Lerans microskala

Angela Casarella[1,2], Dorsa Saaedifar[1], **Jelke Dijkstra**[1]

1 Chalmers University of Technology, Gothenburg (Sweden)

2 Imperial College, London

FORMAS

Vetenskapsrådet

Why?



Tuve landslide, 1977

Killing 9; injuring 60; 600 homeless.

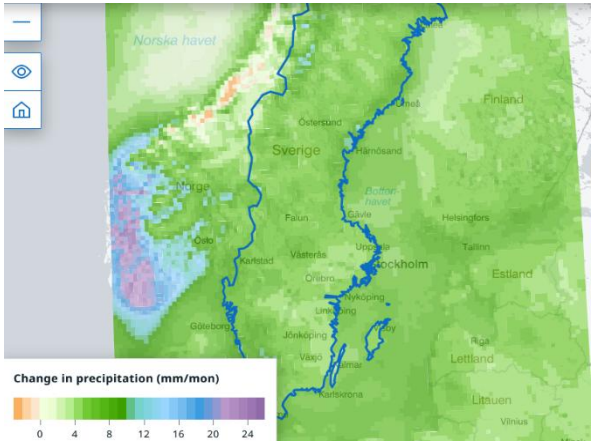
Why?



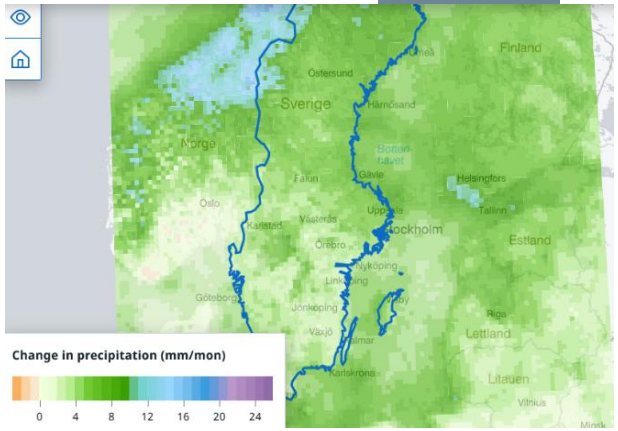
Landslide near Stenungsund, Sweden in 2023

Why?

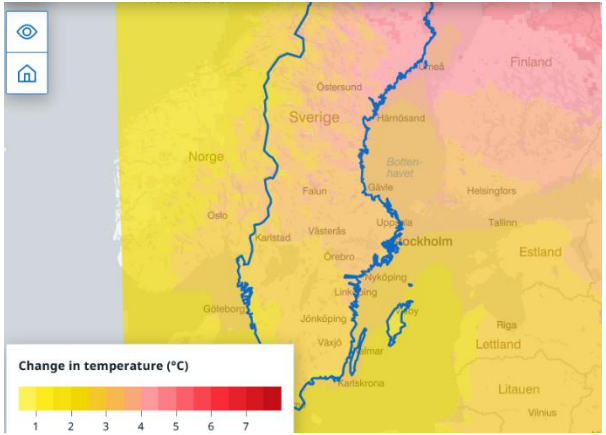
- Environmental loads are changing
- TRV has the ambition to have longer, faster, heavier trains on the same track (maximising capacity)



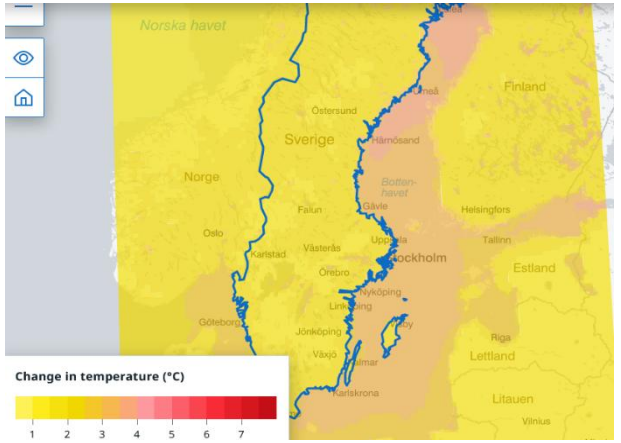
Winter precipitation 2041-2070



Summer precipitation 2041-2070



Winter temperature 2041-2070



Summer temperature 2041-2070

Why?

- Not all quick clay is equal (according to Pusch)
- Are they equally sensitive to changes in environment and/or loads?

