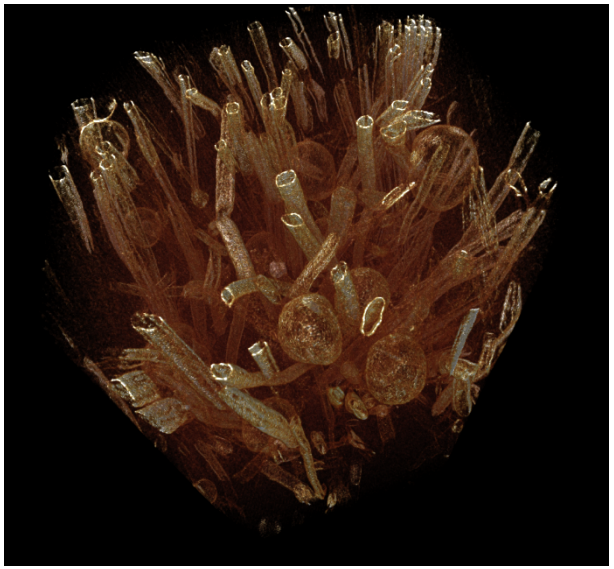
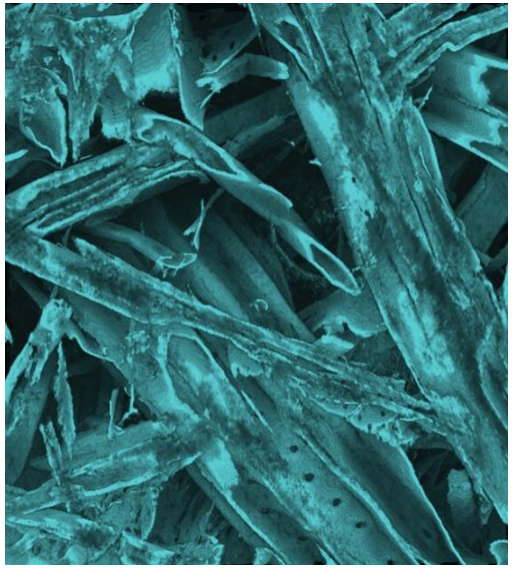
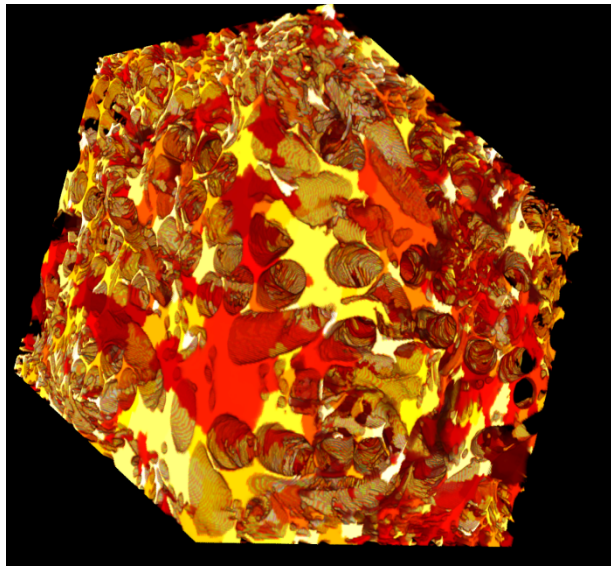
Application of X-ray Tomography in BELBaR WP2

Markku Kataja, Jarno Alaraudanjoki,
Tero Harjupatana

University of Jyväskylä







University of Jyväskylä

- founded in 1934
- one of the largest universities in Finland
- total income 171 million euro
- 7 faculties
- about15,000 students
- staff about 2,600

1934 2009
UNIVERSITY OF JYVÄSKYLÄ

Core Fields in Research and Education

Natural sciences and mathematics

Human-centered sciences

Sport and health sciences

Teacher education

1934 2009
UNIVERSITY OF JYVÄSKYLÄ

Department of Physics (JYFL)

GENERAL

- Faculty and staff : 185 (2010)
- Including non-academic and non-permanent personnel
- Undergraduate students: 550.
- Postgraduate students: 80 .
- Annual intake of physics majors c. 100
- Annual budget c. 14.8 M€ (2010)

RESEARCH

- Main areas: nuclear physics, material physics and high energy physics
- Nuclear physics: Academy of Finland Centre of excellence in 2006 ->
- Accelerator Laboratory: Large Scale Facility of the Training and Mobility of Researchers.
- **Applied physics:** accelerator based applications, nanoelectronics, industrial physics, flow in porous media, multiphase flows, materials science.

Soft condensed matter and industrial physics

Porous materials (transport phenomena, material structure)

-**X-ray micro/nanotomography:** 3D structure of materials even in nm scale.

-Experiments: porosity, diffusivity, permeability

-Numerical simulations of transport properties

Elasticity and fracture of disordered (fibrous) materials

-Ab initio numerical simulations

-Modelling

Multiphase flows

-Ab initio numerical simulations

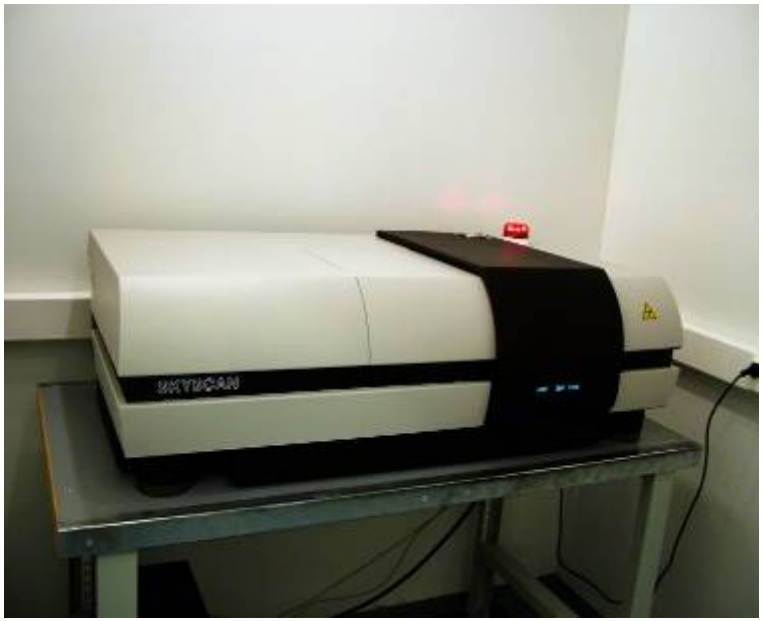
-Experiments: optical tomography, optical boundary layer, ultrasound, droplet absorption, superhydrofobic phenomena

X-ray µCT (Micro X-ray Computed Tomography)

ESRF/(ID19)

- Large scale facility based on synchrotron x-ray radiation
- Grenoble, France
- Many beamlines
- Homogeneous and coherent x-ray beam of high intensity

Table-top scanner



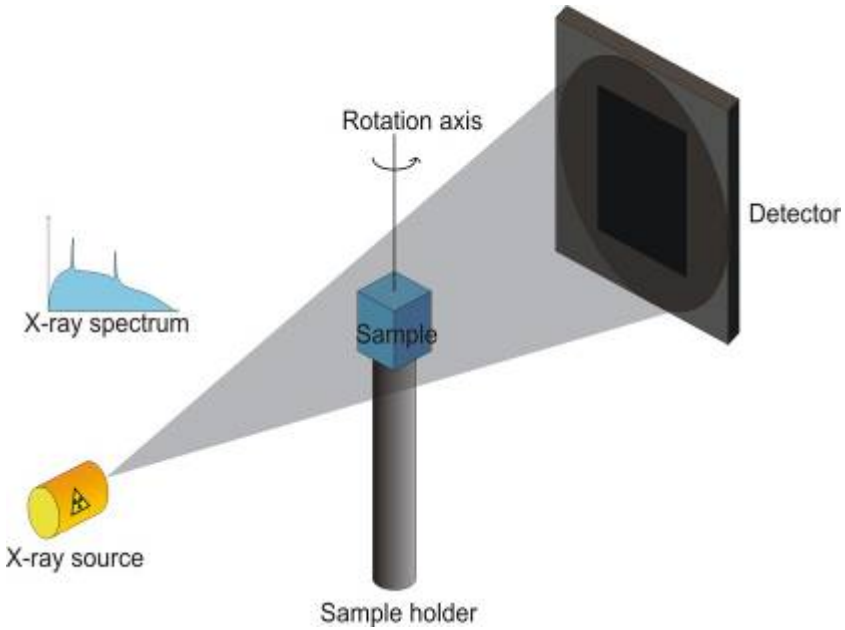
- Skyscan 1172
- Table-top sized (240 kg)
- Continuous incoherent x-ray beam
- Acquired 5/2005

