FINDINGS

The Truth About Quicksand Is Beginning to Sink In

"The Hound of the Baskervilles" ([illegible]) /Photofest

Real quicksand, the kind that is almost impossible to extricate yourself from, is not just water and sand. Salt and clay are also major ingredients in this B-movie plot device, scientists report in the current issue of Nature.

Their study began when Dr. Daniel Bonn, a professor of physics at the University of Amsterdam, was in Iran a

holding the grains together.

Hit with sudden force from, say, a hapless victim, the quicksand gel turns to liquid. Then salt causes clay particles to stick to one another instead of the sand grains, with the result that a victim ends up surrounded by densely packed sand.

The force needed to pull out a person

NY Times,
4 oct. 2005

Fluid avalanches, quicksand and quickclay landslides (“geo-rheology”)

Daniel Bonn
(LPS de l’ENS-Paris and WZI-Amsterdam)

with:
P. Moller (ENS)
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J.O. Fossum, Y. Méheust (NTNU, Trondheim)

"Yield stress fluids"

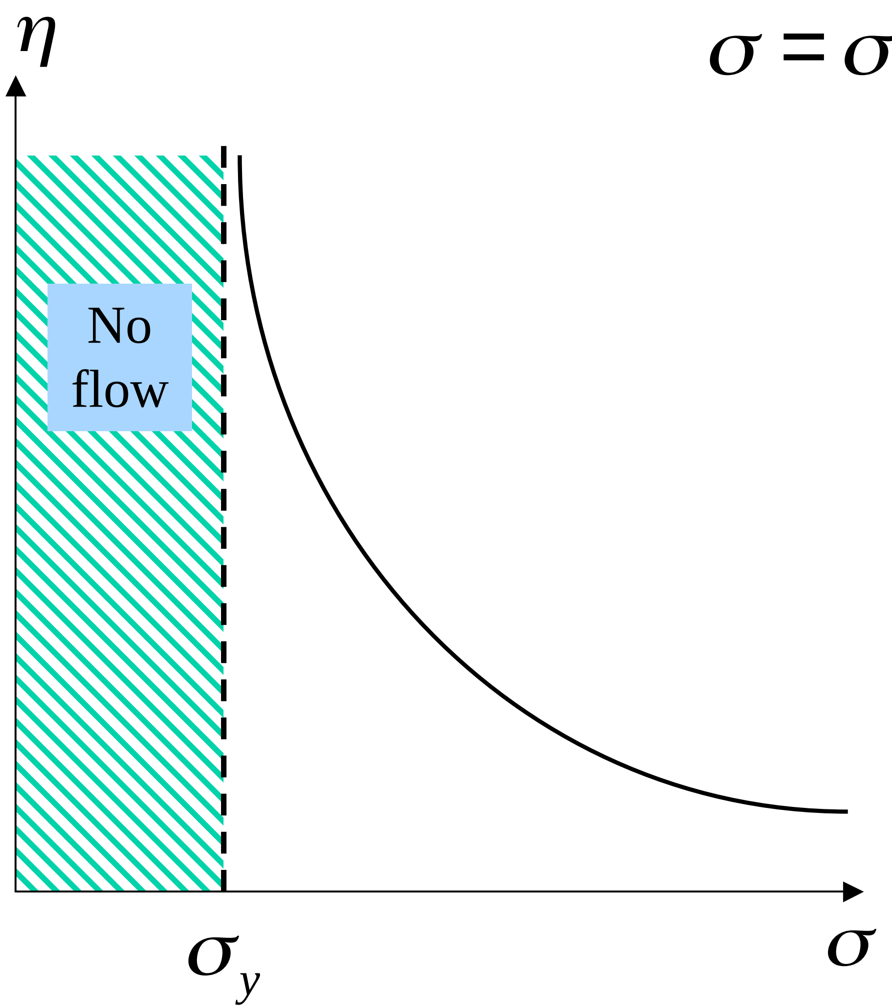
-in your refrigerator: mayonnaise, ketchup, yoghurt, whipped cream…
-in your bathroom: beauty creams, hairgel, shaving foam…
-in civil engineering: (wet) sand, concrete, cement….
-in geophysisics: sand, quicksand, quick clay…

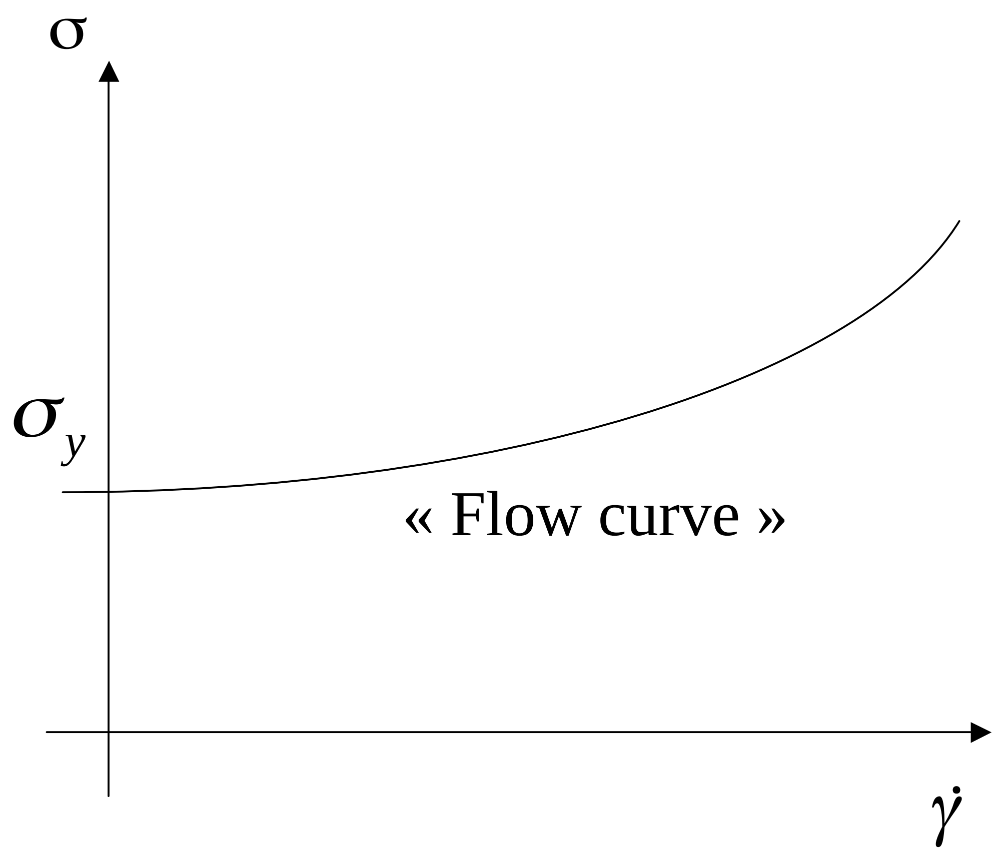
Liquid and solid at the same time!

Yield stress fluids

Simple yield stress fluids: Herschel-Bulkley model

$$\sigma = \sigma_y + k\dot{\gamma}^n$$





Yield stress, thixotropy and aging

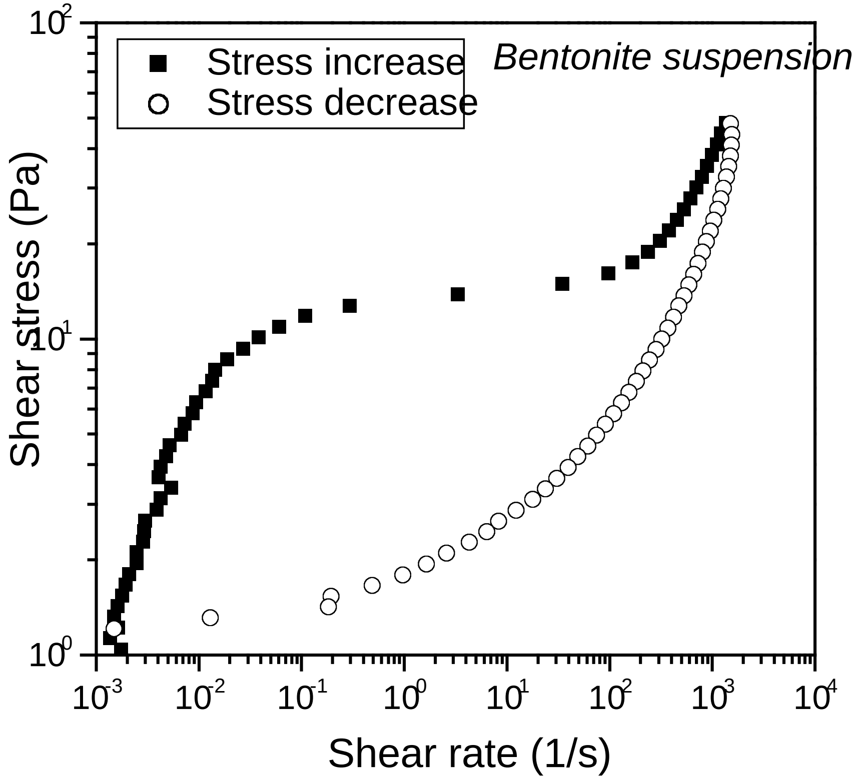
Two **HUGE** problems:

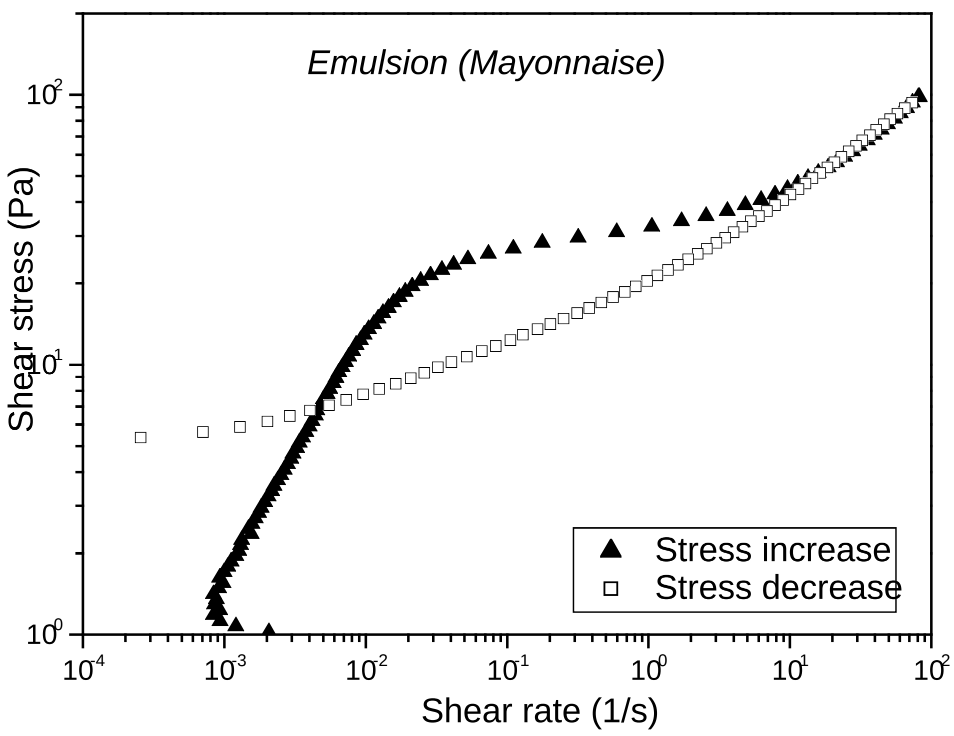
1. Yield stress is difficult, if not impossible to measure experimentally (‘παντα ρει’)
2. Herschel-Bulkley model does NOT account for shear localization (shear banding)

1. Measurement of the yield stress

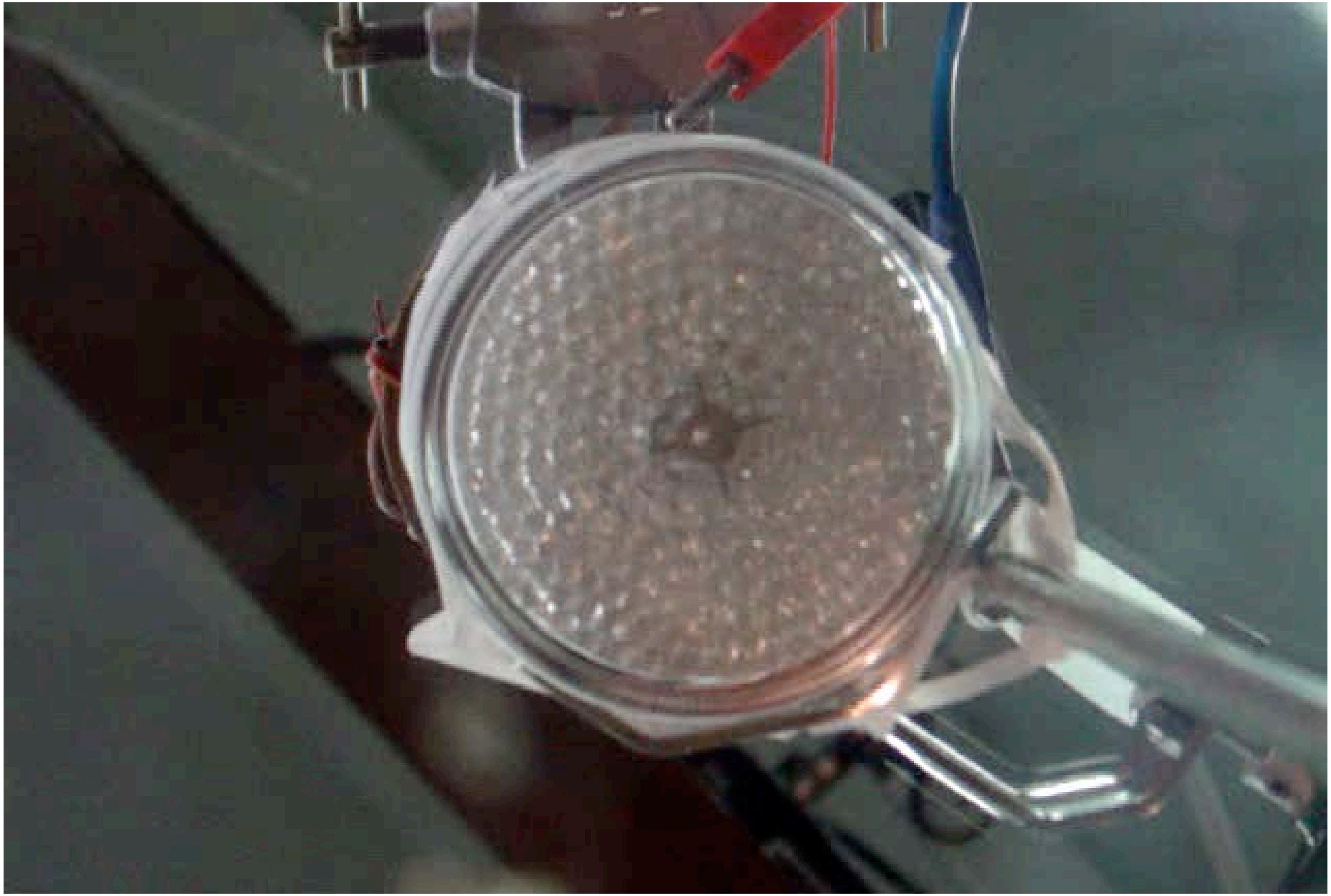
Bentonite suspension: a typical colloidal clay gel
Mayonnaise: a stable emulsion

Stress loop: increase then decrease (time on the order of 2 min.) for different pasty or granular materials



