Progress Update on Rheological Studies

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B+Tech Oy

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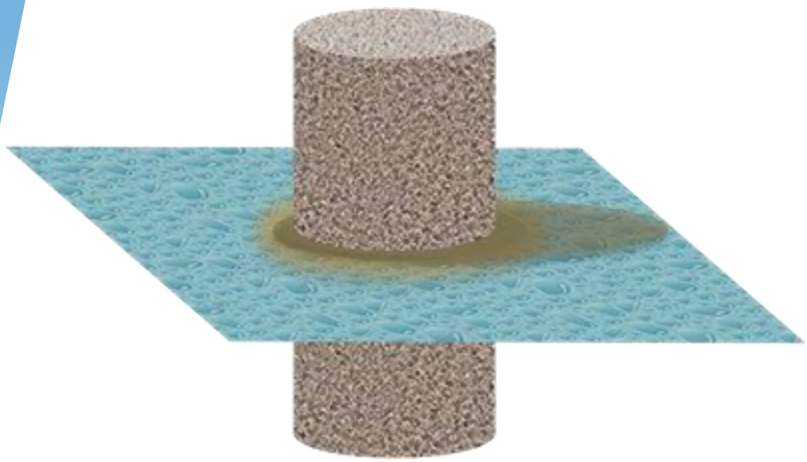
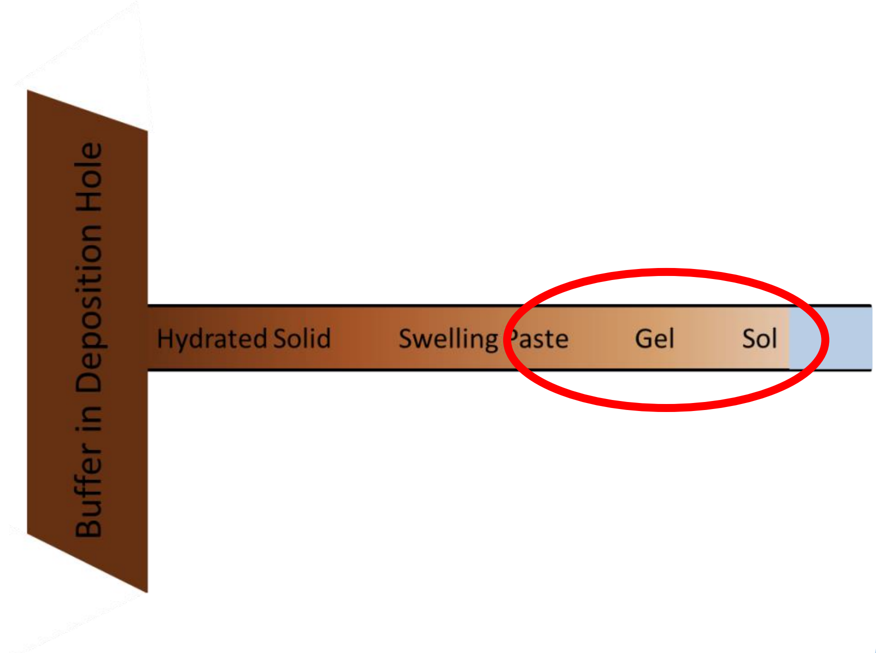
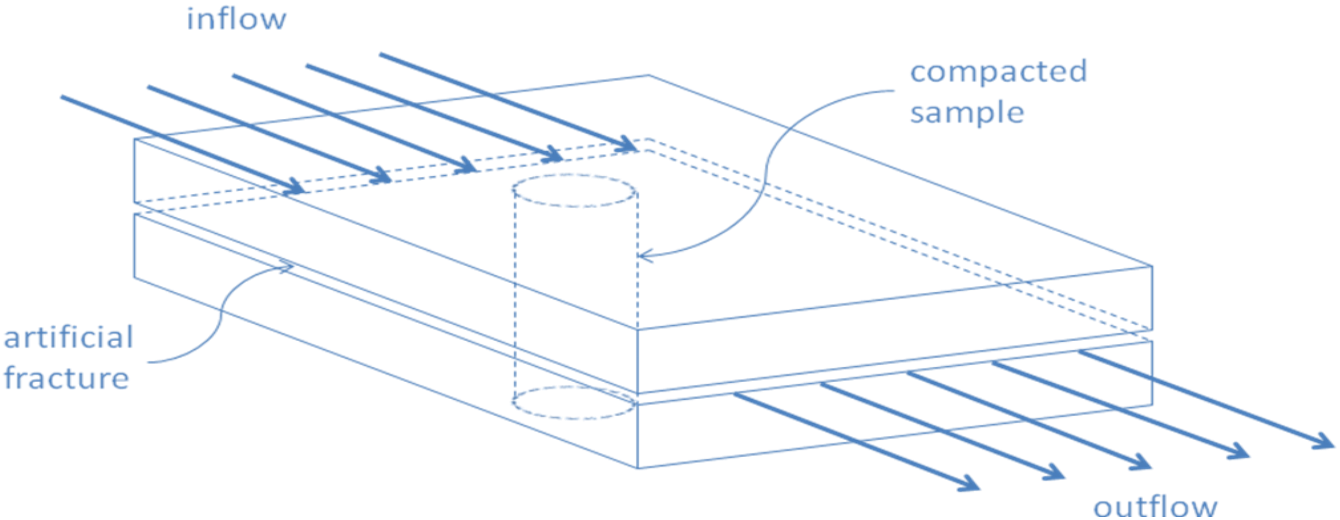
Background

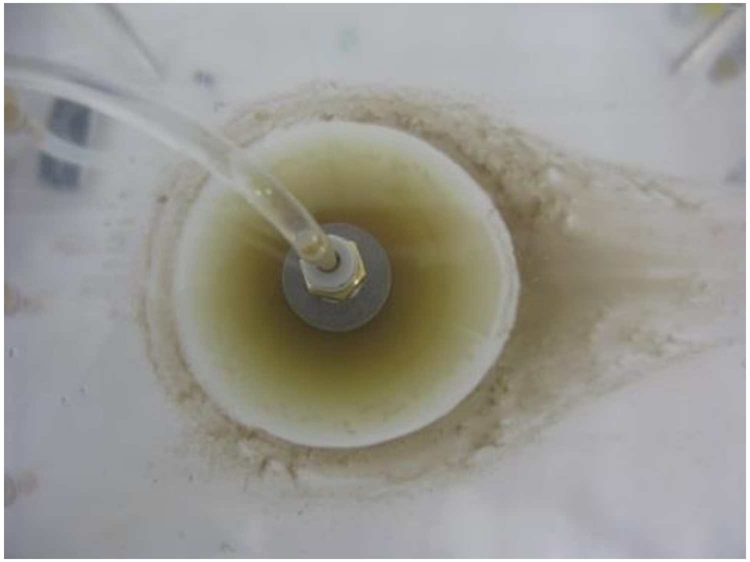


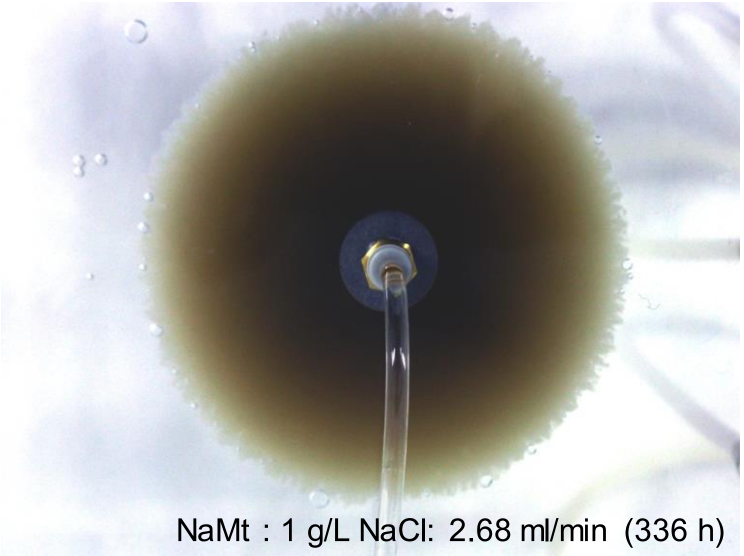


A transmissive fracture intersecting a deposition hole may lead to erosive loss of buffer material as a consequence of material migrating into the fracture

Artificial fracture tests



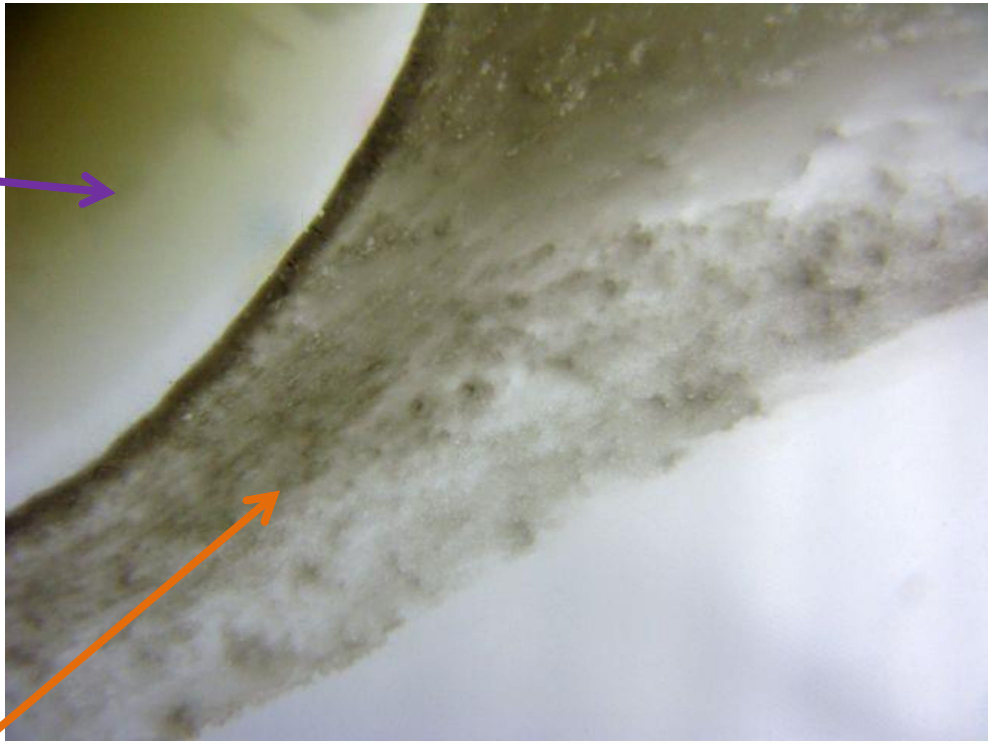




Extrusion/erosion interface

Extruding zone:

- Rigid gel
- G’, G’’