NewX-ray Micro/Nano Tomography Facility:

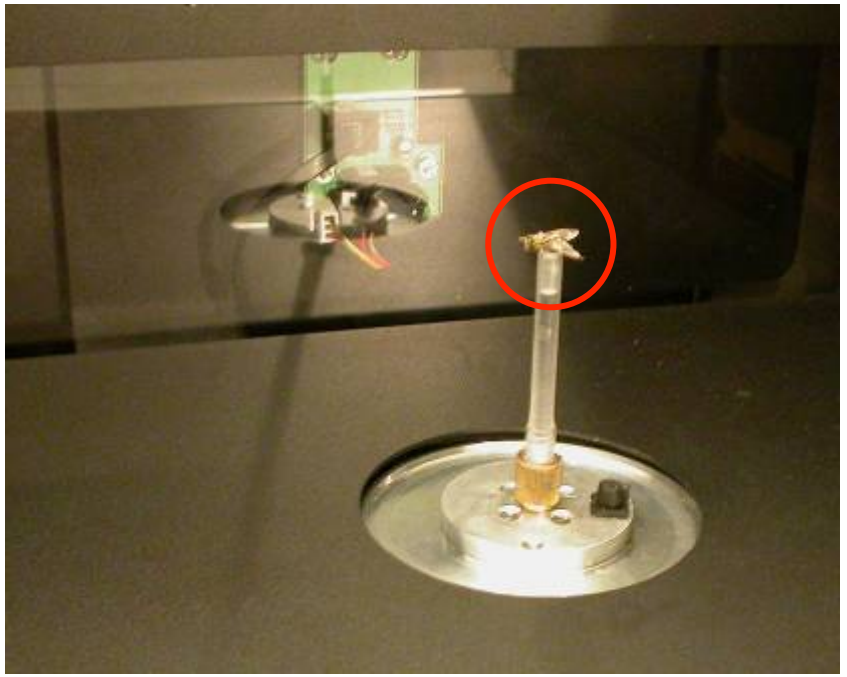
- Multi-Length Scale facility (Xradia)
- Installed June 2009
- Resolution range from 30 µm down to 50 nm
  (Field of view from 40 mm to 15 µm)

Working principle.

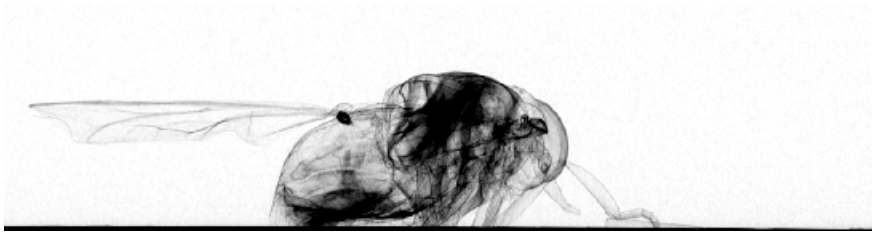
Scanning the sample: ~1000 x-ray images taken from different directions



A sample attached in a sample holder (Horse fly!),
Device: SkyScan 1172



~1000 2D x-ray images:



Computer reconstruction

Layered images*)

*) Tomos (Greek)
~ 'slice', 'layer'.

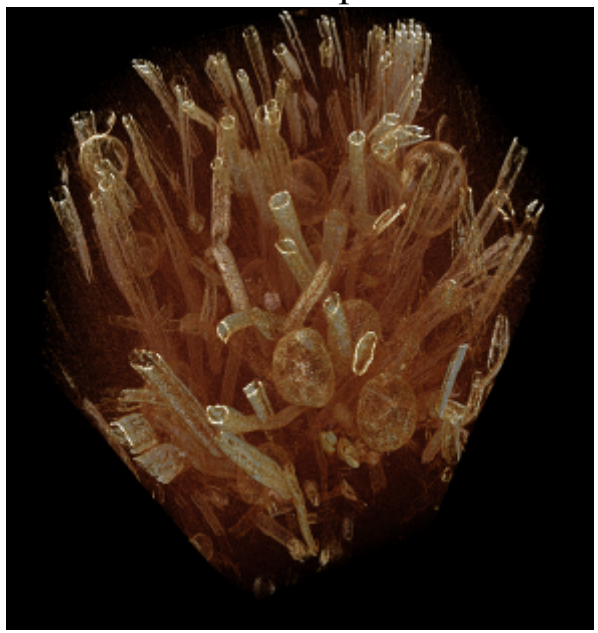
Tomography
~sliced images

-Rendered image.

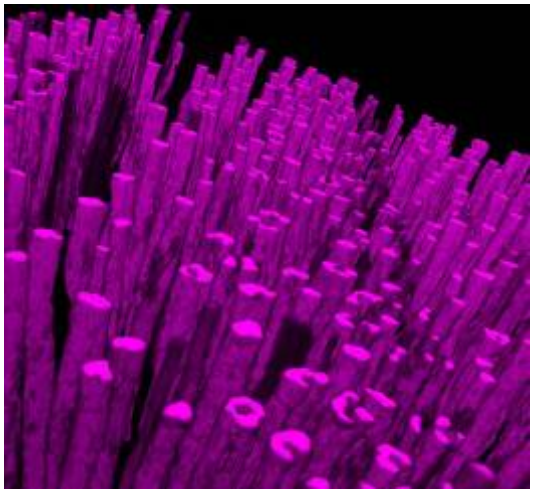
-The actual 3D structure in digital numerical form ➡ Analysis!

