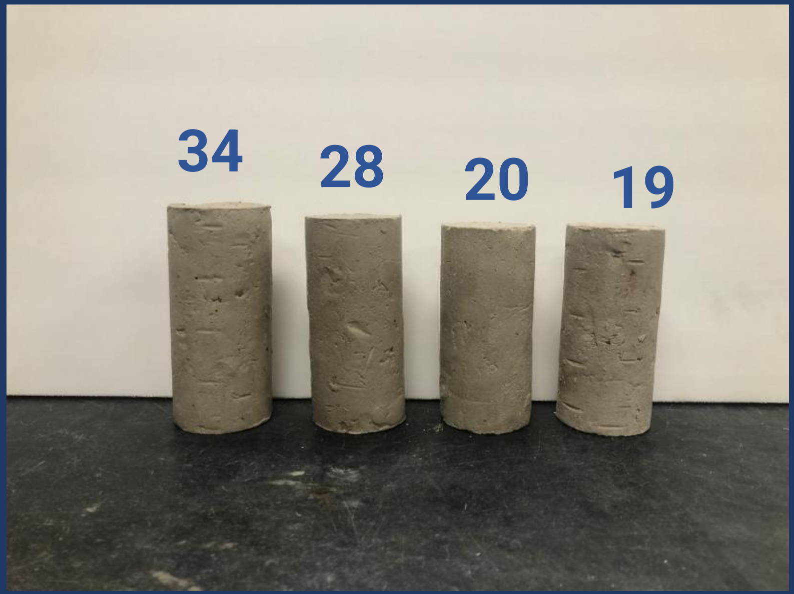

SAND
553

Specimen shrinkage

Smectite

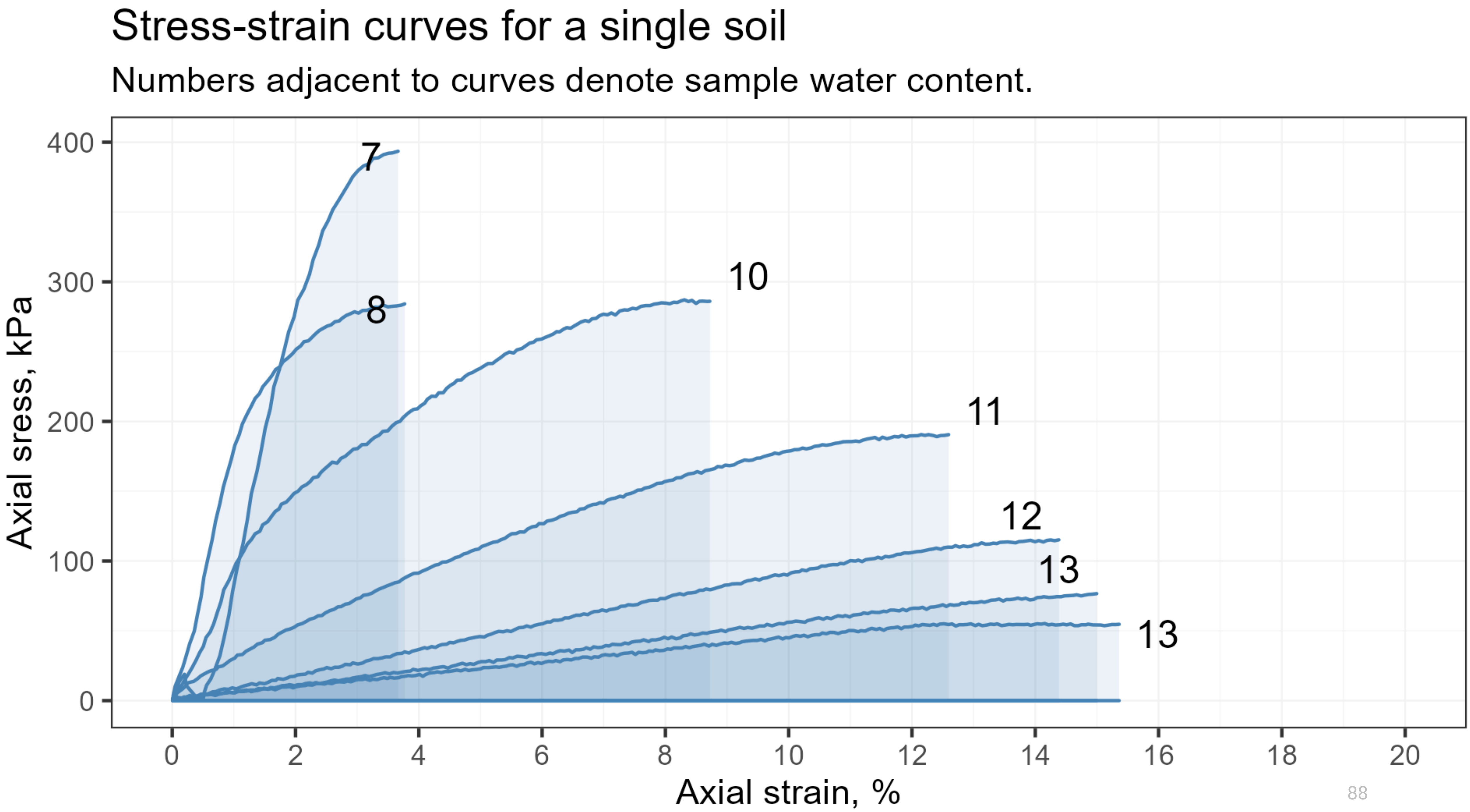


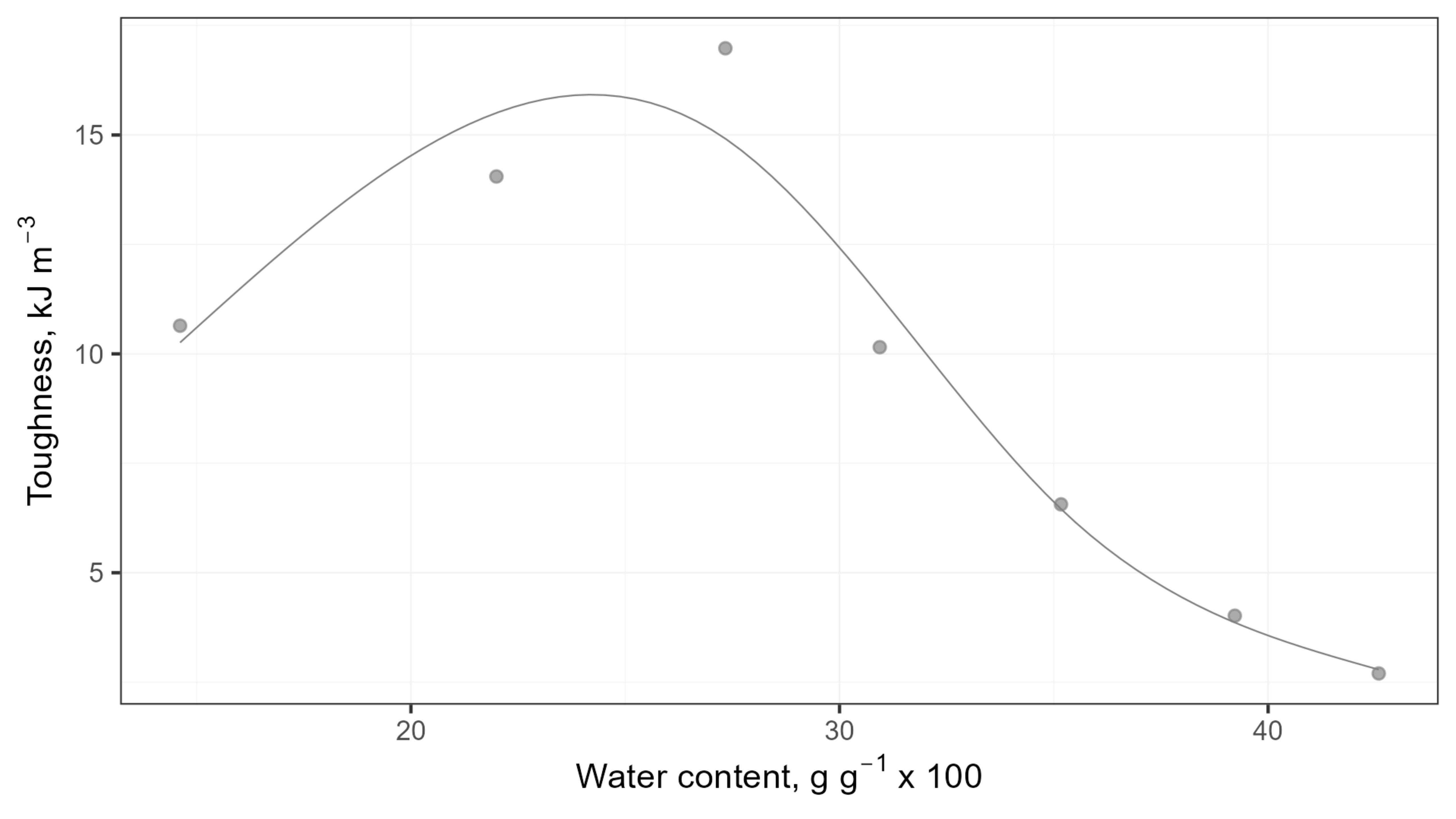
Kaolinite



Illite


DIAMOND


Stress-strain curves for a single soil
Numbers adjacent to curves denote sample water content.
Axial sress, kPa
Axial strain, %
7
8
10
11
12
13
13
0
100
200
300
400
0
2
4
6
8
10
12
14
16
18
20



15
10
5
20
30
40
Toughness, kJ m⁻³
Water content, g g⁻¹ x 100

What toughness value to compare?