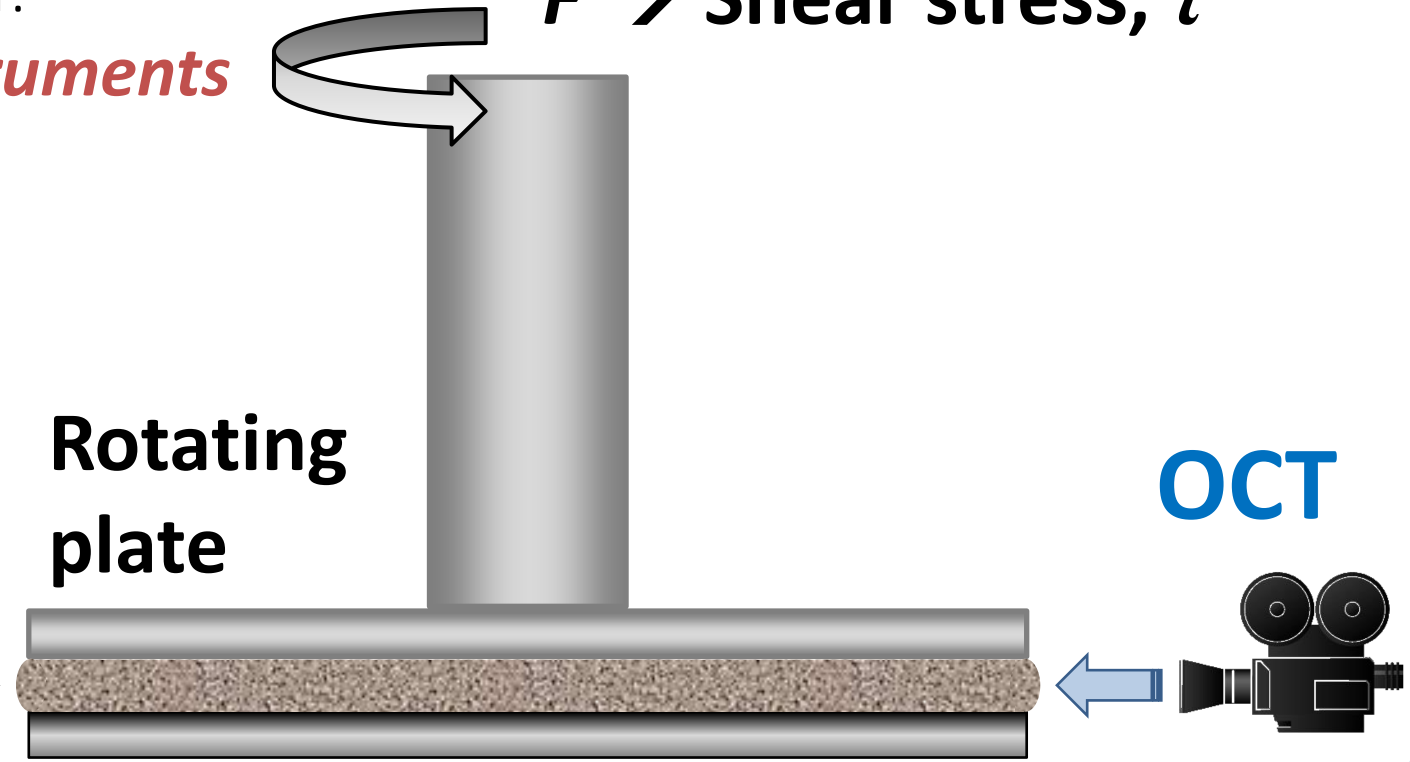


Eroding zone:
- Viscous liquid, shear flow
- Viscosity $\eta(\dot{\gamma})$

Experimental setup

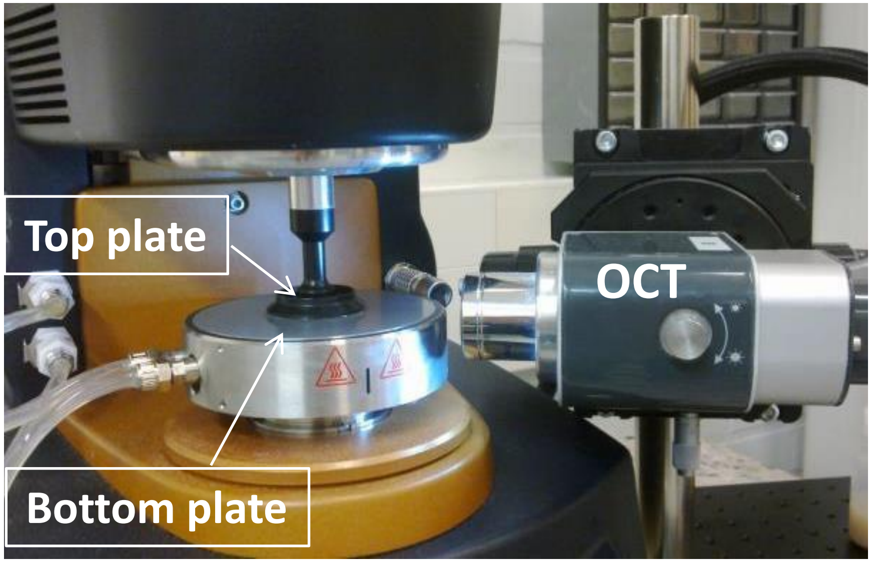
Rheometer:

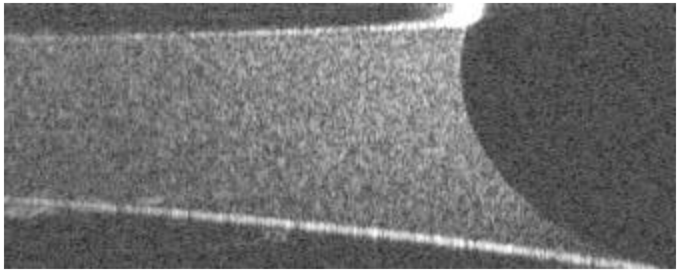
TA Instruments DHR-2



Optical Coherence Tomography

- Optical imaging technique for producing 3D images of semi-opaque samples
- Collects reflected light from the sample. An interferometer is used to filter out scattered light.
- Spatial resolution a few microns. Penetration depth 1 – 2 mm.

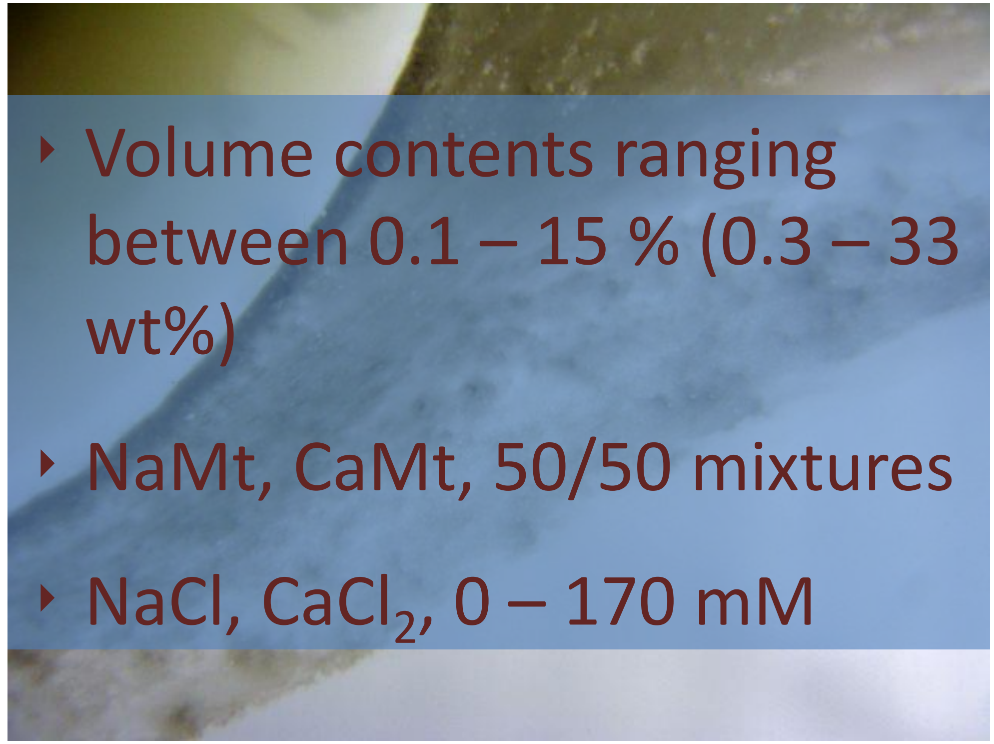




0.1 vol-% NaMt

Aims of the study

- **Relate the strength of the montmorillonite gels to the shear forces exerted on them by the flowing water (can the shear forces break the gels?)**