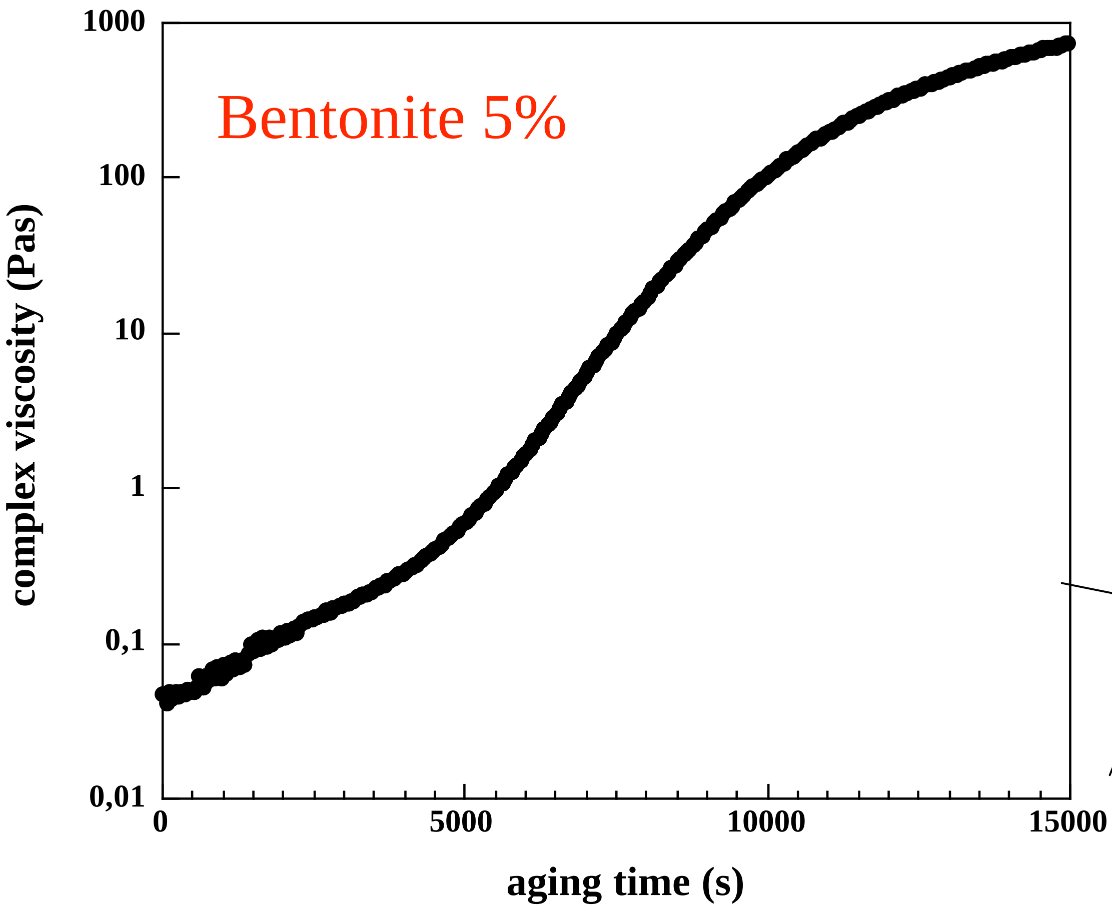


2. Shear localization (banding)



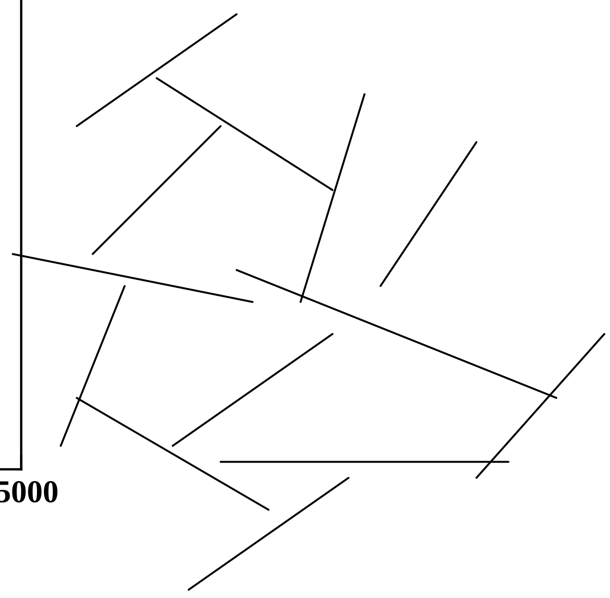
A first important clue: aging

Aging: increase of the viscosity at rest, and at zero (or very low) shear

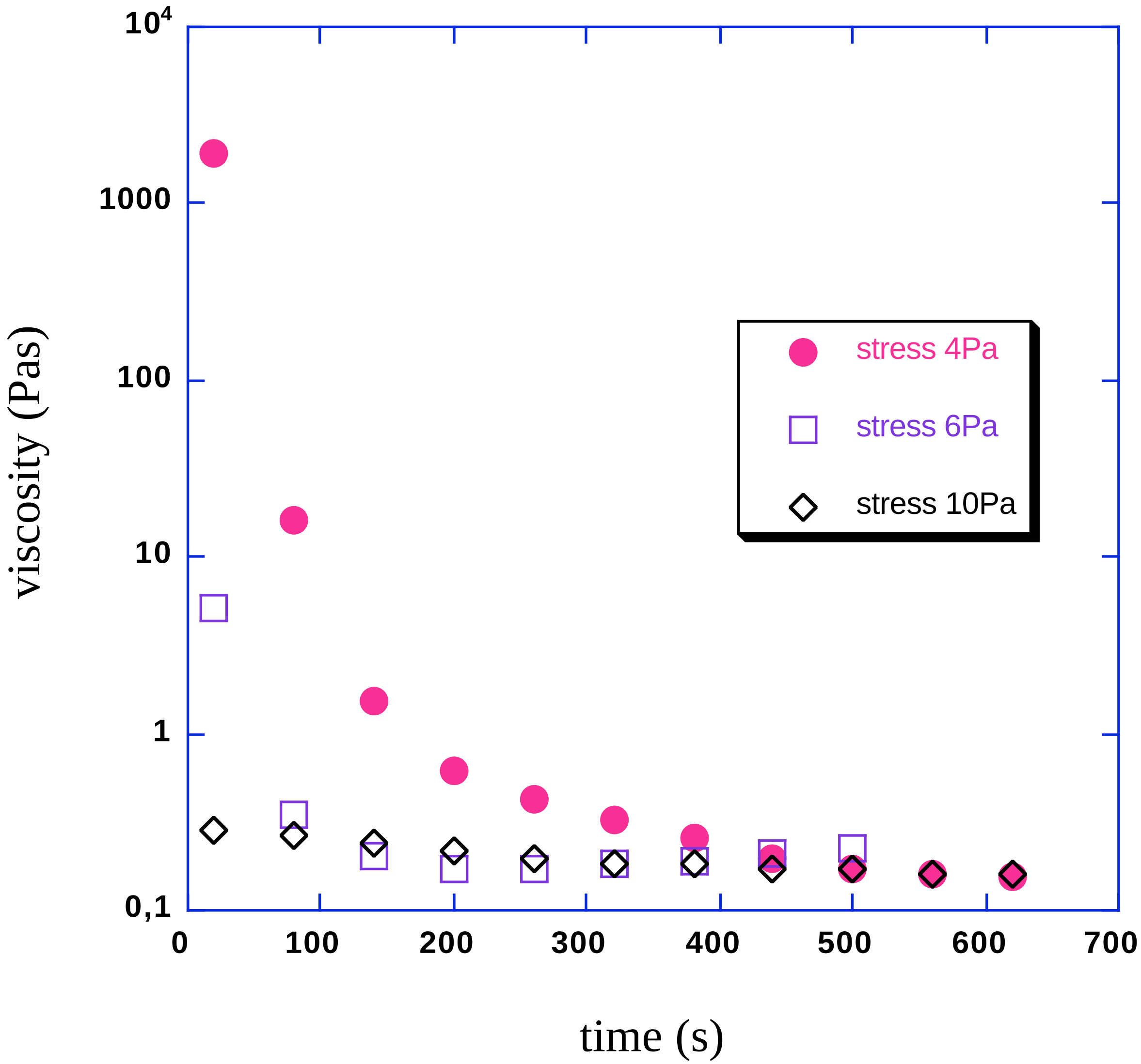


clay gel

"house of cards" structure



Second important clue: « shear rejuvenation » (thixotropy or the «French yoghurt effect »)



Abou et al. J. Rheol. 2003

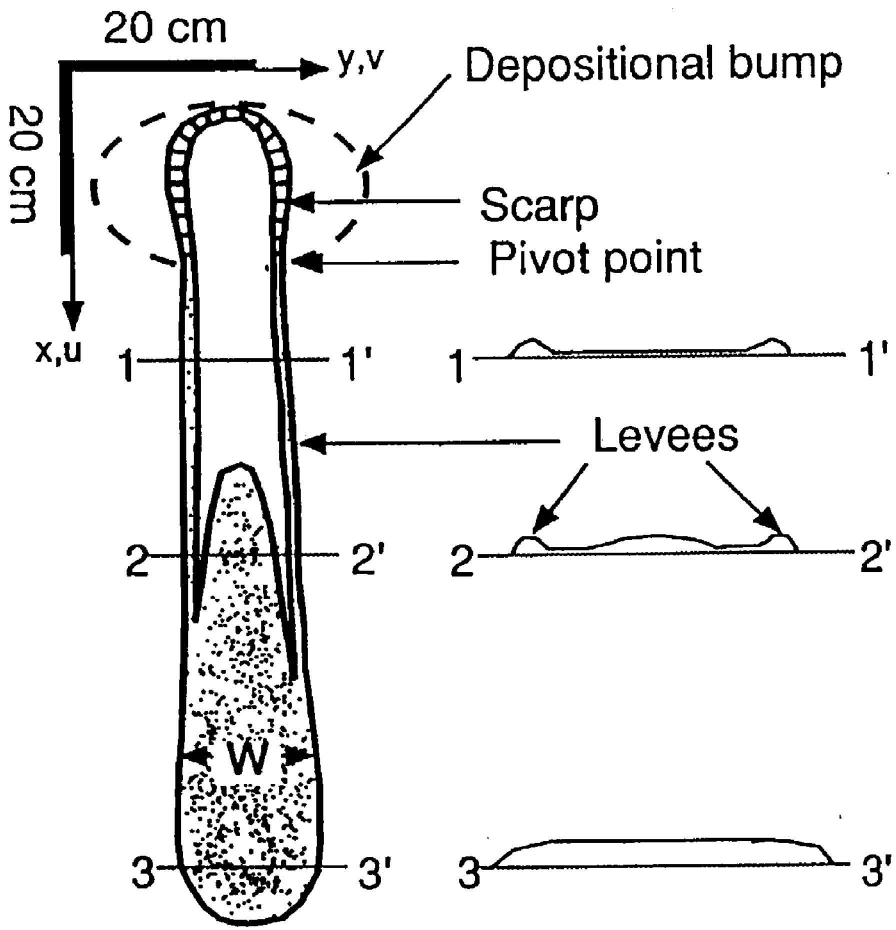
Yield stress, aging and shear rejuvenation

Competition between aging and shear rejuvenation is general for soft materials, and leads to AVALANCHES

Bentonite avalanche on an inclined plane

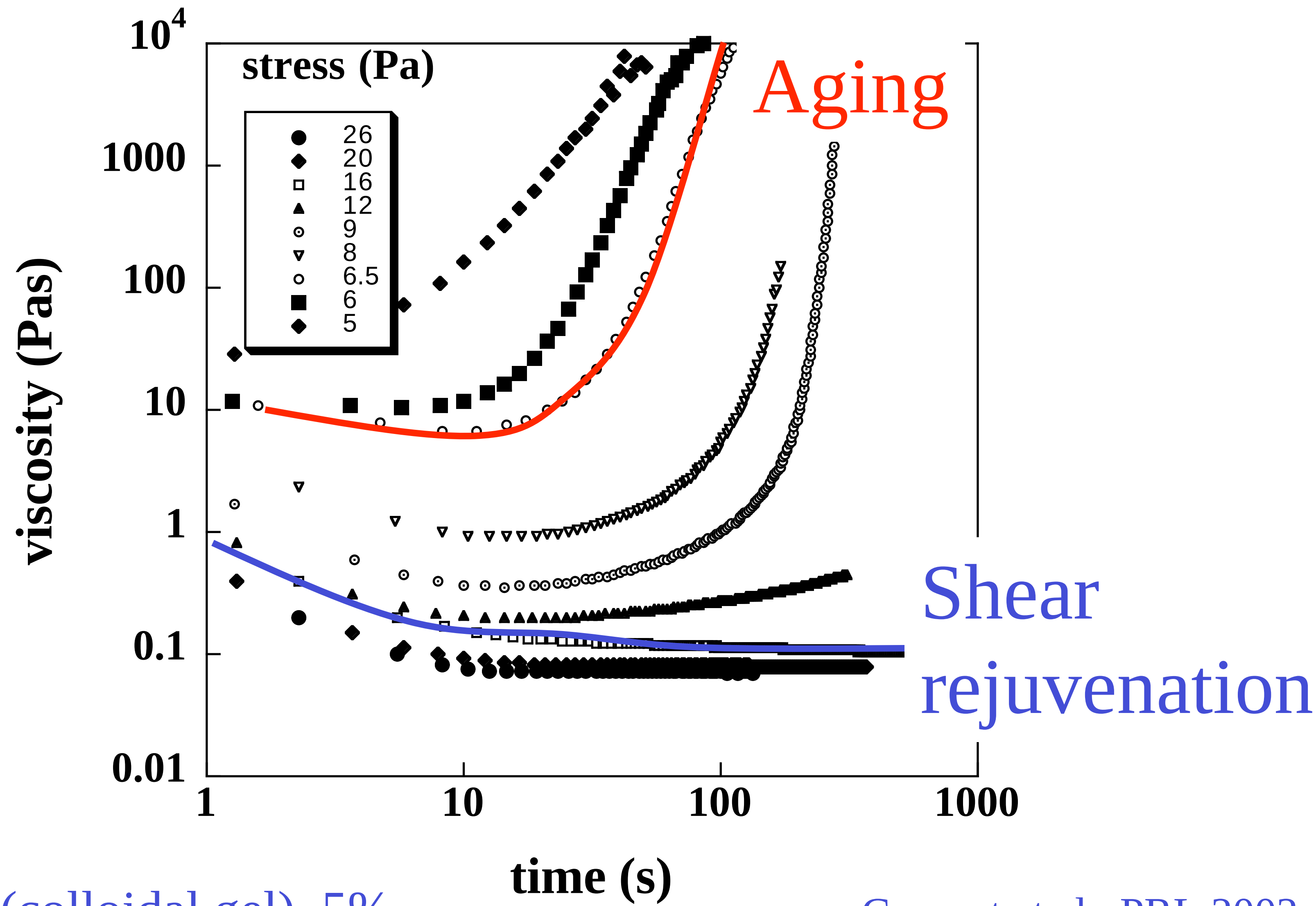
$$\sigma_y = \rho g h \sin(\alpha)$$

Sand avalanches



McDonald and Anderson, 1988

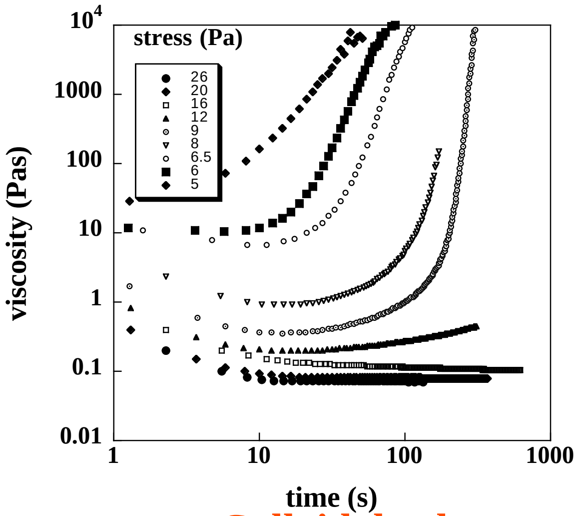
RHEOLOGY: VISCOSITY BIFURCATION



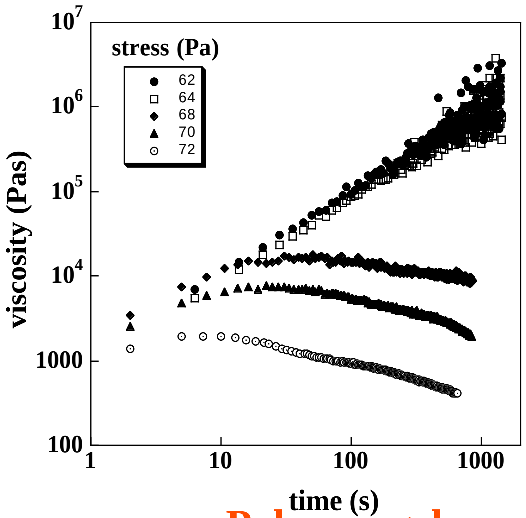
Bentonite (colloidal gel), 5%

Coussot et al., PRL 2002

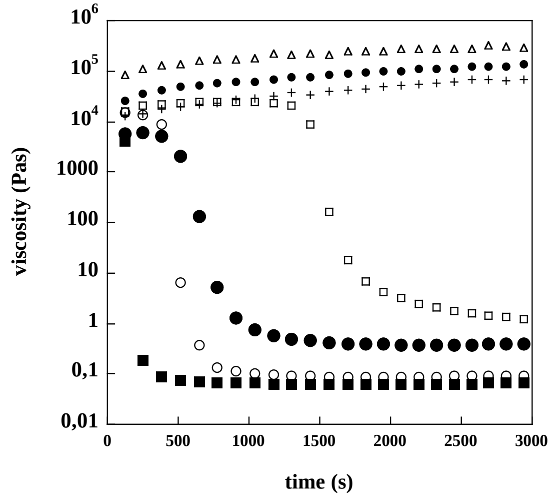
The phenomenon is general!



