

# Transparent soils for studying internal erosion

Hydropower R&D days 2026

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Shane Aulestia

Mar 12<sup>th</sup>, 2026



SWEDISH CENTRE FOR  
SUSTAINABLE HYDROPOWER

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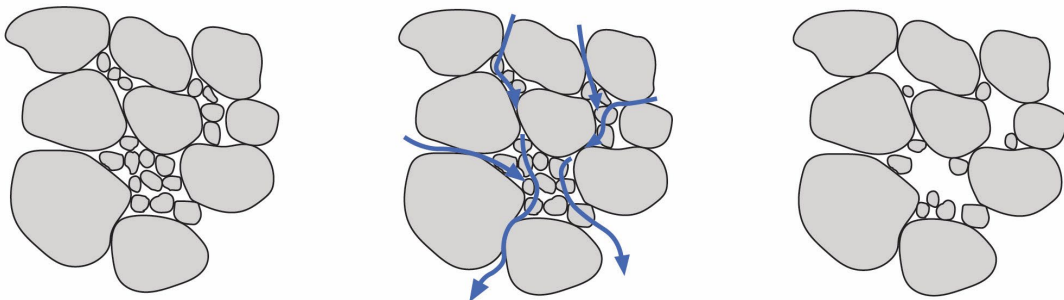
The logo features a large, white, stylized letter 'L' on the right side. To its left, the text 'LULEÅ UNIVERSITY OF TECHNOLOGY' is arranged in three lines: 'LULEÅ' at the top, 'UNIVERSITY' in the middle, and 'OF TECHNOLOGY' at the bottom.

# Introduction

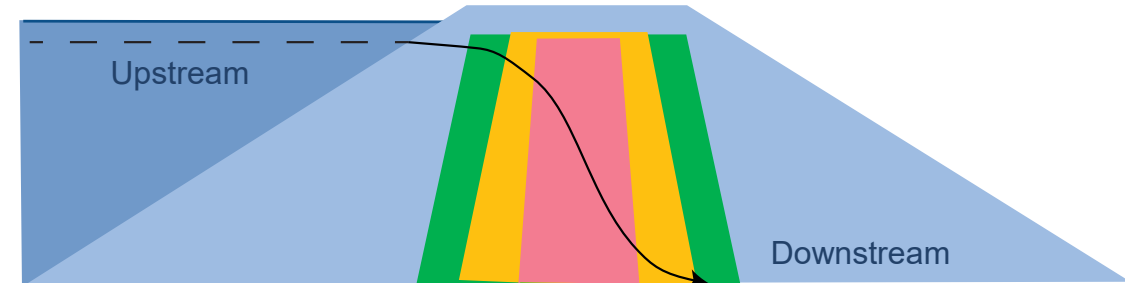
- Swedish dams built up between 1950 – 1970
  - 10 000 approx.
  - 2000 for hydropower operations
  - 190 classified as large dams\*

60% have experienced problems

- Structural damage
- Internal erosion



\*Classification according to the International Committee of Large Dams (Height > 15m)



Core (pink circle)  
Coarse filter (green circle)  
Fine filter (yellow circle)  
Shoulders (blue circle)

Glacial till → due low permeability

However, increased susceptibility to **internal erosion** when one or several fraction sizes are lacking

# Internal erosion



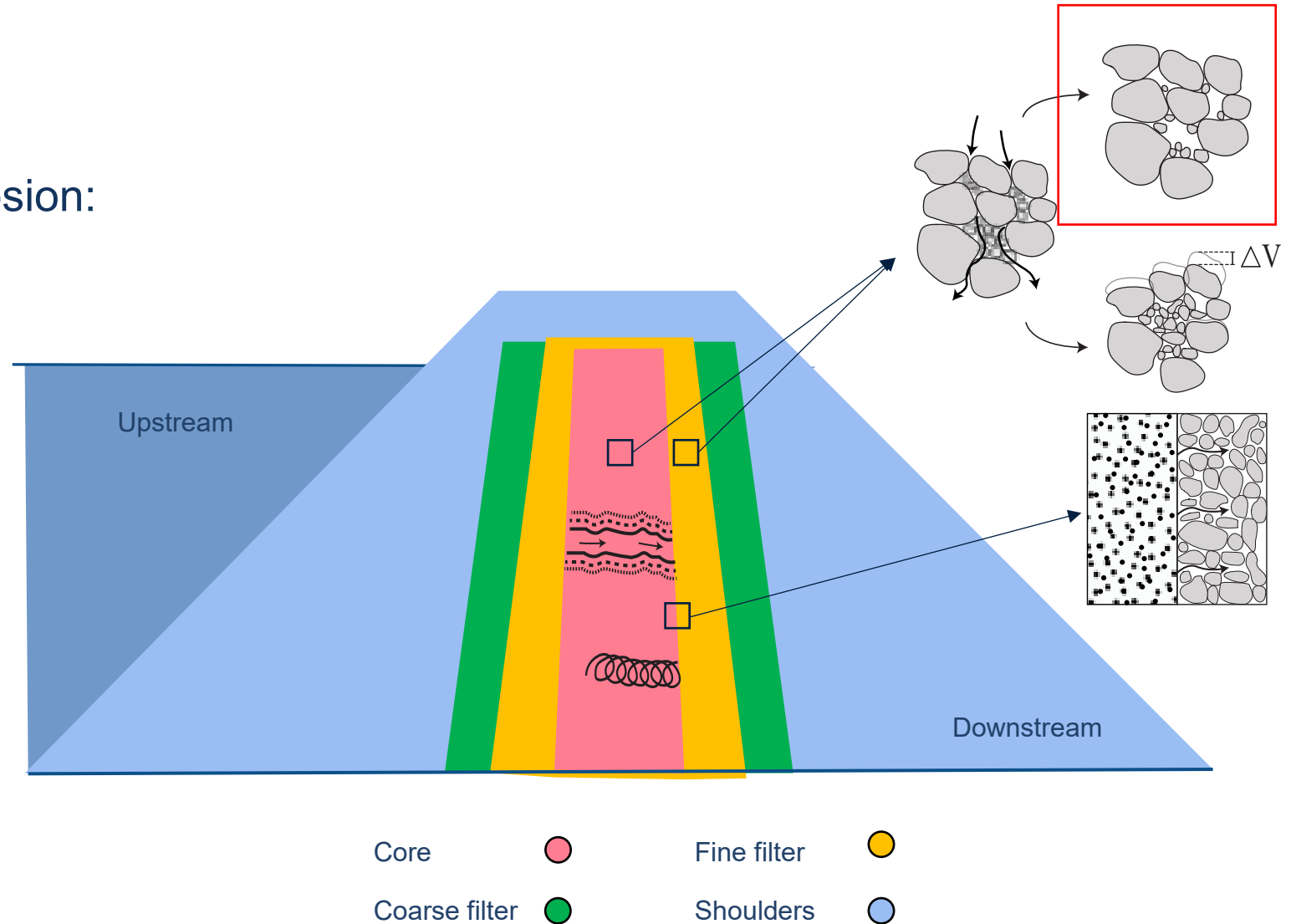
# Internal erosion

## Major factors affecting internal erosion:

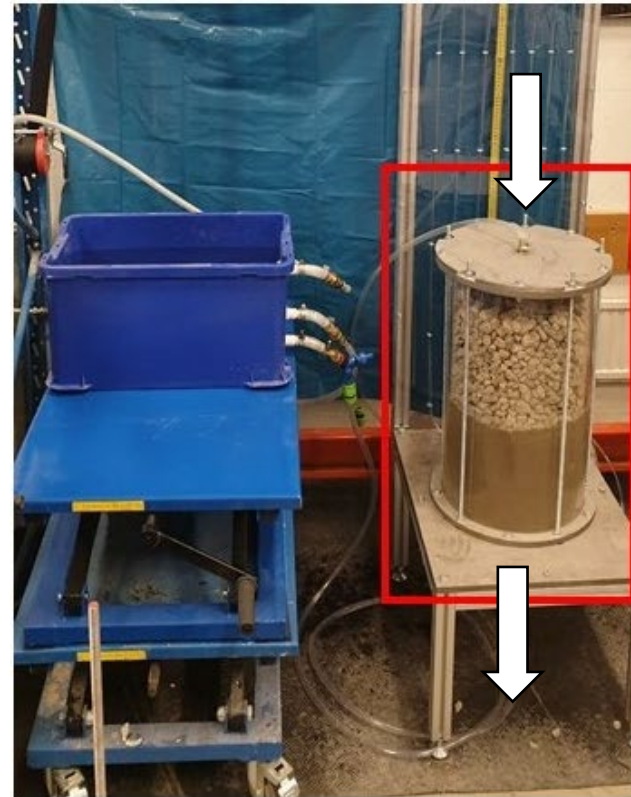
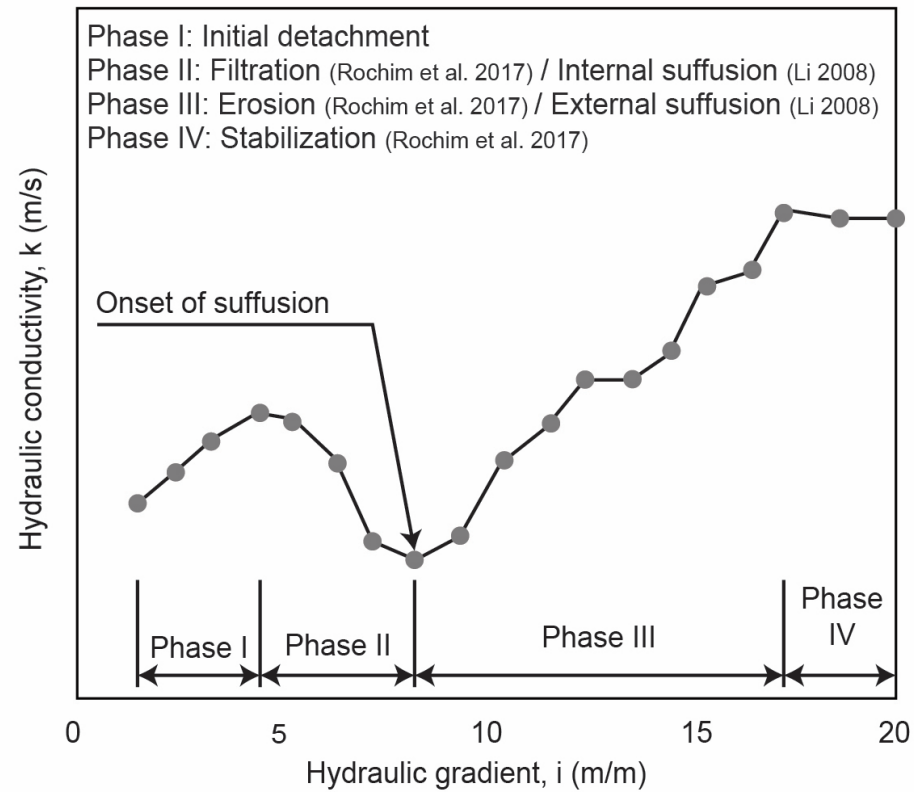
- Particle size distribution
- Stress conditions
- Hydraulic gradient