Lilla Edet (marine)



Skå-Edeby (brackish)



Pusch (1970)

Why

- Prior theories based on SEM, TEM and MIP are biased by sample preparation techniques that remove the water from the sample

Applied Clay Science 152 (2018) 166–172

Contents lists available at ScienceDirect

Applied Clay Science

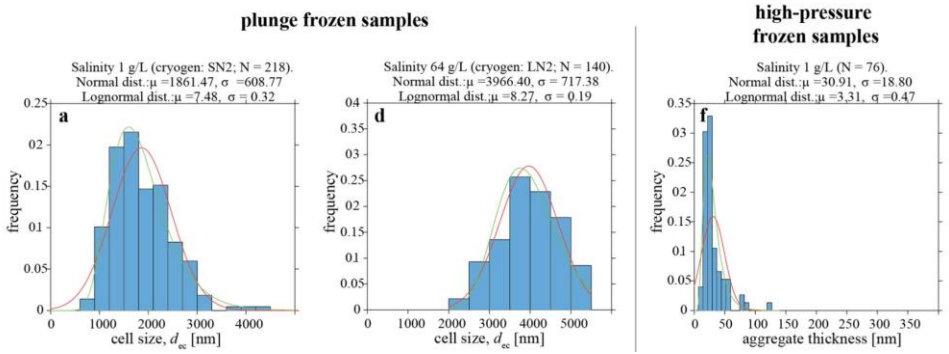
journal homepage: www.elsevier.com/locate/clay

Research paper

Particle arrangements in clay slurries: The case against the honeycomb structure

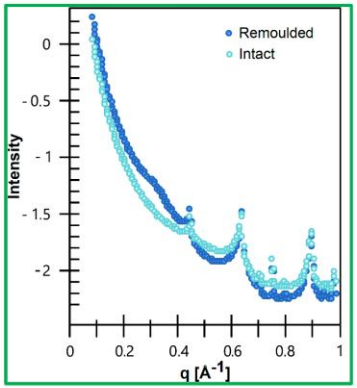
Amer Deirieh[a,*], Irene Y. Chang[b], Michael L. Whittaker[b], Steven Weigand[c], Denis Keane[c], James Rix[c], John T. Germaine[d], Derk Joester[b], Peter B. Flemings[e]

[a] Department of Civil and Environmental Engineering, Tufts University, 200 College Avenue, Medford, MA 02155, USA
[b] Department of Materials Science and Engineering, Northwestern University, 2220 Campus Drive, Evanston, IL 60208, USA
[c] DND-CAT Synchrotron Research Center, Northwestern University, APS/ANL Building 432-A004, 9700 S. Cass Ave., Argonne, IL 60439, USA
[d] Department of Civil and Environmental Engineering, Tufts University, 200 College Avenue, Medford, MA 02155, USA
[e] Jackson School of Geosciences, The University of Texas at Austin, Office JGB 5.318, 2305 Speedway Stop C1160, Austin, TX 78712-1692, USA

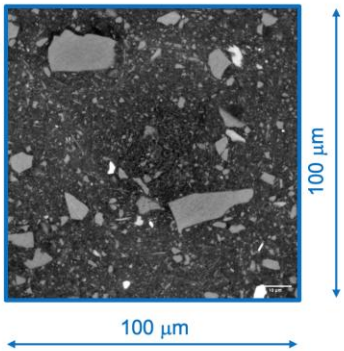


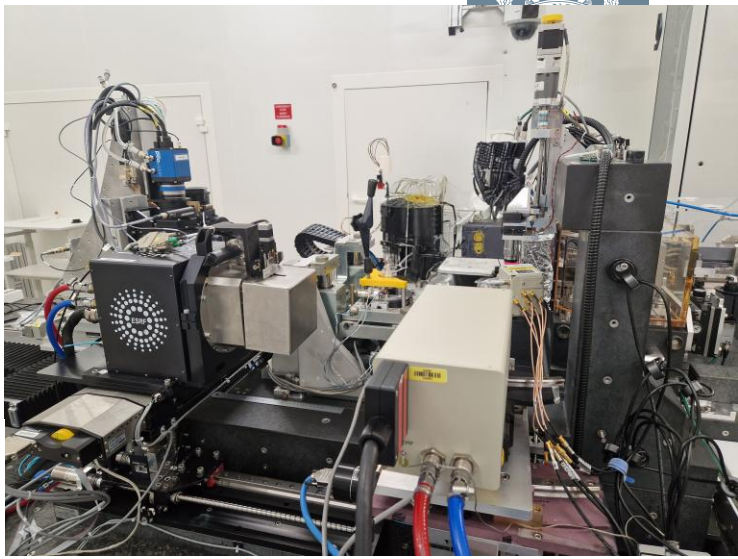
Why?

