# Proposal for rheological studies on montmorillonite suspensions (WP4)

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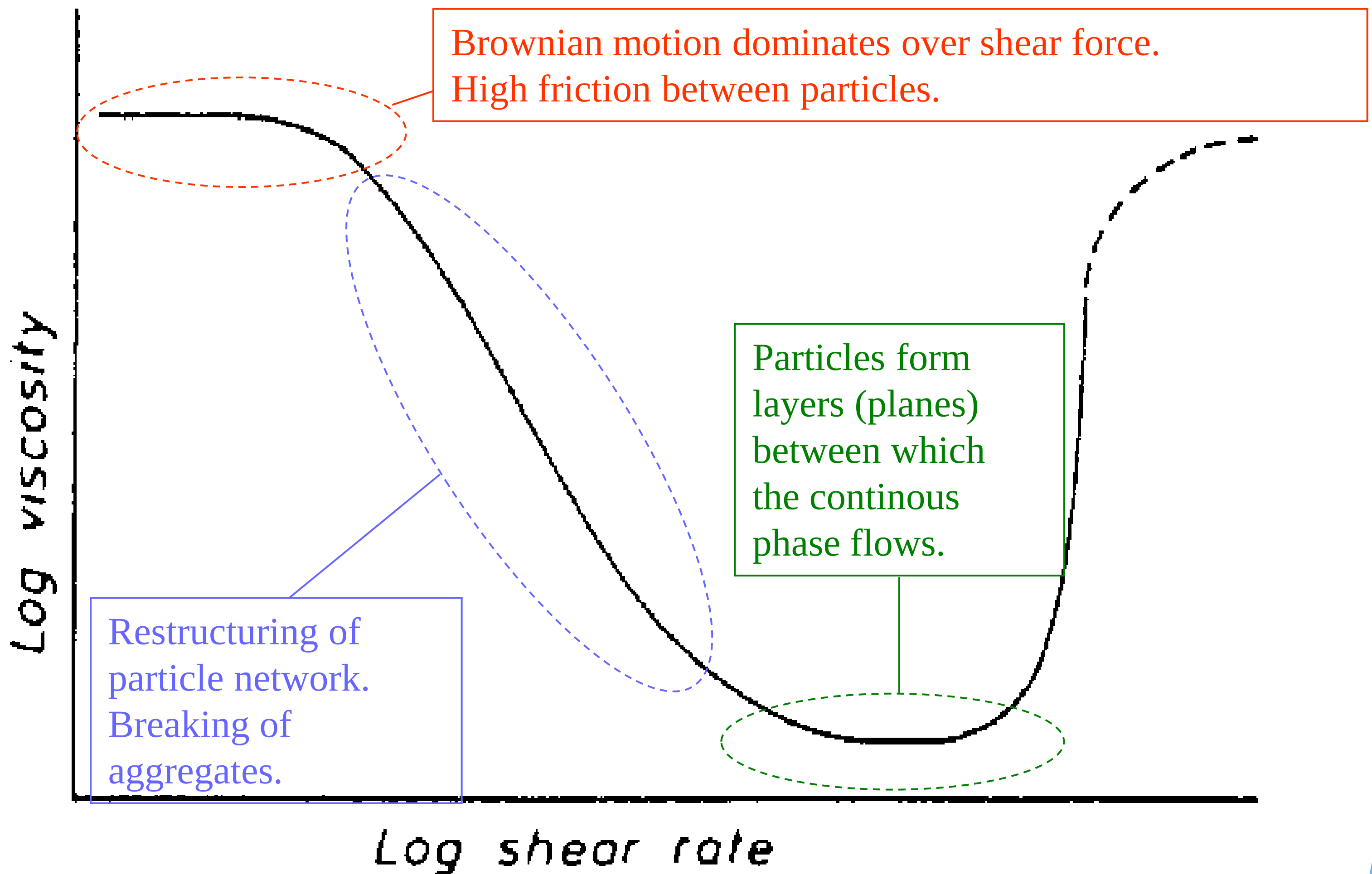
# Suspension viscosity

Most suspensions exhibit shear thinning response.