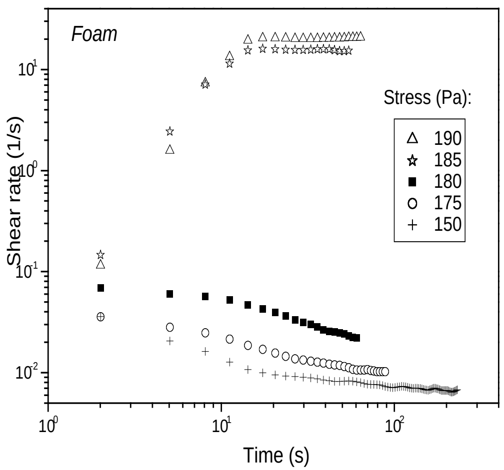
Colloidal gel (Bentonite)



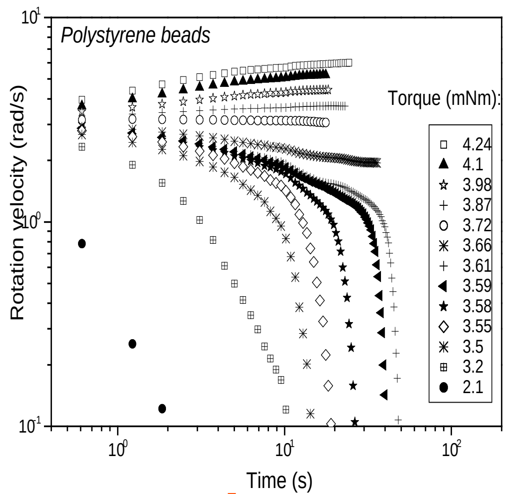
Polymer gel (hairgel)



Colloidal glass (Laponite)



Foam (shaving foam)



Granular matter (polystyrene beads)

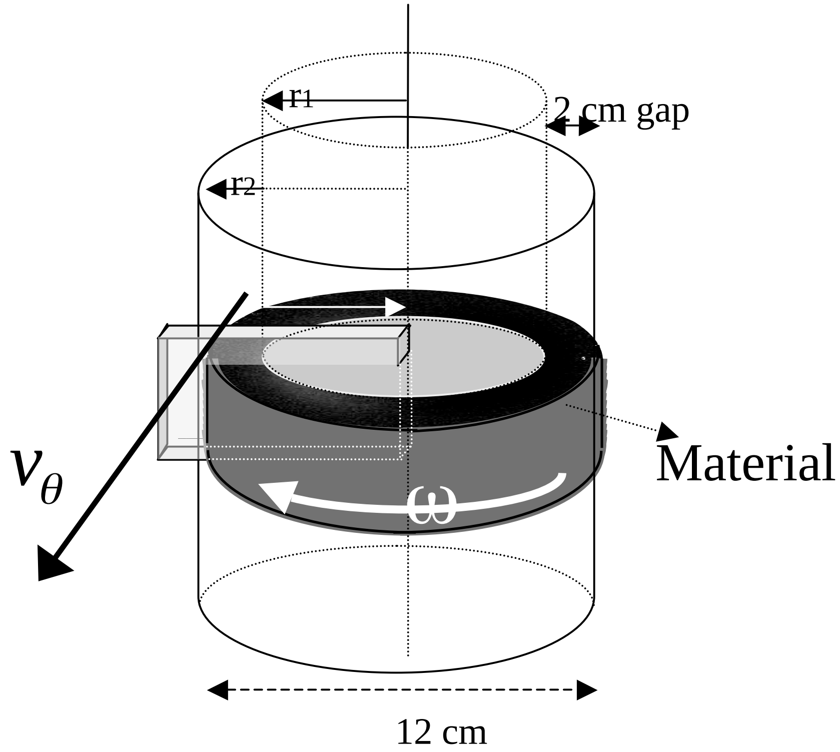
QUESTION: WHAT HAPPENS IF A SHEAR RATE IS IMPOSED THAT IS NOT ACCESSIBLE WHEN FIXING THE STRESS?

Coussot et al., PRL 2002
Da Cruz et al PRE 2003

Vertical MRI, 40cm borehole, 0.5-2.4T

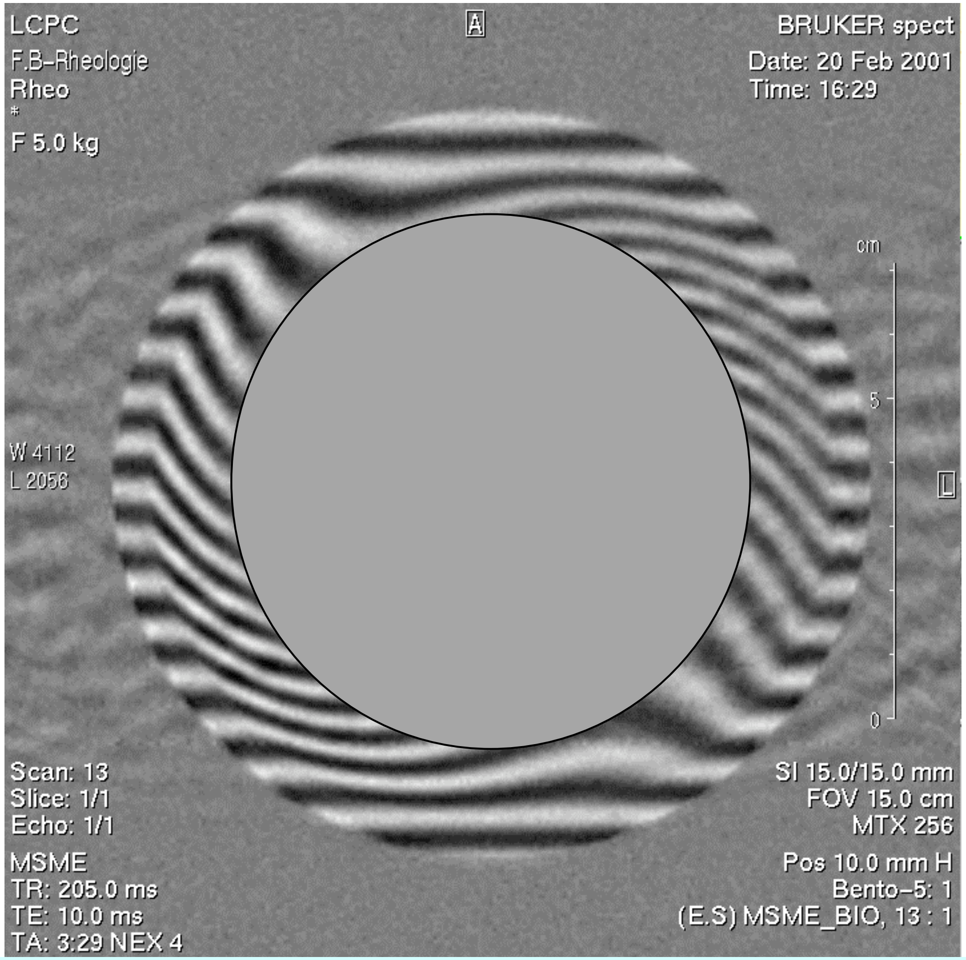
Inserted rheometer

Controlled rotation velocity



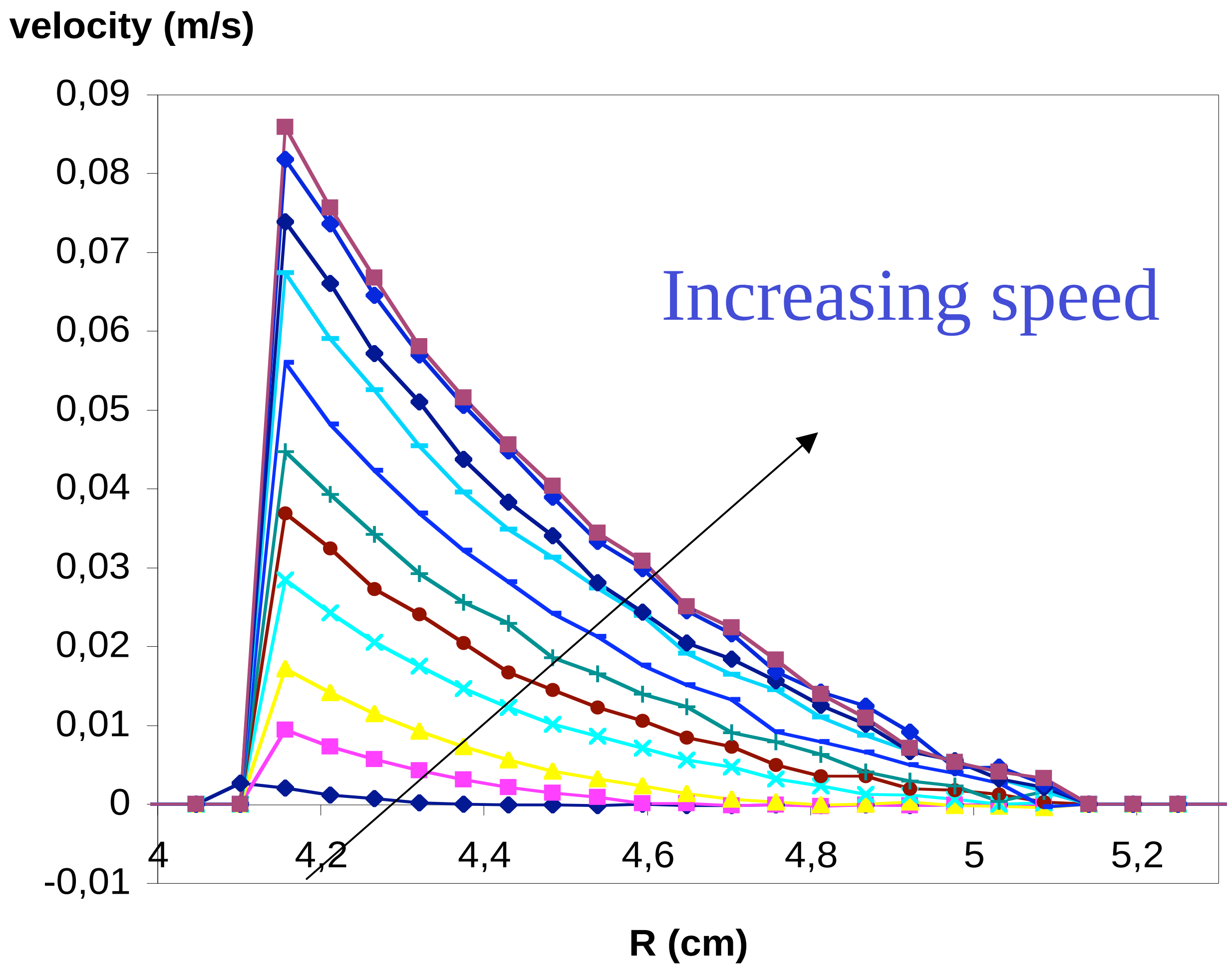
Tangential velocity measured in a central fluid portion

MRI velocity profile measurement in a Couette cell
Bentonite again

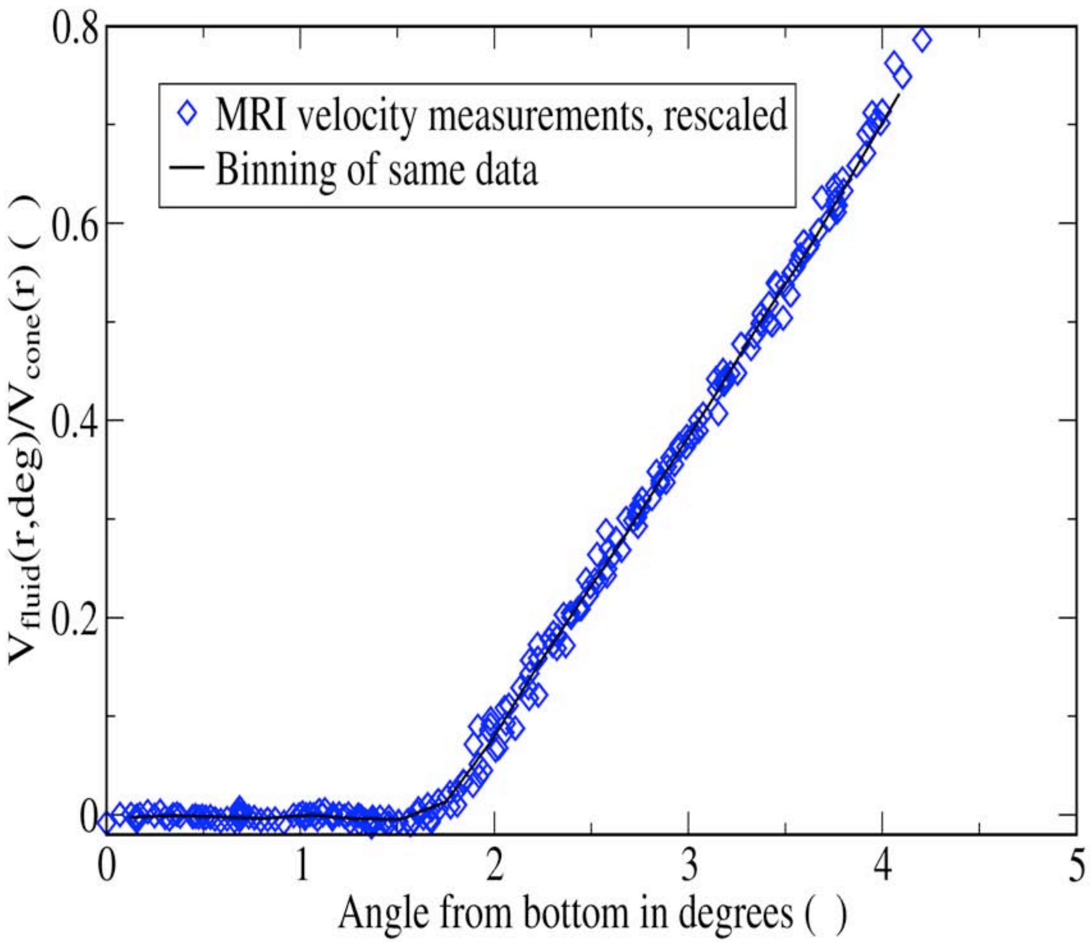


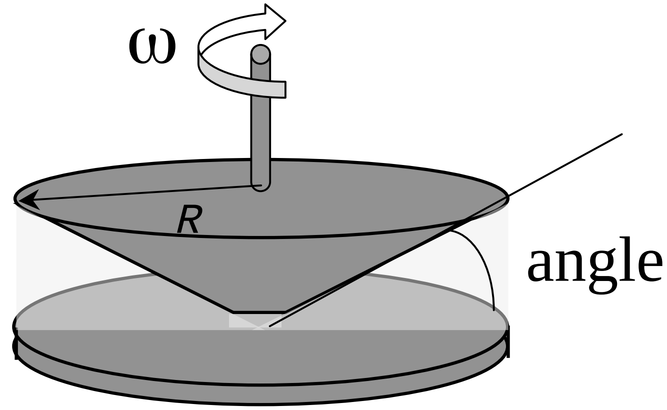
Deformation of fictive lines within the material in a Couette geometry

Velocity profiles: shear localization



MRI on cone-plate: homogeneous stress





Cone-plate cell

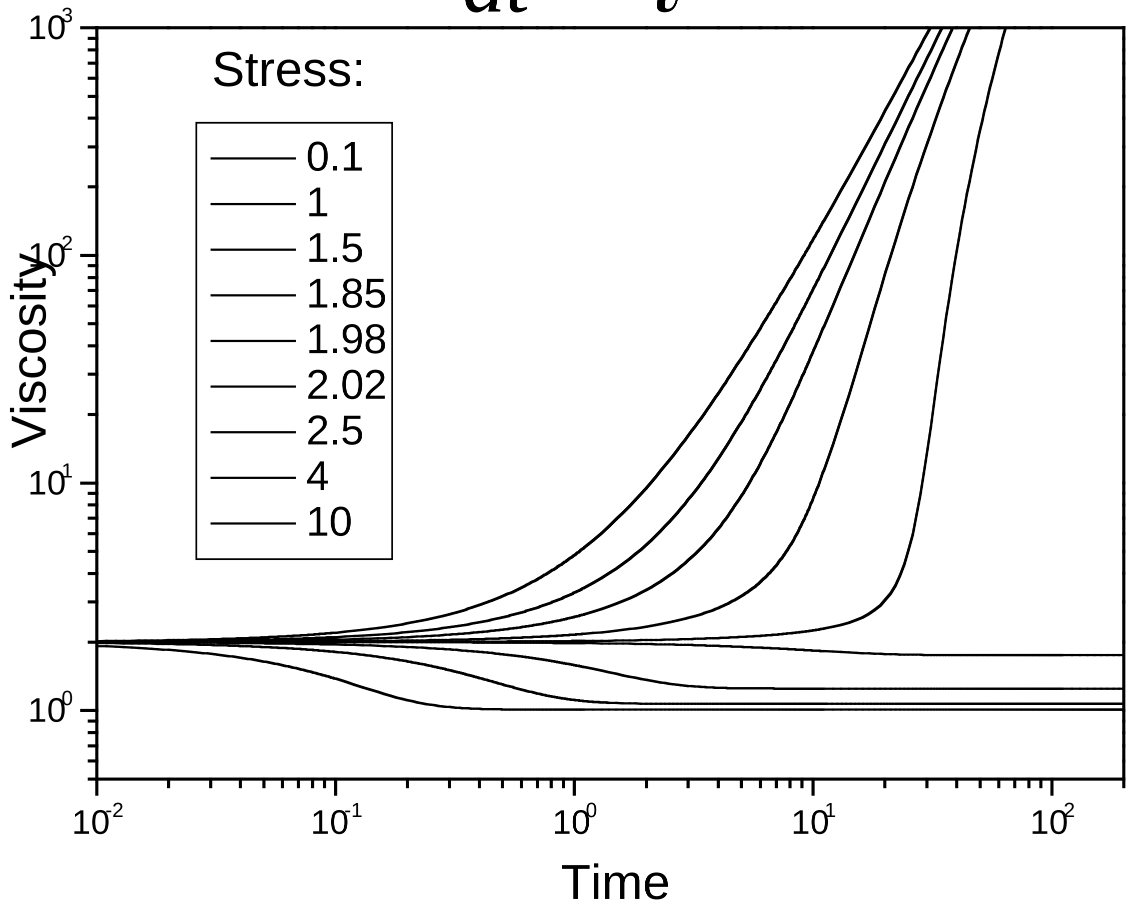
NO NEED FOR STRESS HETEROGENIETY TO GET SHEAR BANDING!