## Mechanisms:

- Backward erosion
- Contact erosion
- Suffusion
- Suffosion
- Concentrated leak erosion



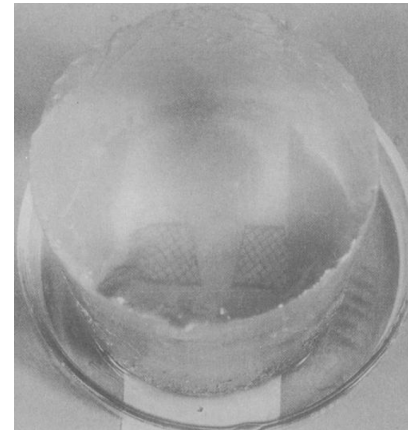
# Susceptibility to erosion



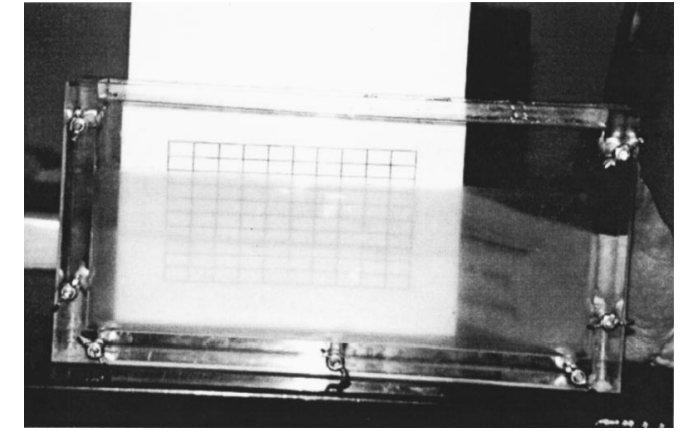
Silva (2022)

# Transparent soils

- "Artificial soil"
- Solid phase and a liquid phase matched refractive index
- Study internal erosion
  - Understand the mechanical behavior
  - Flow path and particle movement



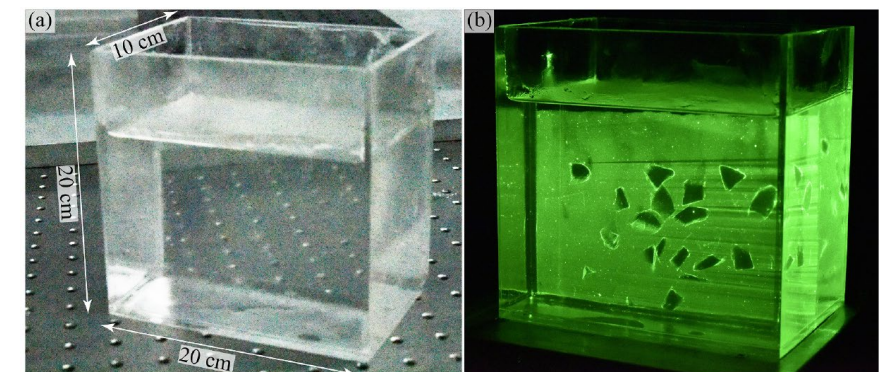
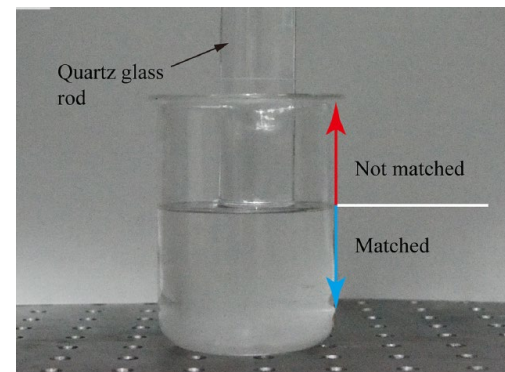
Iskander et al. (1994)



Iskander et al. (2002)

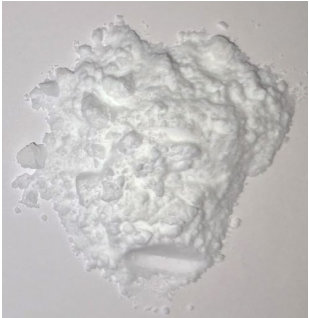






Liu et al. (2003)



Zhong et al. (2022)

# Transparent soils

Family	Amorphous silica powder	Silica gel	Aquabeds	Fused quartz	Laponite
Illustration					
Best suited for modeling	Clay/silt size granular materials	Sand	Flow of water in soil or very weak marine deposit	Saturated and unsaturated sand	Soft marine clays
Pore fluid	Mineral oil and paraffinic solvent blend or calcium bromide brine		Water	Mineral oil blend or sucrose solution	Water

Based on Iskander et al. (2015)

# Research objectives

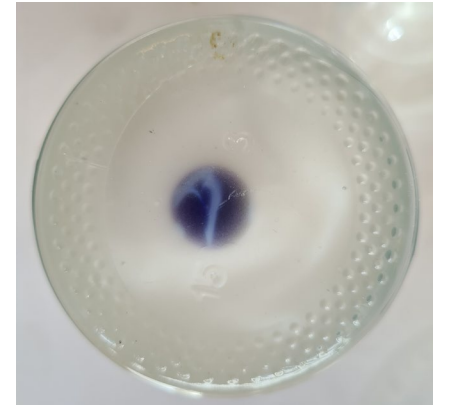
Glacial tills



Could transparent soils be used to replicate hydro-mechanical properties of glacial tills?