- Toughness is a function of water content

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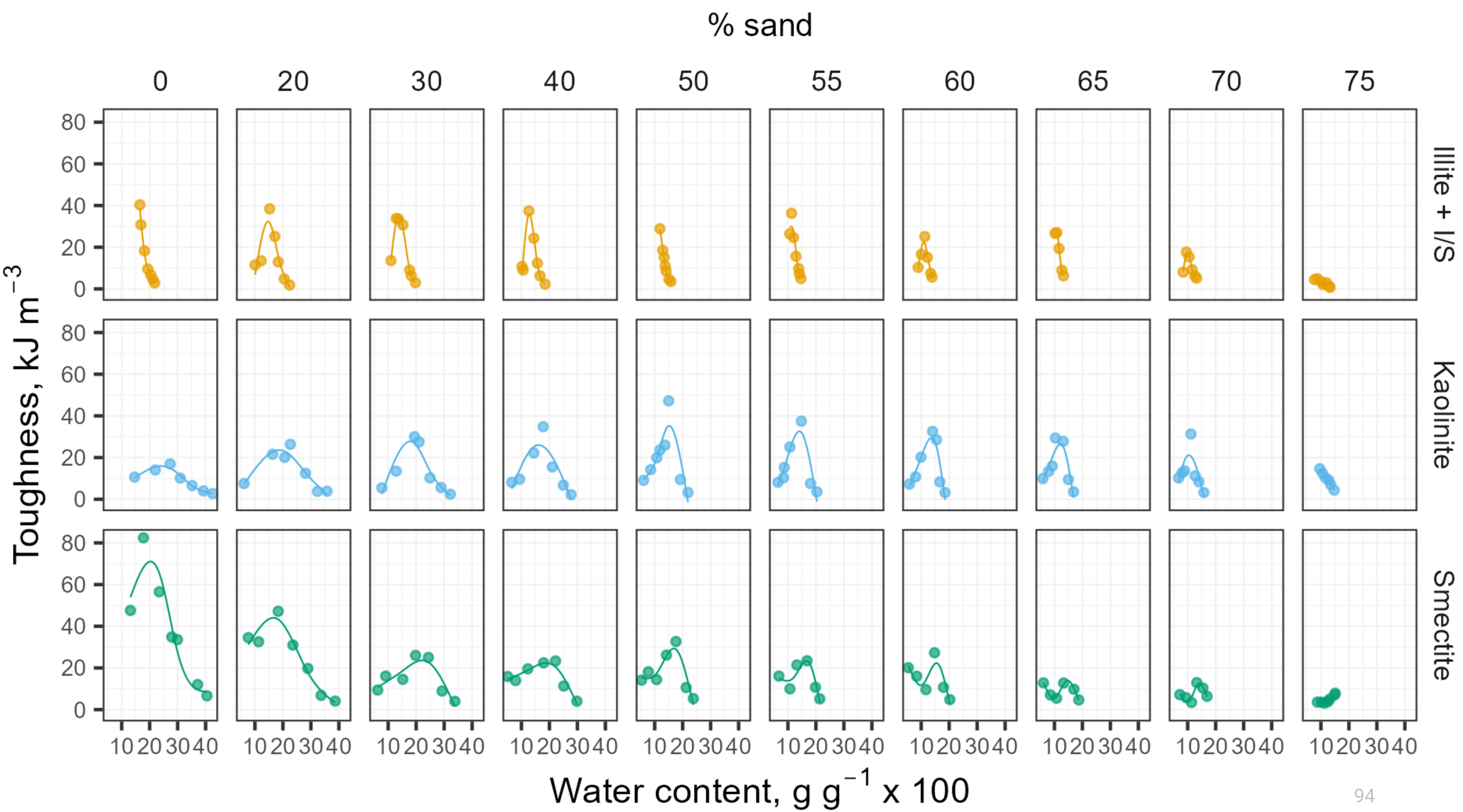
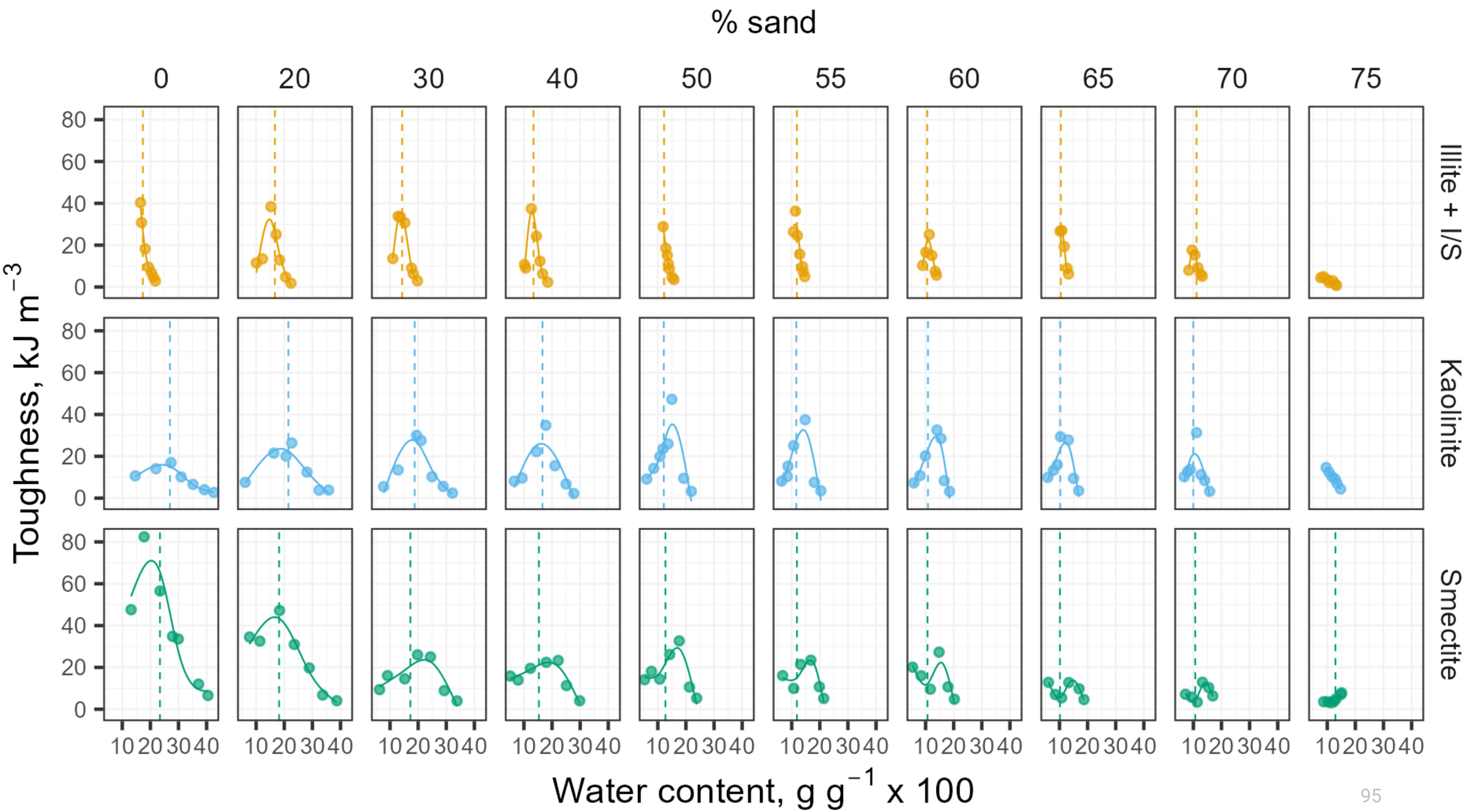
- Must choose representative value for a given soil