Simplest possible model

Instantaneous state of structure (degree of jamming) λ $\xrightarrow{\text{e.g.}}$ $\eta(\lambda) = \eta_0(1+\lambda^n)$

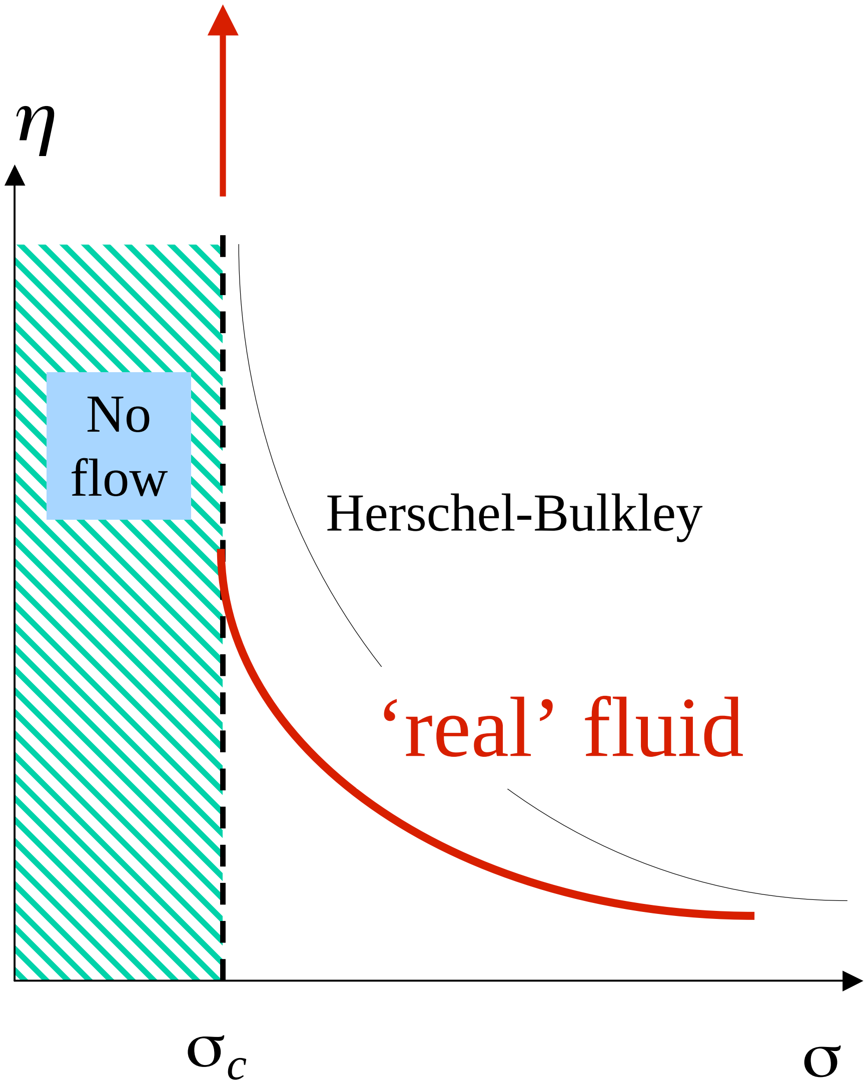
$$E \propto \lambda$$

$$\frac{d\lambda}{dt} = \frac{1}{\tau} - \alpha\dot{\gamma}\lambda$$

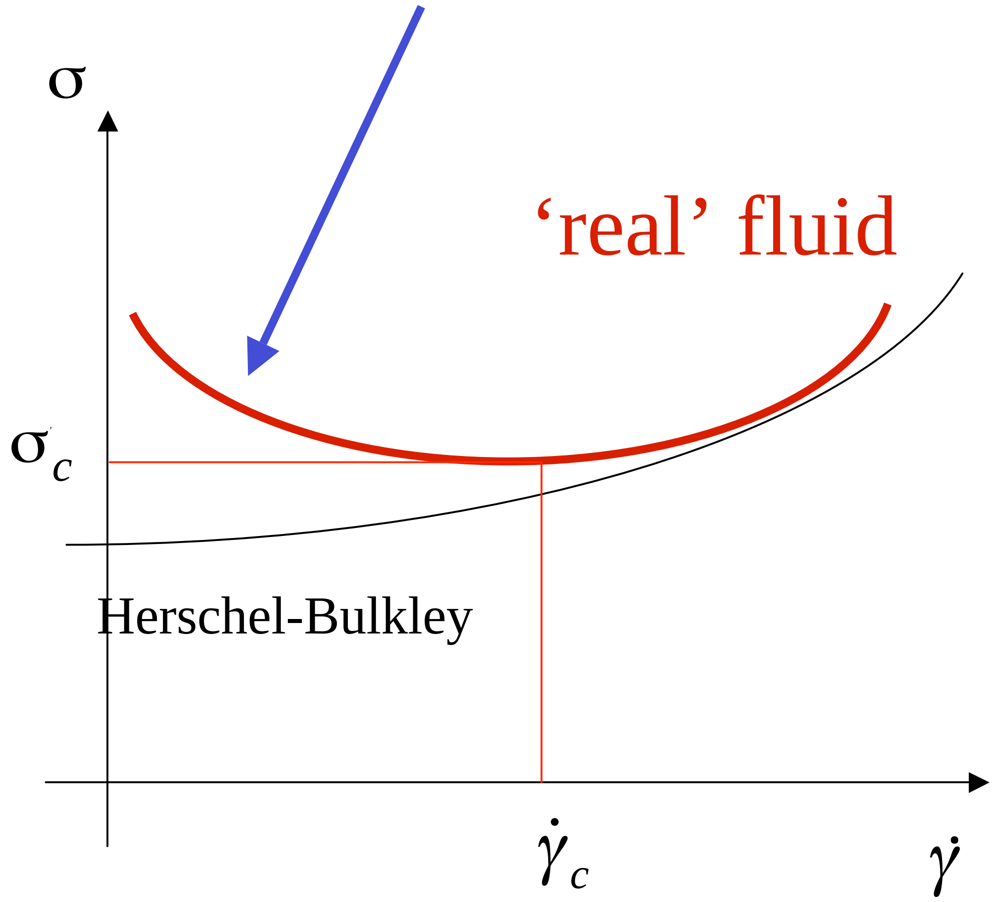


Coussot et al.,
PRL 2002
J. Rheol. 2002

Yield stress, shear rejuvenation & aging

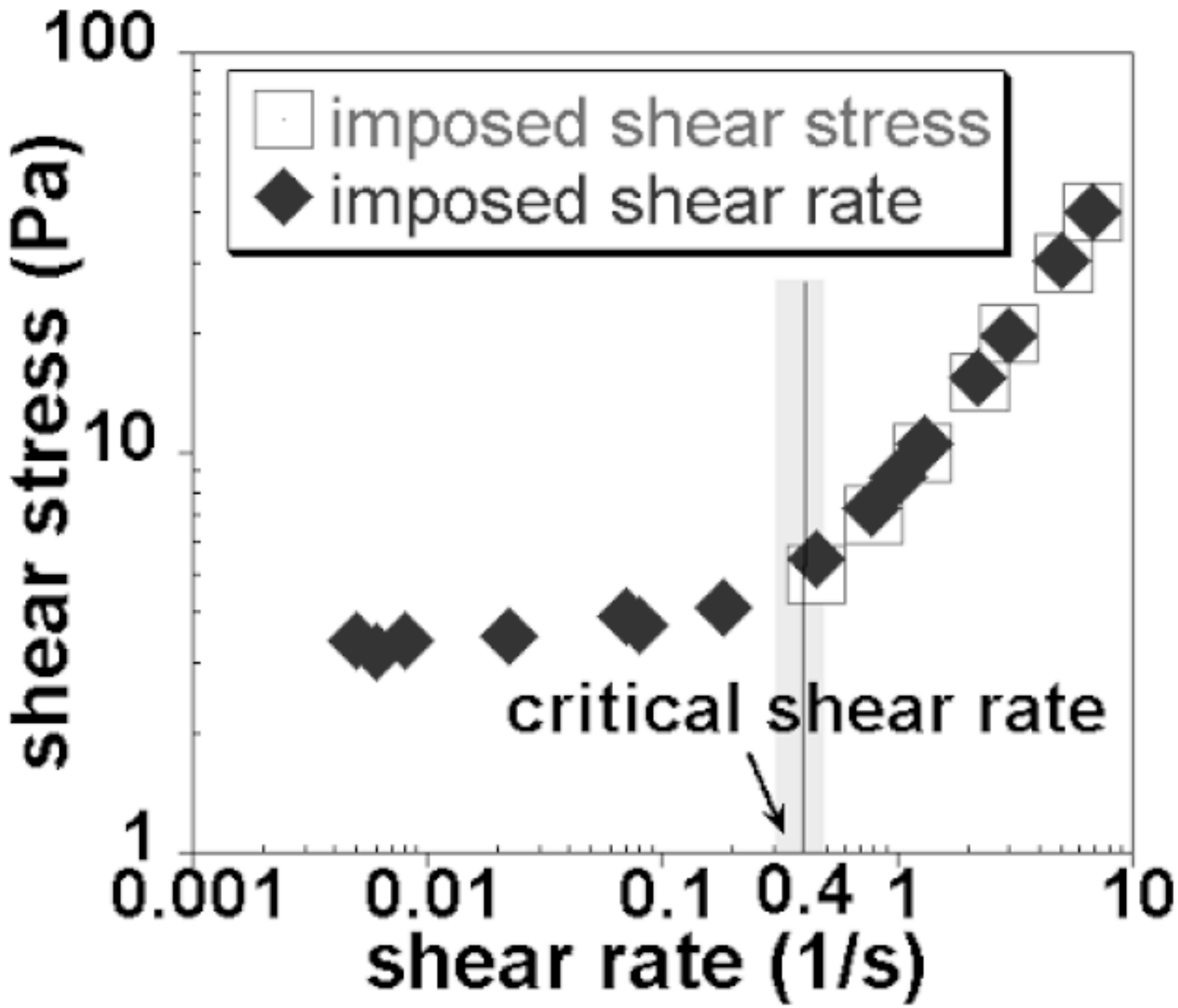


«Unstable flow curve »



Coussot et al., PRL 2002,
J. Rheol. 2002

The overall picture:



Wet granular material: Huang et al., PRL 2005

Rheology conclusion

Interplay between yield stress and thixotropy is GENERAL for structured complex fluids (we, in any case, haven't found an exception) and lead naturally to

-a viscosity bifurcation

-shear localization and

-a critical shear rate

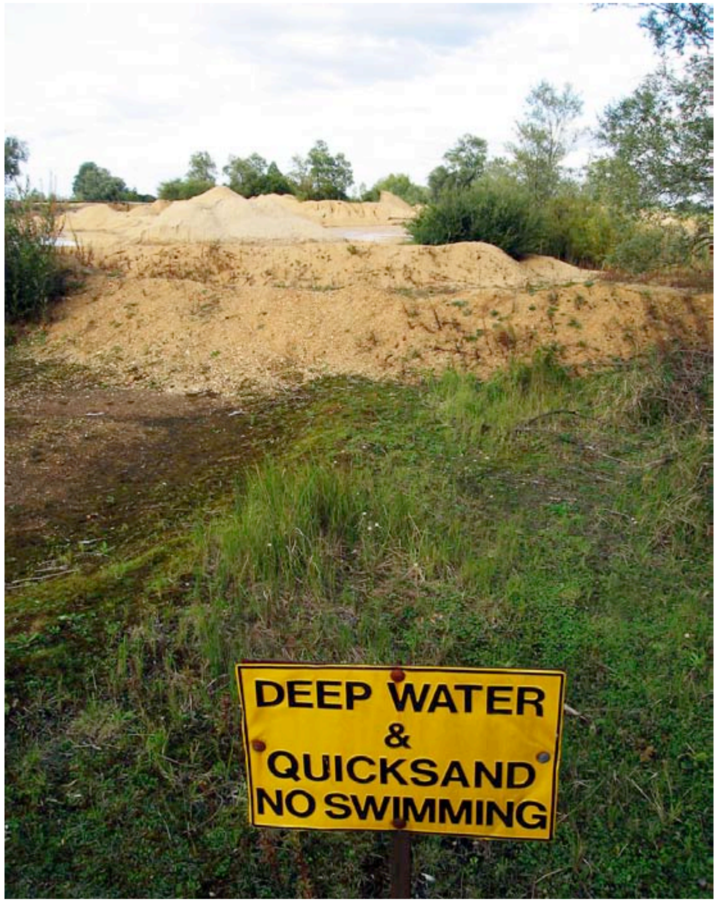
All this implies that the yield stress in NOT a property of the material, since the critical stress for the bifurcation depends on the (shear) history of the material. This provides a natural explanation for the irreproducibility of the experimentally determined yield stress. Experimentally: preshear is needed for reproducible results

Coussot et al., Phys.Rev.Lett 2002, Huang et al., Phys.Rev.Lett 2005,
Moller et al. Soft Matter 2006 (minireview, free download)

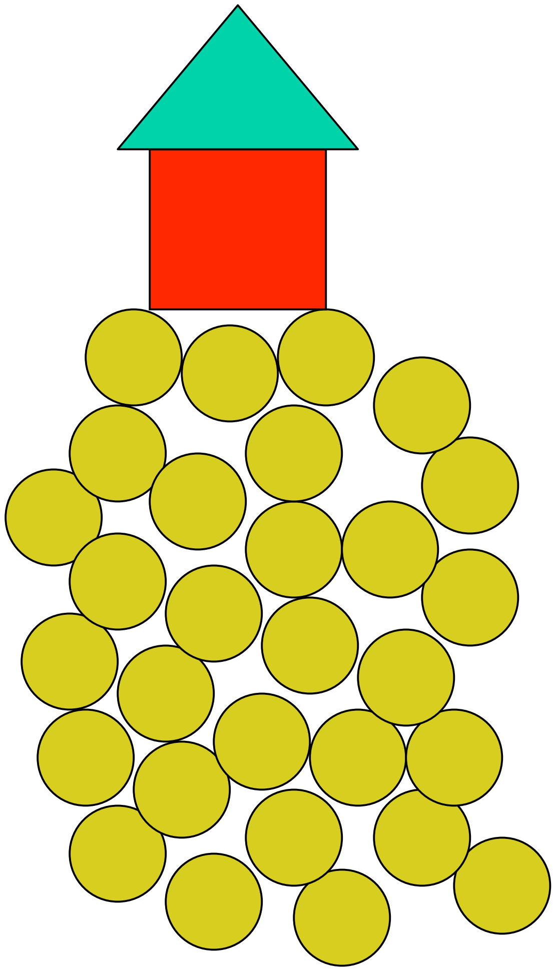
Geo-rheology...