Tomographic image gallery

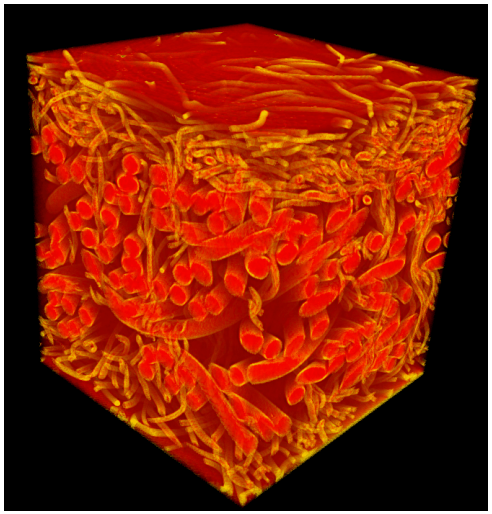
Wood fibres in composite material



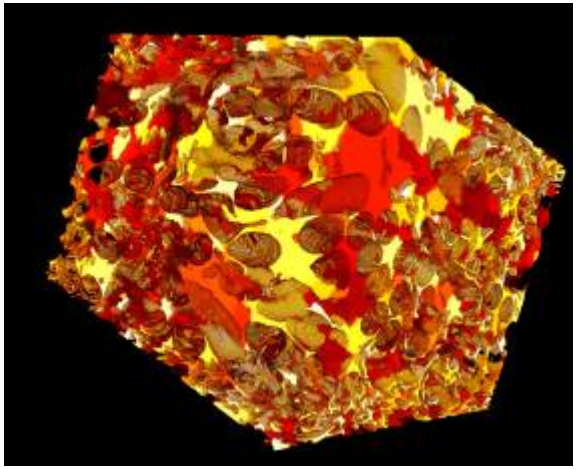
Vessels in wood



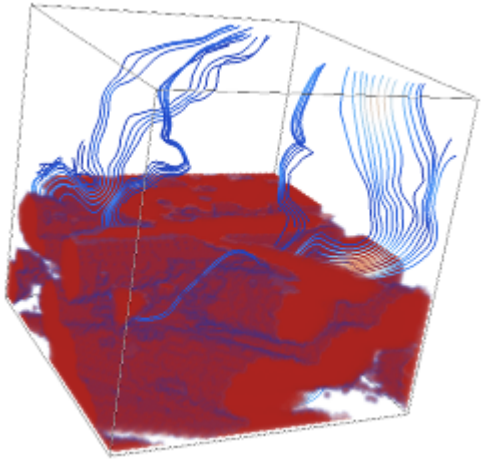
Deformation of felt under compression



Pore space of felt segmented into individual pores

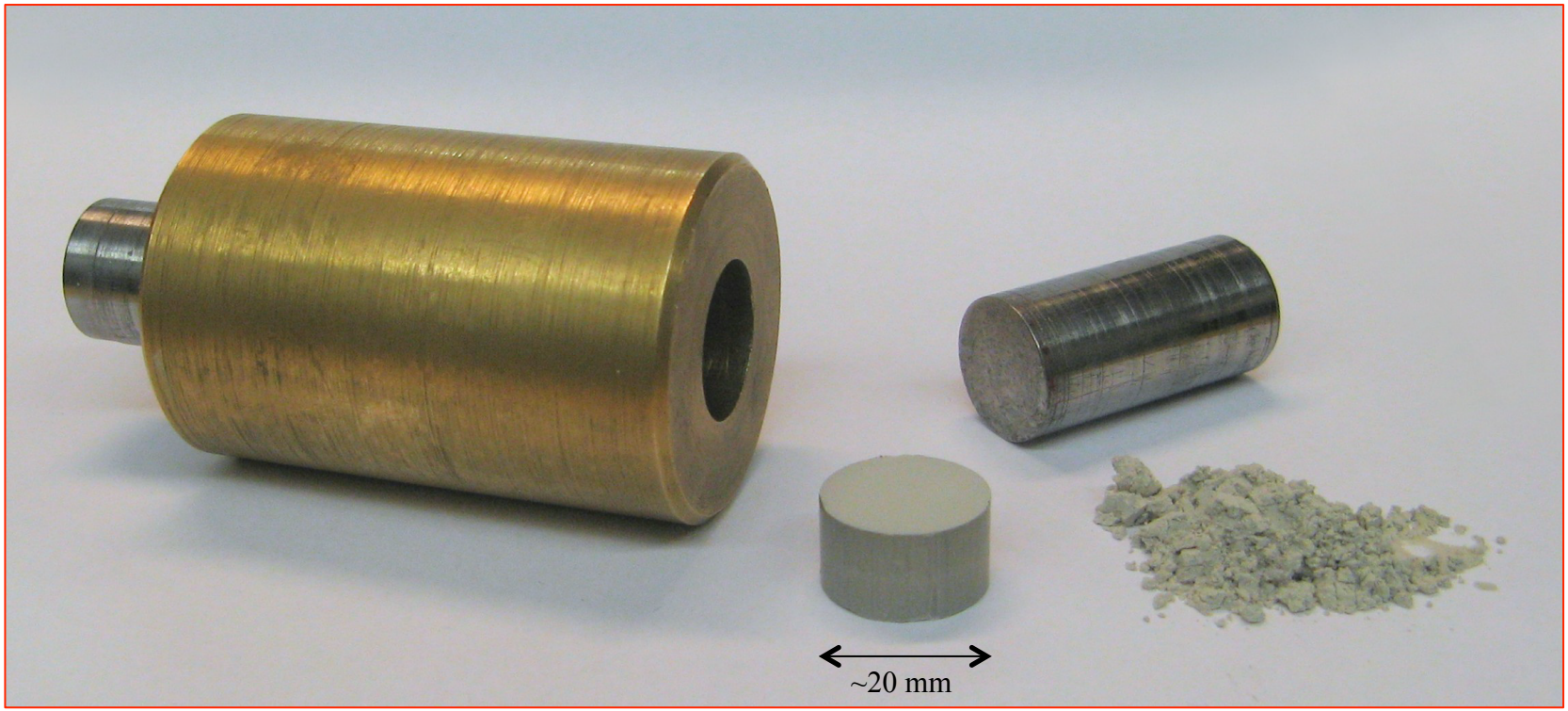


Computed flow lines of fluid through a felt

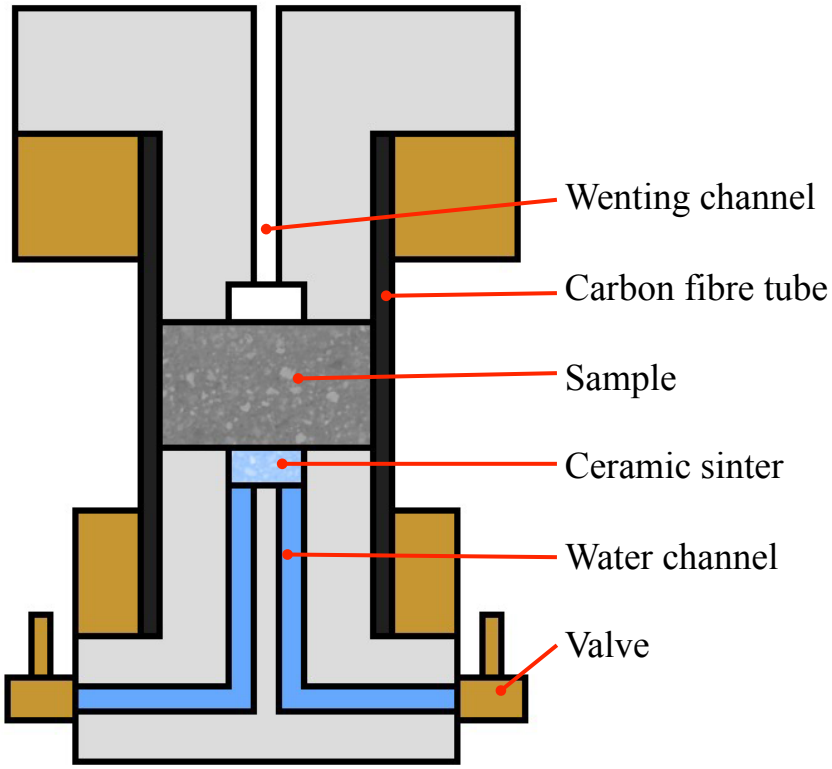


Application in bentonite 1: Wetting in constant volume

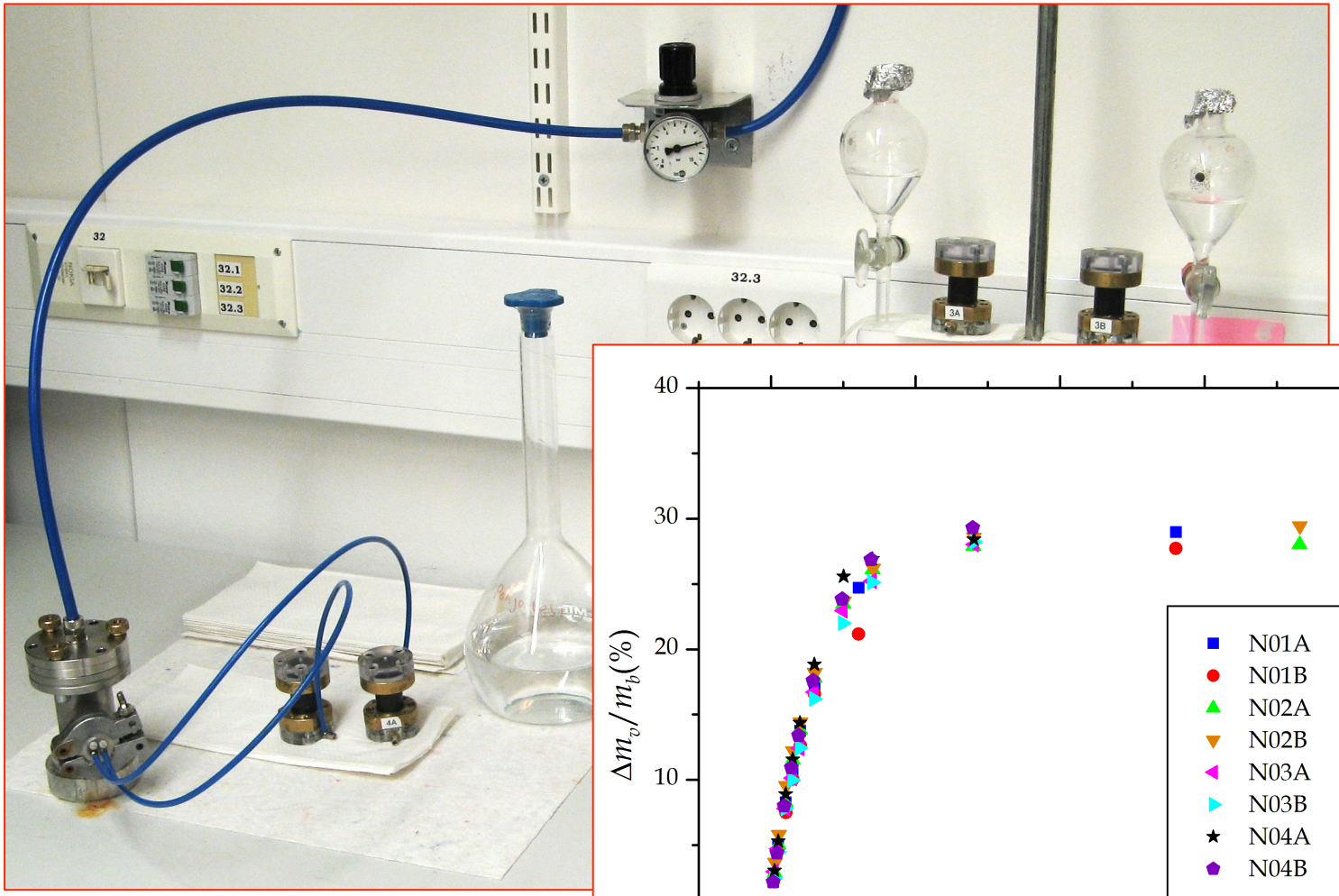
- Simultaneous measurement of water transport and deformation of bentonite in 3D using X-ray tomography.
- Sample material: Compacted purified bentonite
  95% montmorillonite, 5% quarz
  + added tracer particles (hollow glass spheres)