- Particle size distribution
- Compressibility
- Permeability

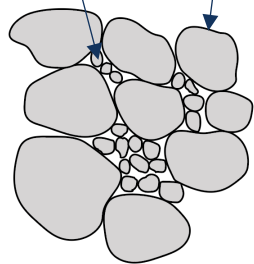
Transparent soils



# Process to create a transparent soil



Silica powder      Silica gels



Calcium bromide brine



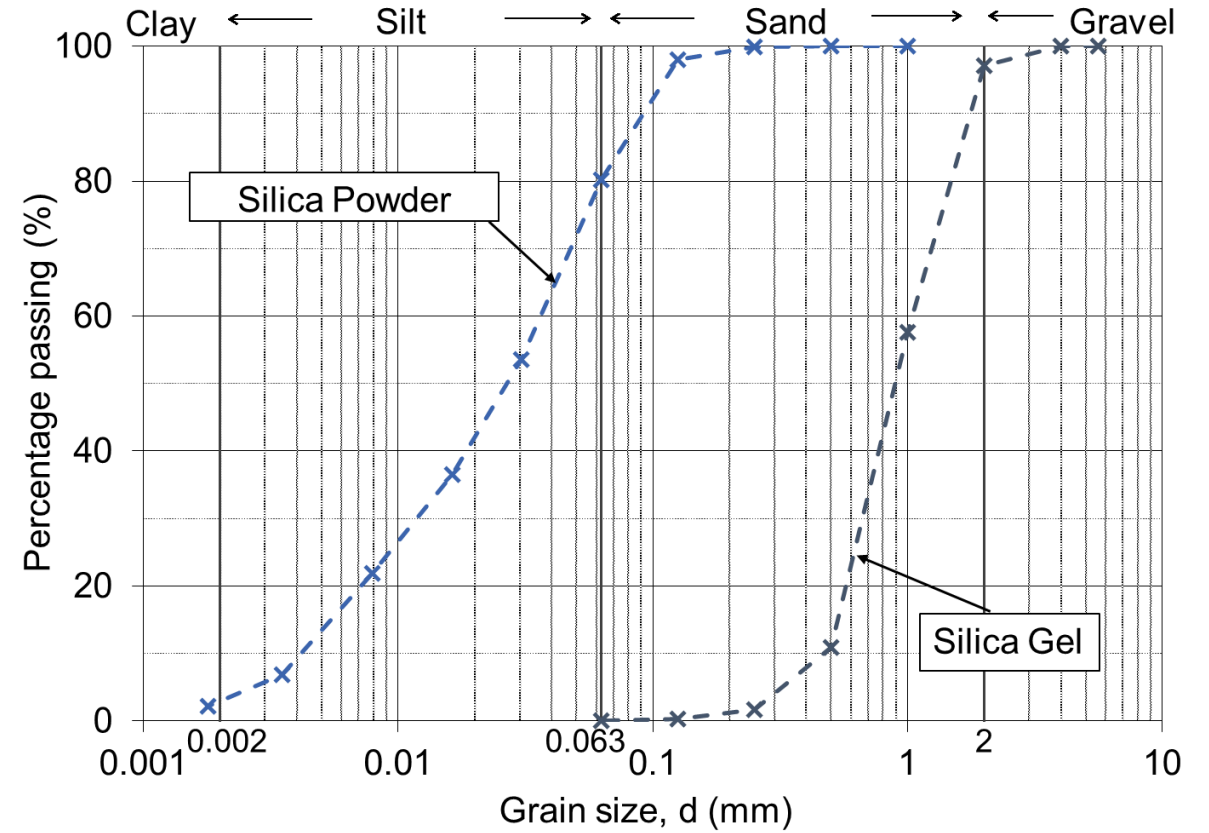
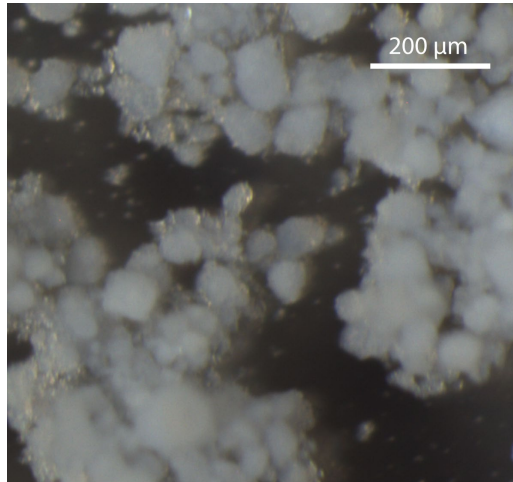
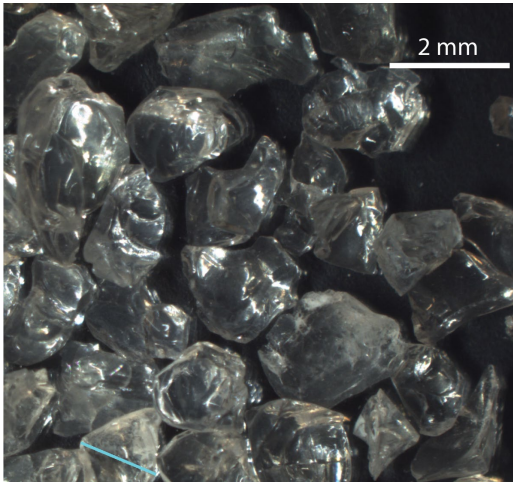
Transparent soil



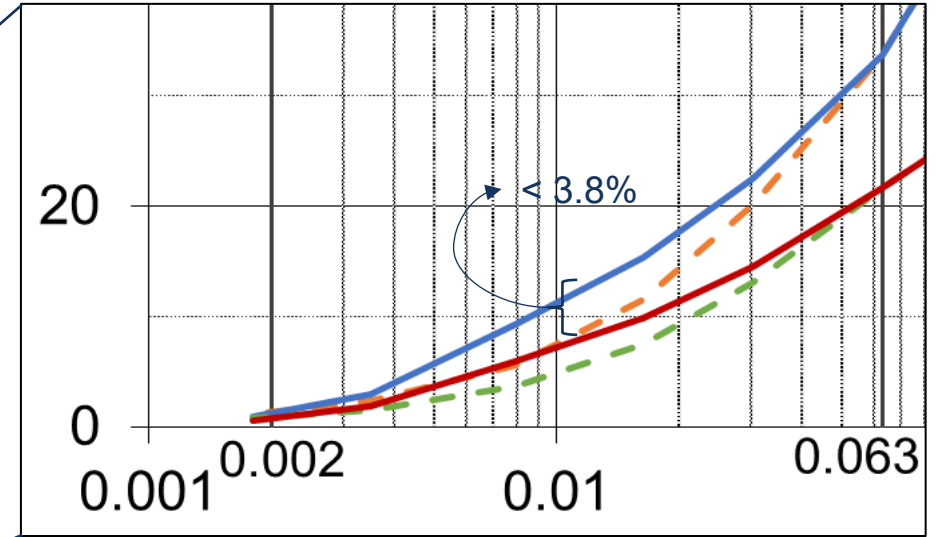
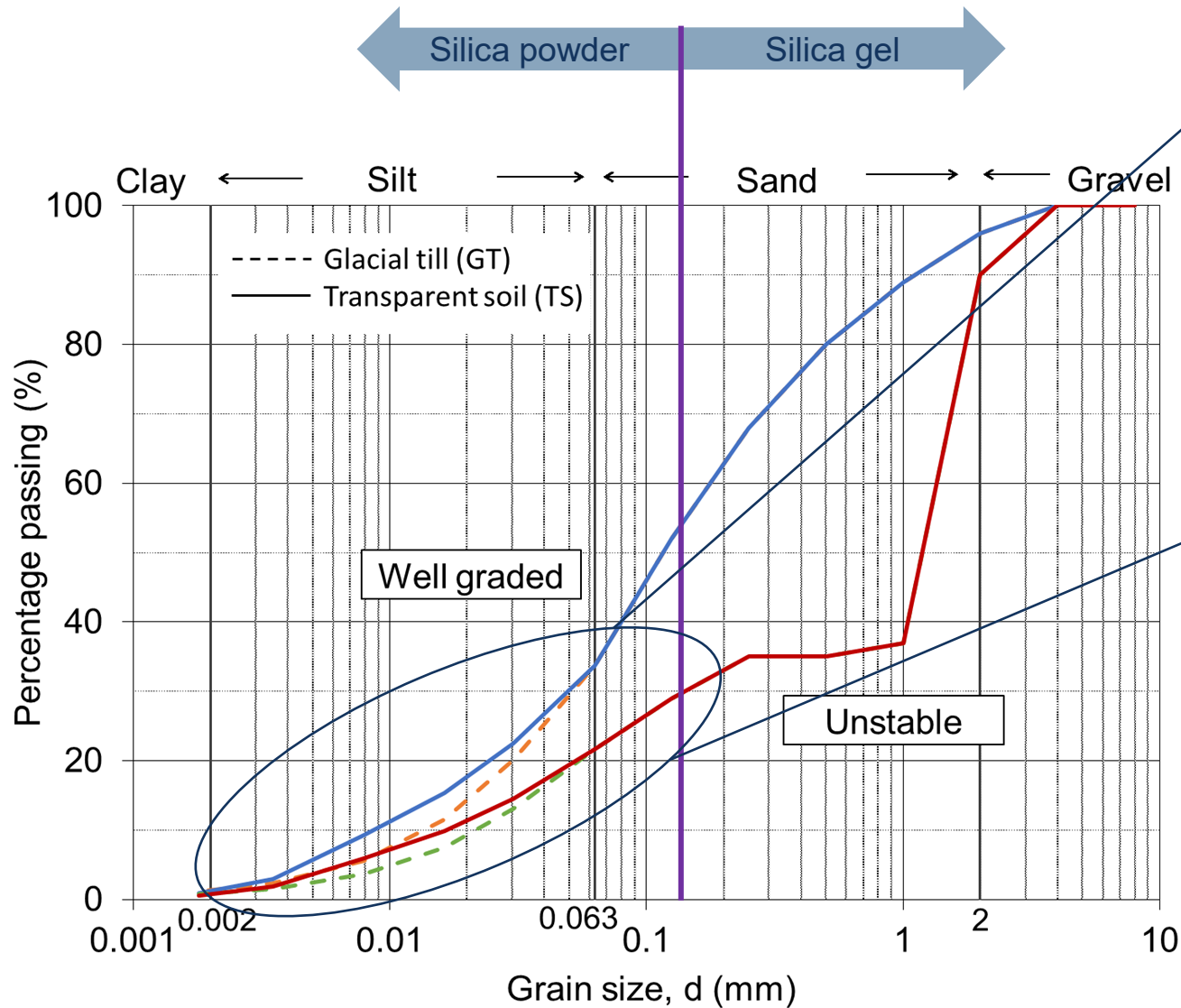
4