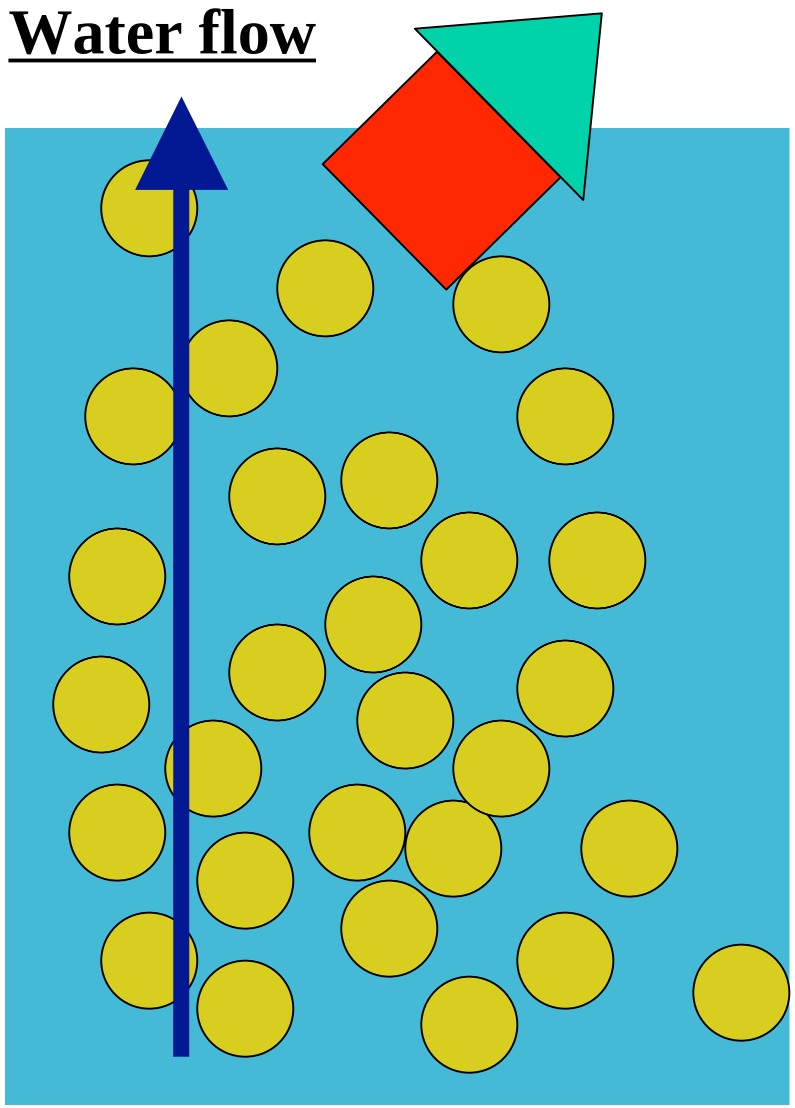
This provides a <u>common framework</u> (the rheological properties)
To describe glasses, gels, granular matter, emulsions, clayey soils…..

Applications in geophysics? Landslides, quicksand?



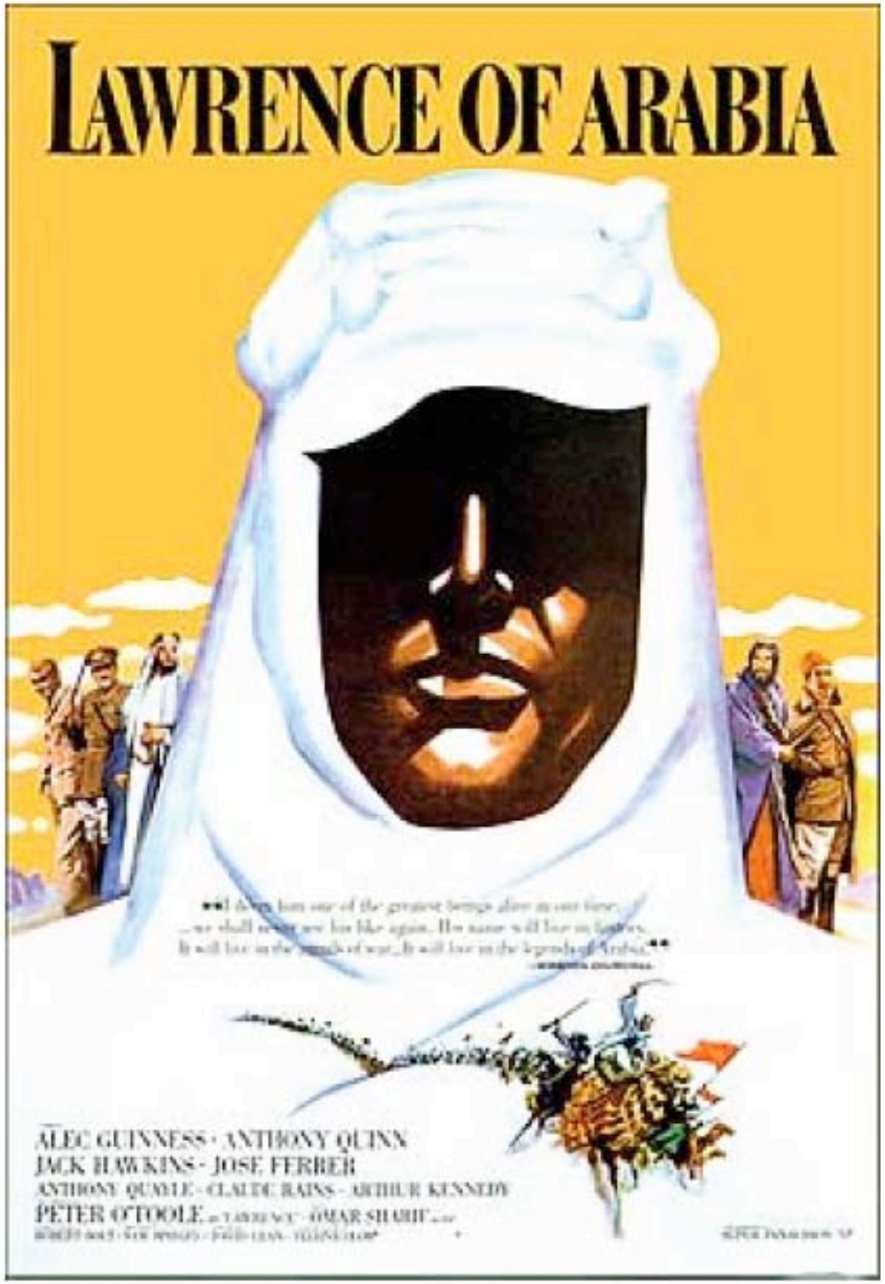
Earthquake quicksand
(‘geophysicists quicksand’)





Eartquake quicksand (Japan, 1964)

Desert quicksand



Lawrence: Well, I, it's, uh, let me see, I killed two people. One was a boy. That was yesterday. I led him into a quicksand. The other was a man. That was before Aqaba anyway. I had to execute him with my pistol.

..and Daud slowly sinks away into the quicksand and dies.

Dry laboratory quicksand

D. Lohse et al.

Nature 2005

Hound of the Baskervilles

« Real quicksand »

(Crusoe, Tarzan, Flash Gordon, Jungle Book, King Solomons Mines…..)

Quicksand

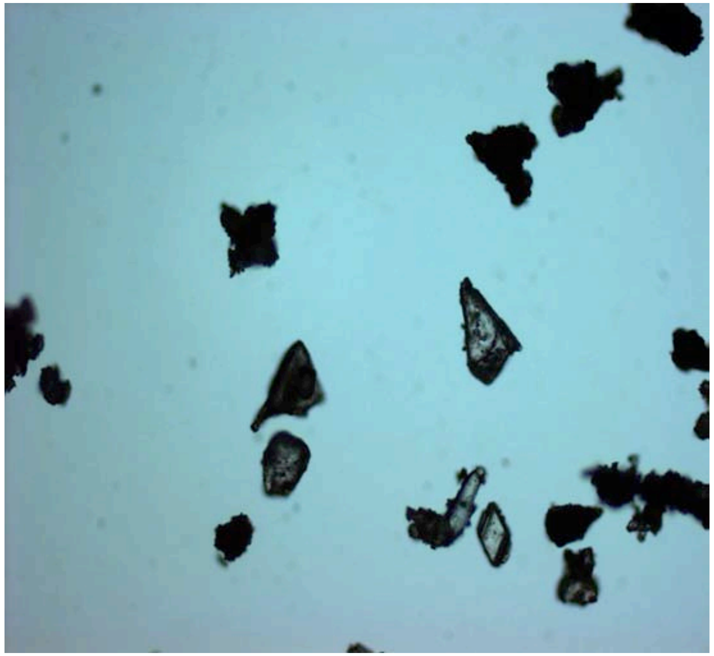
Three Quicksand Myths:

1) once in, don't move
2) once in, hard to get out
3) once in, one drowns

Salt lake between Teheran and Qom

What is quicksand?

Natural quicksand
From Qom-Iran (salt lake)
And Tarfaya-Maroc (close to the sea)
Sand+water + CLAY +SALT



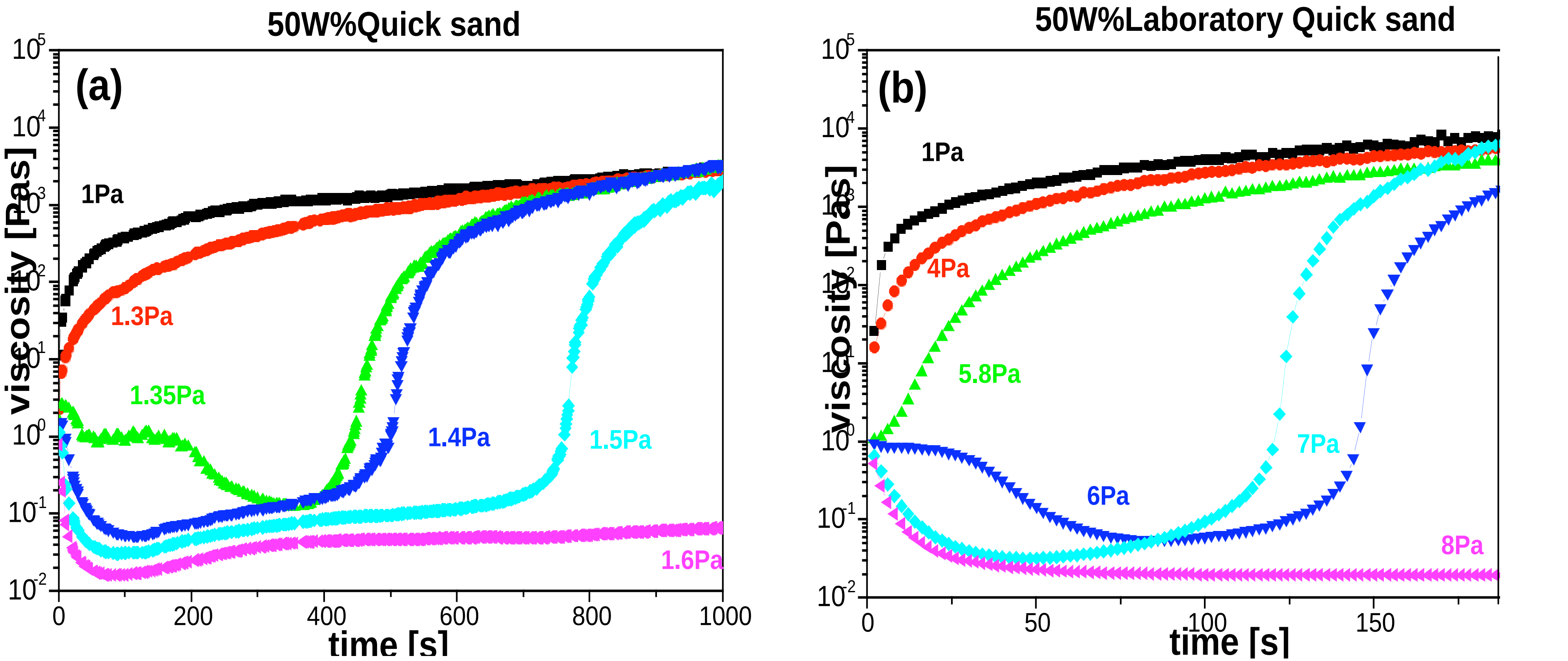
Size of the sand particles 20-50µm

Gypsum	Quartz	Cristobali te	Hematite	Swelling Clays
50%	25%	15%	3%	7 %

Results of X-ray analysis

other forms of quicksand:
-fluidized sand
-loose sand

Rheology of quicksand

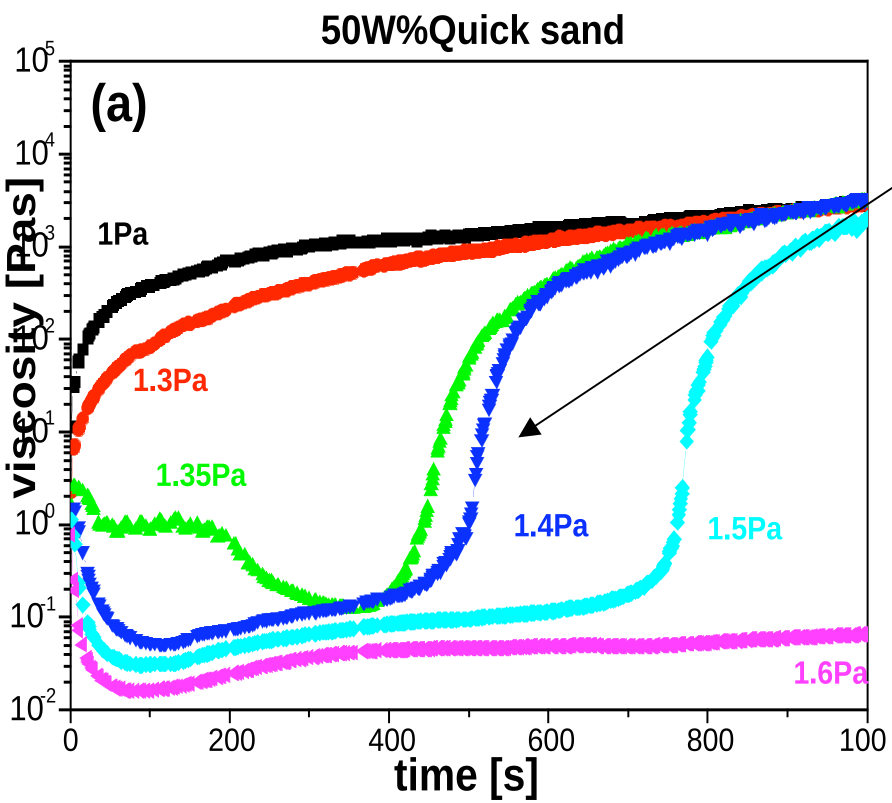


salinity 10^{-1} mole/l ——— salinity $>2.10^{-2}$ mole/l

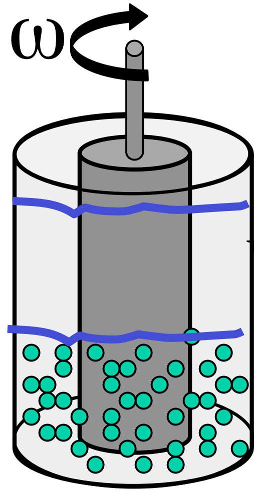
Don’t move: difference between sinking:1mm/15 min and 1m/s

By mixing sand and clay (bentonite) in salt water, “laboratory quicksand” can be created.

....and phase separation



Phase separation: sedimented sand with a very high viscosity: $\phi \approx 0.8$ You're stuck!