# Couette geometry

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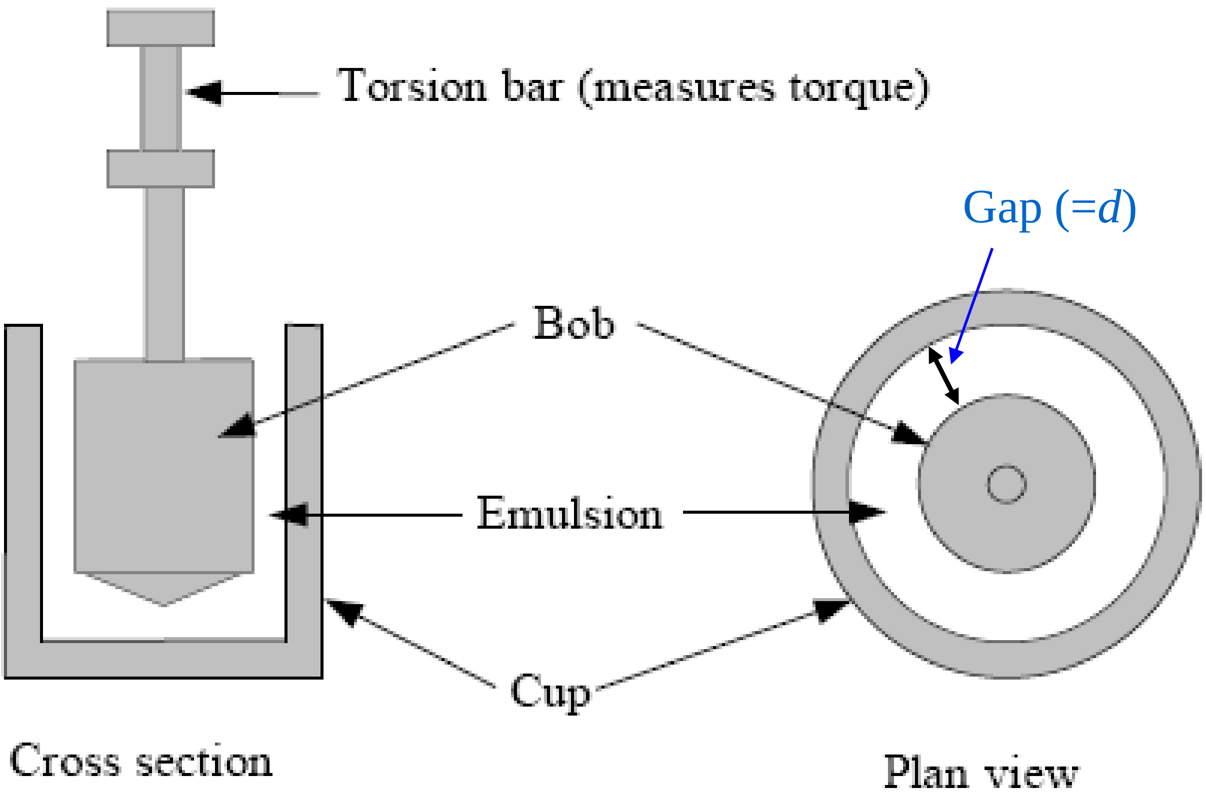
The most common method to study particle network structures at rest is by performing small angle oscillatory shear measurements