What toughness value to compare?

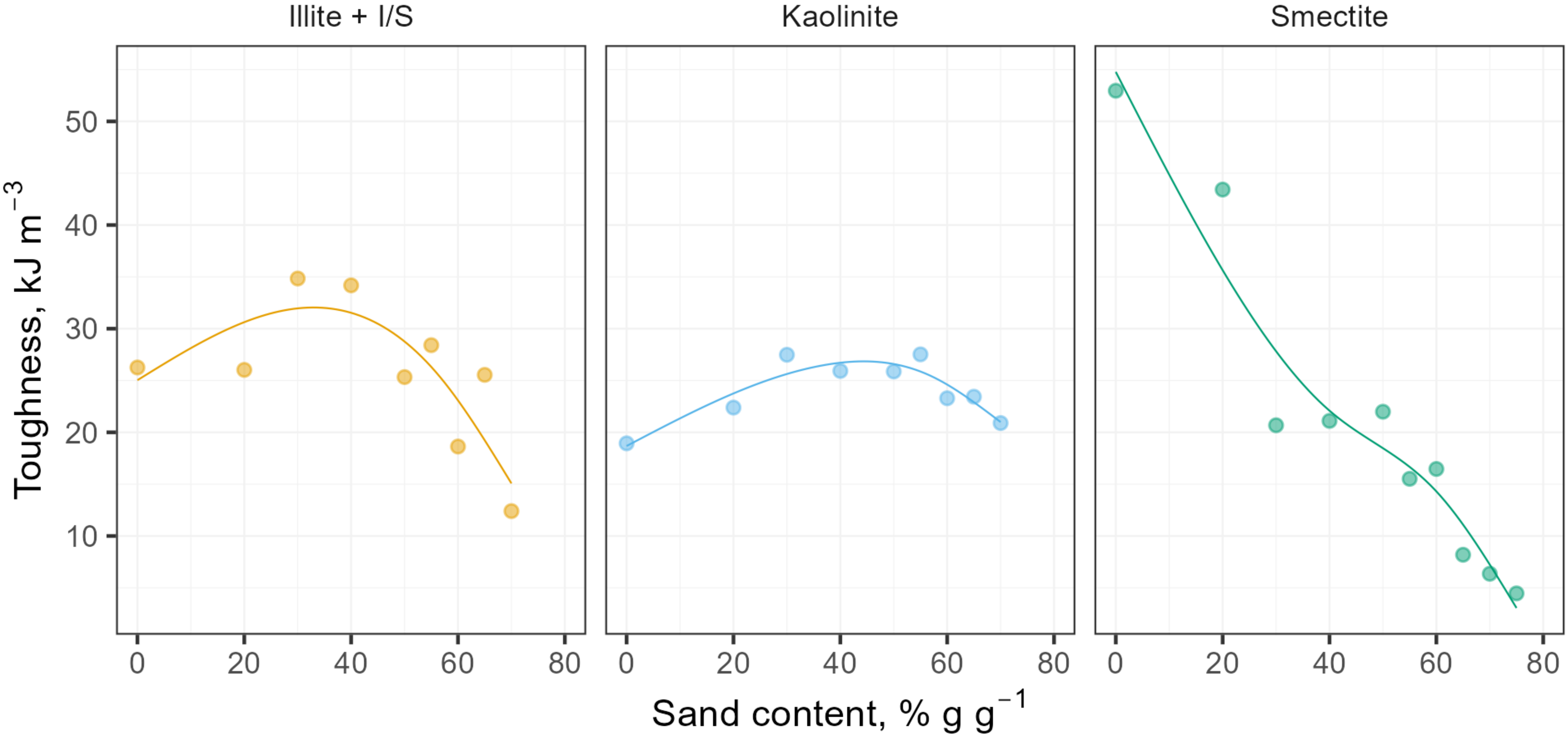
- Toughness is a function of water content
- Must choose representative value for a given soil
- PL widely used and understood; traditional brittle-ductile threshold