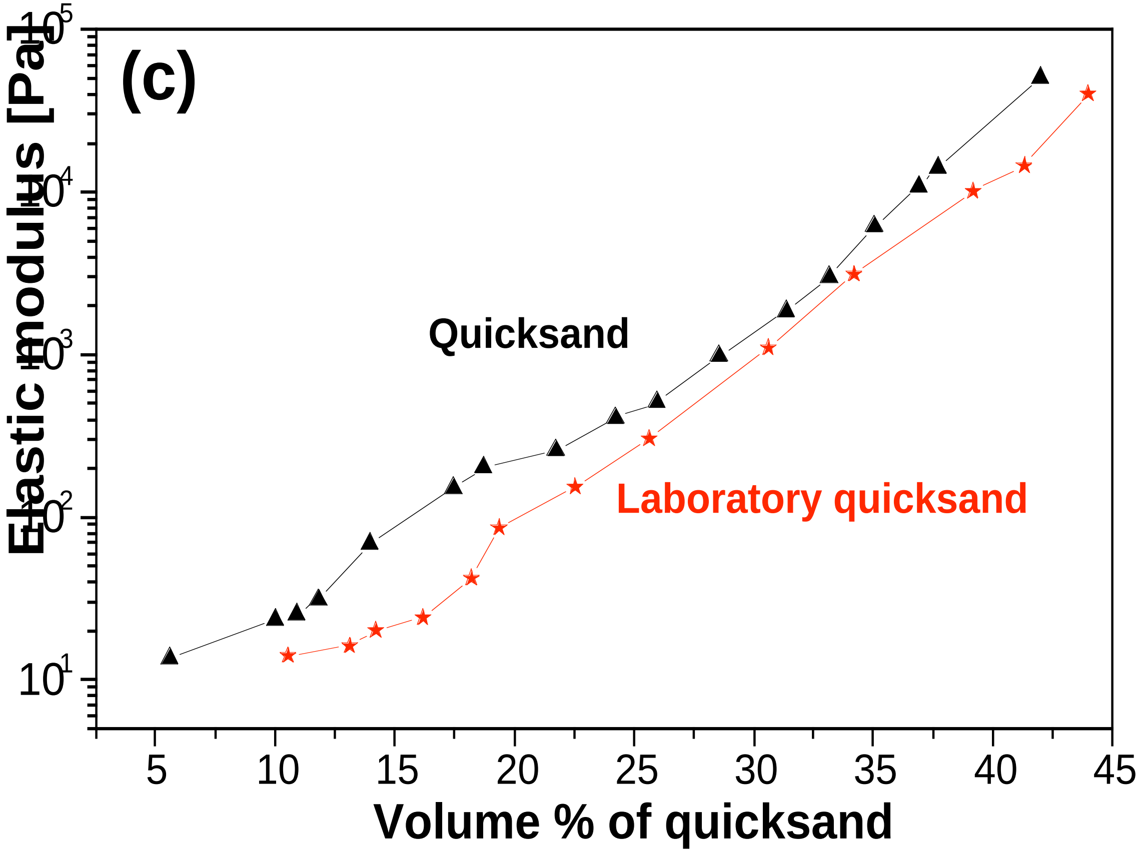


To get your foot out you have to introduce water in the sand packing: at 1 cm/s : $F=10^4$ N!

From salt lake: salinity 10^{-1} mole/l

Salt is essential for the collapse: salinity needs to be $>2.10^{-2}$ mole/l for the laboratory quicksand

Elastic modulus from rheology



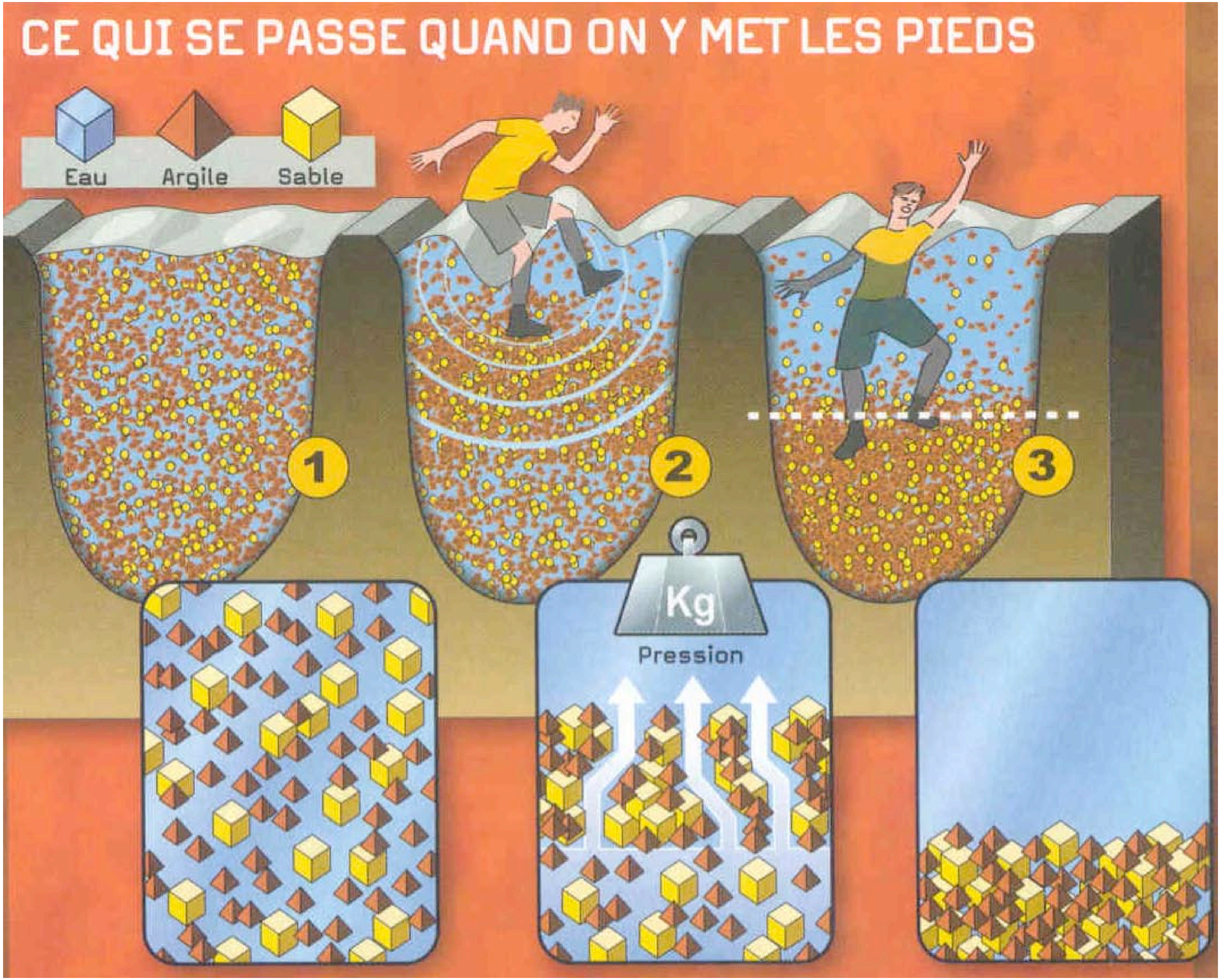
Quicksand can support the weight of an adult person at ϕ=0.4!

$$\frac{F}{A} = \frac{50kg * 10m/s^2}{10^{-2} m^2} = 5 \cdot 10^4 Pa \approx E$$

(supposing normal and shear forces to be similar)

Piling up oranges

More than 2/3 of space occupied by the oranges


CE QUI SE PASSE QUAND ON Y MET LES PIEDS
Eau
Argile
Sable
1
2
3
Kg
Pression

Sinking test....

Quicksand

Three Quicksand Myths:

1) once in, don't move: TRUE
2) once in, hard to get out: TRUE

(there is a way to get out, however..)

1) once in, one drowns: FALSE

(but beware….the high tide may come in)

A. Khaldoun et al., Nature 2005

But…what is quick clay????

Quick clay landslides

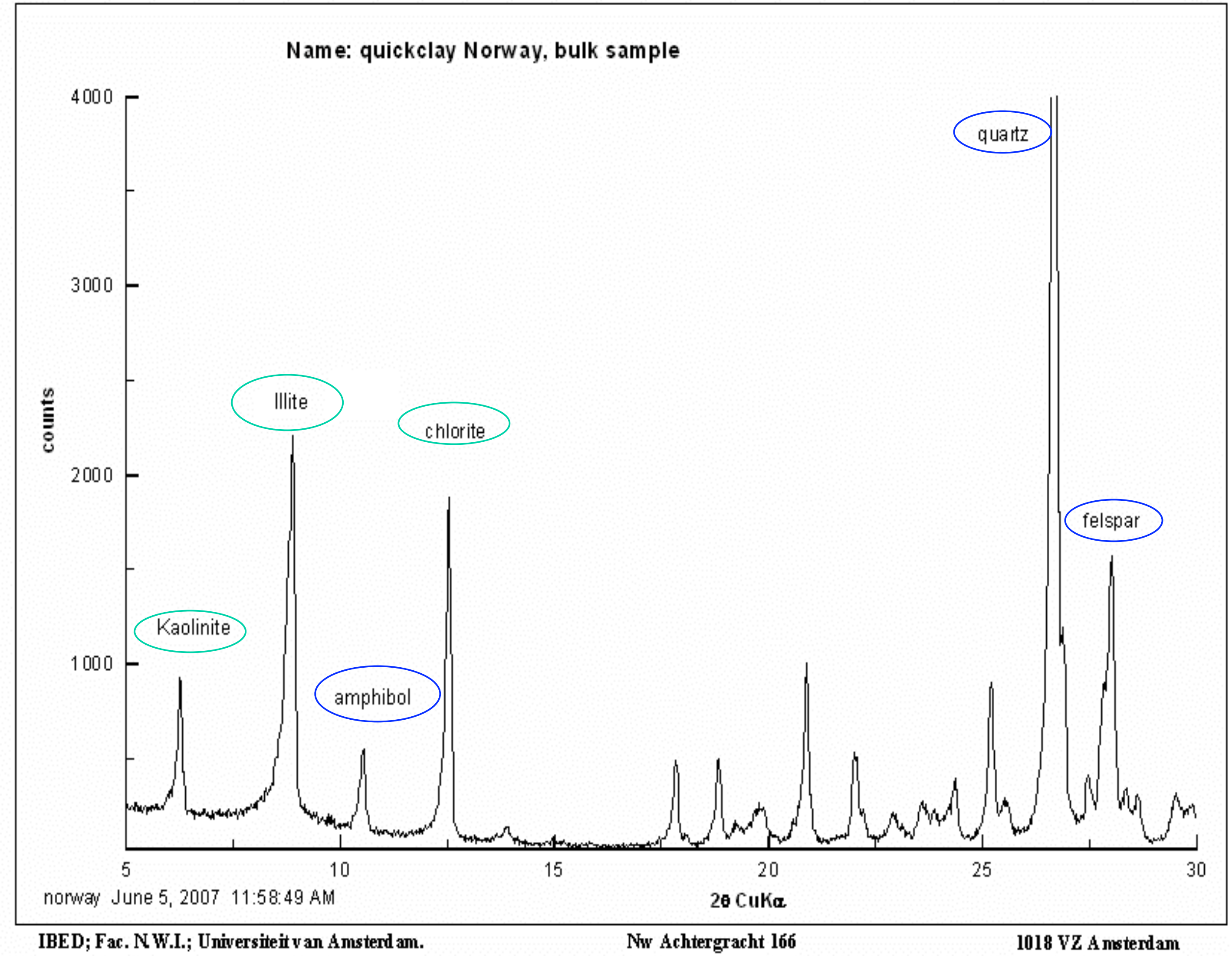
With: Jon Otto Fossum and Yves Méheust
Department of Physics NTNU, Trondheim University (Norway)

Quick clay landslides (the Rissa raset)

St Jean-Vianney, 1971, Canada

WHAT IS QUICKCLAY?

Natural quickclay from Trondheim, Norway (Bulk sample)



60-80%

non swelling clays:

- illite
- chlorite
- some kaolinite

20-40%

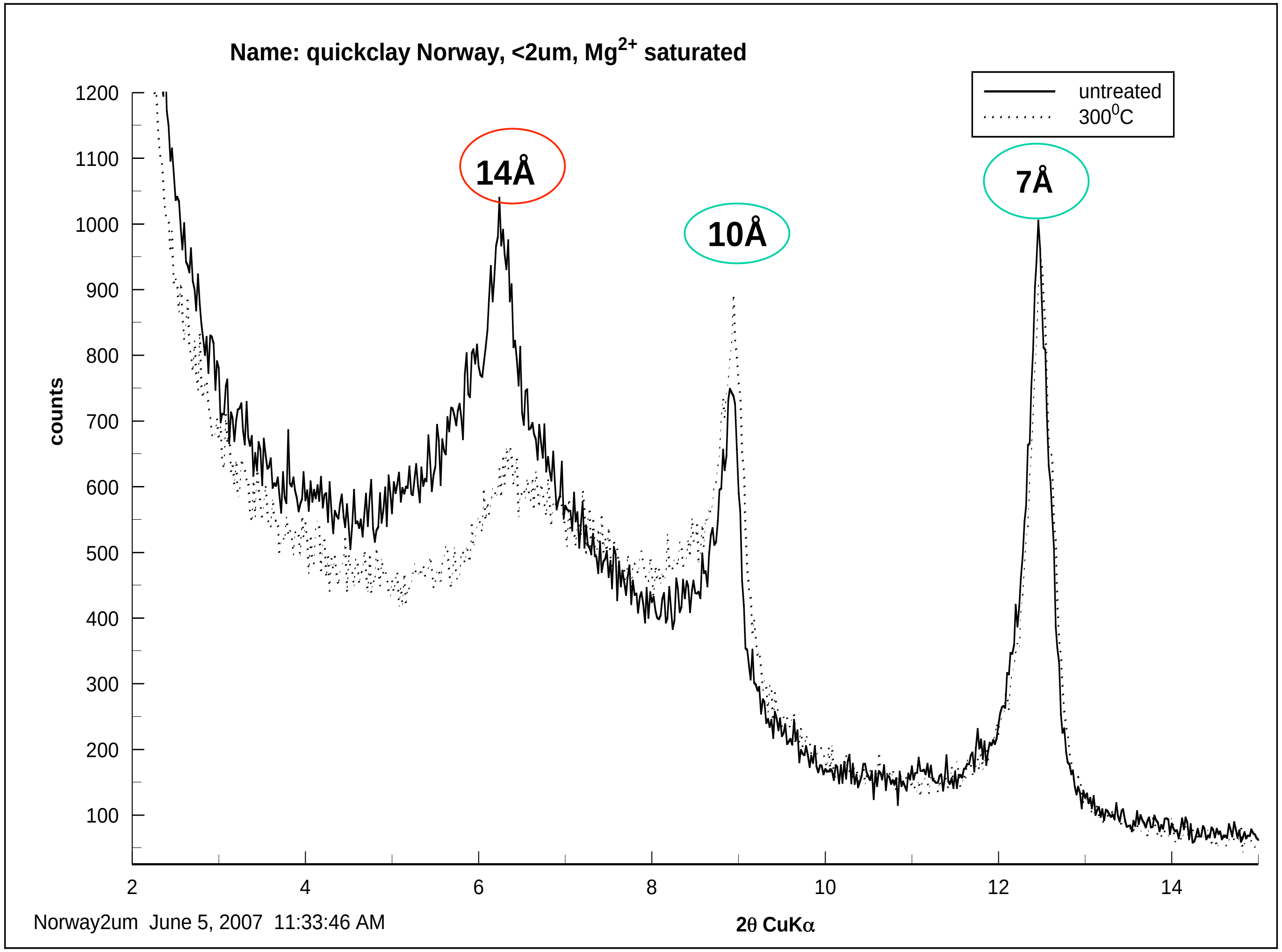
primary minerals:

- Quartz
- amphibol
- felspar
- pyrite

WHAT IS QUICKCLAY?

Natural quickclay from Trondheim, Norway

<2µm fraction of the sample



IBED; Fac. N.W.I.; Universiteit van Amsterdam.

4%

swelling clays:

- Vermiculate
- montmorillonite

96 %

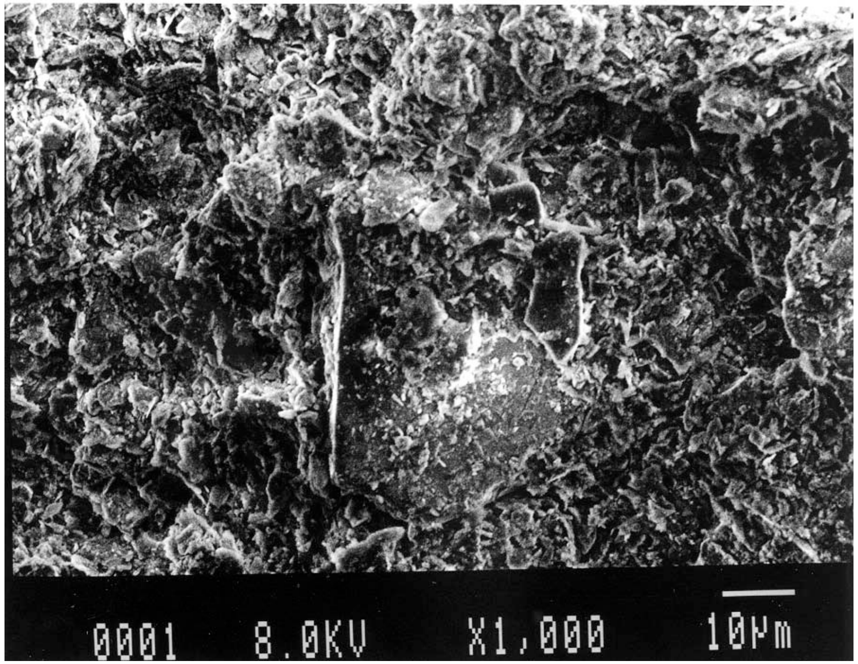
non swelling clays:

- illite
- kaolinite

WHAT IS QUICKCLAY?