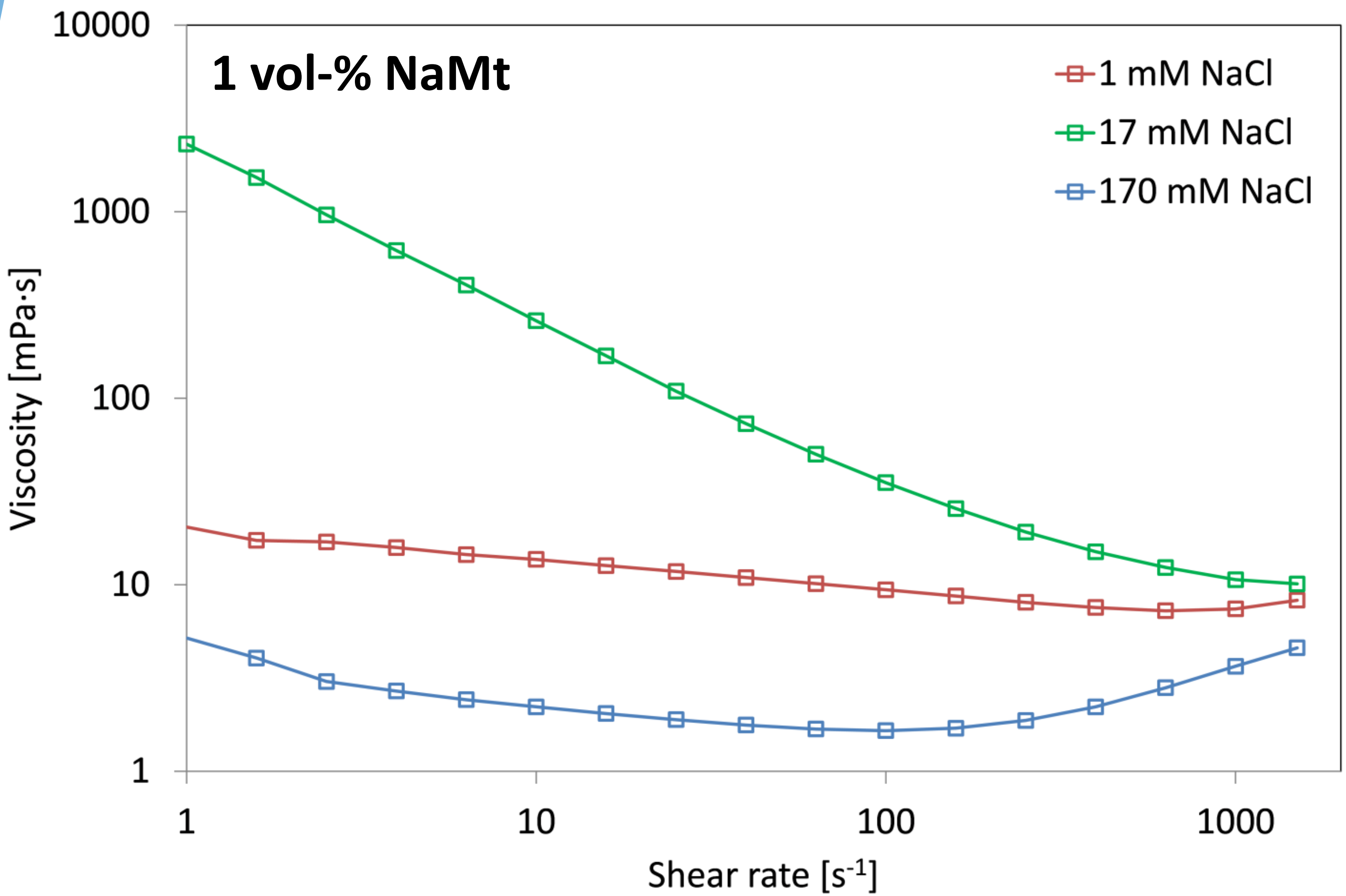


- **Study the rheological properties of montmorillonite suspensions in order to gain new knowledge on the microstructural ordering and dynamics**

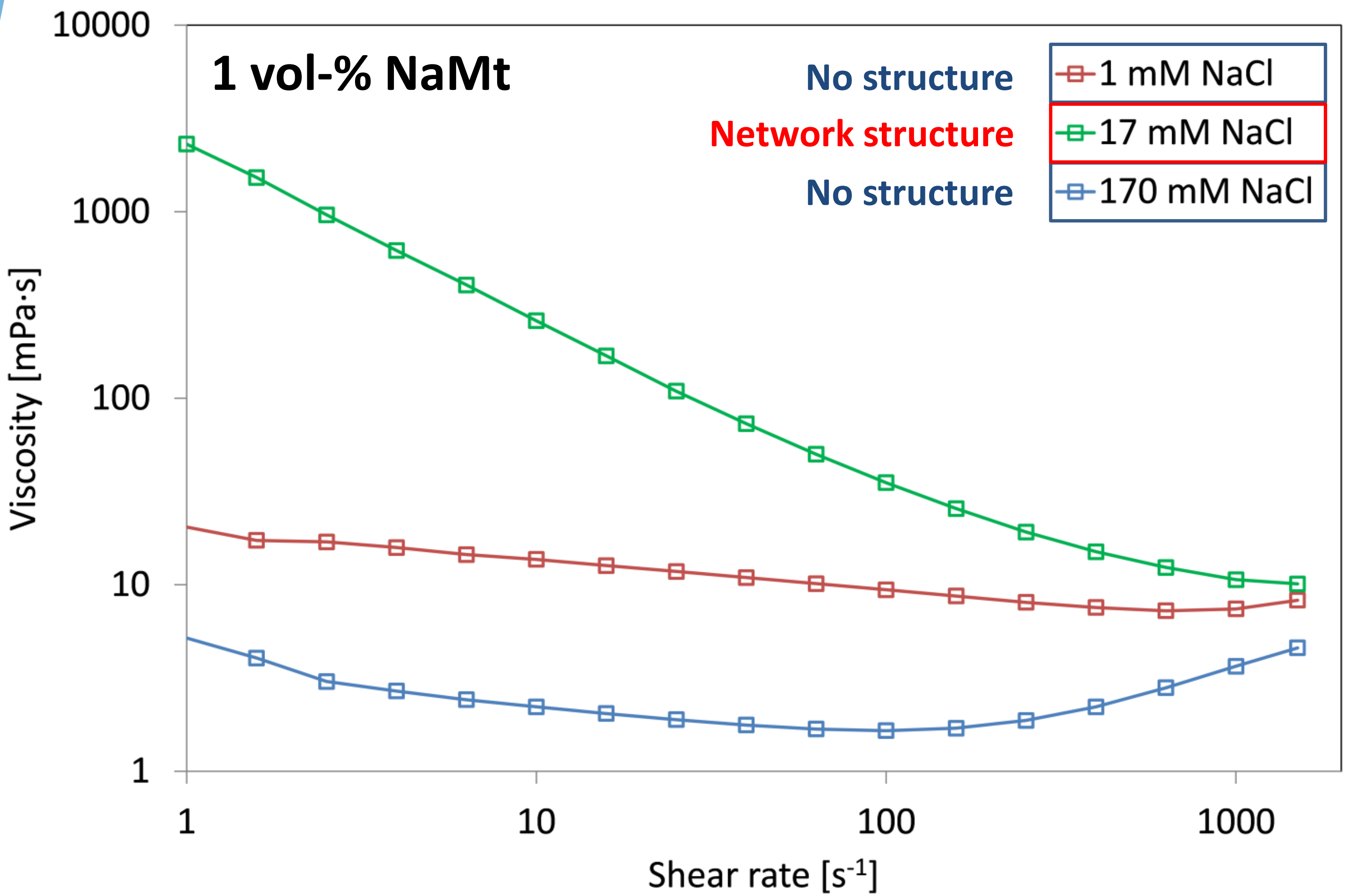
General observations

- **Most samples (up to 1 vol-%) exhibit a nearly Newtonian behavior with a viscosity around 10 mPa·s (or lower).**
- **Ca-montmorillonite clearly has a lower tendency to form volume-spanning gel-like structures as compared to Na-montmorillonite, but on the other hand, Ca-montmorillonite forms stronger individual flocs.**
- **Evidence was found that edge-face interactions seem to be important for the build-up of a network structure**

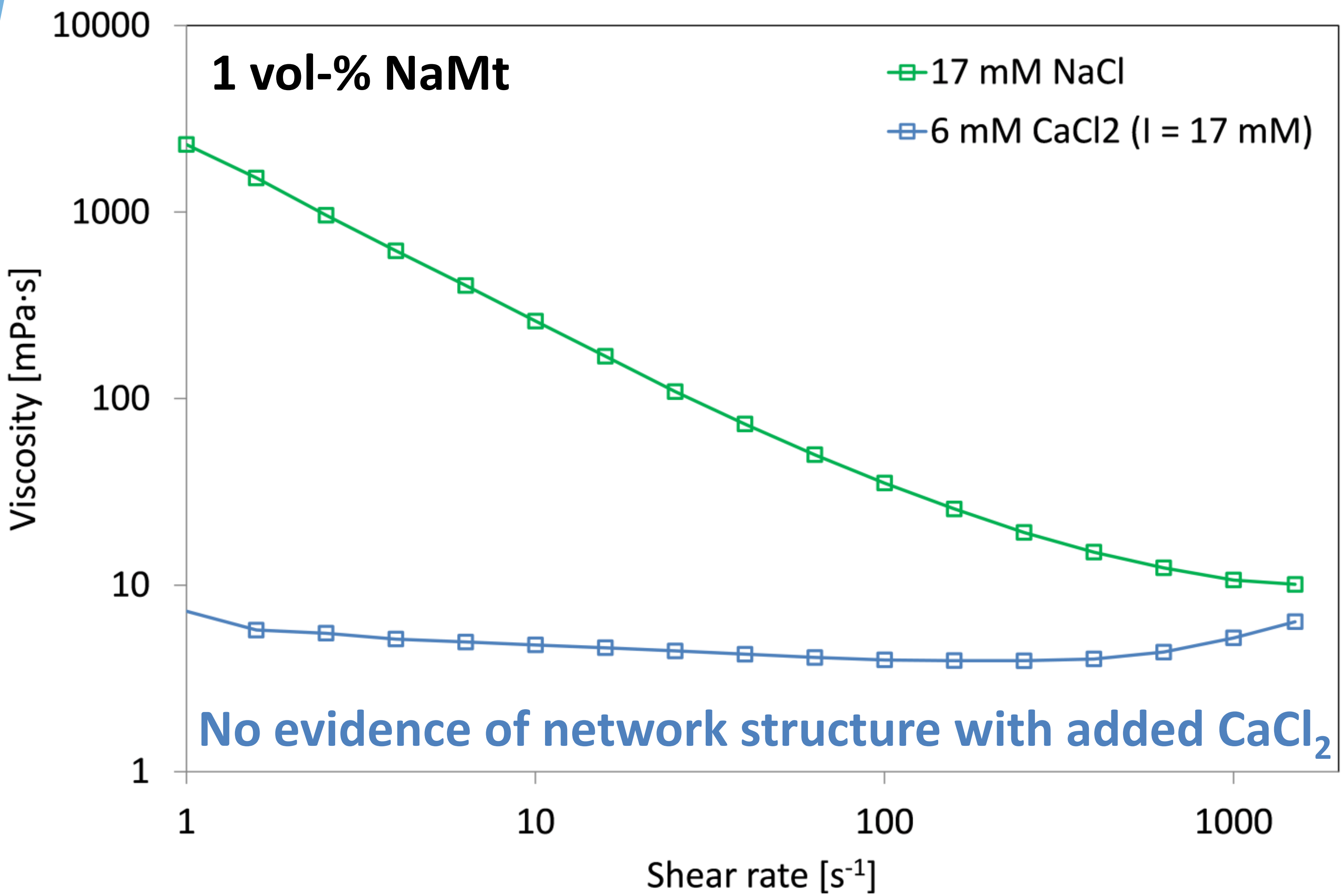
Shear sweeps (1)



Shear sweeps (1)