# Materials: Solid phase



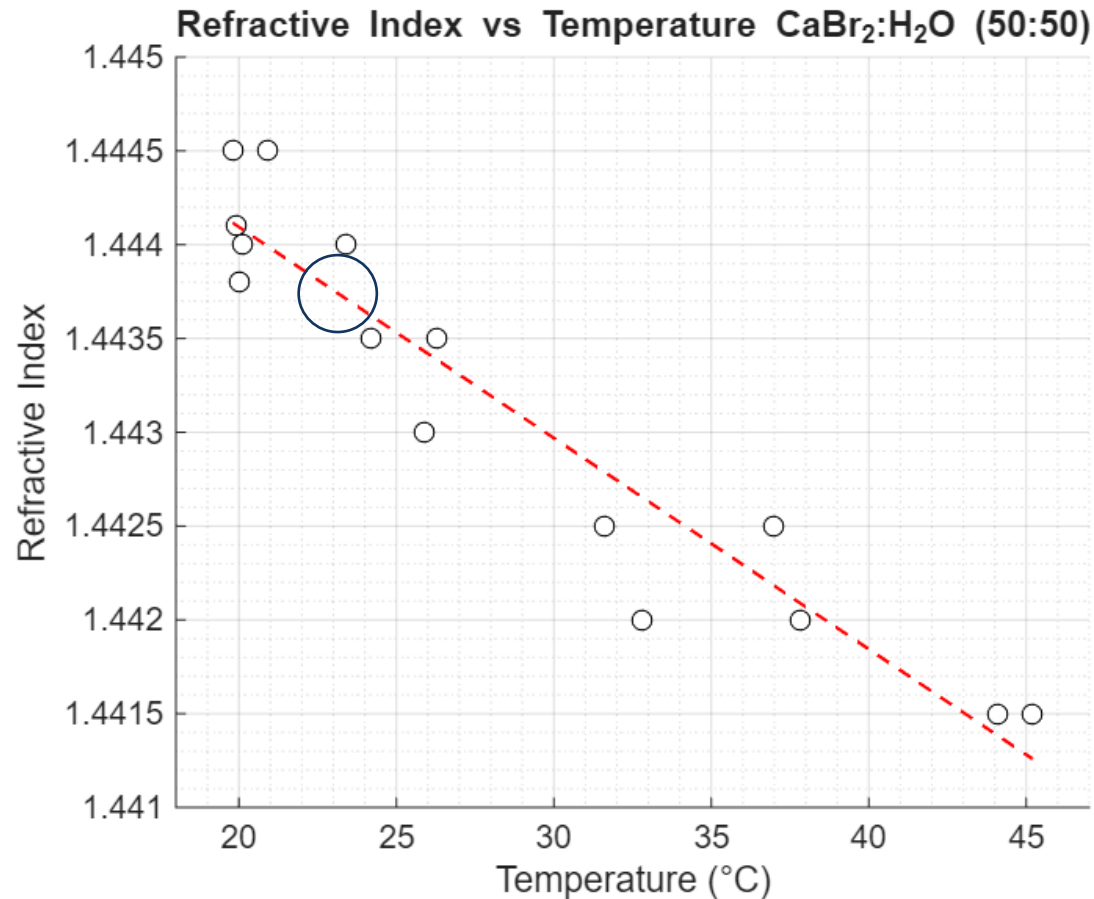
# Materials: Solid phase



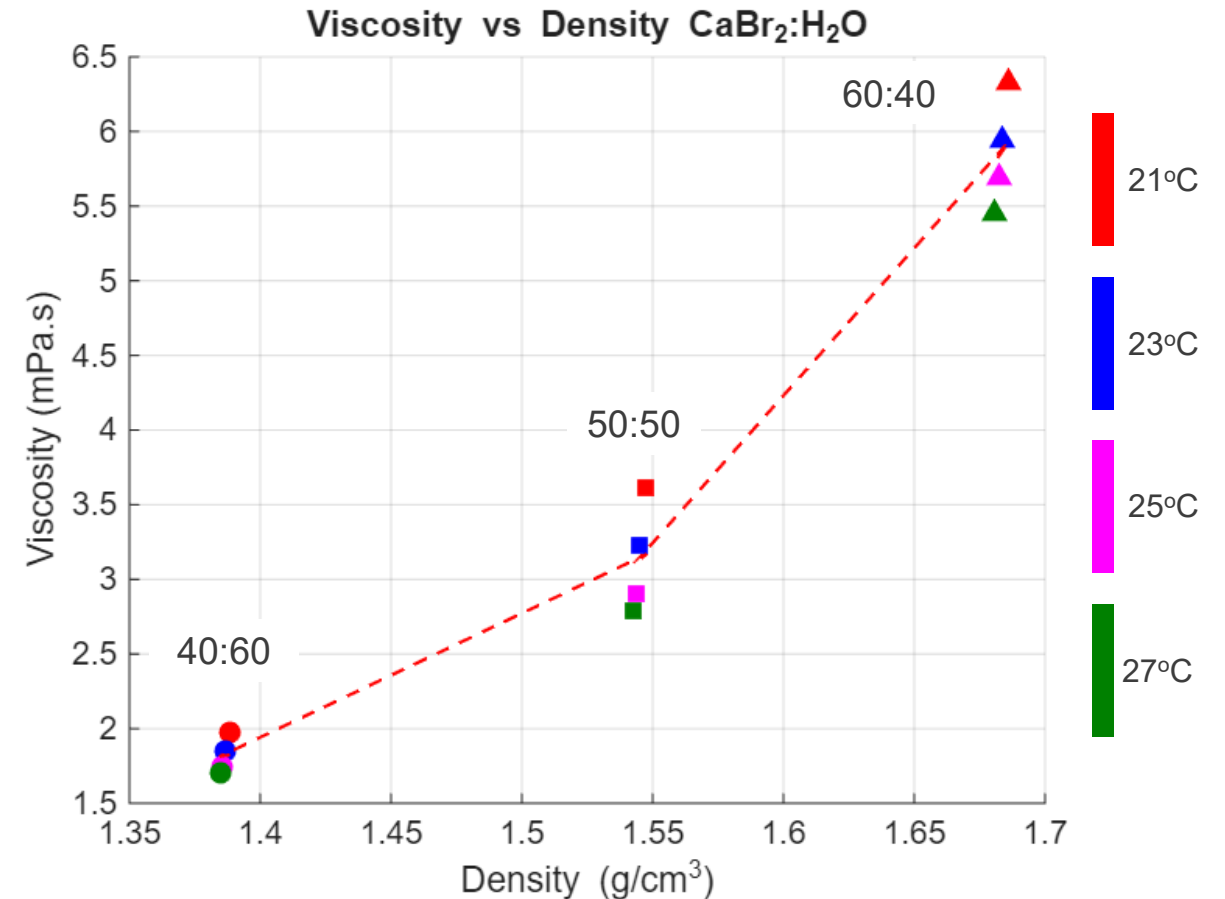
Gradation	Silica Gel (%)	Silica Powder (%)
Well graded	48	52
Unstable	71	29

# Materials: Liquid phase

## Refractive Index

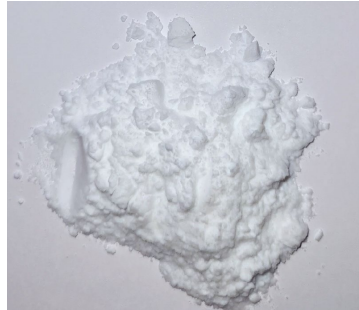


## Different density than water



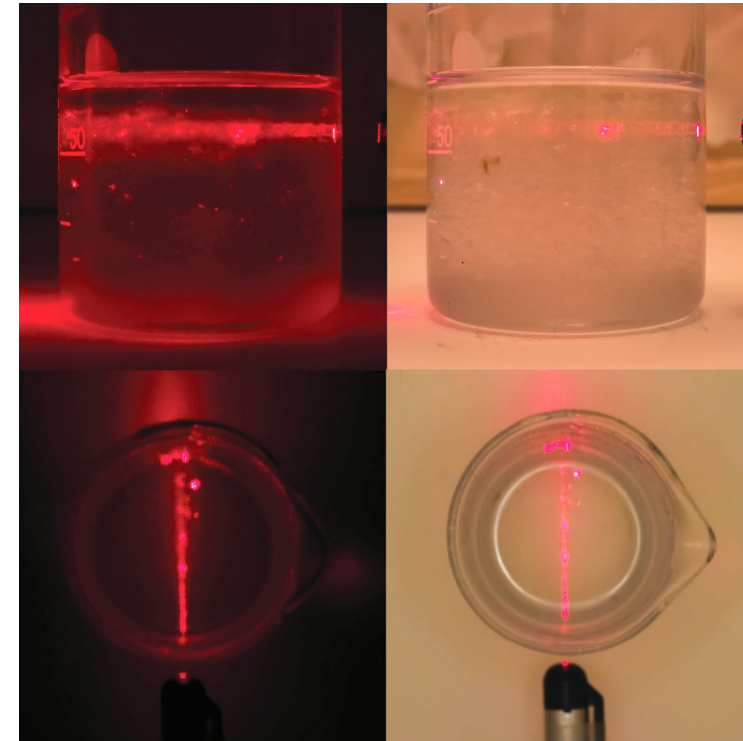
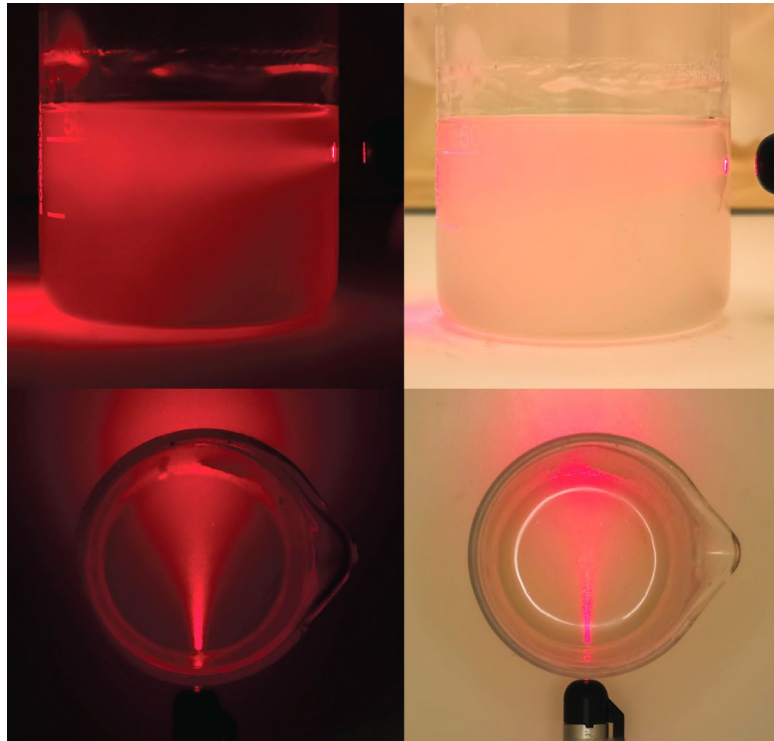
# Laser test