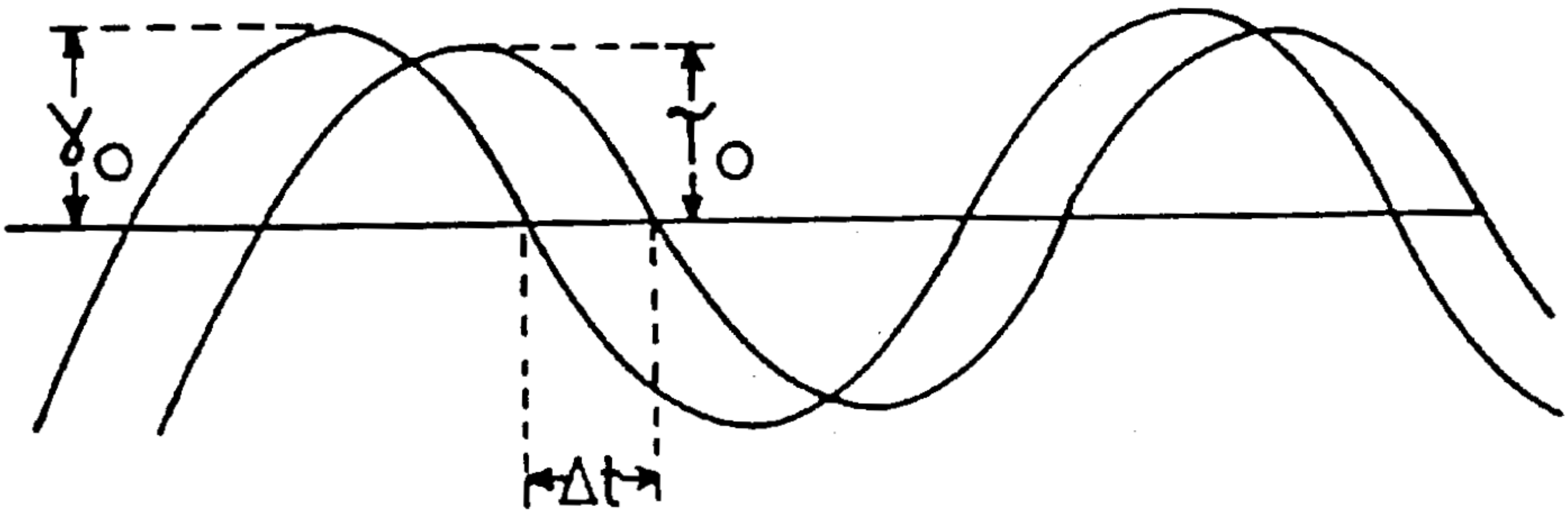



$$\frac{F}{A} = \tau = \eta \frac{U}{d}$$

# Oscillatory shear

A sinusoidal strain ($\gamma_0$) is applied on the system. The magnitude of the response ($\tau_0$) and phase angle ($\delta$) are measured.

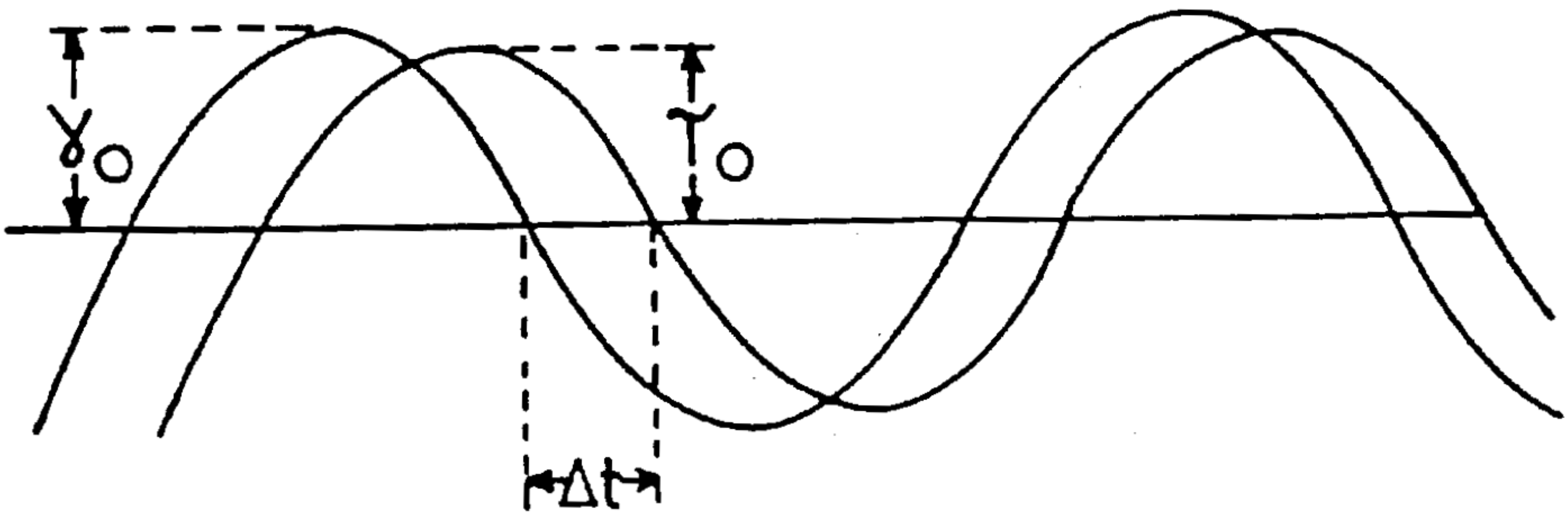
- Perfectly elastic system: $\delta = 0$
- Perfectly viscous system: $\delta = 90$