- New methods enable to study samples in their undisturbed wet state









MAX IV

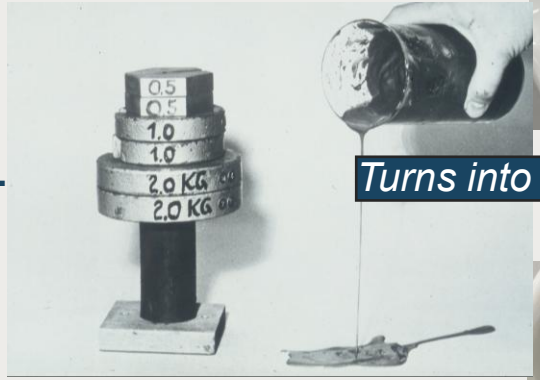
ESRF
The European Synchrotron

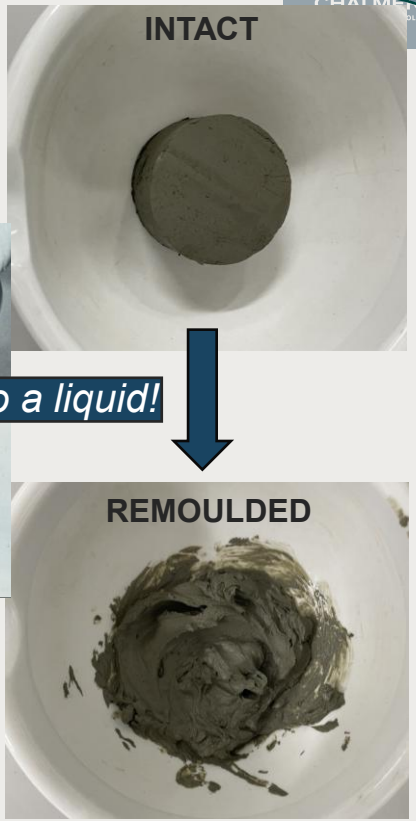
What is quick clay?

- **META-STABLE CLAY:** irreversible transition **from solid to liquid** under a hydro-mechanical disturbance

- Natural **water content higher than LL**

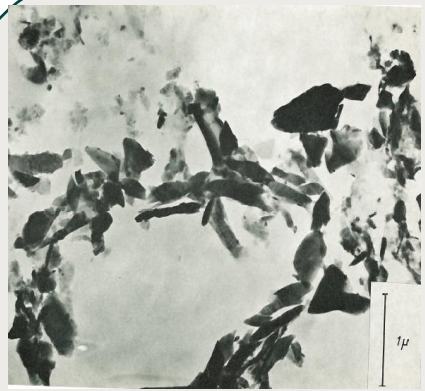
- Located in previously **glaciated areas** such as Canada, Alaska, Scandinavia, and northern Russia



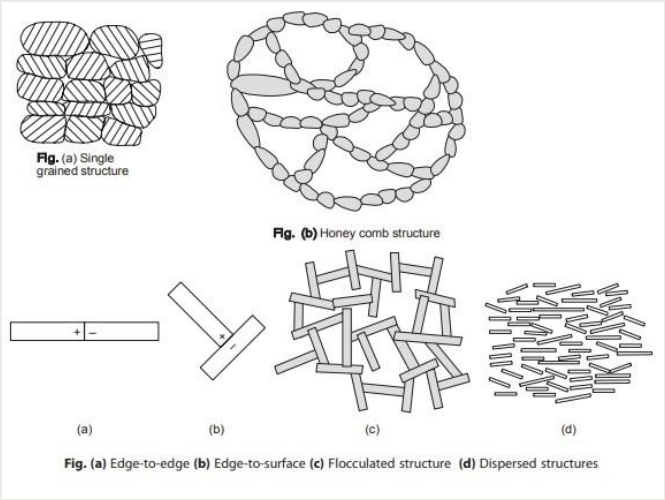


Factors of importance (from lit. rev.)

- Salinity
- Mineralogical composition
- Particle size and fabric
- Organic content



Pusch (1966)



According to Mitchell & Huston (1969), the cause of high sensitivity in clays is the collapse of fabric which occurs upon remoulding

But also microstructure strongly affected by rock flour and silt

Research question:

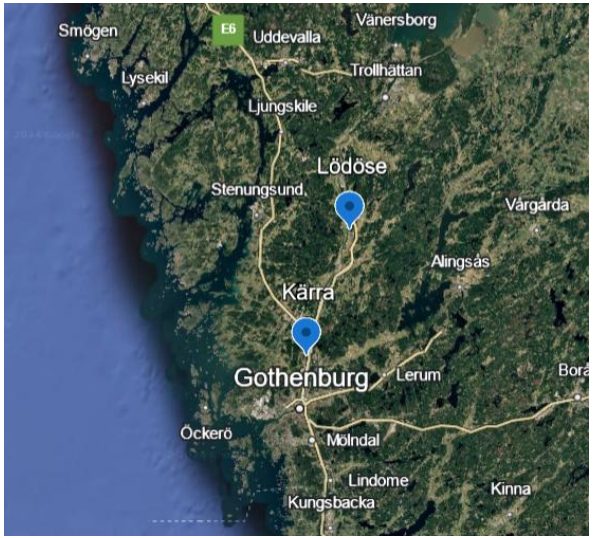
Why quick clay is quick?

Research approach to investigate microstructure:

Comparing the microstructure of different types of sensitive clays in their undisturbed state

Sample details

- Kärra
  - West bank of Göta river
  - Depth: 7 m
  - Sensitivity (S_t): 20
- Lödöse:
  - 35 km from Kärra site
  - East bank of Göta river
  - Depth: 5.5 m
  - Sensitivity (S_t): > 50



Bulk XRD

Mineral	Kärra clay	Lödöse clay
SILICATES		
Quartz	20.0	23.7
K-feldspar	8.4	14.8
Plagioclase	10.4	23.6
Amphibole	1.6	3.3
Chlorite	4.5	5.1
Kaolinite	8.1	2.3
Dioctahedral 2:1 layer silicates	31.6	17.5
Trioctahedral 2:1 layer silicates (fine-grained biotite or phlogopite)	2.0	7.0
CARBONATES		
Calcite	8.6	1.4
Aragonite	0.1	0.2
Dolomite/Ankerite	2.4	0.8
Siderite	1.3	
SULFIDES		
Pyrite	0.6	0.2
OXIDES/HYDROXIDES		
Rutile	0.3	0.3