Silica powder

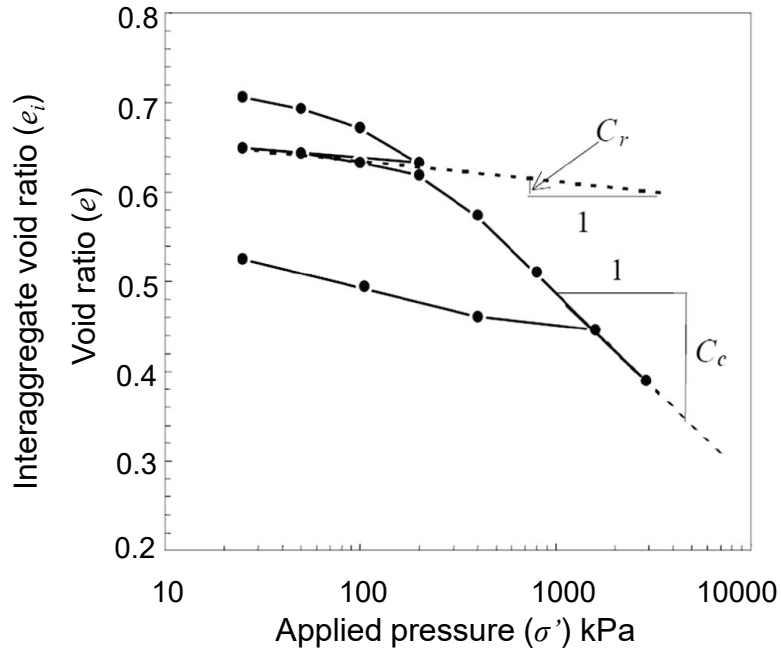


+  
Brine  
( $\text{CaBr}_2 \cdot \text{H}_2\text{O}$ )

Silica gel



# One dimensional consolidation



$C_c$  = compression index  
 $C_r$  = re-compression index

Coefficient of consolidation

$$C_v = \frac{k}{m_v \gamma_w} = \frac{k}{\frac{\Delta e}{\Delta \sigma' (1 + e_{av})} \gamma_w}$$

Interaggregate void ratio

$$e_i = \frac{V_v - V_{vi}}{V_s + V_{vi}} = \frac{e - a \gamma_s}{1 + a \gamma_s}$$

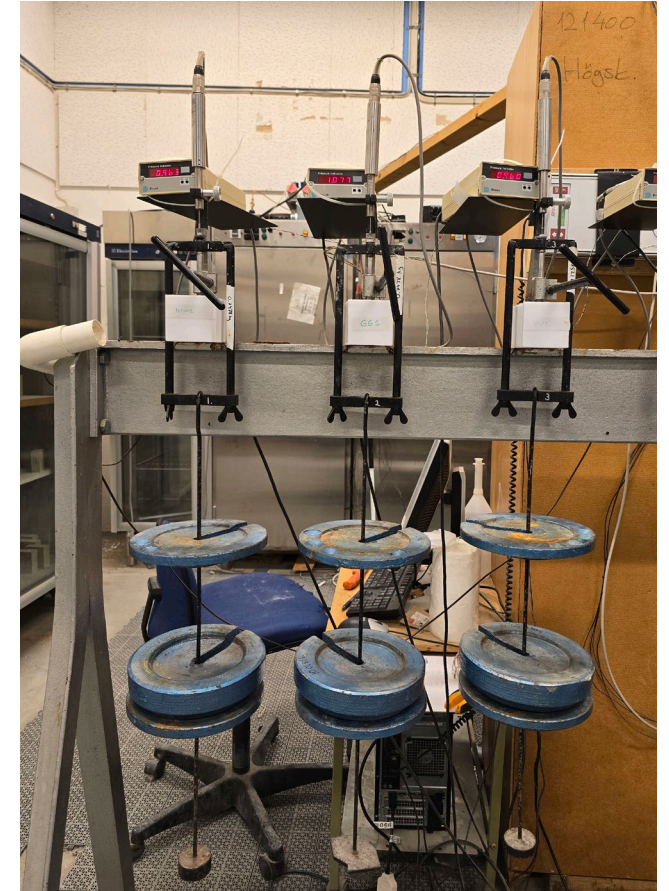
$V_v$  = total volume of voids

$V_{vi}$  = volume of voids inside solid aggregates

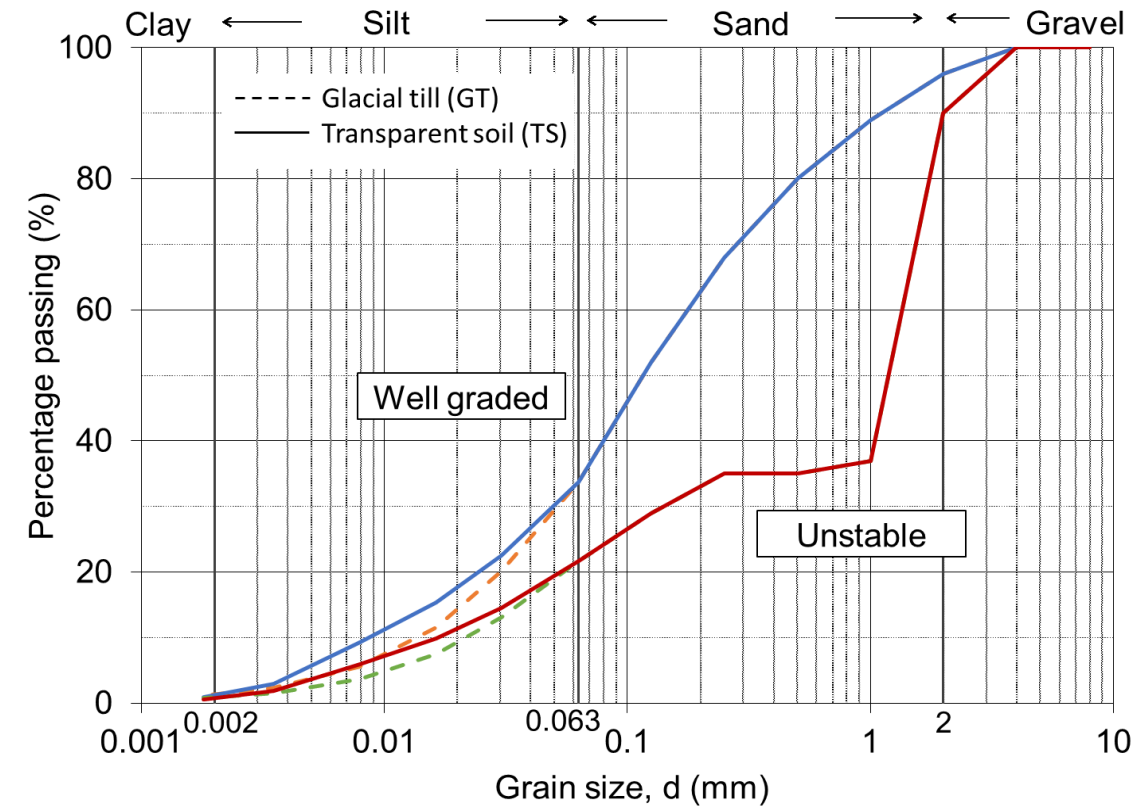
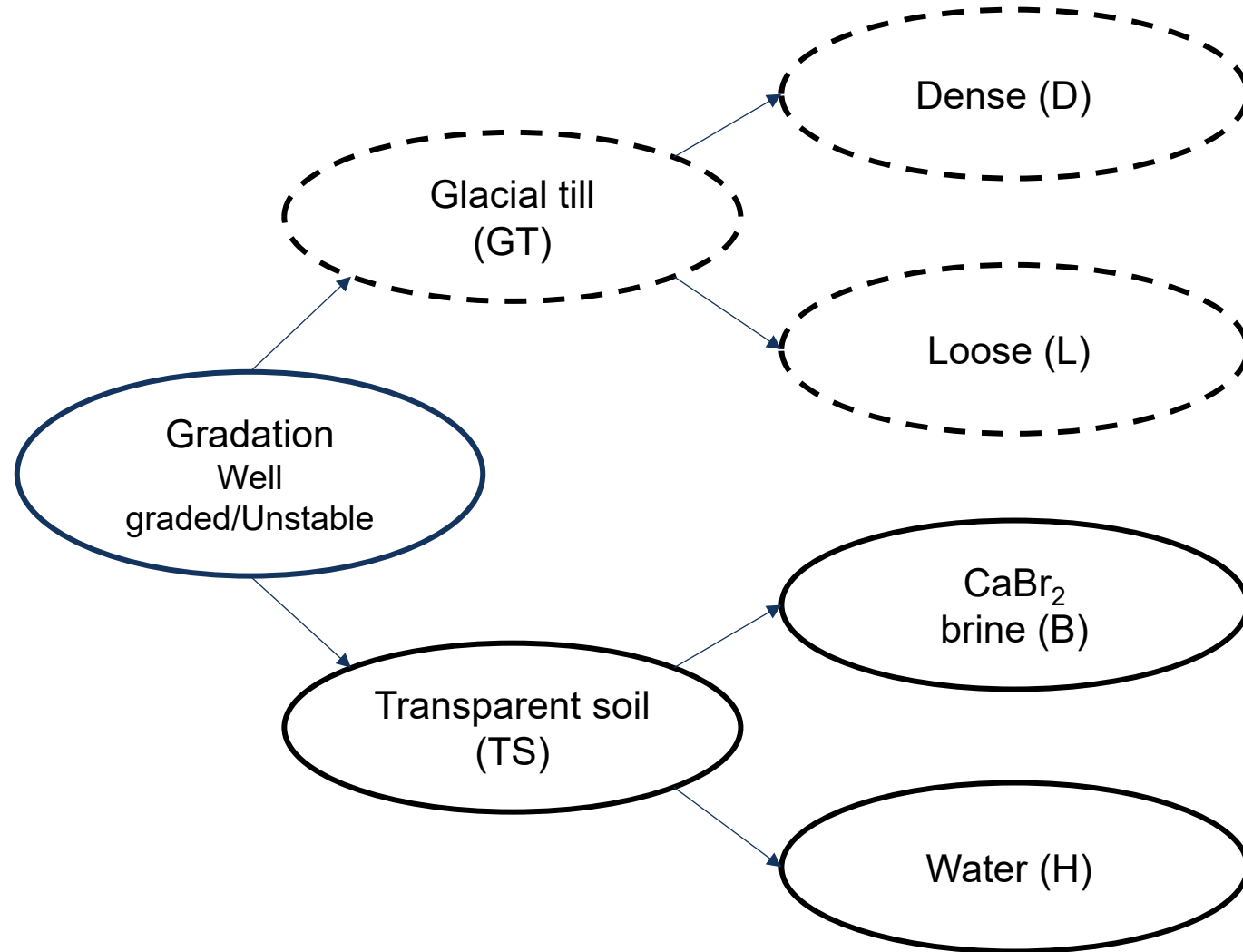
$V_s$  = volume of solids