Natural quickclay from Trondheim (Norway)

SEM microscopy



The quartz particles are small and also plate like!!

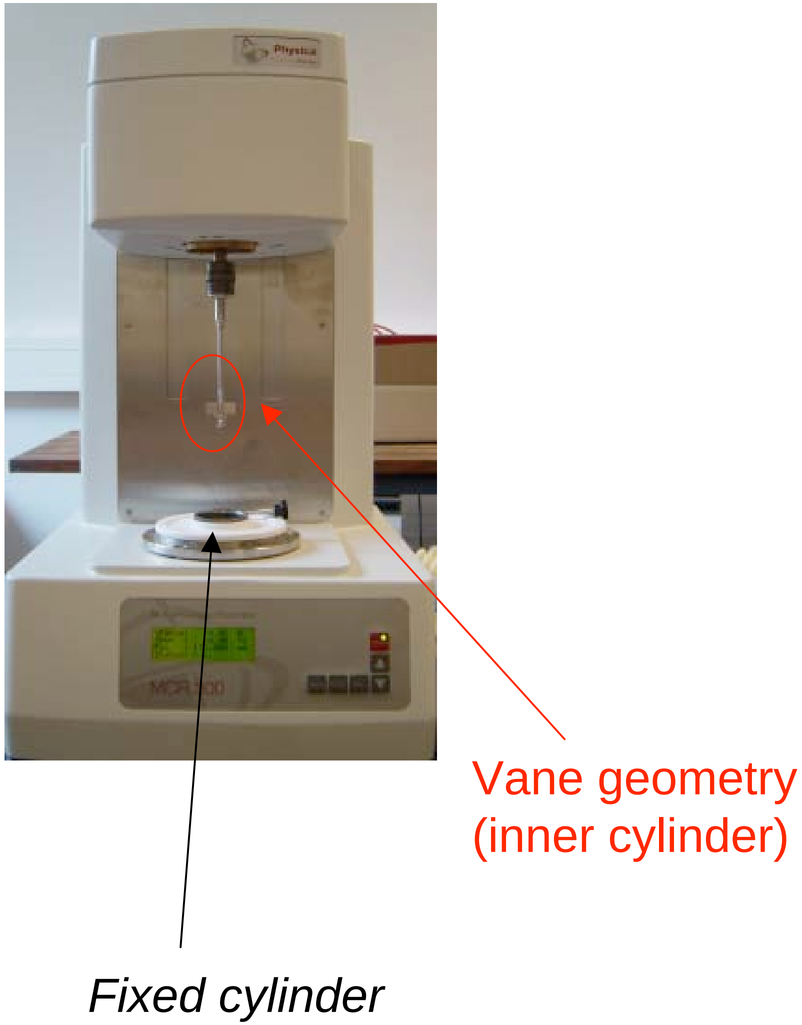
Texture analysis

	%
μm	Quickclay (Norway)
2000-1000	0.00
1000-500	0.01
500-250	0.01
250-125	0.00
125-63	0.08
63-16	17.58
16-2	46.62
<2	34.69
Total	98.99

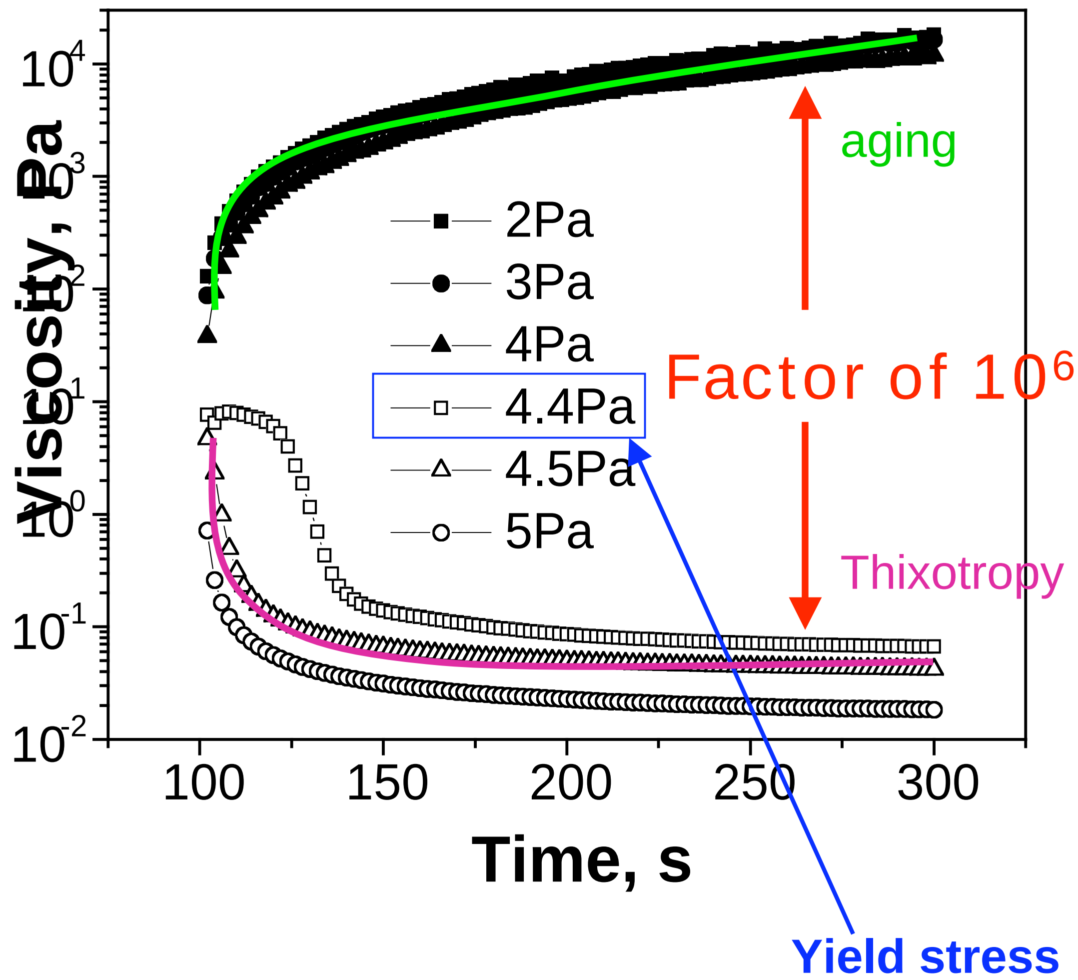
The particles are in the fine silt size

RHEOLOGY of QUICKCLAY

Catastrophic liquefaction above a certain stress (=slope)



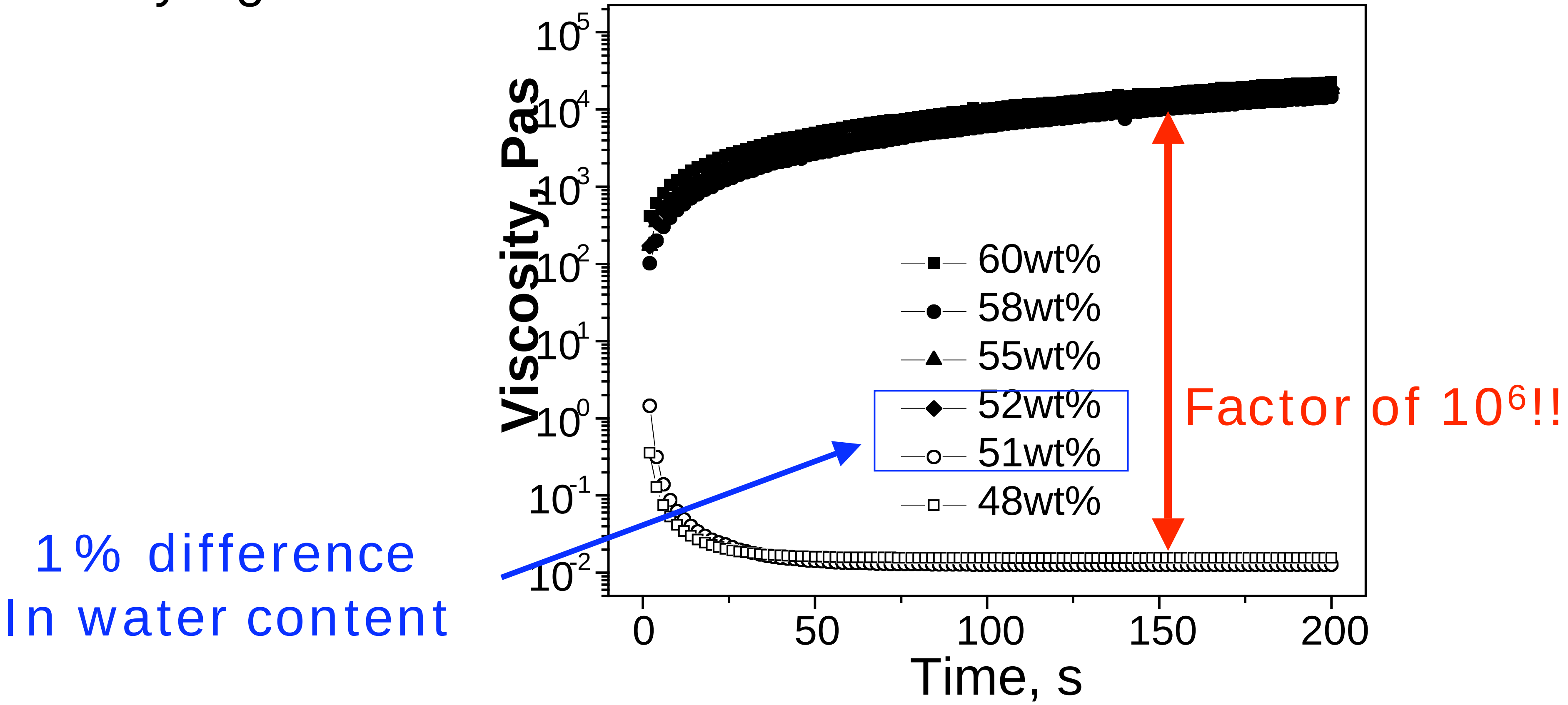
50 wt% natural quickclay



RHEOLOGY of QUICKCLAY

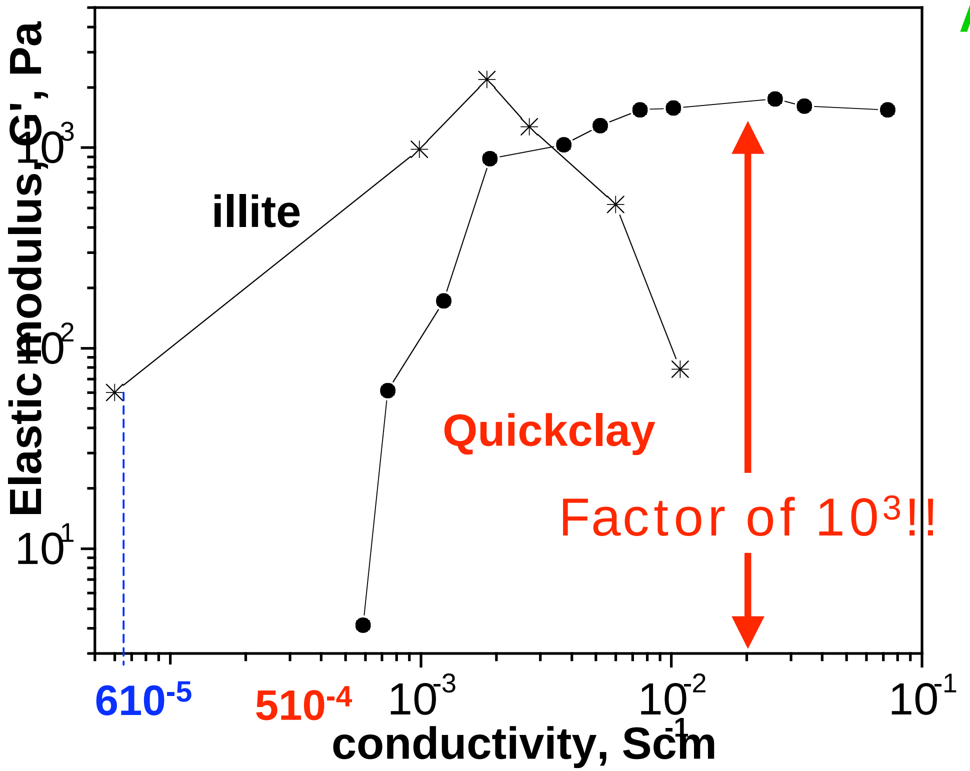
Catastrophic liquefaction (After rain)!!

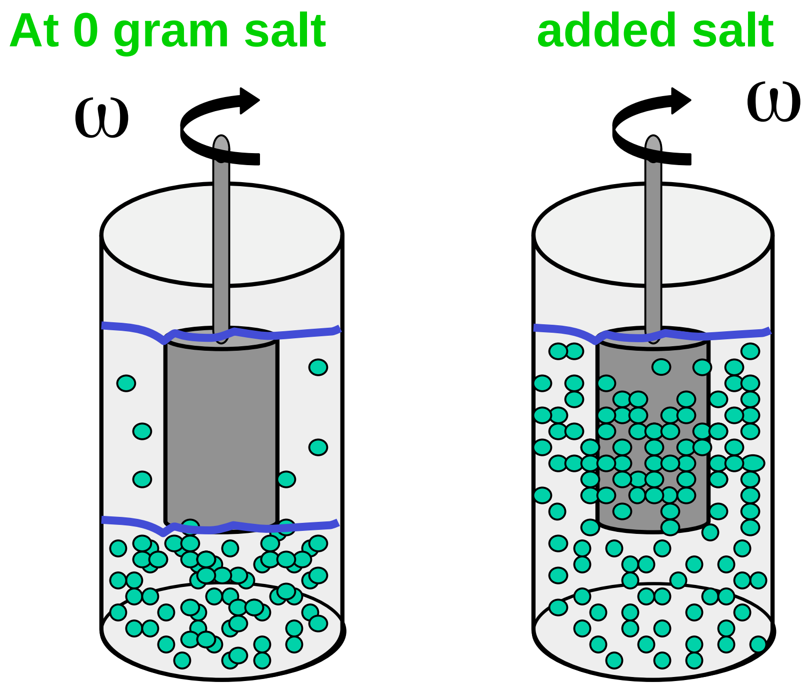
- At fixed Shear stress, 5Pa (=fixed slope)
- Varying water content