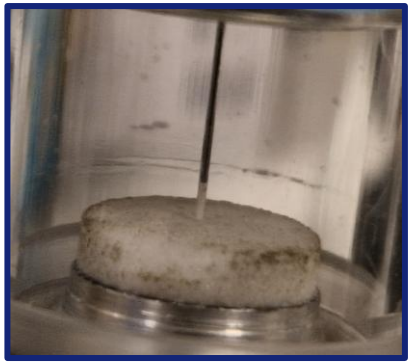
Composition of pore water

Sample	w (%)	Na concentration (M)	K concentration (M)	Mg concentration (M)	Ca concentration (M)	Total concentration (M)
Kärra	80	0.1875	0.0133	0.0068	0.0060	0.2136
Lödöse	75	0.0014	0.0024	0.0016	0.0089	0.0143

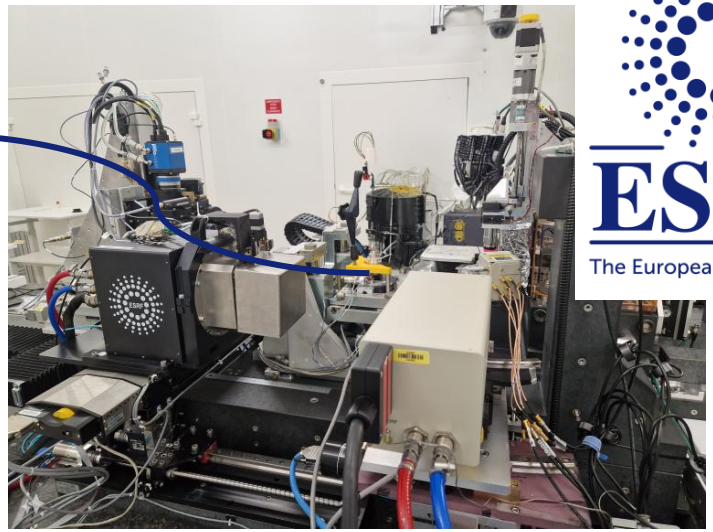
X-ray phase contrast nano-holotomography

ID16b at ESRF

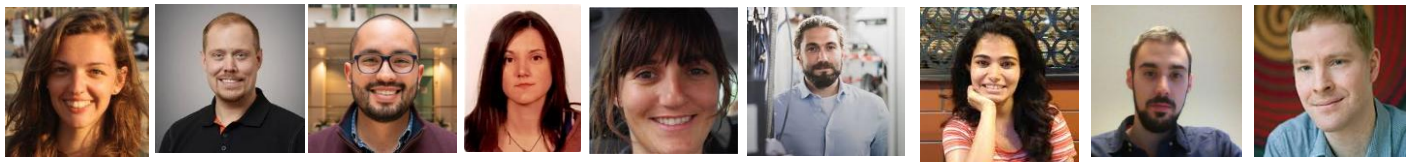
Zoom on sample



300 µm diameter
capillary tube



ESRF
The European Synchrotron



Results

Nano-holotomography

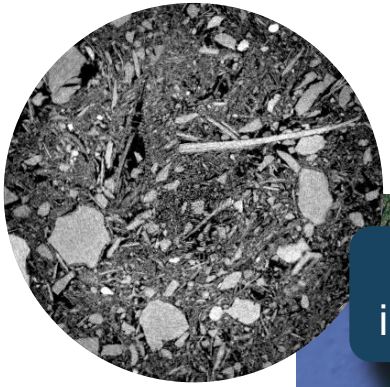


Kärra Clay
Intact sample cored from 5 m depth
Pixel size: 50 nm
Horizontal cross-section 128µm diameter
Phase contrast - 4 distances
Beam energy: 29.6 keV
Projections: 2160 per scan
Exposure: 15 ms
Field of view: 128×108×108 µm³
Total scan time: 20 minutes

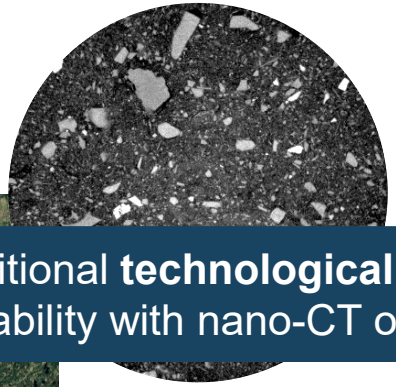
Results

Nano-holotomography

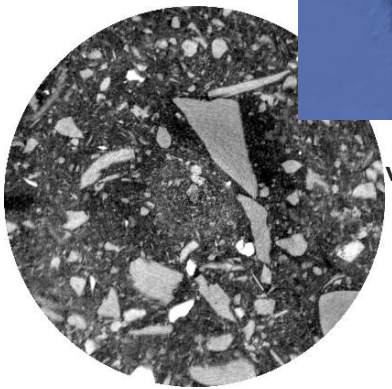
Kärra - intact



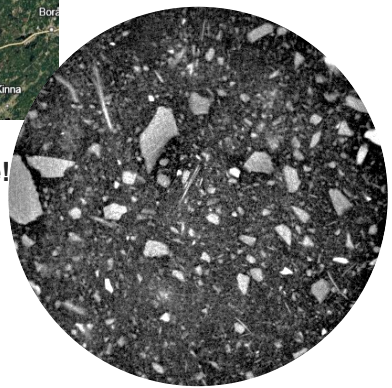
Lödöse - intact



Kärra - remouldded



Lödöse - remouldded





35 km can make a very big difference!