$\gamma_s$  = unit weight of solids (g/cm<sup>3</sup>)

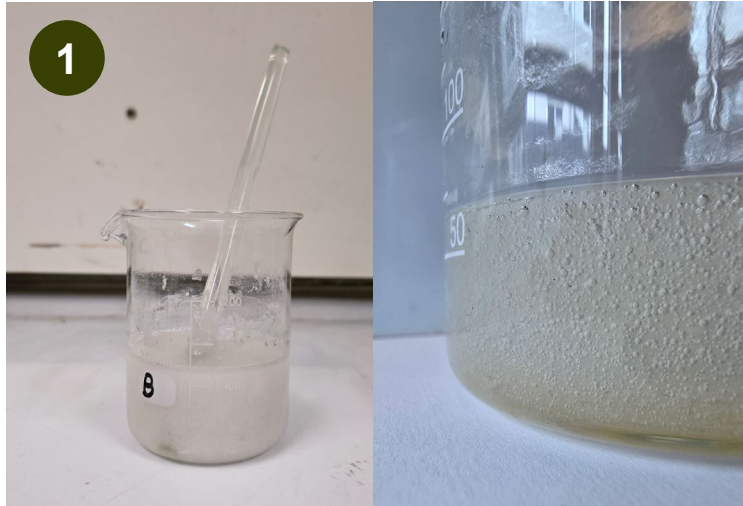
$a$  = absorption capacity (cm<sup>3</sup>/g)



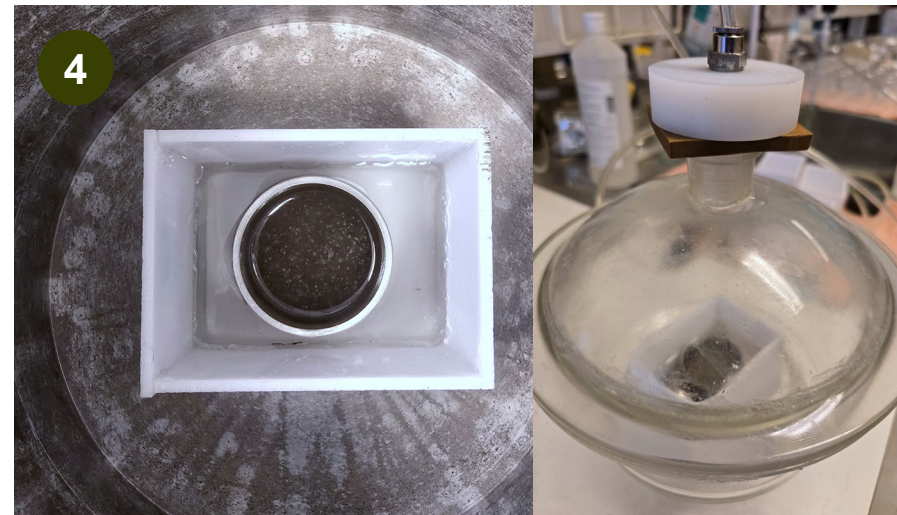
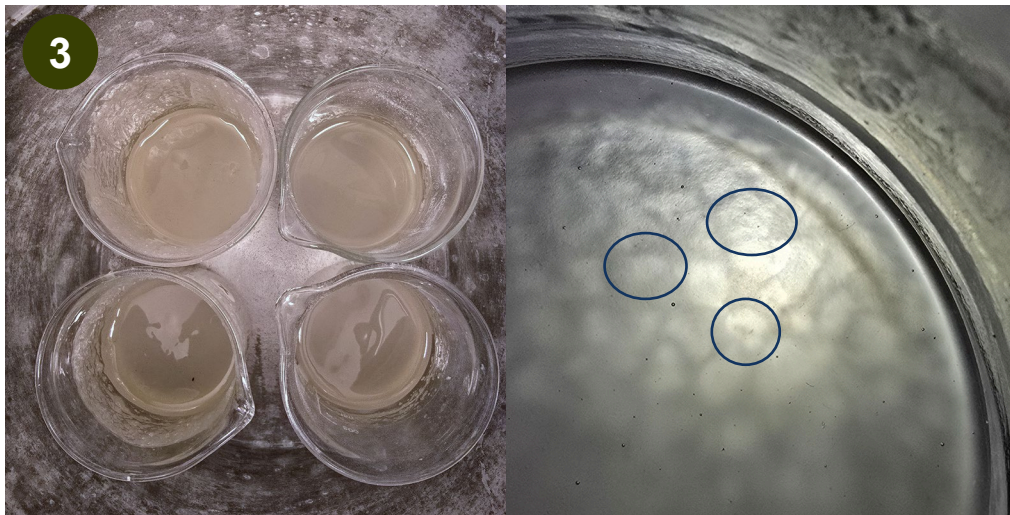
# Samples tested



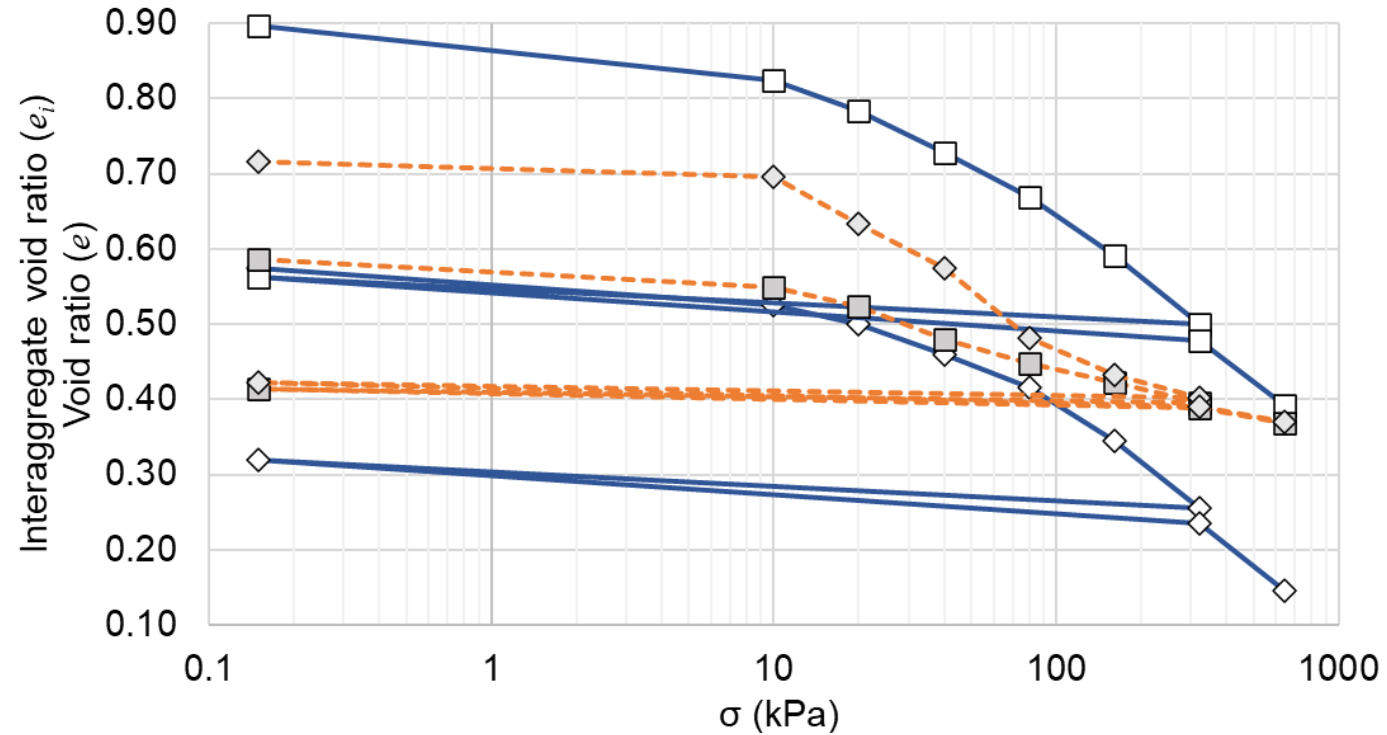
# Samples for one dimensional consolidation