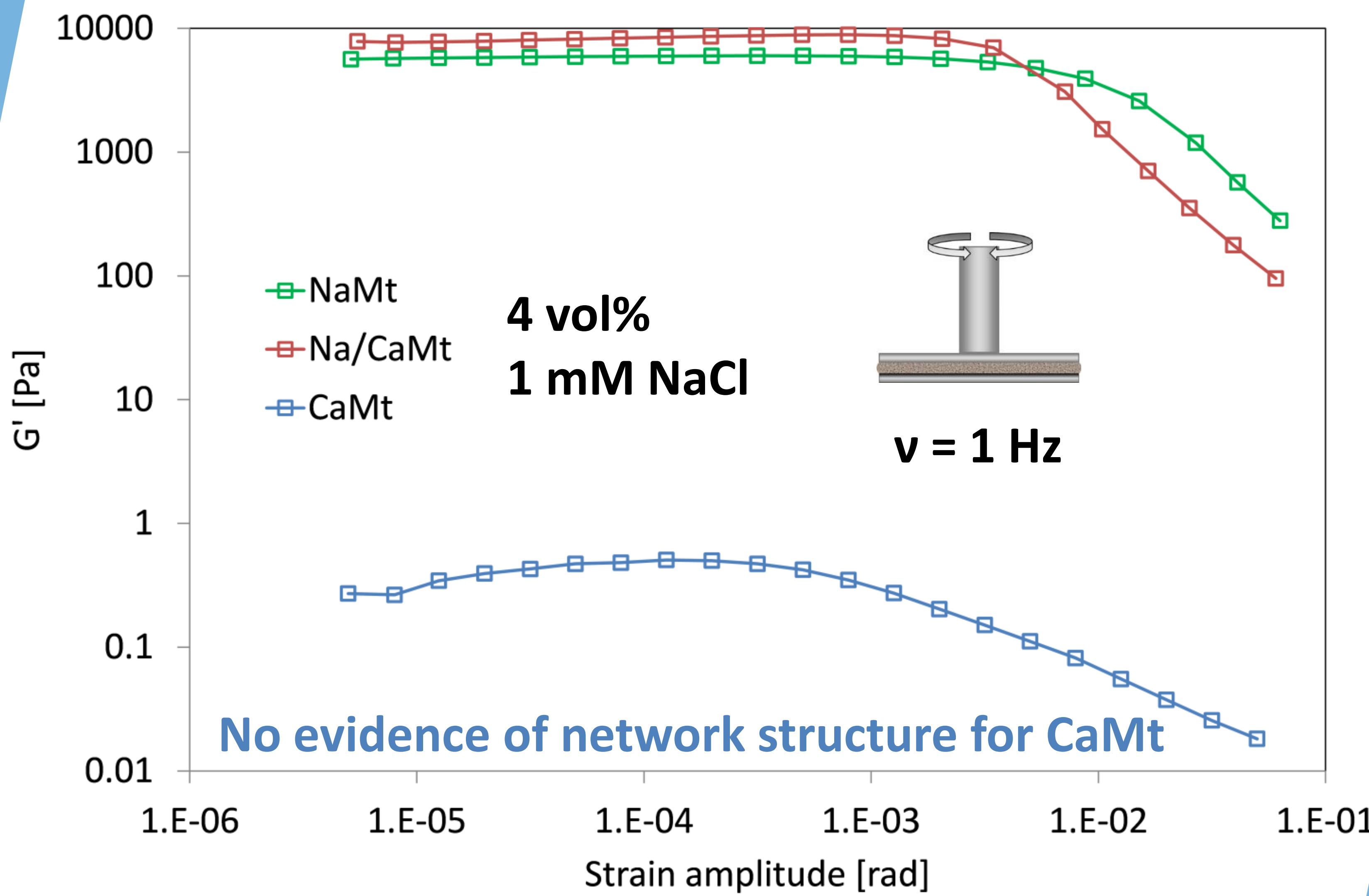


Shear sweeps (2)

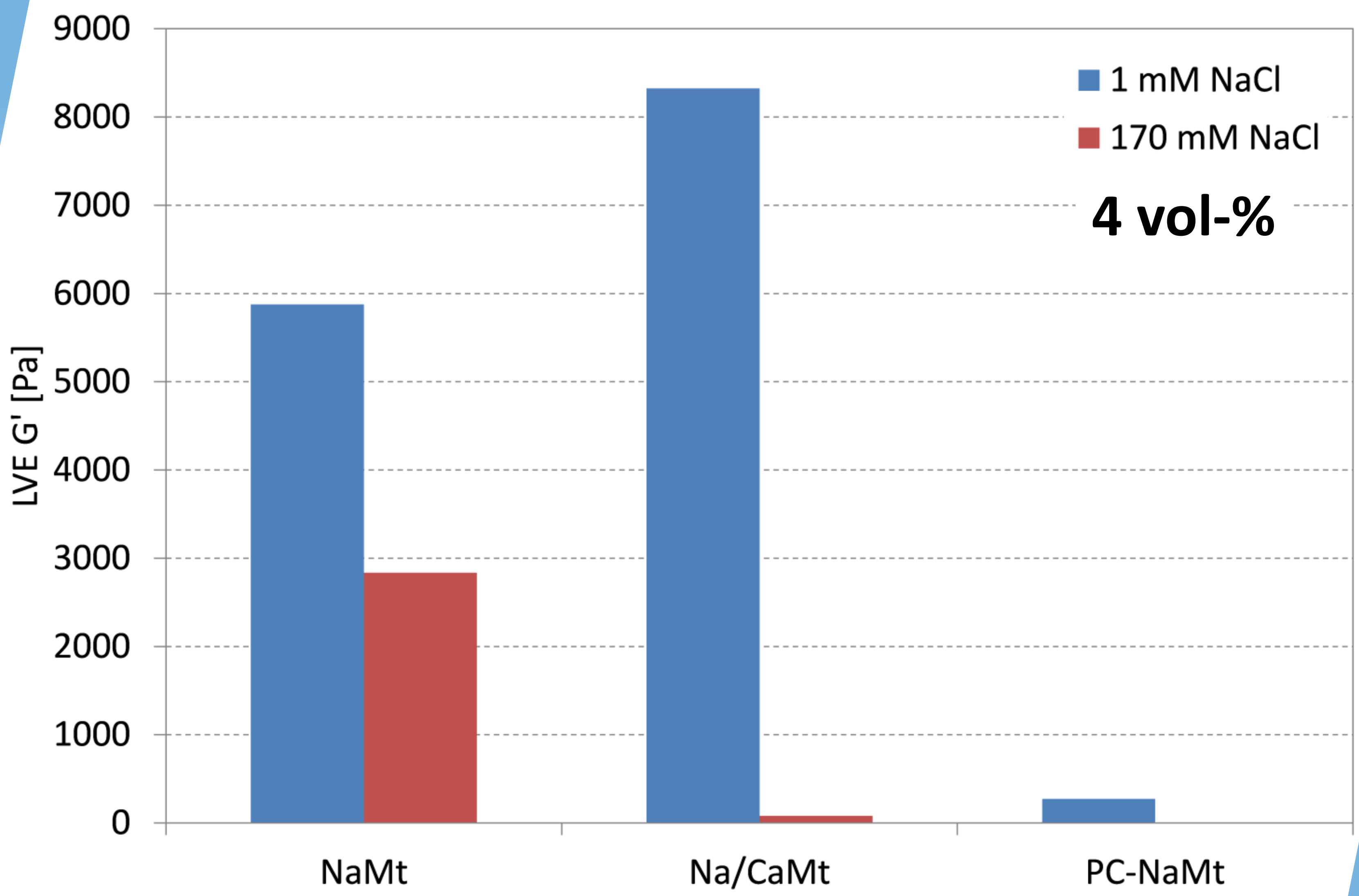


The extruding zone

Effect of interlayer cation

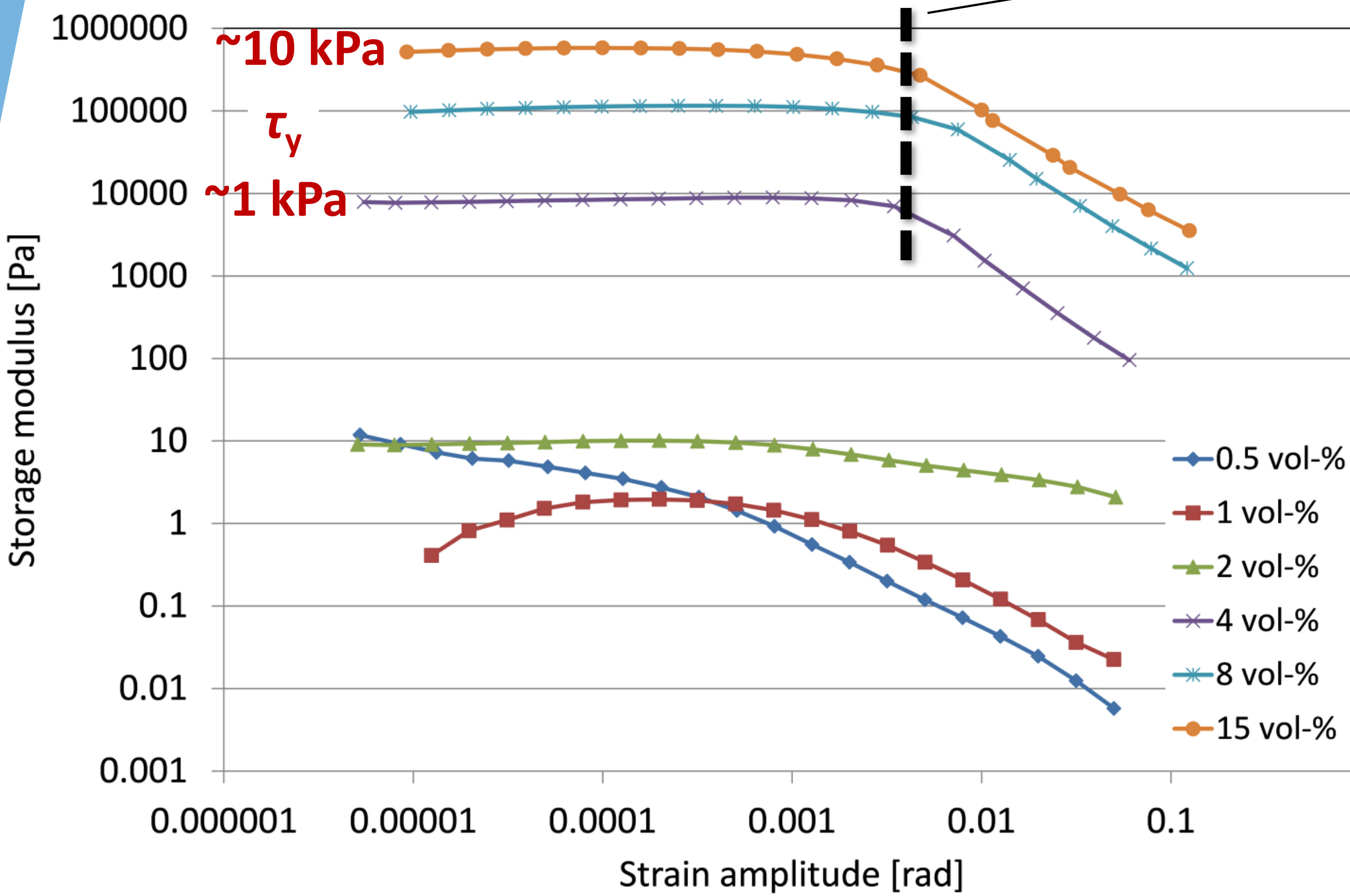


Effect of ionic strength



50/50 Na/Ca-Mt, 1 mM NaCl

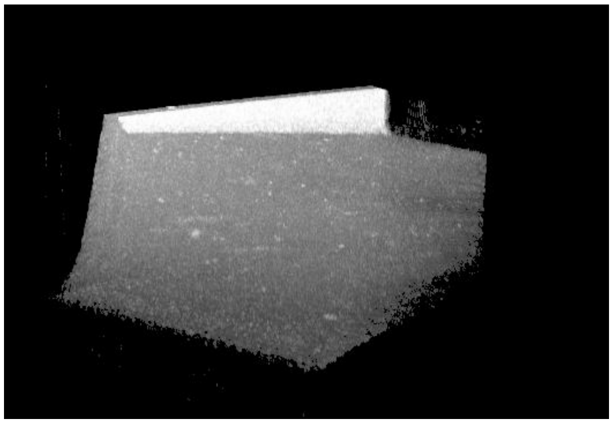
Similarity in long-range structure?