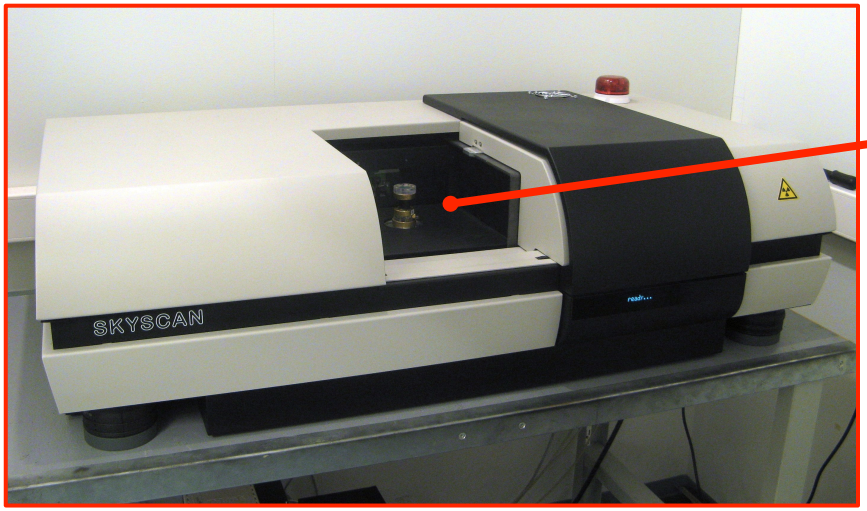
Sample holder for wetting and x-ray imaging

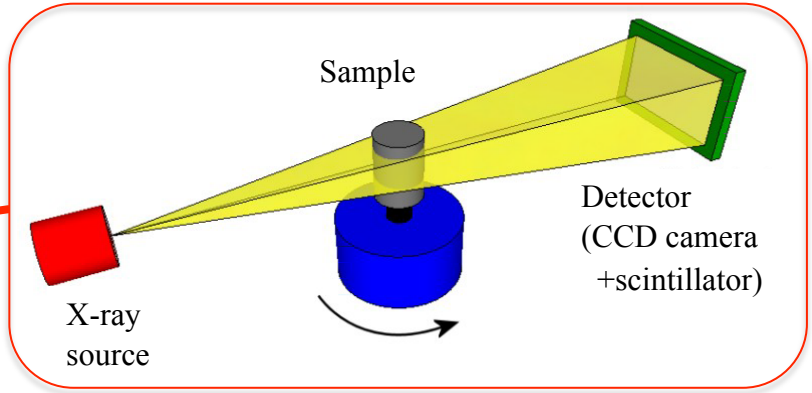


Wetting arrangement.



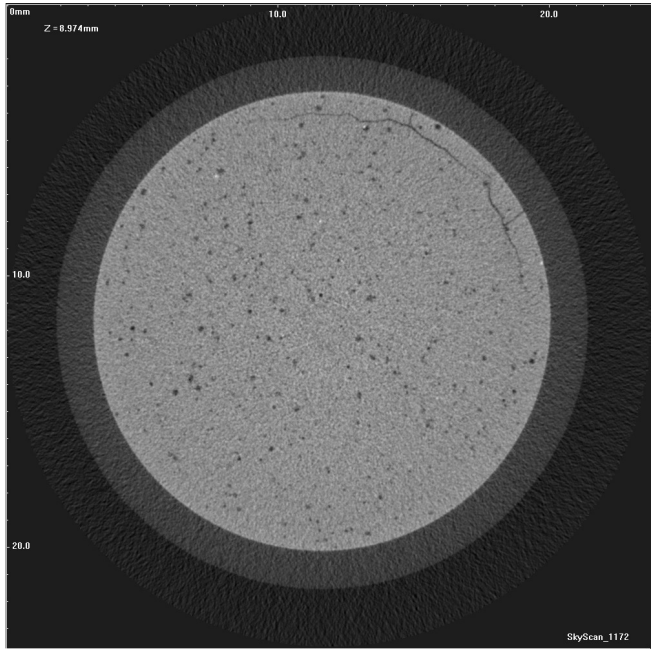
X-ray tomography



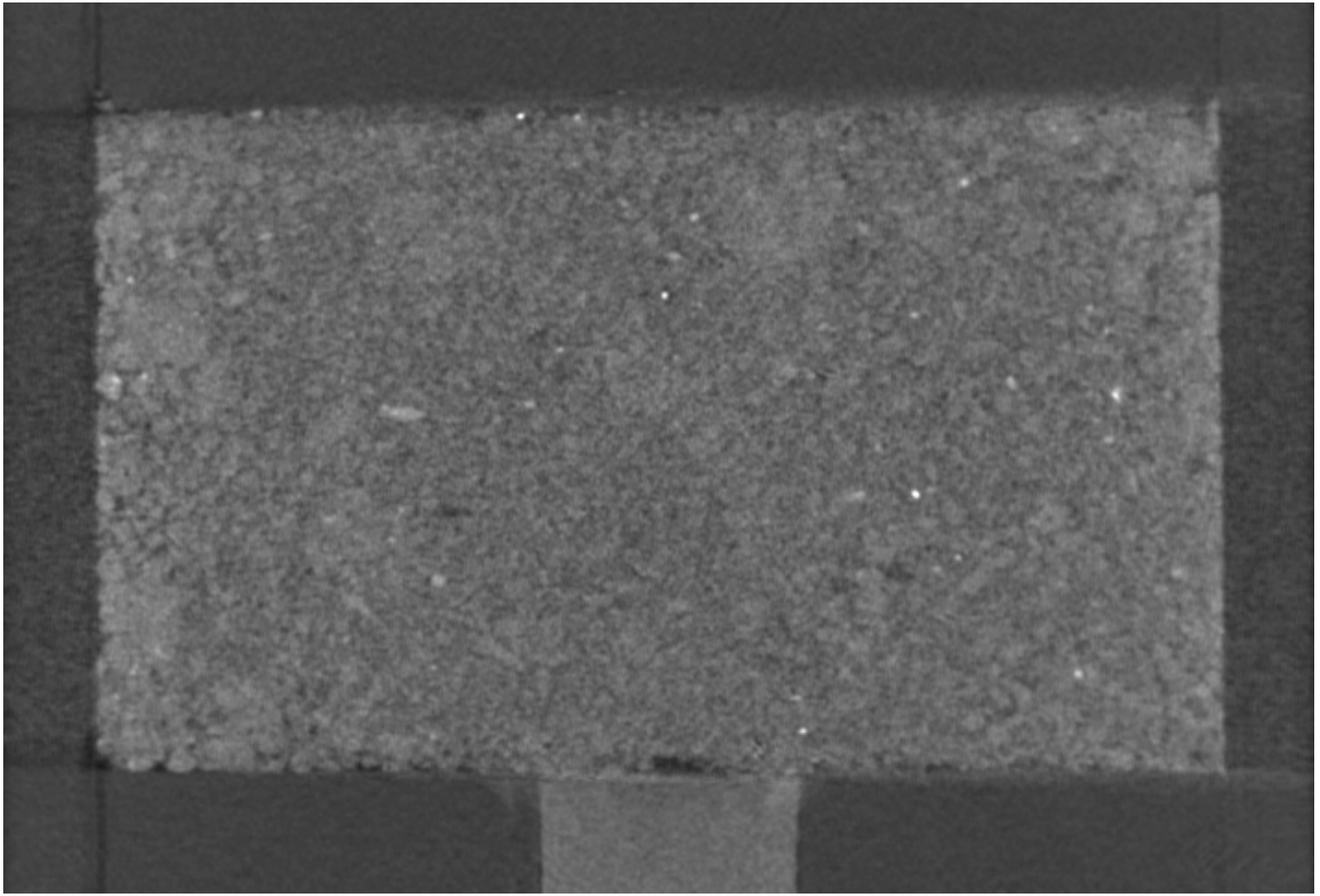


- Table-top scanner (SkyScan 1172)
- Resolution 40 µm - 1 µm
- Sample size 50 mm - 2 mm