Tested up to 640kPa

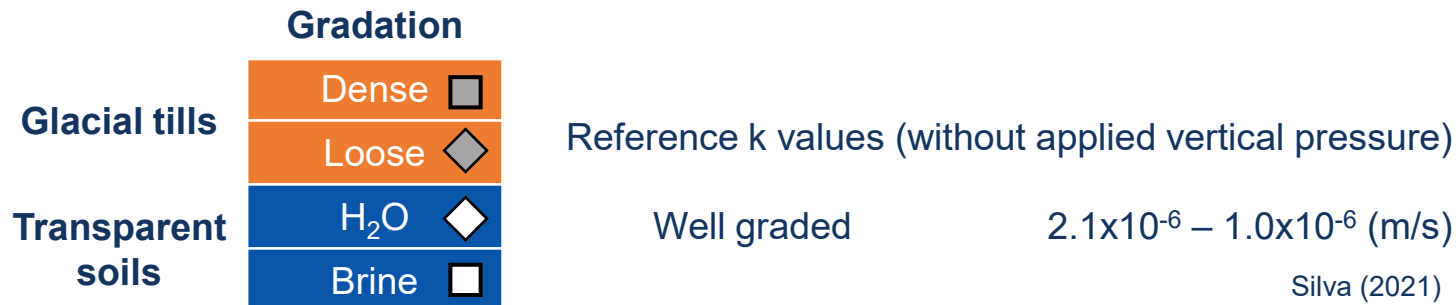
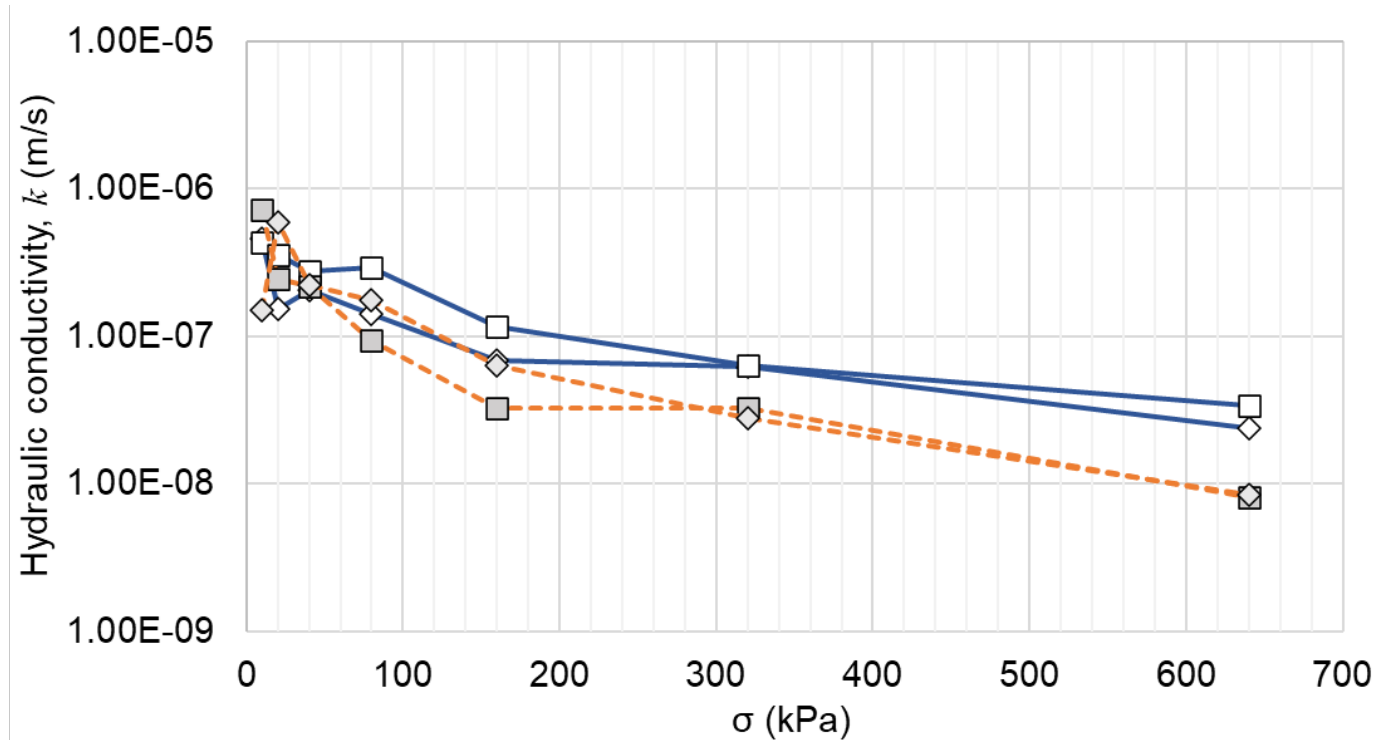


# Well graded samples (W)

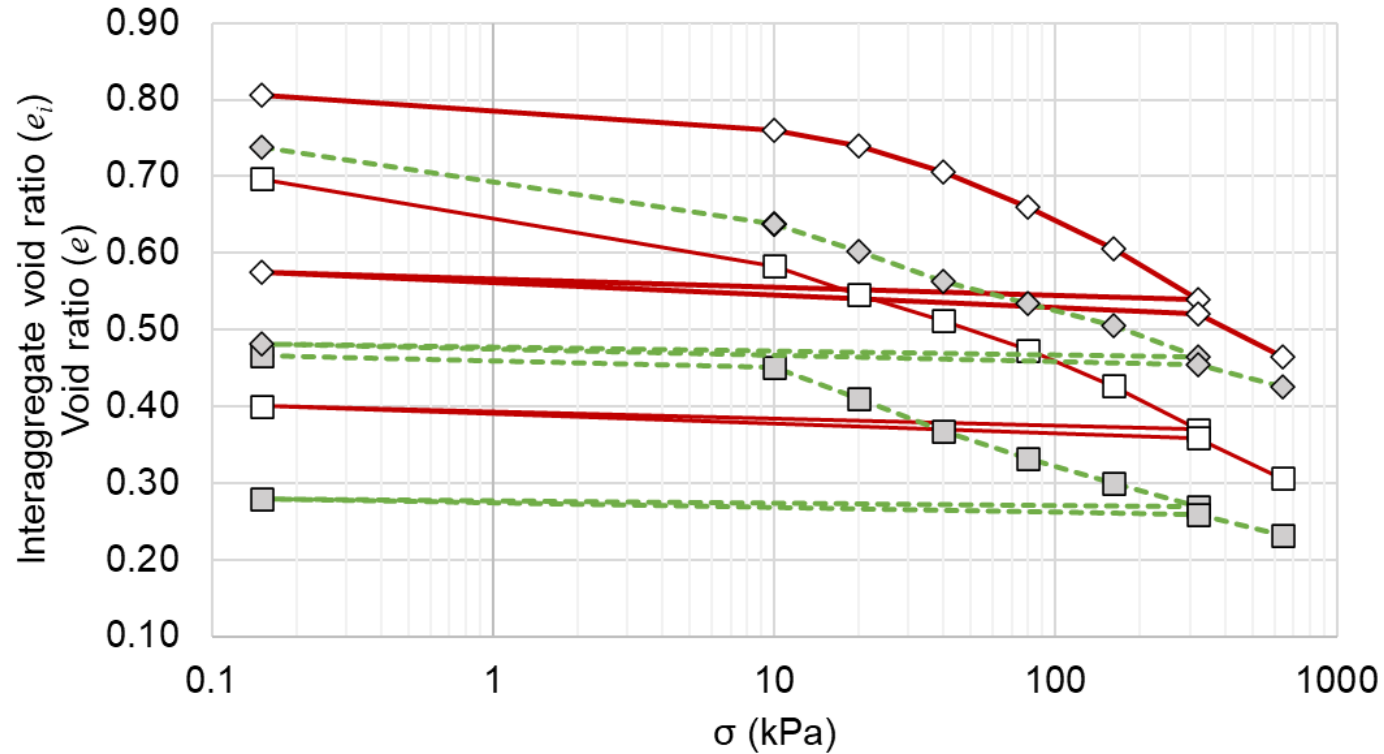


	Gradation	$C_c$	$C_r$	$\Delta e$ or $\Delta e_i$
Glacial tills	Dense <span style="display:inline-block; width:1em; height:1em; background-color:gray; border:1px solid black;"></span>	0.105	0.007	0.22
	Loose <span style="display:inline-block; width:1em; height:1em; background-color:gray; border:1px solid black; transform: rotate(45deg);"></span>	0.174	0.009	0.35
Transparent soils	H <sub>2</sub> O <span style="display:inline-block; width:1em; height:1em; background-color:white; border:1px solid black; transform: rotate(45deg);"></span>	0.262	0.026	0.43
	Brine <span style="display:inline-block; width:1em; height:1em; background-color:white; border:1px solid black;"></span>	0.260	0.025	0.50