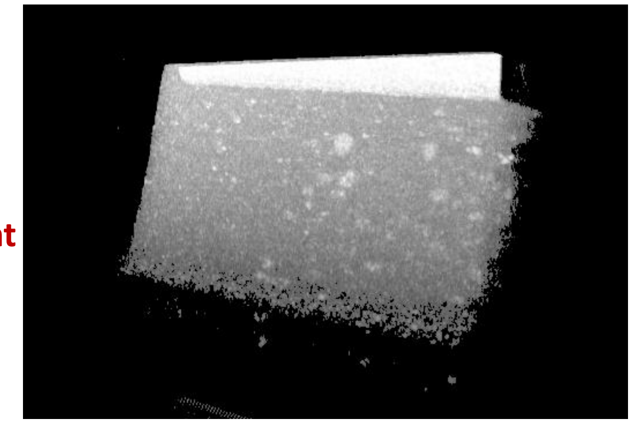
Structure break-up

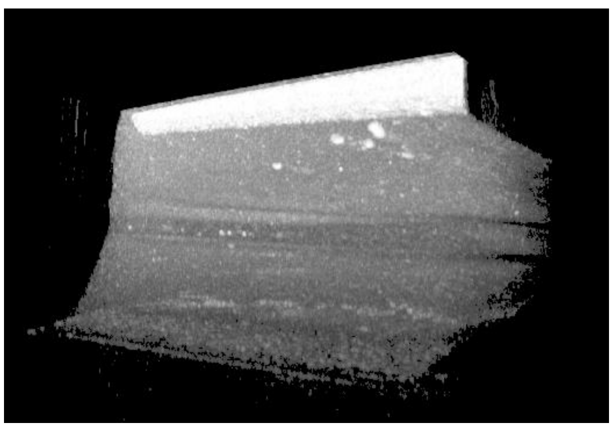
NaMt, 4 vol-%
17 mM NaCl

50/50 Na/CaMt, 4 vol-%
1 mM NaCl

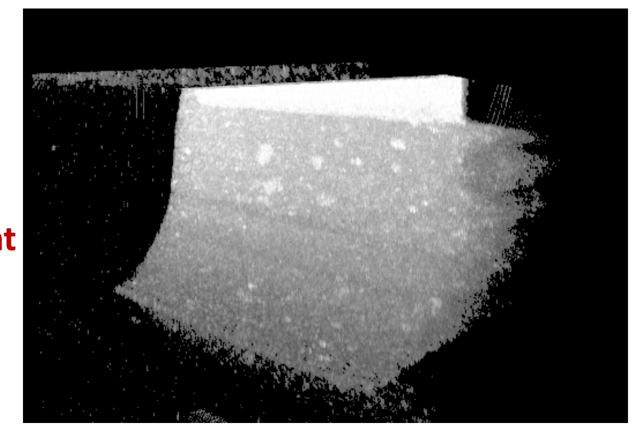


Before measurement

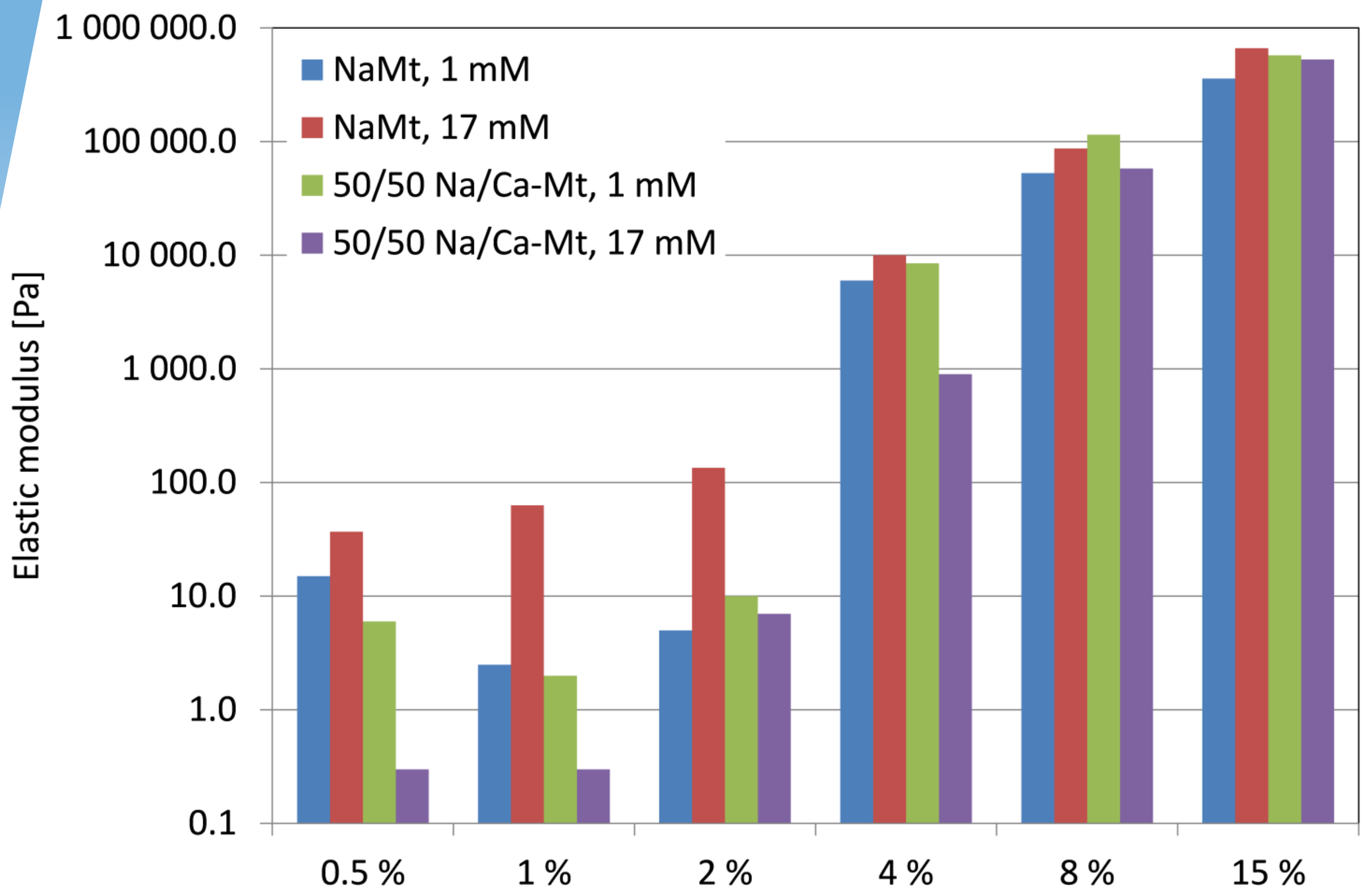




After measurement

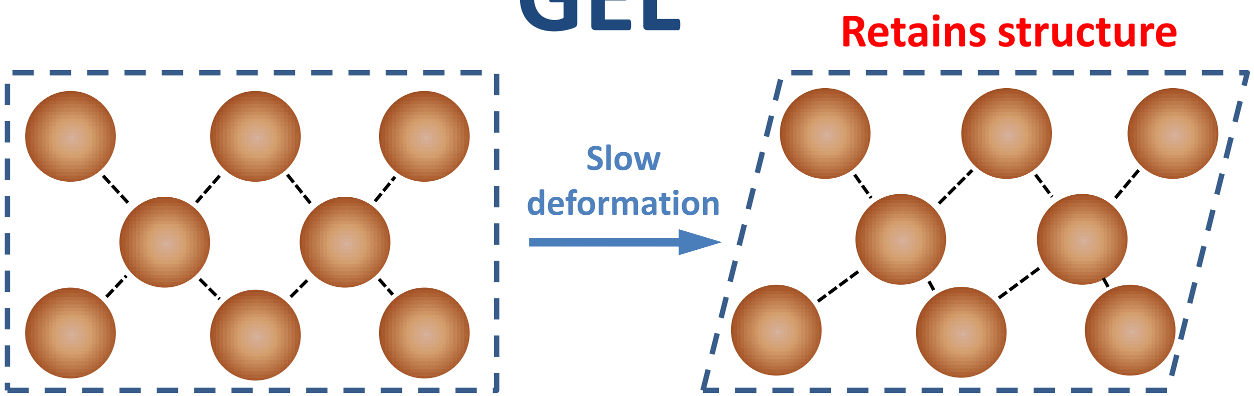


Elastic modulus overview

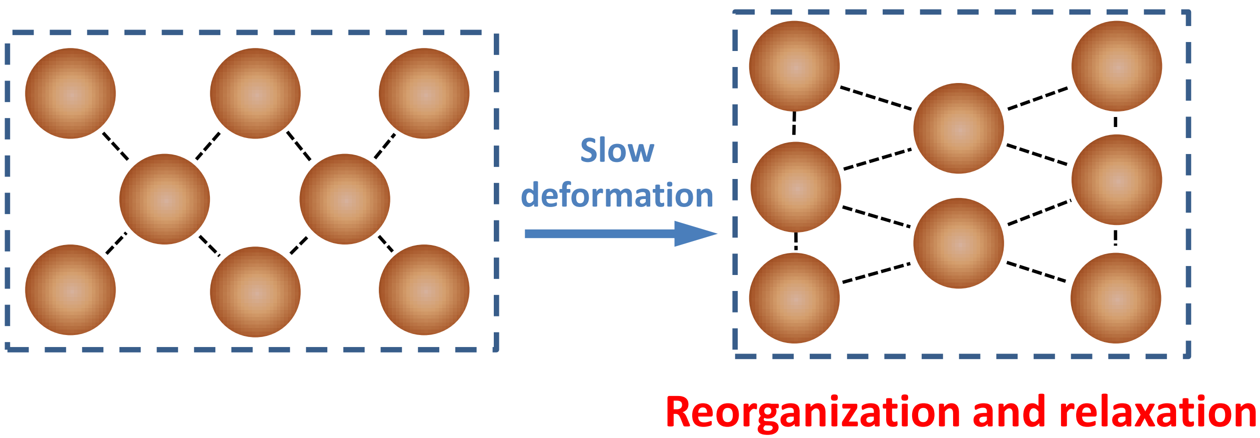


Response to very low shear rate

GEL



VISCOELASTIC FLUID