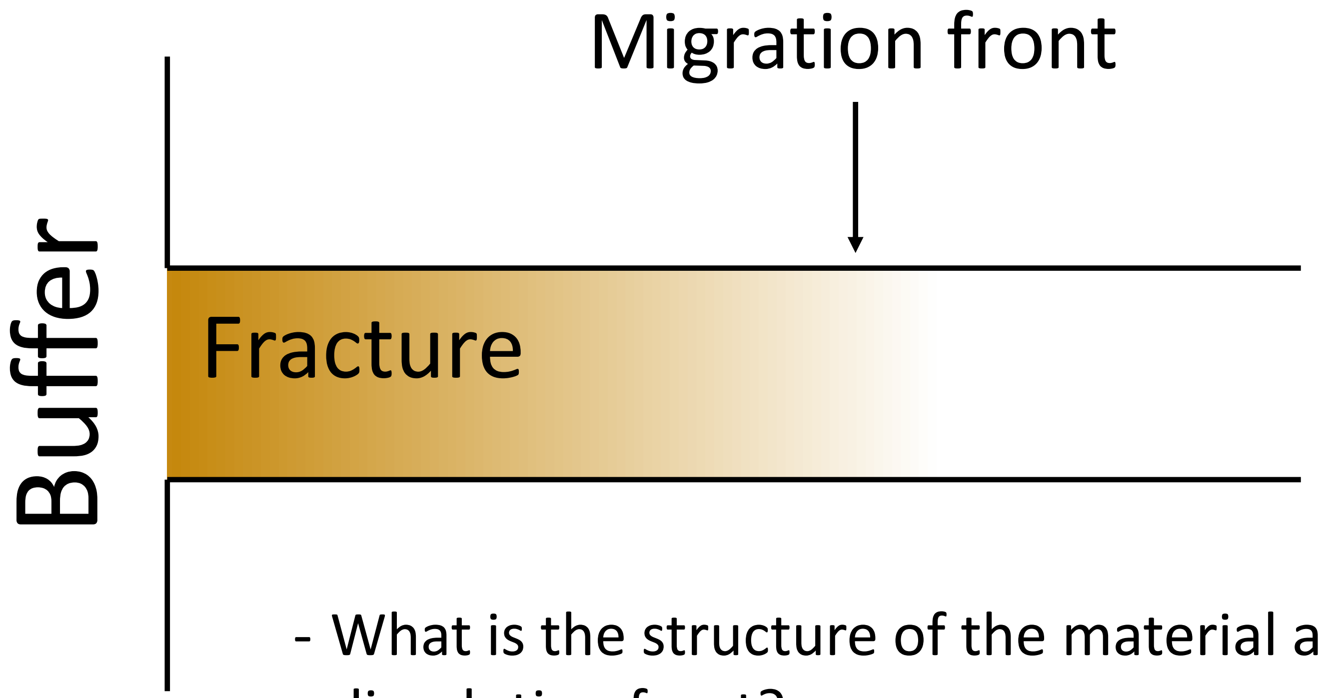
# Oscillatory shear

$$G^* = \frac{\tau'}{\gamma'}\exp(i\delta) = \frac{\tau'}{\gamma'}(\cos\delta + i\sin\delta)$$

$$G^* = G' + iG'' \begin{cases} G' = (\tau'/\gamma')\cos\delta \\ G'' = (\tau'/\gamma')\sin\delta \end{cases}$$



# Scenario




- What is the structure of the material at the dissolution front?
- If a network structure is likely to form, what is the flow velocity (i.e. shear rate) required to disrupt it?