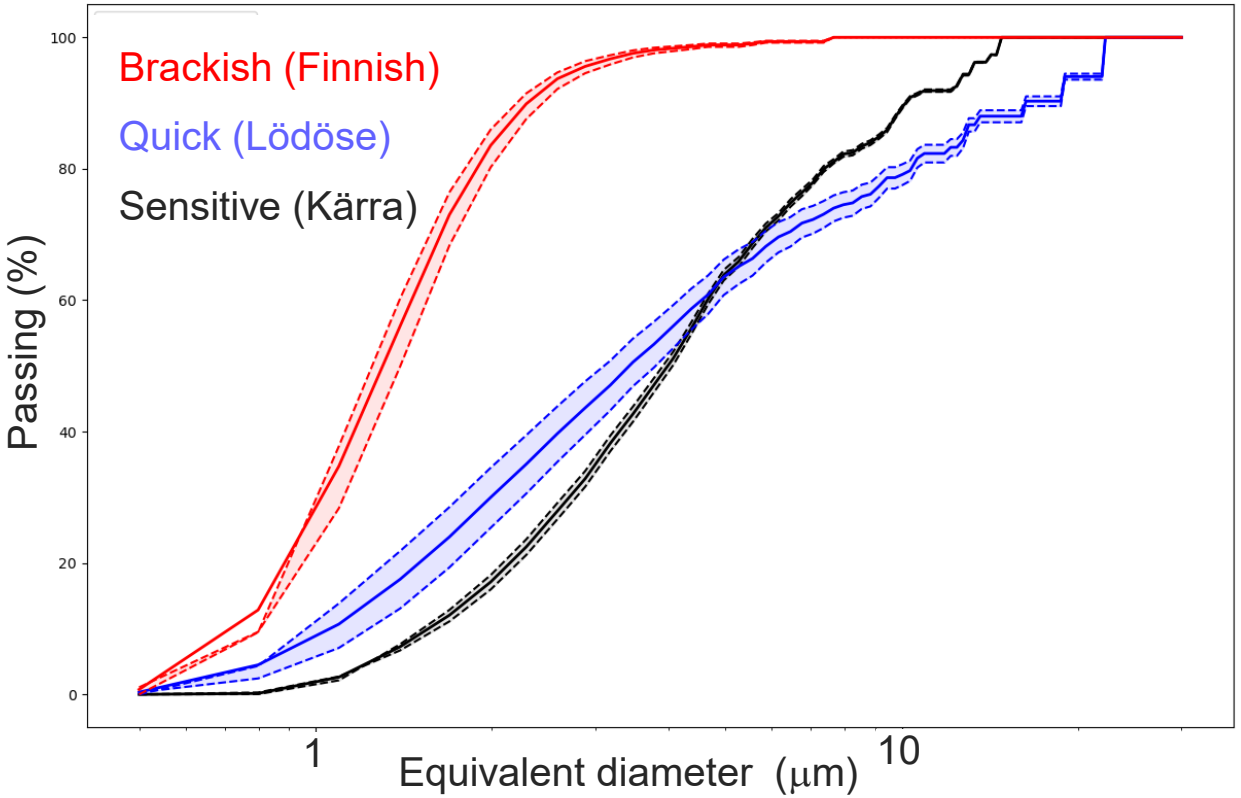
Additional **technological difficulties** in sample stability with nano-CT of remoulded samples

Nano-CT is not sufficient to capture the phenomena (for now!)

- …re individual …t be distinguished
- Non-homogeneous particle size and shape of the coarser fraction
- Difficulties in quantifying the micro-porosity, even worse when remoulded

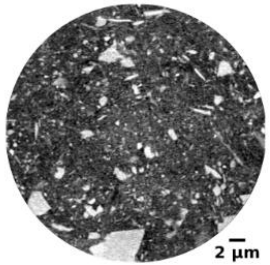
Results

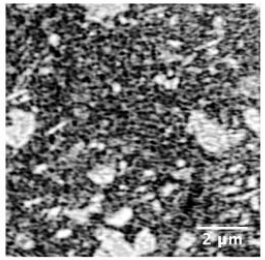
PSD from image data for particles > 0.5 μm