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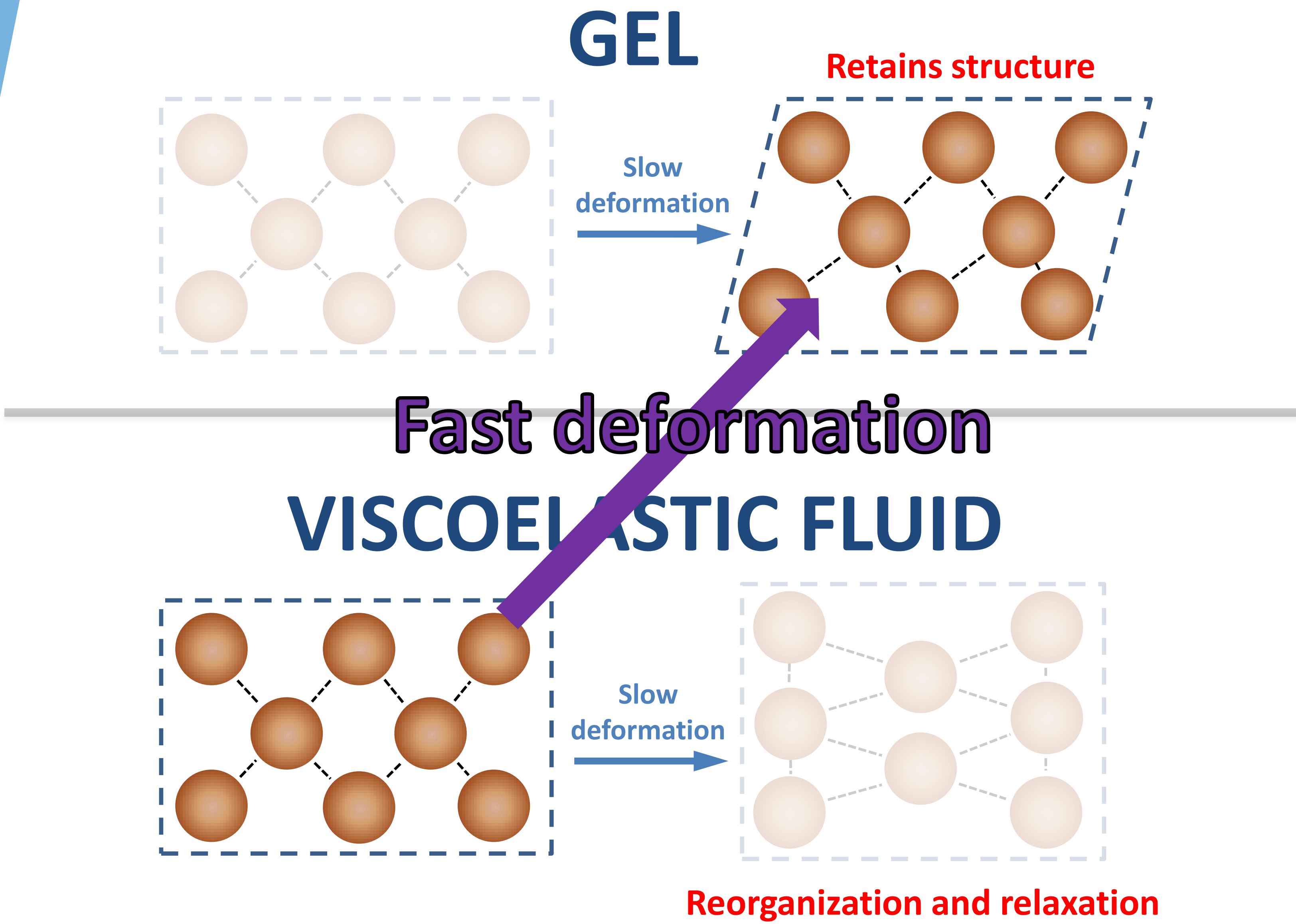
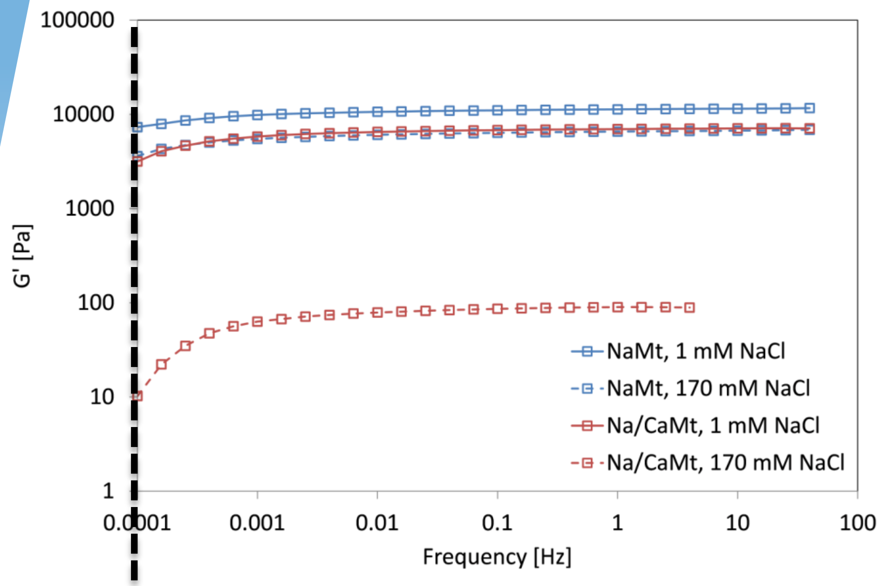
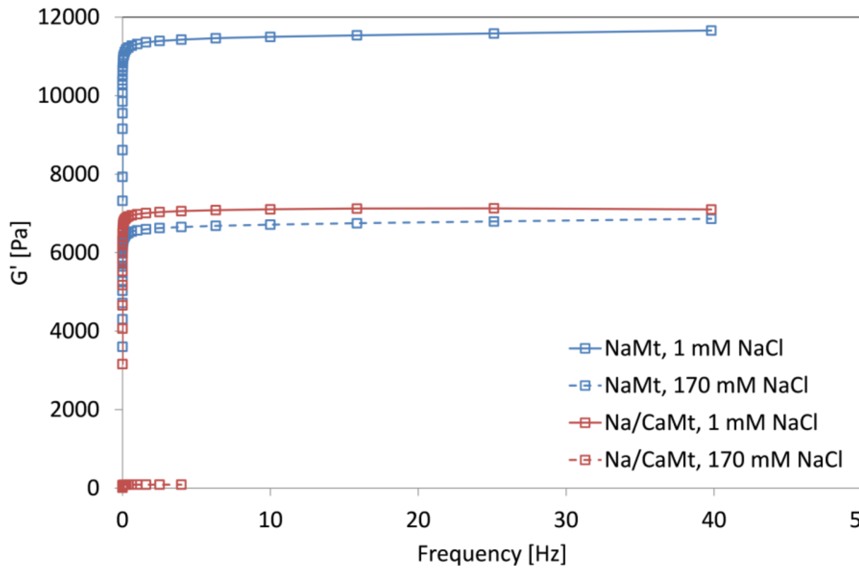


Frequency sweeps, 4 vol-%

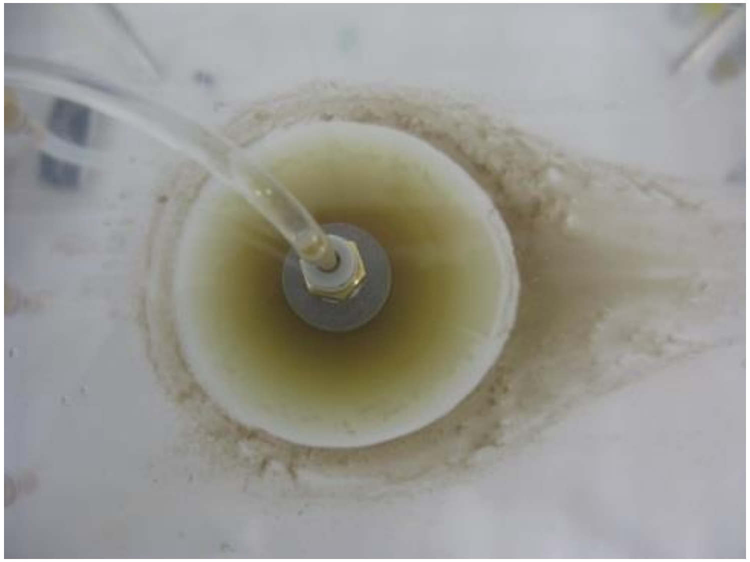




v ~10^{-9} m/s
(outer edge)

A significantly smaller elastic response at low frequencies indicates that structural relaxation occurs. This suggests that these systems do not demonstrate true gel-like behavior.