# Particle networks

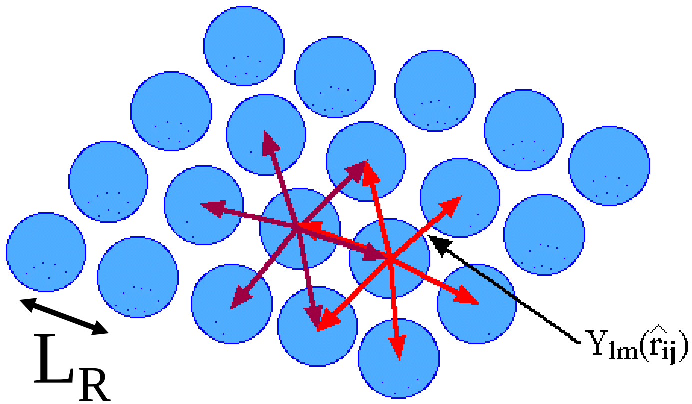
The elastic modulus is directly proportional to the network strength.

The characteristic length of the particle network can be probed by oscillatory shear.

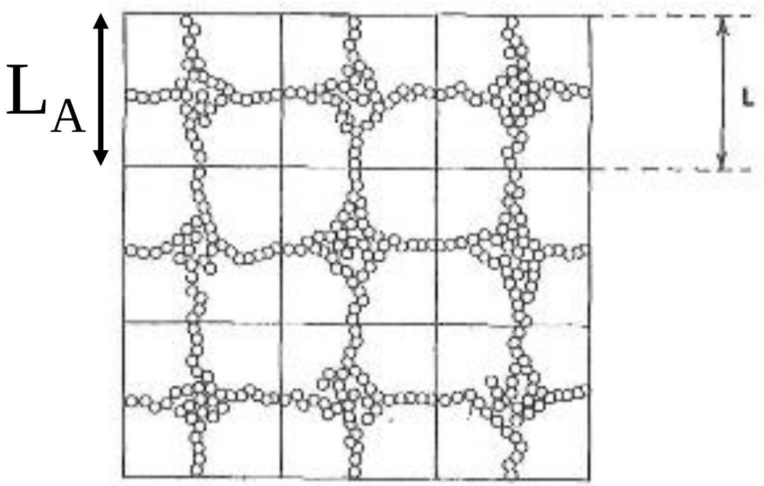
The characteristic length of a repulsive network ($L_R$) is proportional to the particle size and the characteristic length of an attractive network ($L_A$) is proportional to the average distance between clusters of particles, hence:

$$L_A > L_R\ (\sim d_p)$$

It should therefore be possible to distinguish between these two states by oscillatory shear.