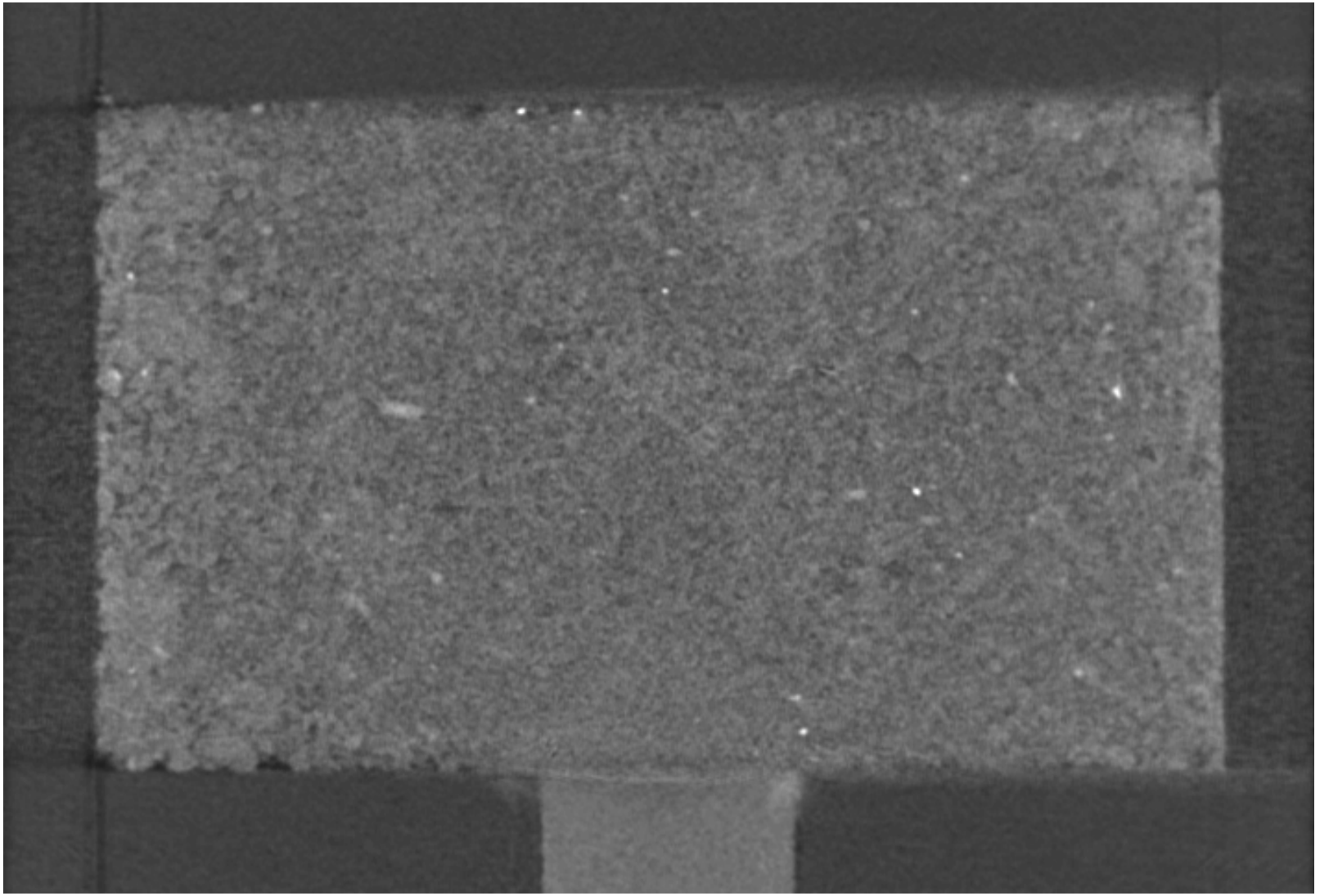
Single horizontal layer of purified bentonite sample