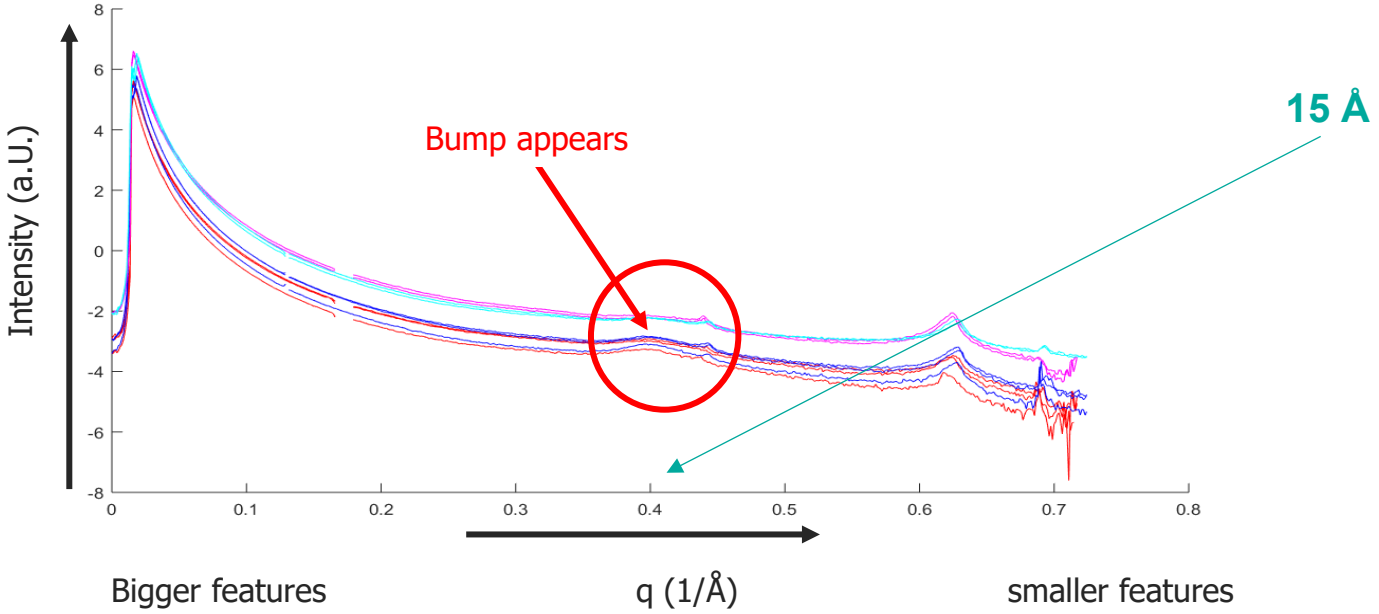
Results
WAXS

Preliminary wide angle x-ray scattering results on intact *vs.* remoulded Utby clay





Birmpilis *et al.*, (2022)