% sand
0
20
30
40
50
55
60
65
70
75
Illite + I/S
Kaolinite
Smectite
Toughness, kJ m^{-3}
80
60
40
20
0
10 20 30 40
Water content, g g^{-1} x 100


% sand
0
20
30
40
50
55
60
65
70
75
Illite + I/S
Kaolinite
Smectite
Toughness, kJ m^{-3}
Water content, g g^{-1} x 100
0
20
40
60
80
10
20
30
40

Predicted toughness at the plastic limit for sand-clay mixtures



Values computed using spline fit for toughness vs. water content.

Maximum toughness varies by sand content and interacts with clay type

- Toughness and shear strength increase with drying to ~PL, then decrease once below PL (enhanced brittleness)

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- Similar to the findings by Barnes (2009, 2013), Teng (2020), and Nagaraj (2016)

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- Toughness and shear strength increase with drying to ~PL, then decrease once below PL (enhanced brittleness)

- Similar to the findings by Barnes (2009, 2013), Teng (2020), and Nagaraj (2016)

- More research needed to relate toughness to threshold water content

Overall summary and conclusions

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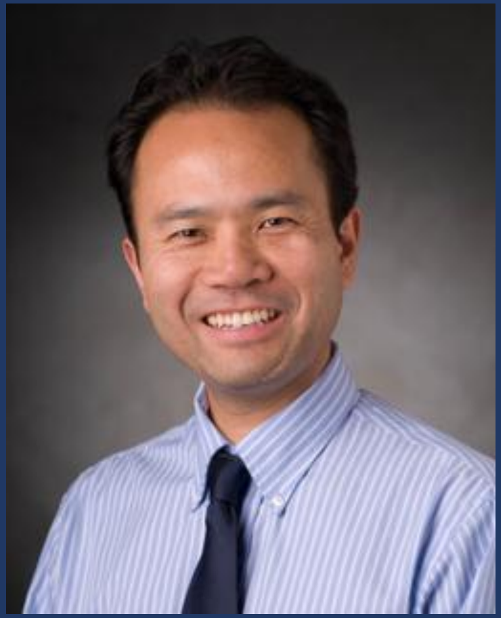
- Lower boundary measured with cleat- mark test; upper boundary is more difficult to define
- Range may be expanded using higher-plasticity clay but at the cost of maintenance & cracking potential
- Future directions:
  - Develop simpler alternatives to cleat-mark test
  - Relate ball response soil stiffness + plasticity

Thank you!

Dr. Andrew McNitt

Dr. Patrick Drohan

Dr. Sridhar Komarneni



Dr. Tong Qiu

Thank you!

KAFMO
KEYSTONE ATHLETIC FIELD MANAGERS ORGANIZATION

PENNSYLVANIA
TURFGRASS COUNCIL

SAFE
The Foundation for Safer Athletic Fields

Ian Royer

Hunter Finn

Thank you!