Drag force



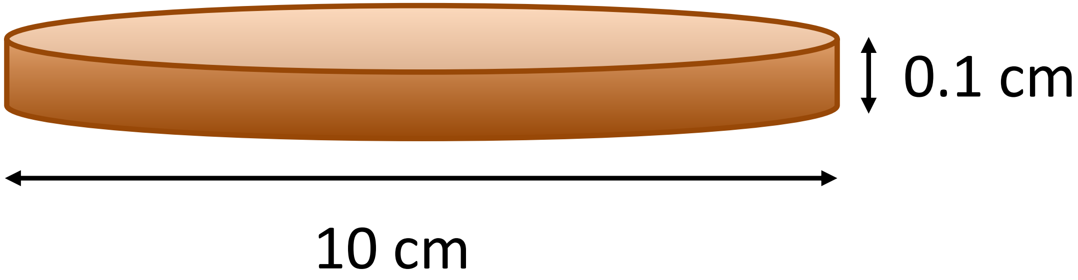
Drag force on a smooth cylinder of area A:

$$F_D = C_D (1/2) \rho v^2 A,$$

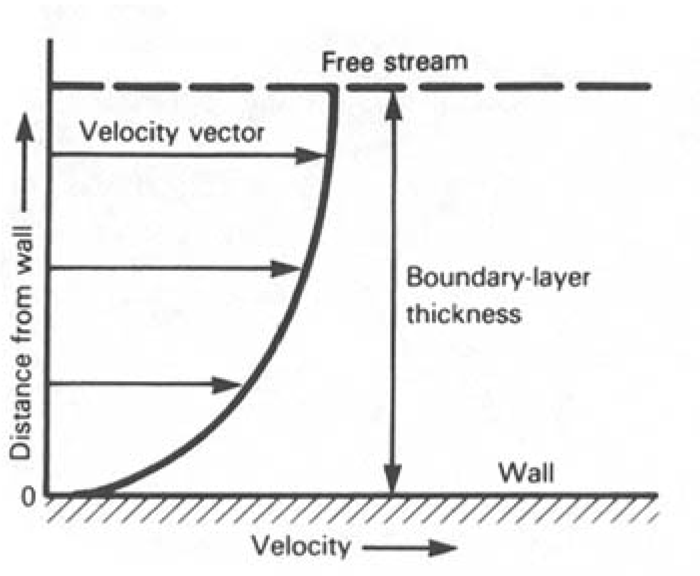
$$C_D = 24/\mathrm{Re}$$

v = 10^{-4} m/s

⇒ $F_D \lesssim 3$ μPa



Shear stress at interface

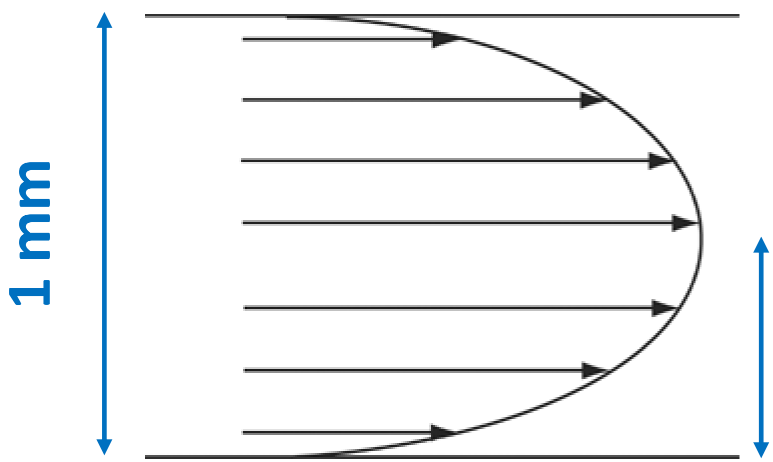


$$\tau = \eta \frac{v}{d}$$

d (0.5 mm) ⇒ τ = 0.2 mPa

d (5 µm) ⇒ τ = 20 mPa

What value for viscosity?

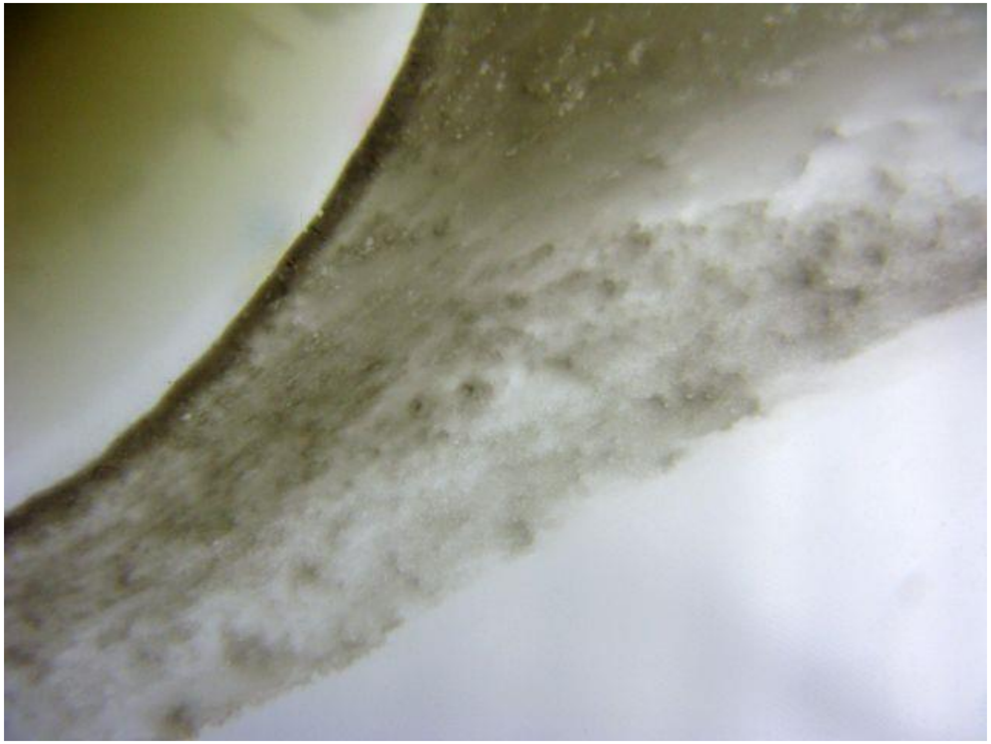


d_{max} = 0.5 mm

Summary

Small likelihood of particle detachment due to expexted shear forces.

At low frequencies, relaxation was observed, suggesting that the system is dynamic over long time-scales or not at equilibrium.



Future actions

- **Continue rheological experiments – autumn 2014**

  - CaMt at high solids contents

- **≥ 1 scientific publication**

- **Contribute to BELBaR deliverable 4.9 ” *Rheology of attractive and repulsive montmorillonite/bentonite gels*”**