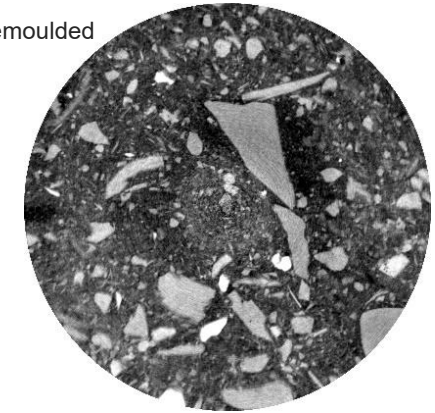
Results

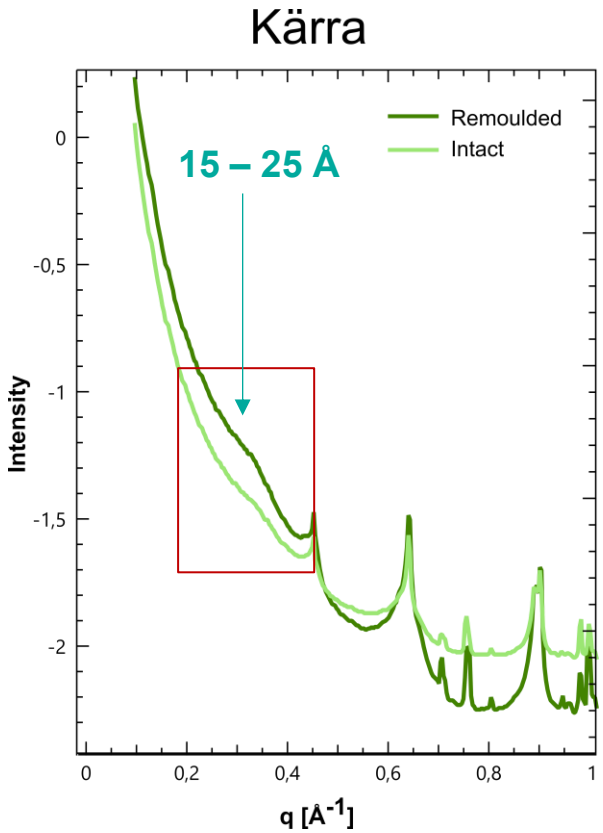
WAXS

Kärra - intact



Kärra - remoulded

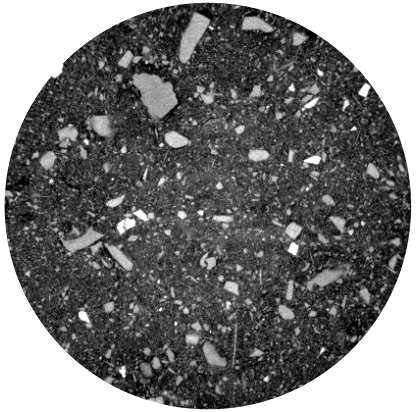




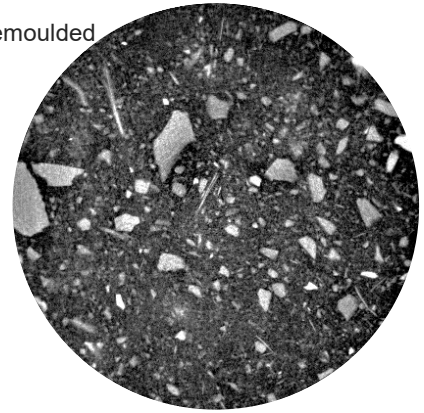
Results

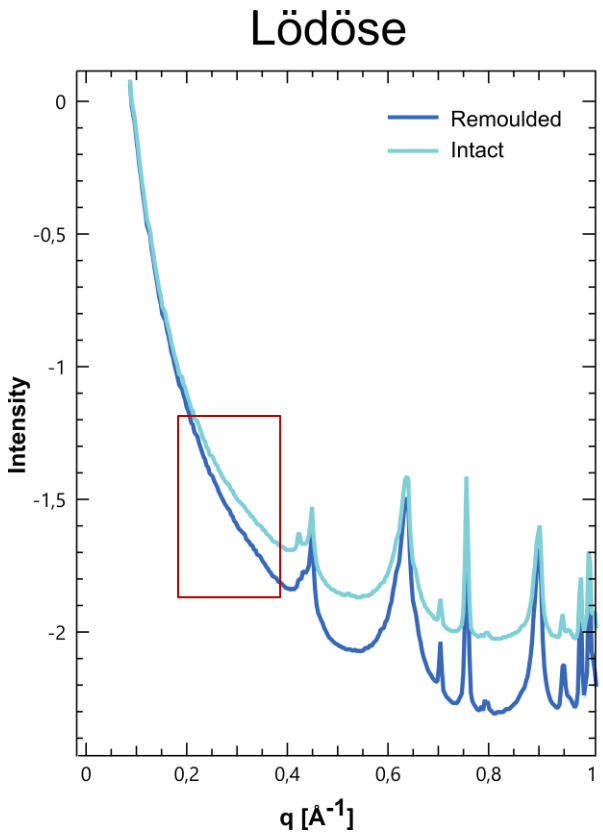
WAXS

Lödöse - intact



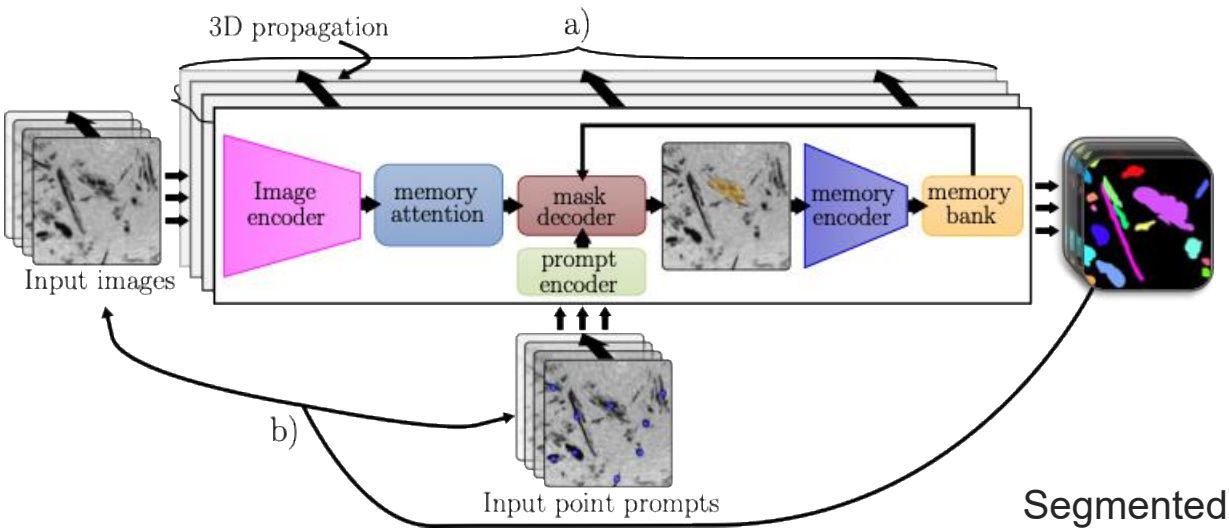
Lödöse - remoulded

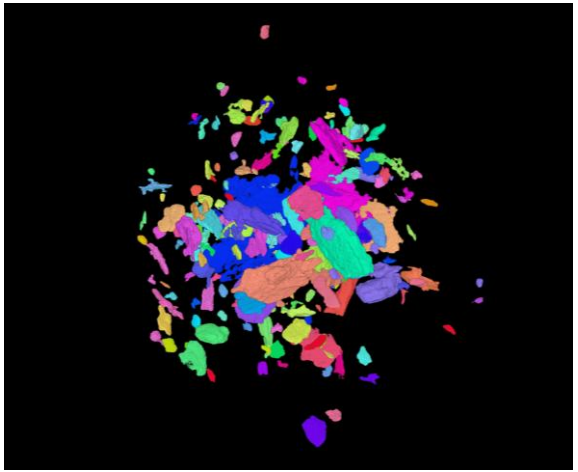




Outlook
Advanced image analysis

- Master thesis Theo Örtendahl (now PhD student)