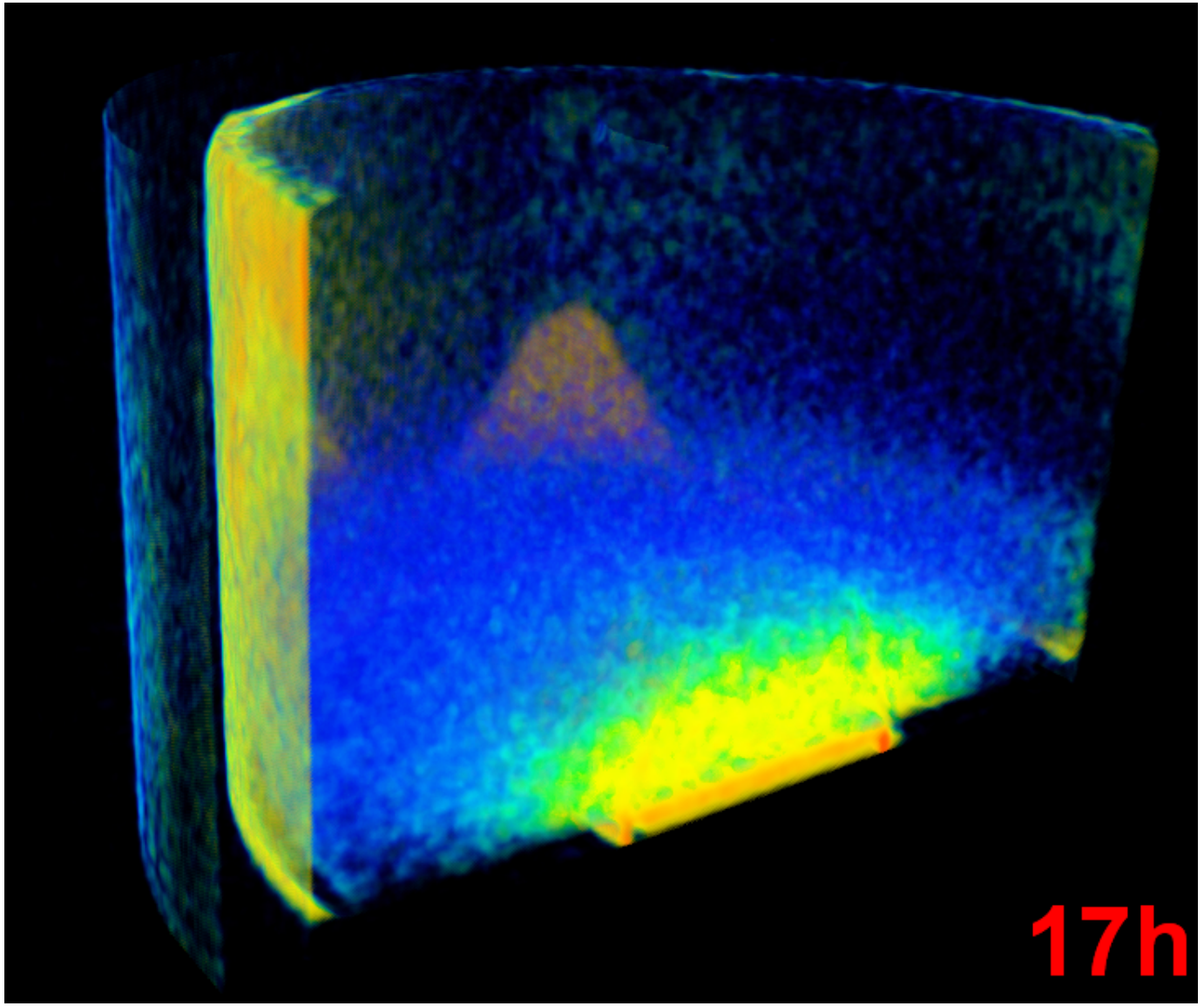
T=0; Dry compressed sample



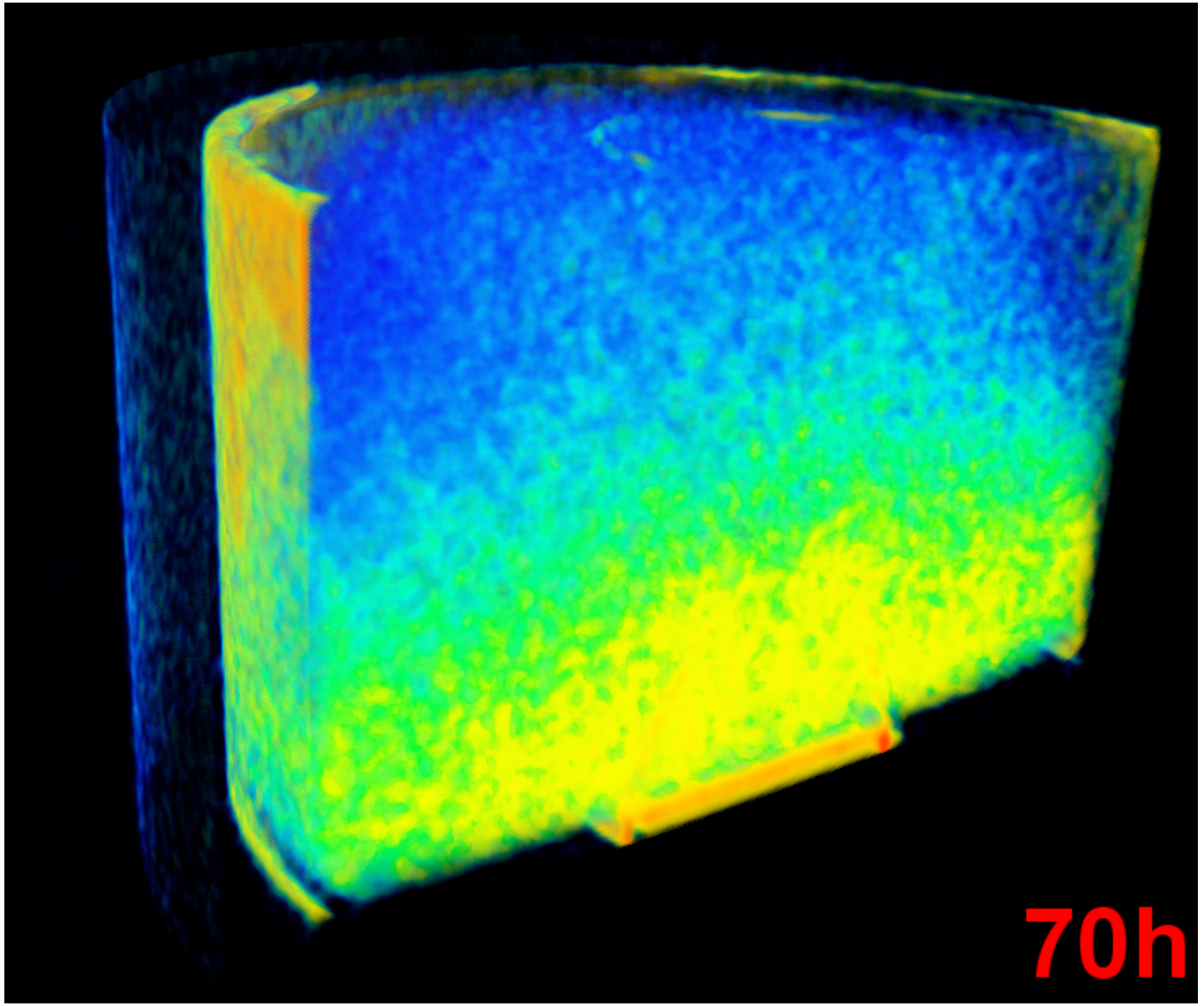
T=1 day; Moisture content 3%



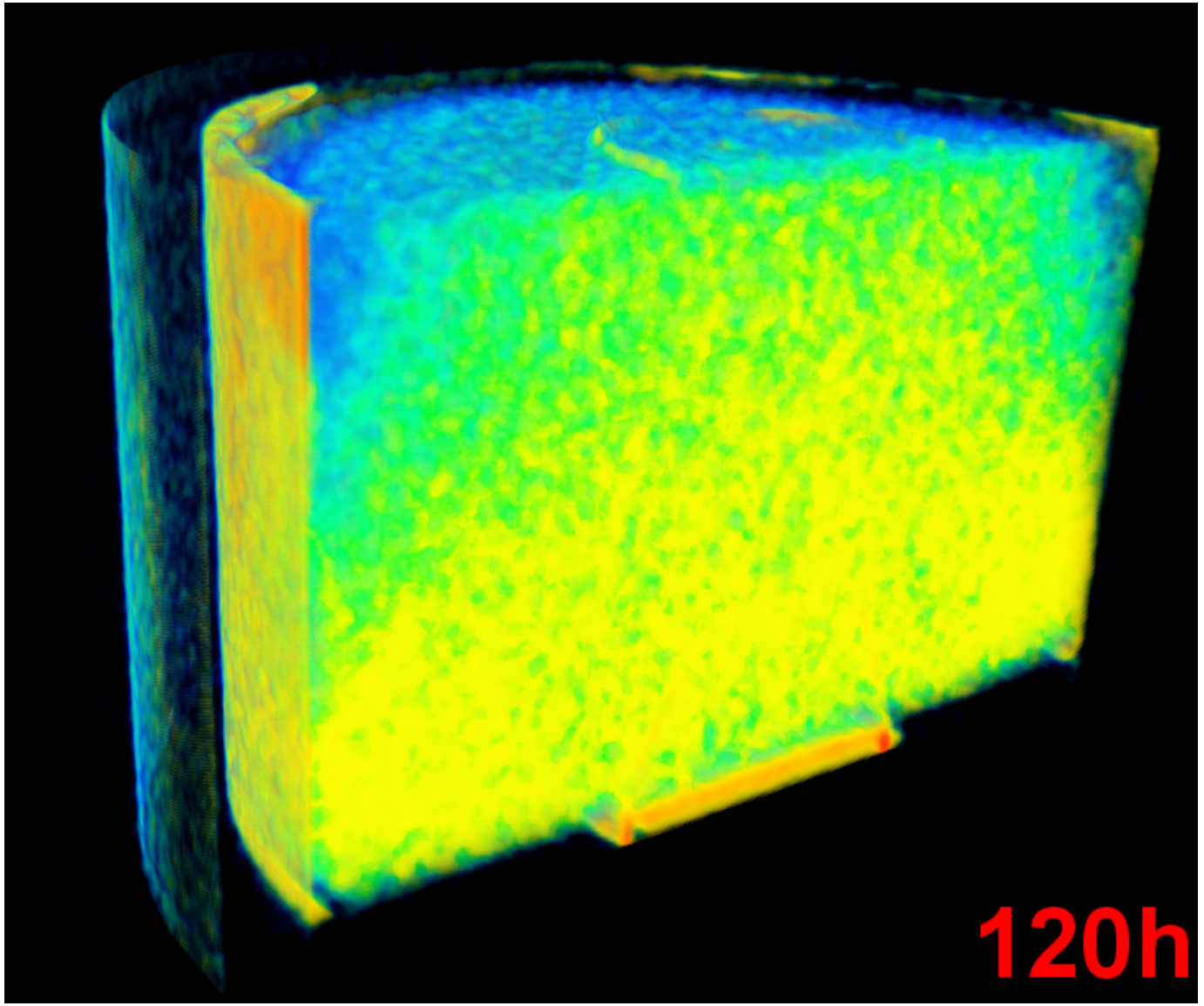
Wetting process.