Subcontractor

VTT Expert Services, Jyväskylä

DHR-2

www.tainstruments.com

Telesto Spectral Domain OCT

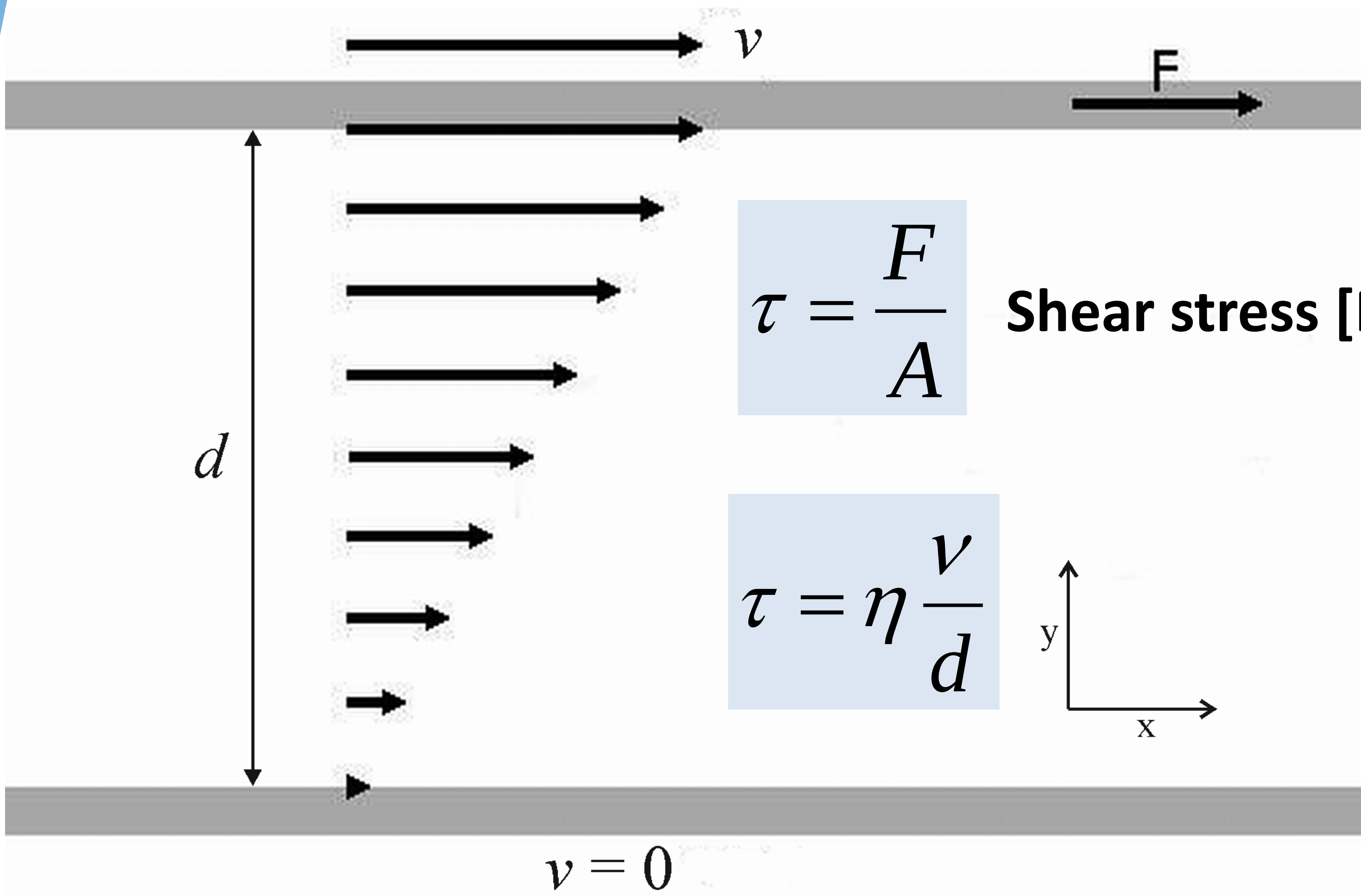
www.thorlabs.com

Acknowledgements

- ***Posiva Oy***

- ***The EC, BELBaR***

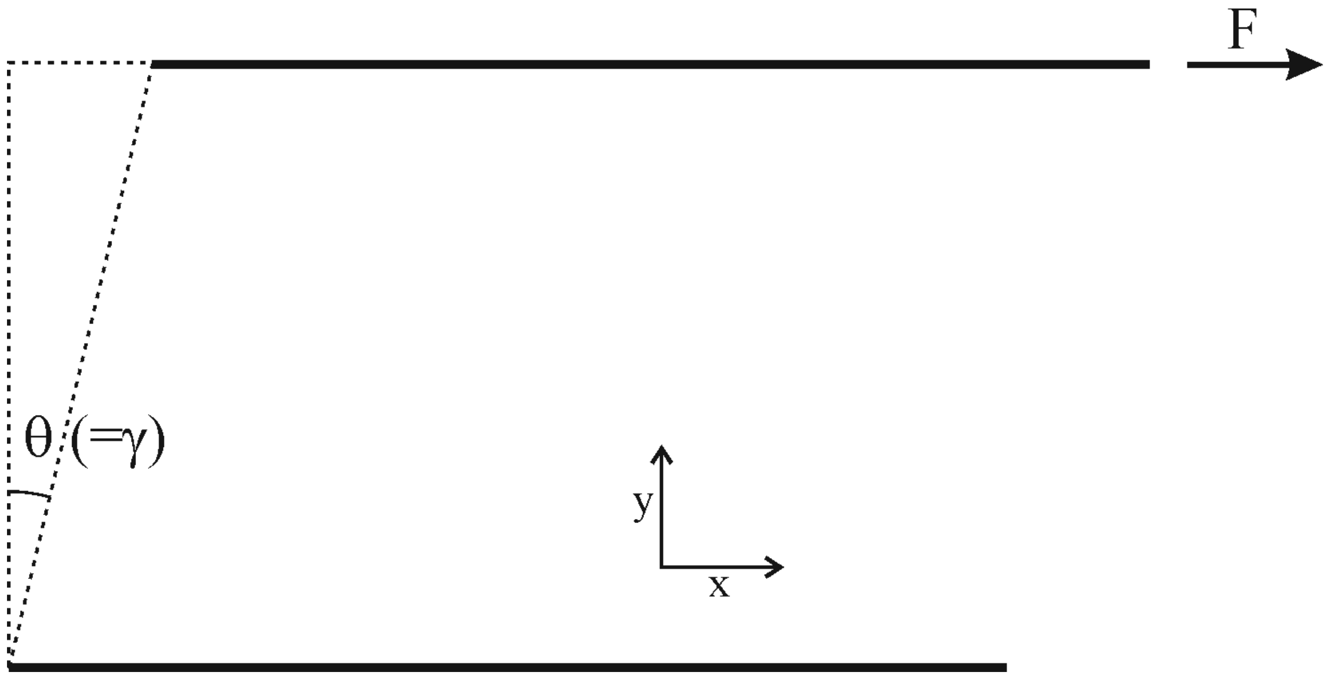
Basic definitons



$$\tau = \frac{F}{A}$$ **Shear stress [Pa]**

$$\tau = \eta \frac{v}{d}$$

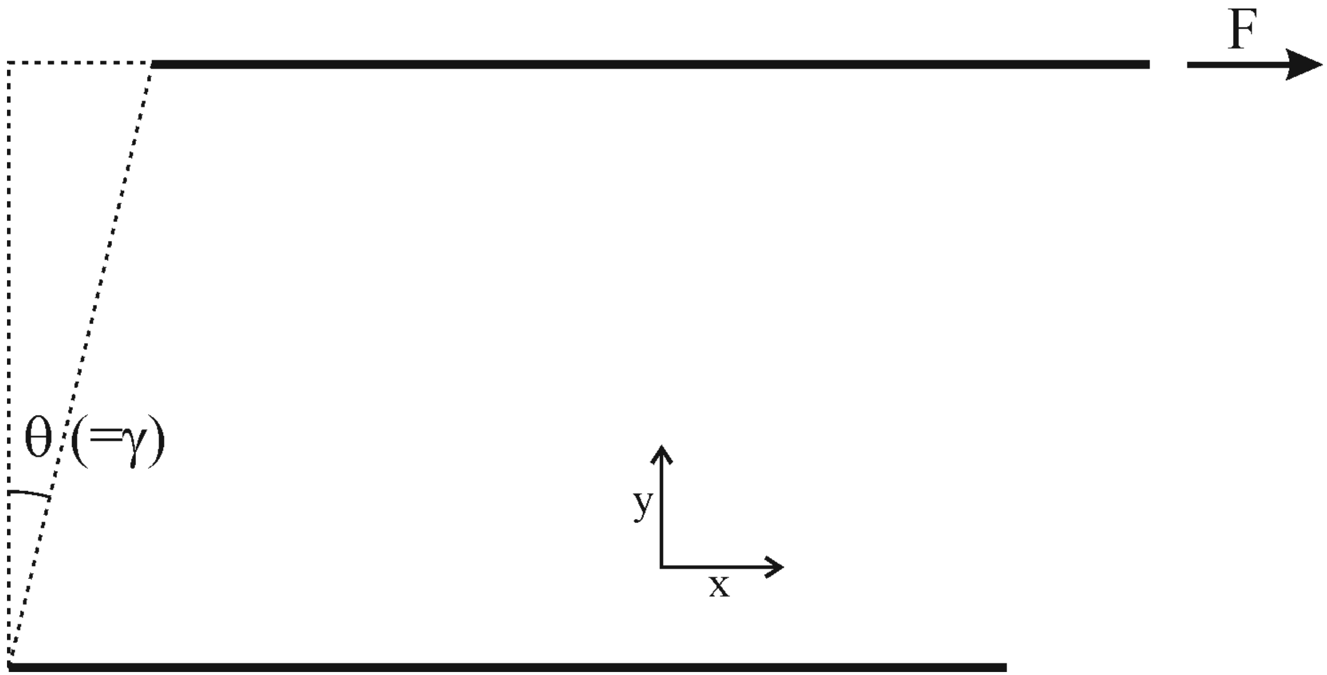
Strain – static case



Ridigity modulus [Pa]

$$G = \frac{\tau}{\gamma} \Rightarrow \tau = G\gamma$$

Strain – dynamic case



Viscosity [Pa·s]

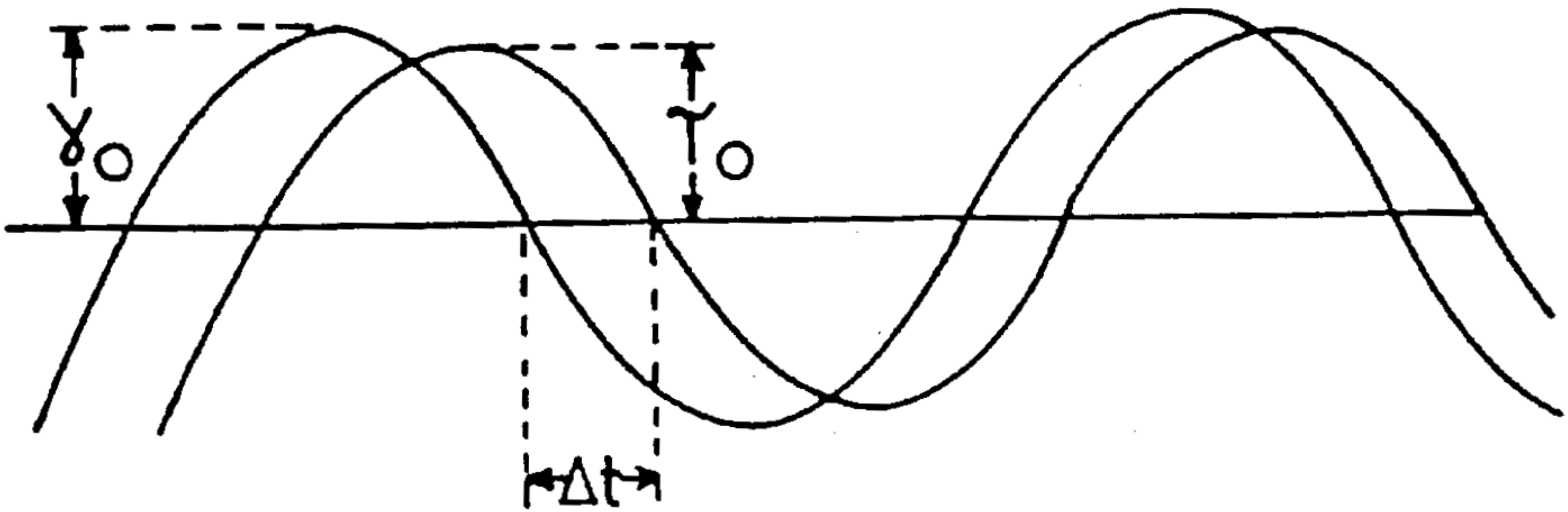
$$\eta = \frac{\tau}{d\gamma/dt} = \frac{\tau}{\dot{\gamma}}$$

Oscillatory shear

A sinusoidal strain (γ_0) is applied on the system. The magnitude of the response (τ_0) and phase angle (δ) are measured.

- Perfectly elastic system: $\delta = 0°$
- Perfectly viscous system: $\delta = 90°$

$$G^*(\omega) = \frac{\tau(t)}{\gamma(t)}$$

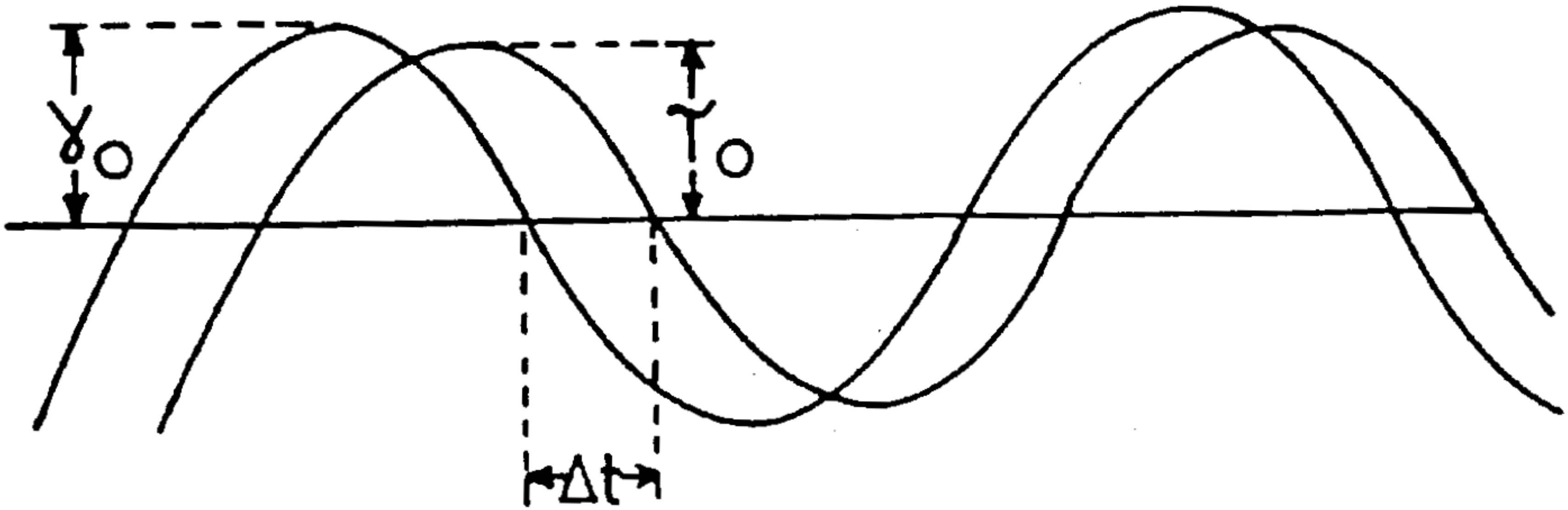


Linear viscoelasticity

$$G^* = \frac{\tau_0}{\gamma_0}\exp(i\delta) = \frac{\tau_0}{\gamma_0}(\cos\delta + i\sin\delta)$$

$$G^* = G' + iG''$$

$$\begin{cases} G' = (\tau_0/\gamma_0)\cos\delta \\ G'' = (\tau_0/\gamma_0)\sin\delta \end{cases}$$



Yield stress overview