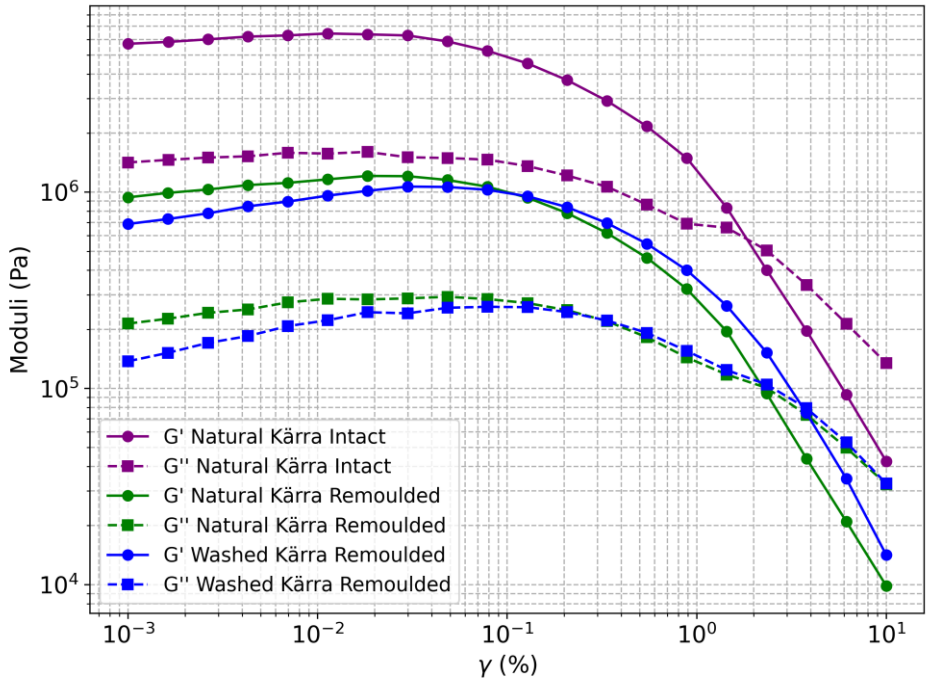


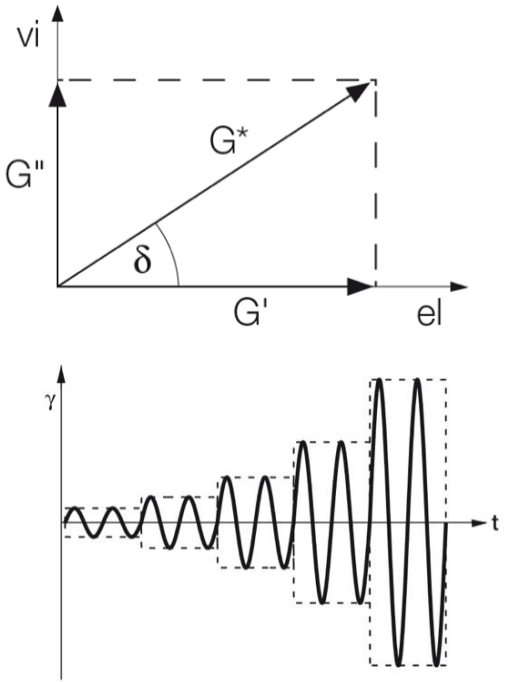


Segmented kaolinite particles in suspension

Outlook
Rheological response

- Internship Eline Martin (École Nationale des Ponts et Chaussées)





Conclusion

- Non-destructive x-ray techniques enable the investigation of clay at micro- and nano- scale in its natural undisturbed state (SATURATED)
- Although X-ray phase-contrast nano-holotomography enables the submicron spatial resolution for catching silt, rock flour and large clay particles, it does not (yet!) allow for resolving fabric of the illite-rich clay matrix → we need to go one scale down (subnanometre)
- Even though Kärra and Lödöse are only 35 km apart, the clays are very different at MACRO, MICRO and NANO scale

So what?

- We are more aware of the unkowns
- Susceptibility for environmental change is real
- We cannot just study one type of sensitive clay
- Fundamental research matters (but is hard work)

So what?

- We are more aware of the unkowns
- Susceptibility for environmental change is real
- We cannot just study one type of sensitive clay
- Fundamental research matters (but is hard work)



As we know, there are **known knowns**; there are things we know we know. We also know there are **known unknowns**; that is to say we know there are some things we do not know. But there are also **unknown unknowns** – the ones we don't know we don't know.