LABORATORY QUICKCLAY

Salt effect

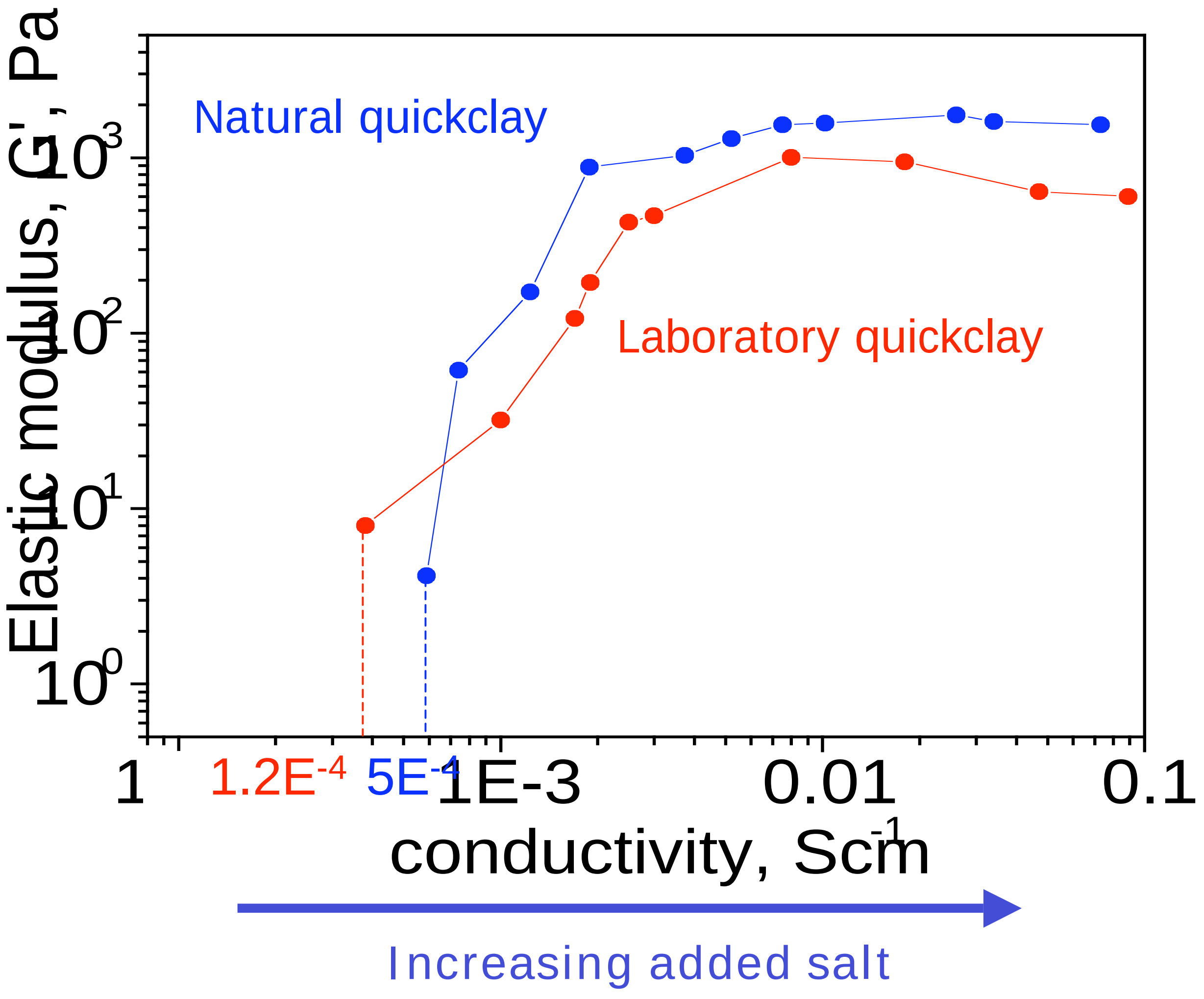




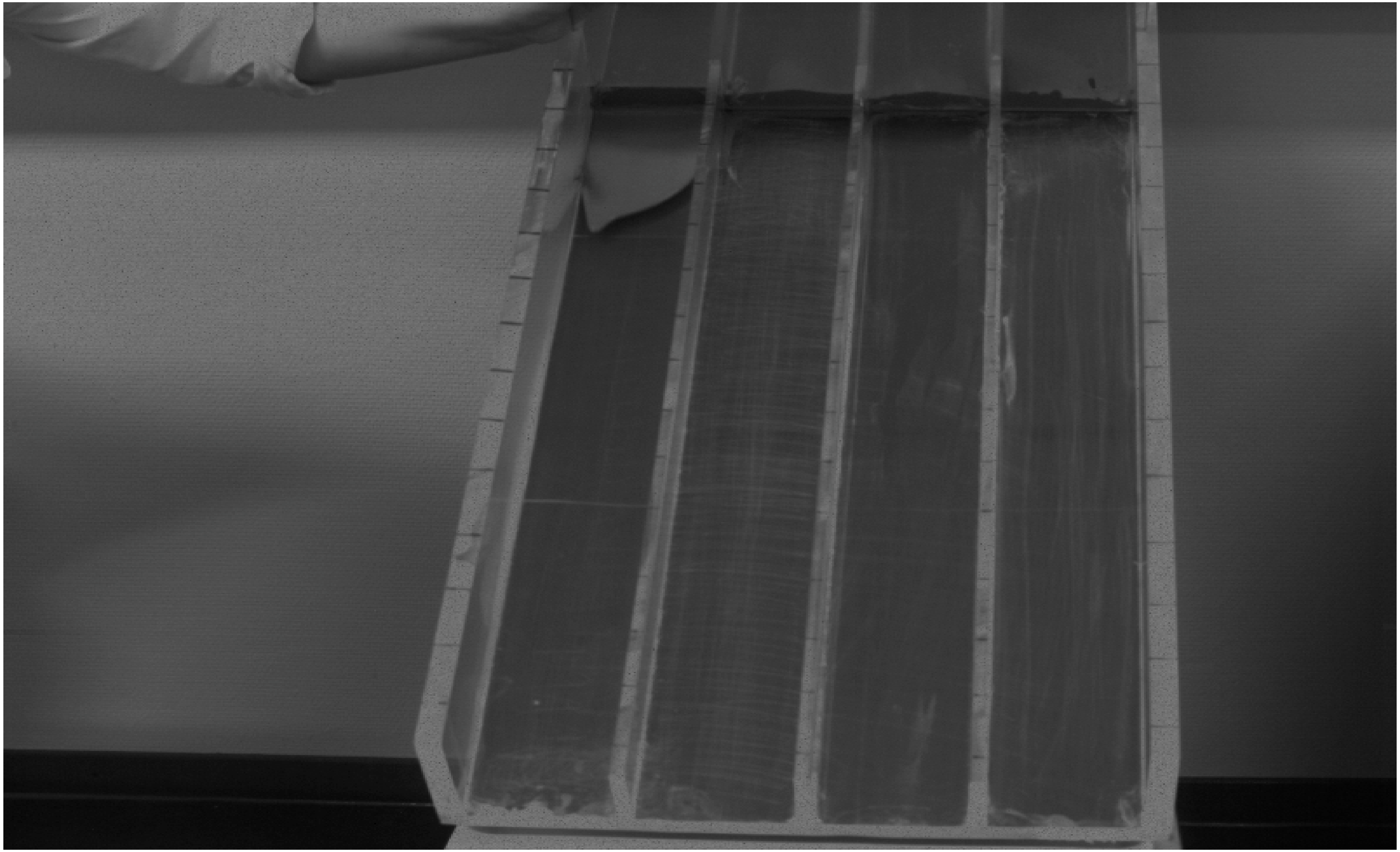
Increasing added salt (steps of 0.005g)

LABORATORY QUICKCLAY

Laboratory quickclay is:
3% washed bentonite +97% illite

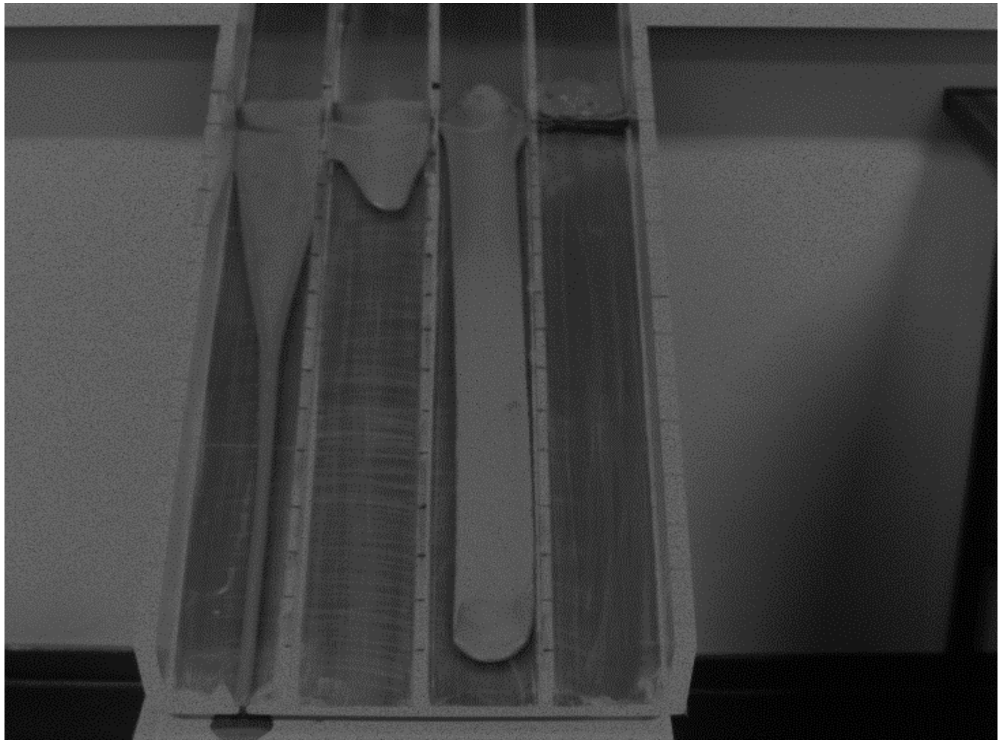


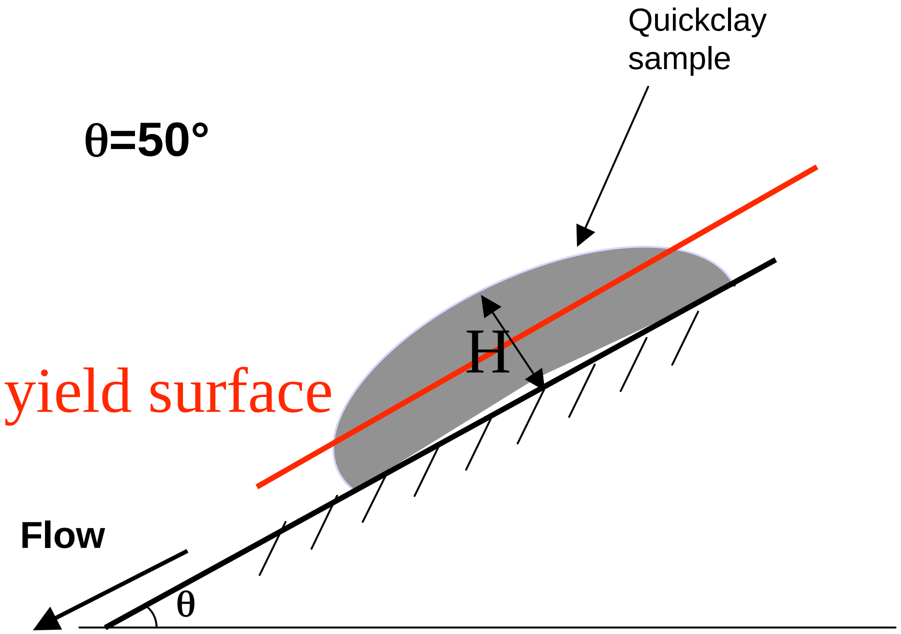
Laboratory landslides



LANDSLIDE EXPERIMENT

Depending on the WATER CONTENT, Quickclay has FOUR !!! different flow regimes:

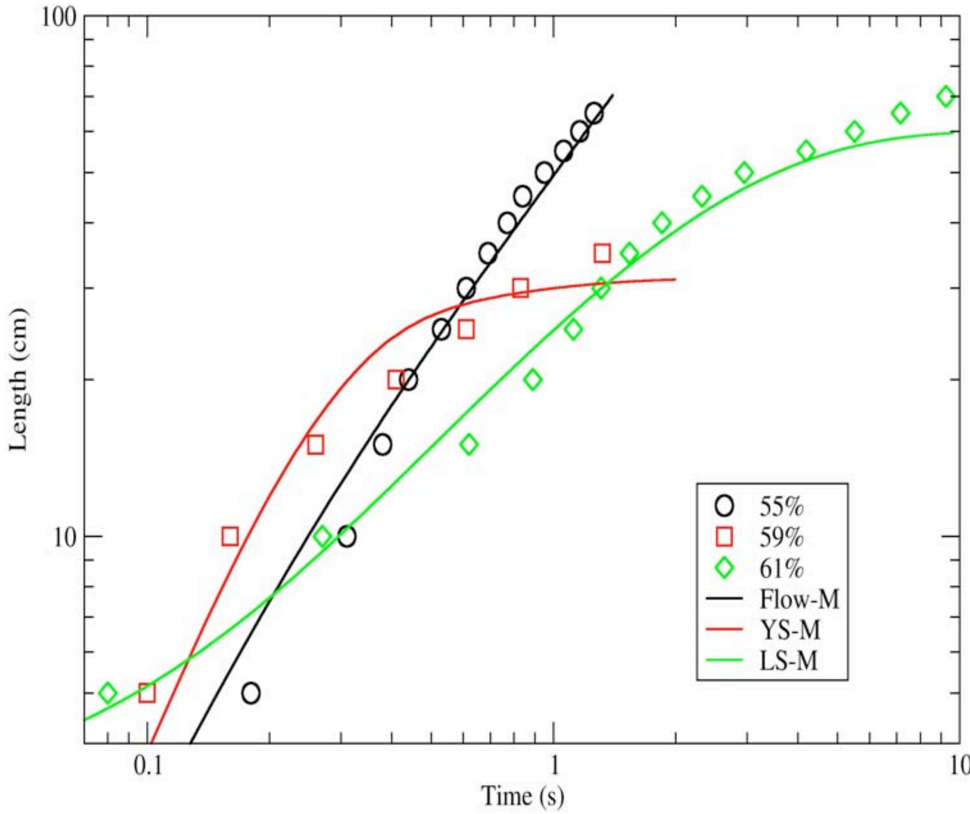


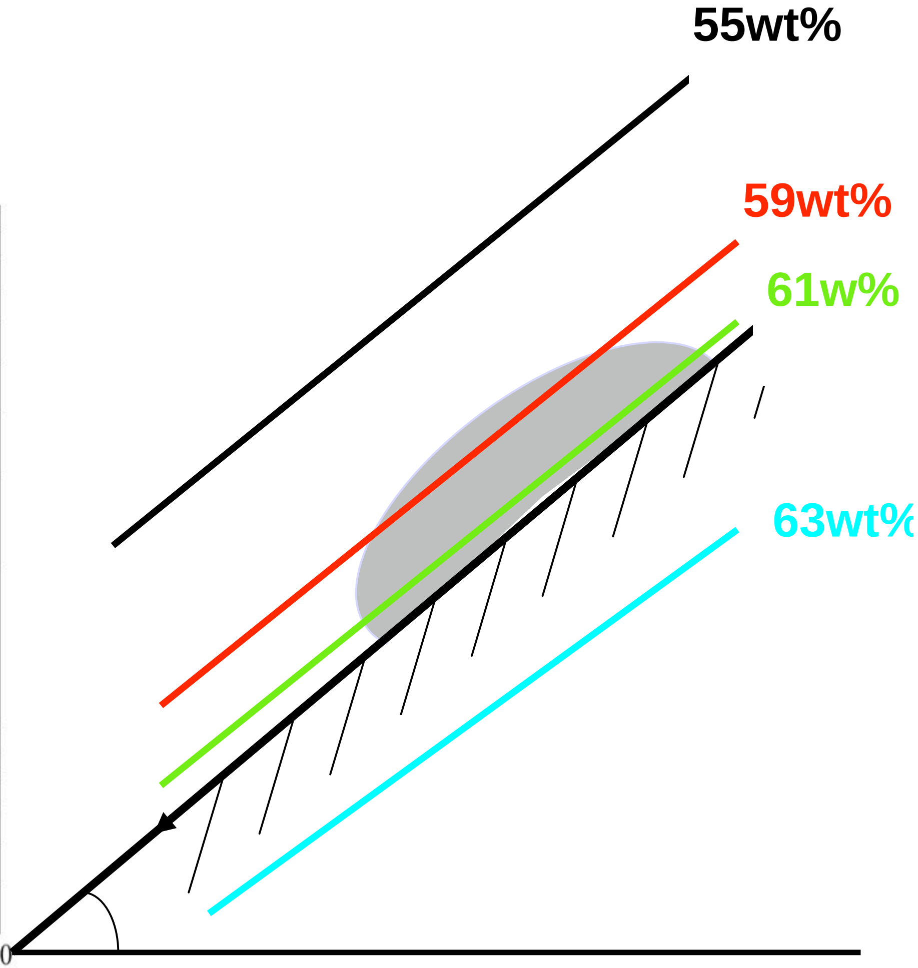


$$\sigma = \rho g (H - y) \sin\theta = \sigma_y$$

Landslide experiment

$$\sigma = \sigma_y + \eta\dot{\gamma}^n$$





CONCLUSION

-Yield stress problem solved to a great extent, leading to new physical phenomena: ‘fluid avalanches…..’
“Geo-rheology” allows for a quantitative insight into geophysical phenomena:
-quicksand: one cannot drown…..
-landslides of clayey soils travel much farther than predicted by models…but now that we understand the rheology, we can do much better.