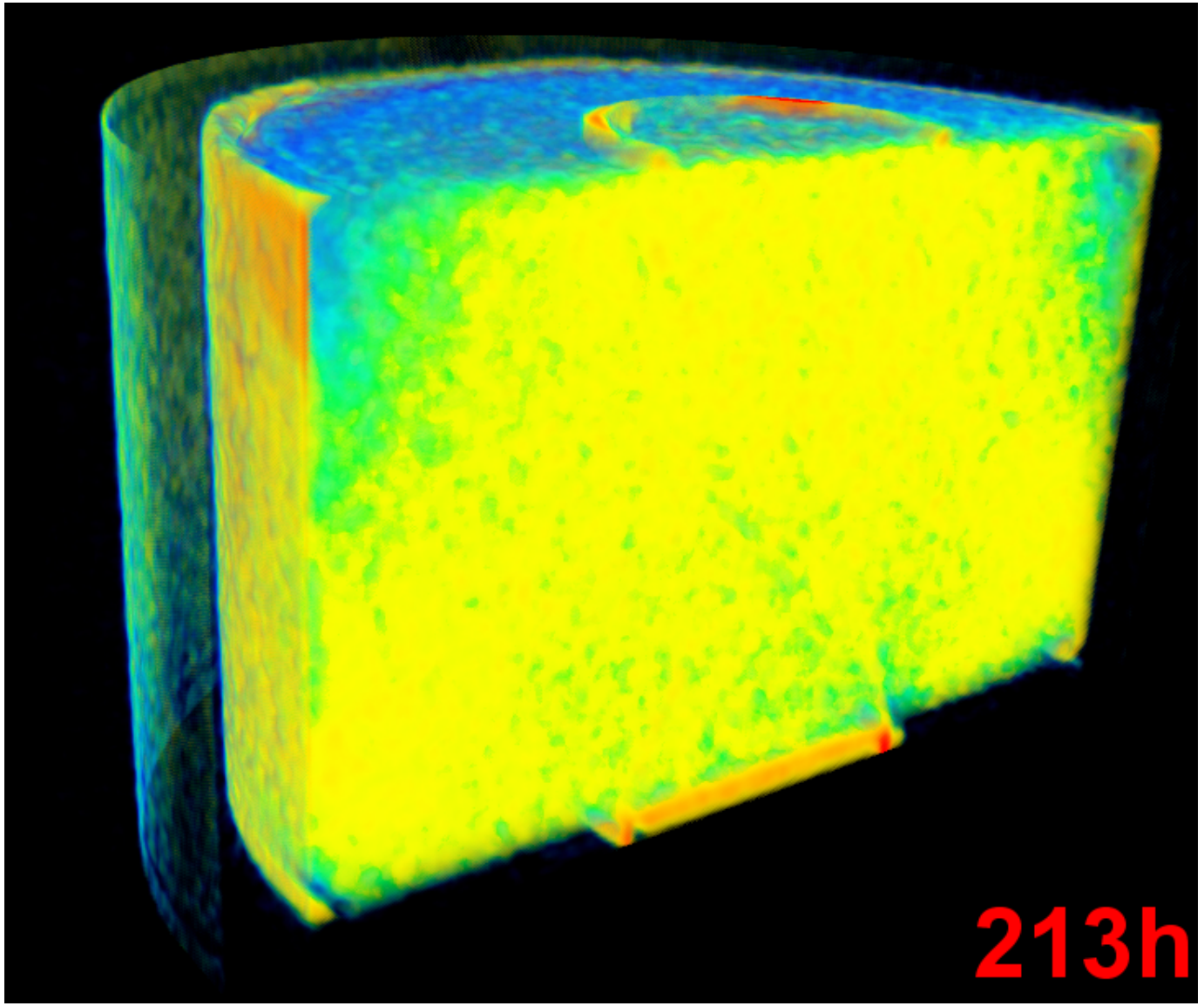
Wetting process.



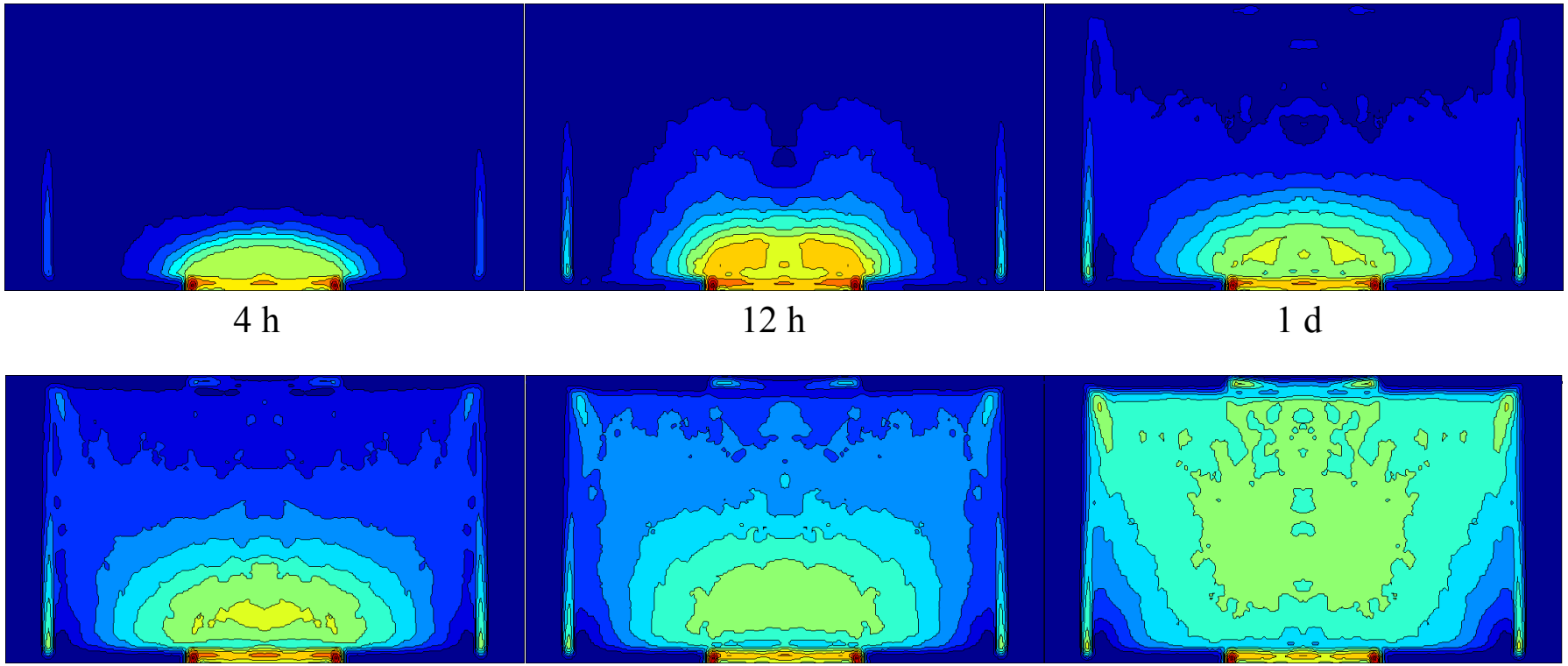
Wetting process.



Wetting process.