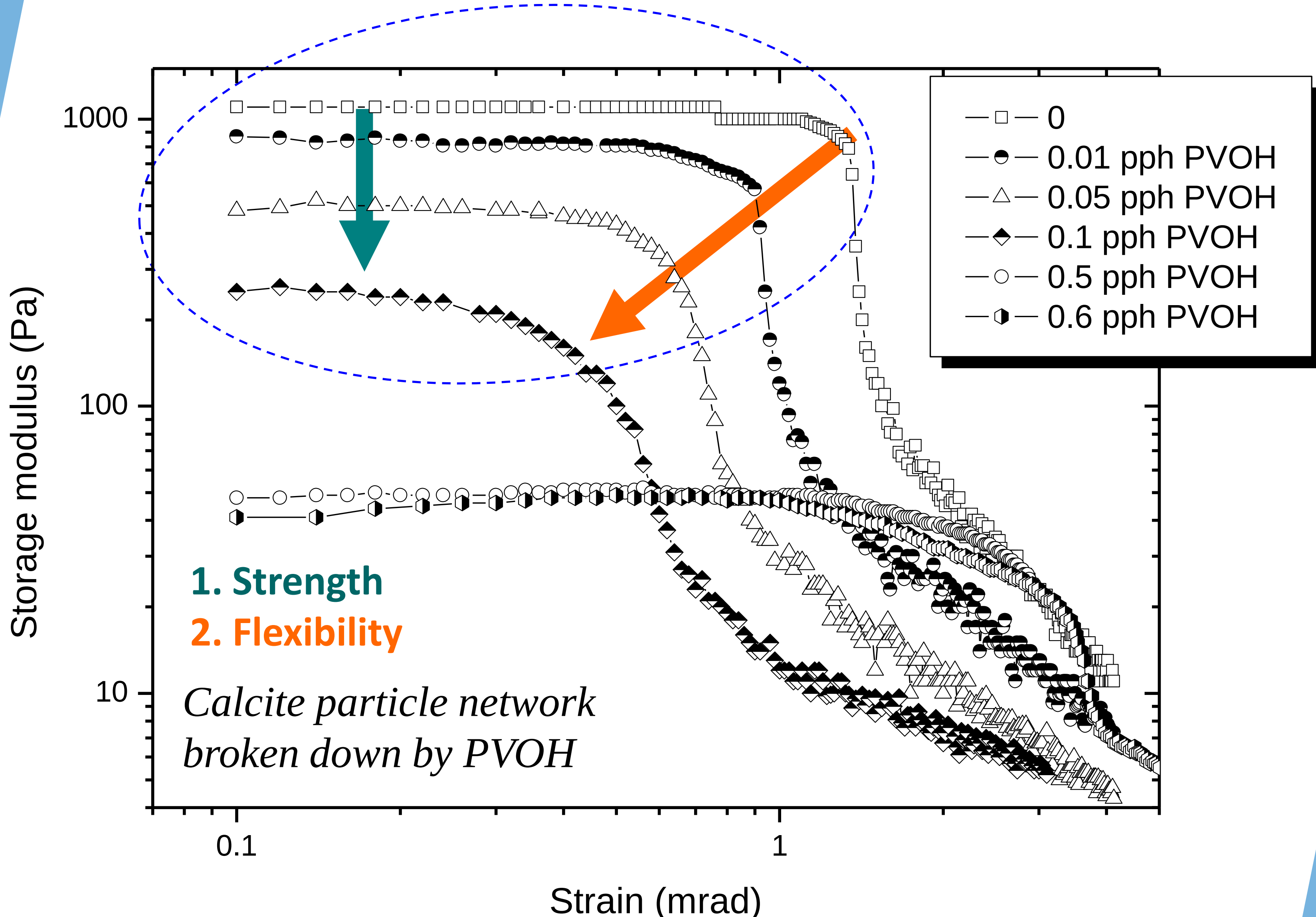



Repulsive network




Attractive network

# Example



1000
100
10
Storage modulus (Pa)
0.1
1
Strain (mrad)
0
0.01 pph PVOH
0.05 pph PVOH
0.1 pph PVOH
0.5 pph PVOH
0.6 pph PVOH
1. Strength
2. Flexibility
*Calcite particle network broken down by PVOH*

# Methods

- Small-amplitude oscillatory shear (SAOS) tests will be performed to determine whether particles are in a well dispersed state or arrange into a network
- SAOS tests will simultaneously be used to study mechanical properties (strength, flexibility) of montmorillonite particle networks
- Creep tests at varying constant low shear rates are utilized in order to evaluate the effect of low water flow velocities on particle network integrity

# Experimental settings

- Solids content
  - Focus on low solids content (< 5 vol-%), but may go higher
- Ionic strength ≤ 1 M
- Temperature (25 C)
- Oscillatory shear
  - Mainly strain sweeps at low to medium frequency (≤ 1 Hz)
- Creep tests
  - Low constant shear rates (< 0.1 $s^{-1}$)
  - How to establish a meaningful link between shear rates and actual water flow velocities?

# Goals

- Determine the state (repulsive or attractive network or sol) of montmorillonite suspensions at low solids contents as a function of pH and ionic strength
- Gain fundamental structural information about montmorillonite particle networks by determining the critical length scales at which the network structure breaks down
- Make an assessment of particle network strength (if one exists) in order to estimate a critical (water) flow velocity at which the network disrupts
- Sol/gel transition