# Well graded samples (W)

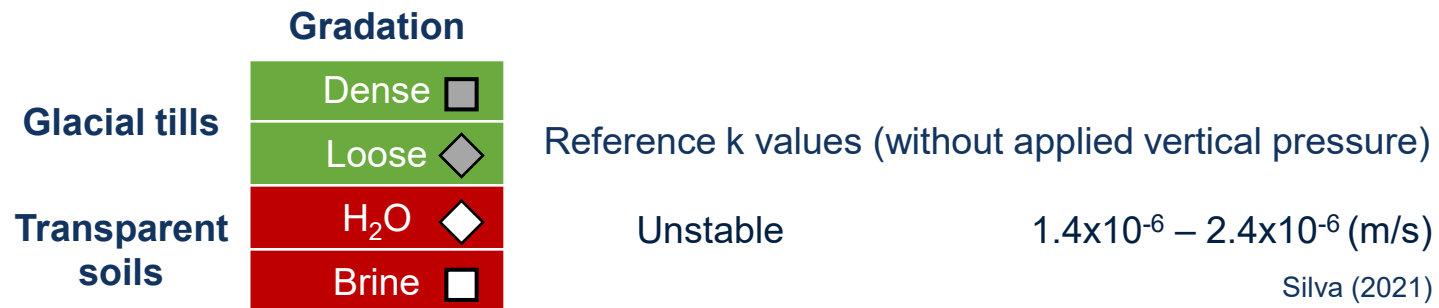
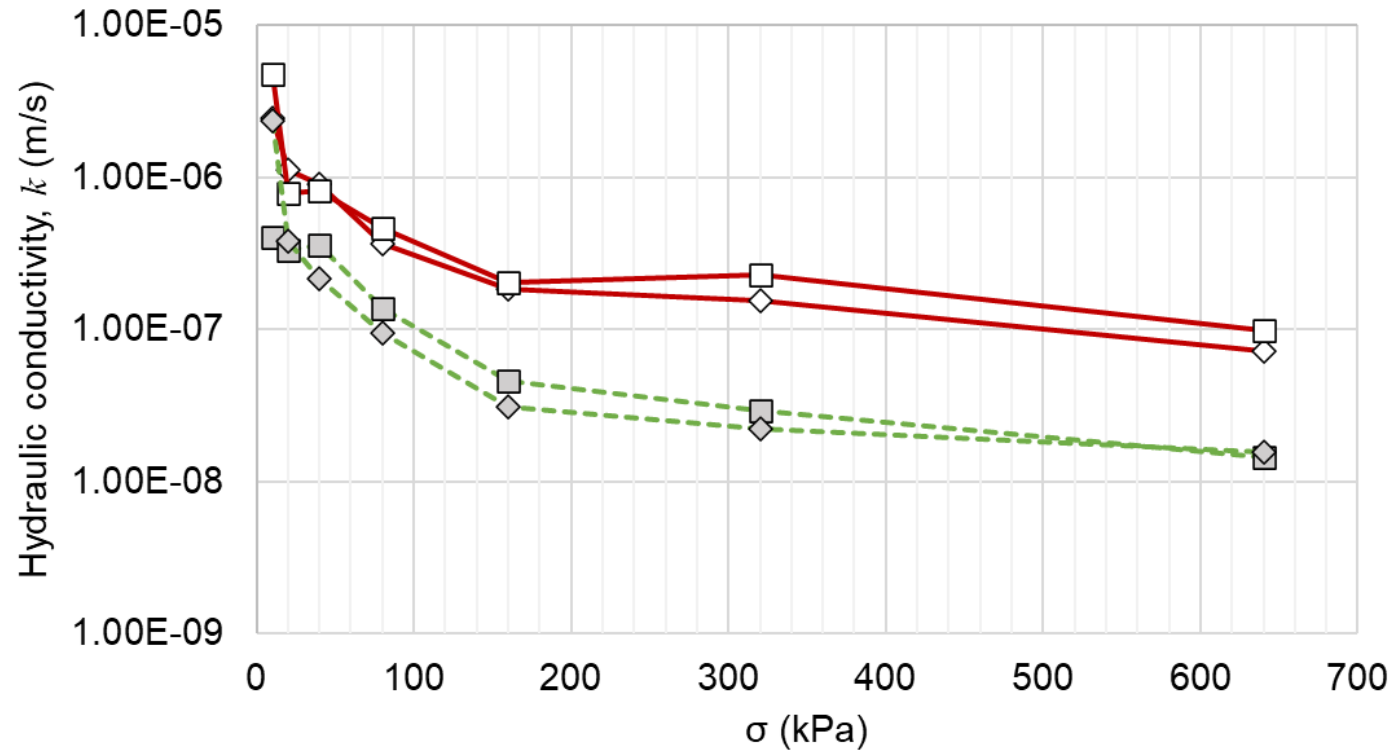


# Unstable samples (U)



	Gradation	$C_c$	$C_r$	$\Delta e$ or $\Delta e_i$
Glacial tills	Dense <span style="display:inline-block; width:10px; height:10px; background-color:gray; border:1px solid black;"></span>	0.101	0.006	0.23
	Loose <span style="display:inline-block; width:10px; height:10px; background-color:gray; border:1px solid black; transform: rotate(45deg);"></span>	0.116	0.008	0.31
Transparent soils	H <sub>2</sub> O <span style="display:inline-block; width:10px; height:10px; background-color:white; border:1px solid black; transform: rotate(45deg);"></span>	0.199	0.017	0.34
	Brine <span style="display:inline-block; width:10px; height:10px; background-color:white; border:1px solid black;"></span>	0.159	0.012	0.39

# Unstable samples (U)

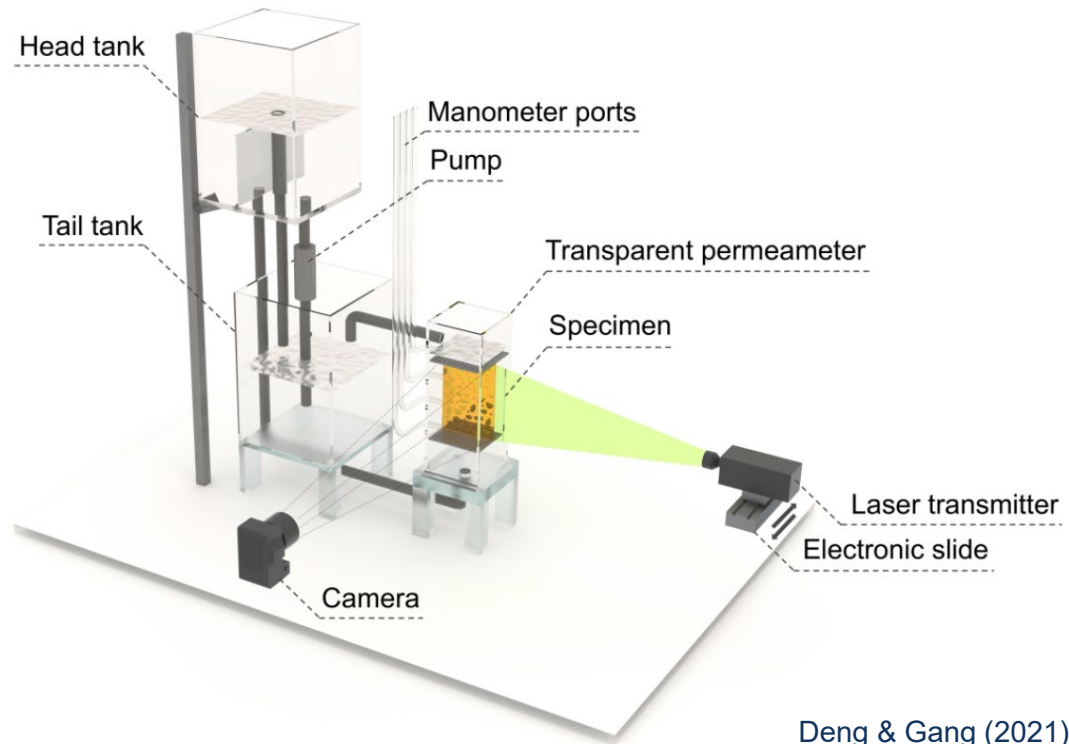


# Conclusions

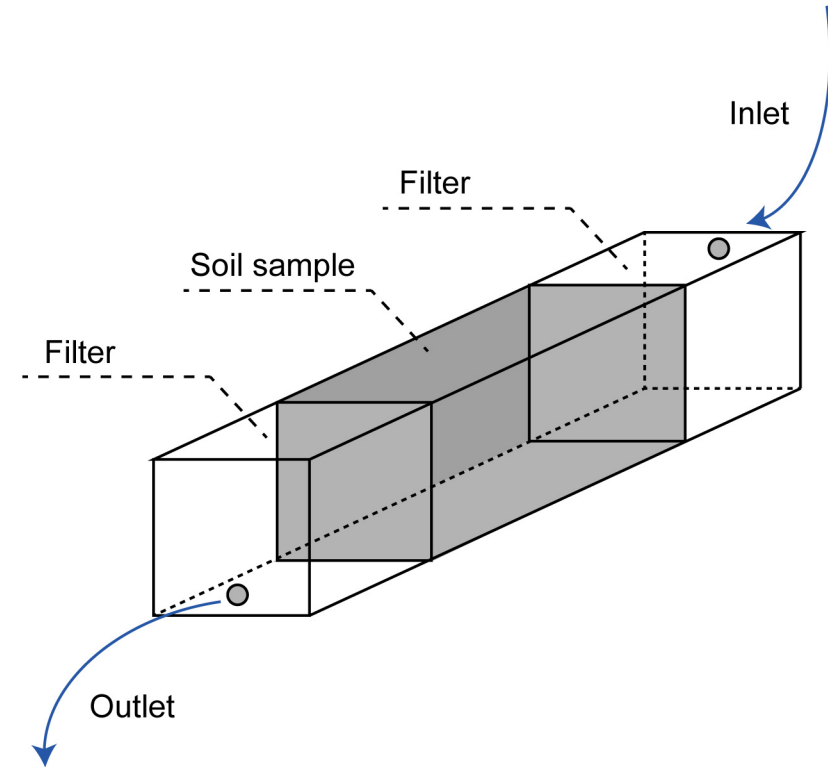
- Transparent soils could be used as **alternative** to study hydro-mechanical behavior in glacial tills.
- **Not reproduce absolute magnitudes**, yet transparent soils capture **qualitative behavior** in glacial tills.
- **Gradation is key** - lower content of fine particles mixtures (unstable) show the closest match with glacial tills.
- Pore fluid choice influences stress-strain behavior but **does not alter overall hydraulic trends**.

# Future work

## Transparent soils



## Glacial tills





THANK YOU FOR YOUR ATTENTION



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