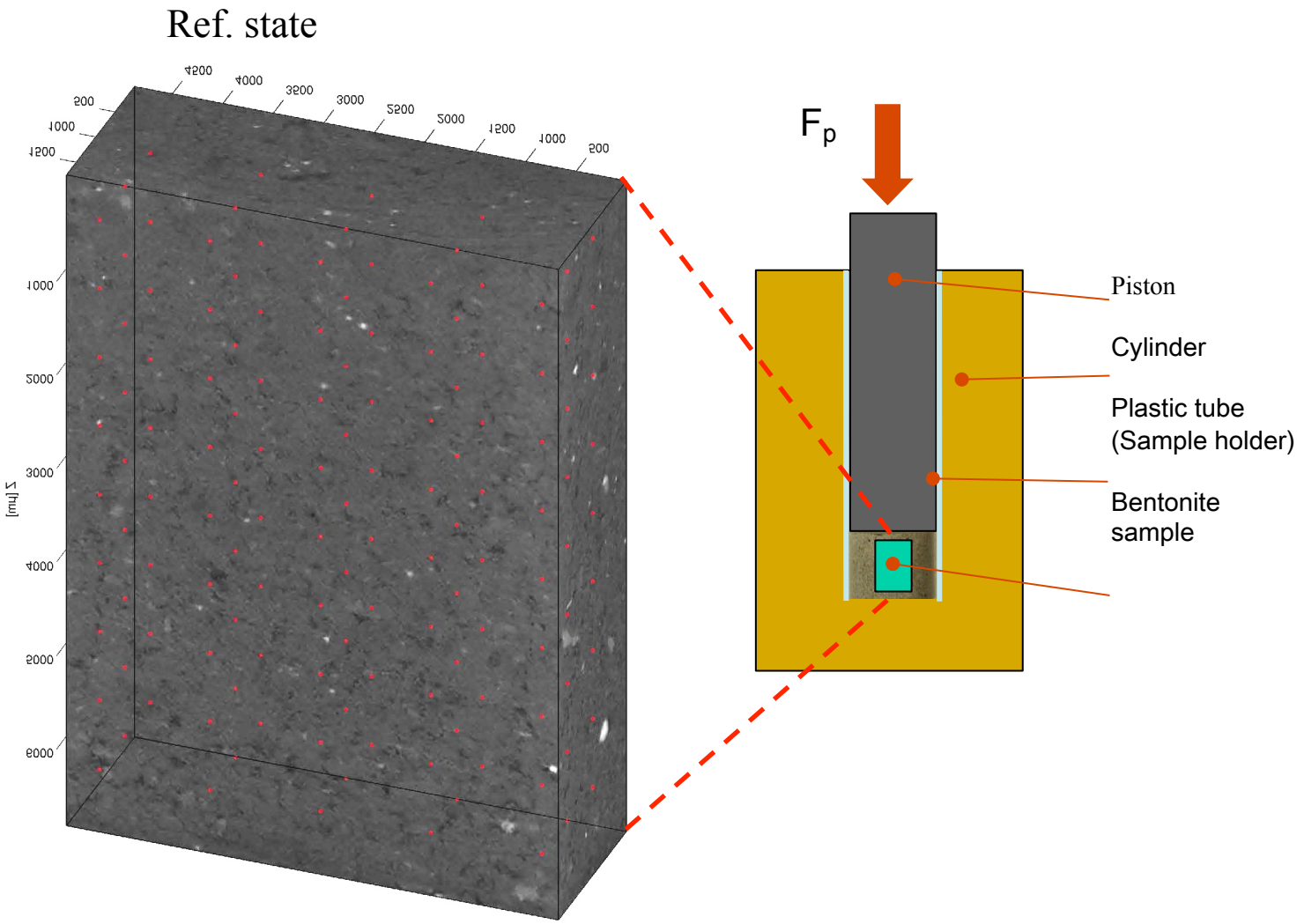


Water transport (cylindrical average)
Calibrated water content



Application 2: Monitoring 3D deformation of bentonite clay

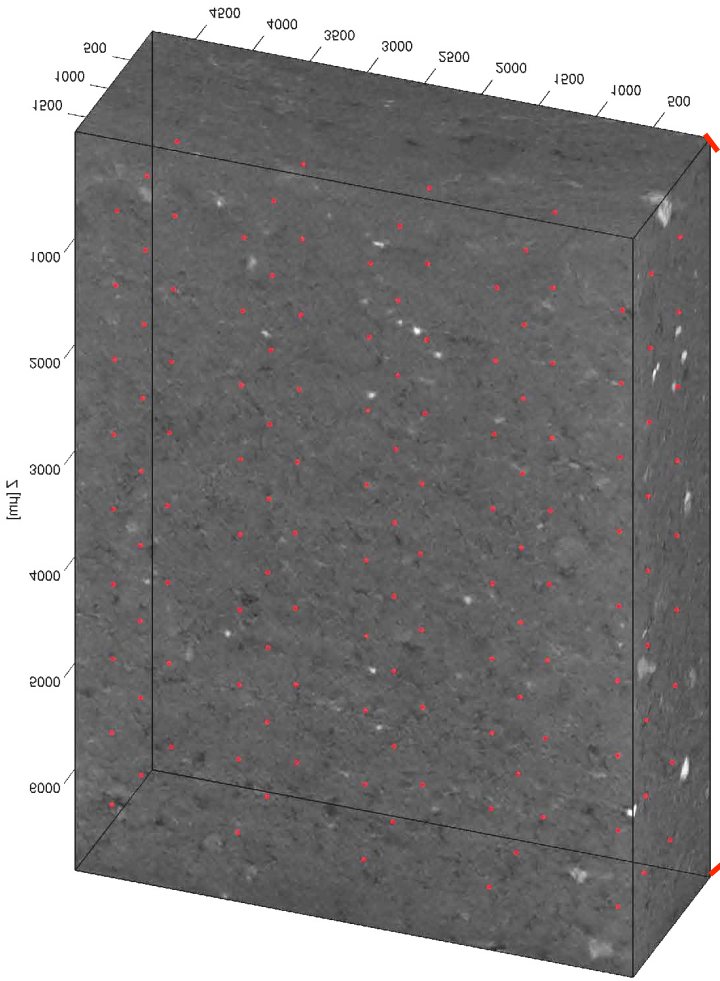
Test case: Simple compression

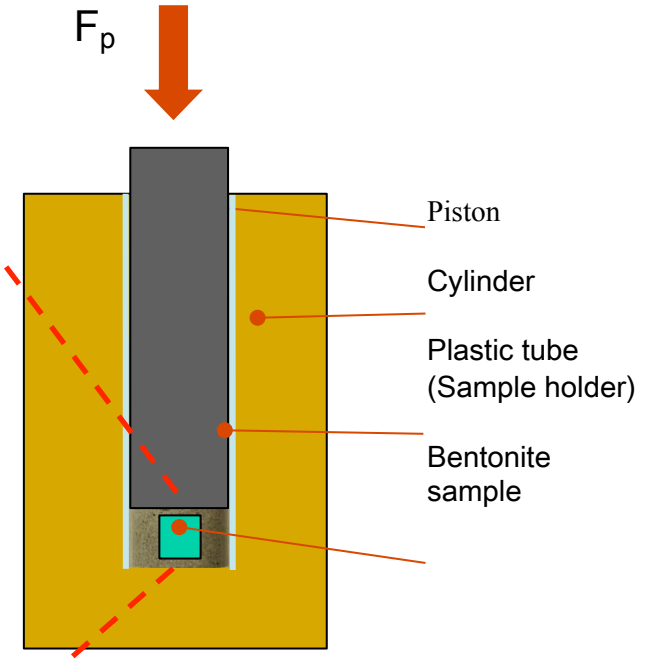


Application 2: Monitoring 3D deformation of bentonite clay

Test case: Simple compression

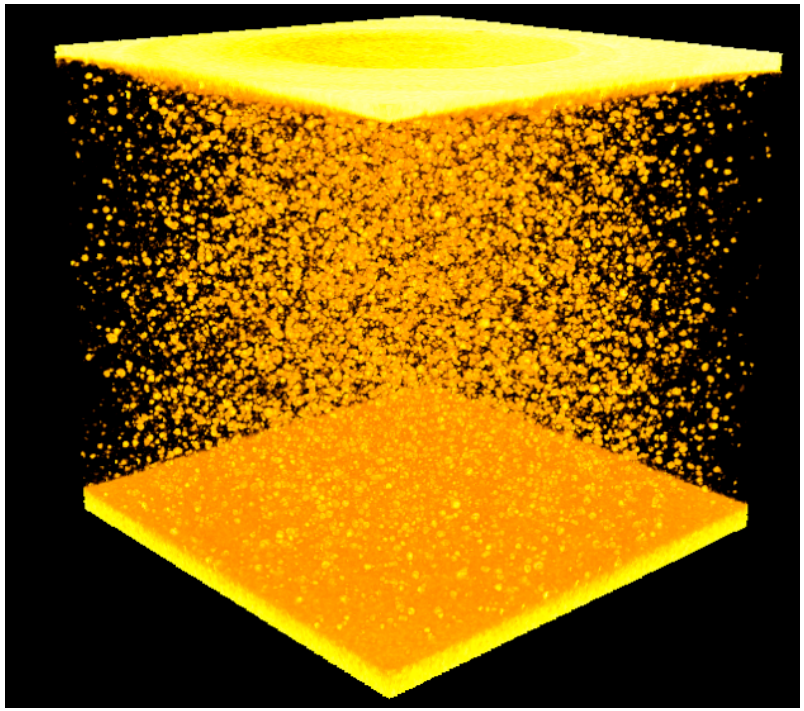
Compressed. state





3D Displacement field computed by correlating two tomographic images

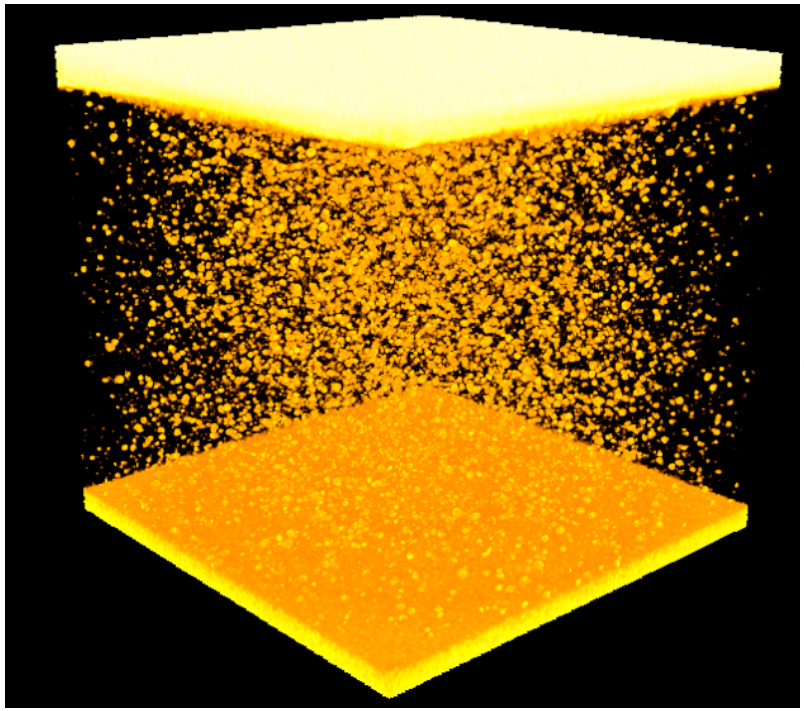
Thresholded image
(marker particles only)
Reference state



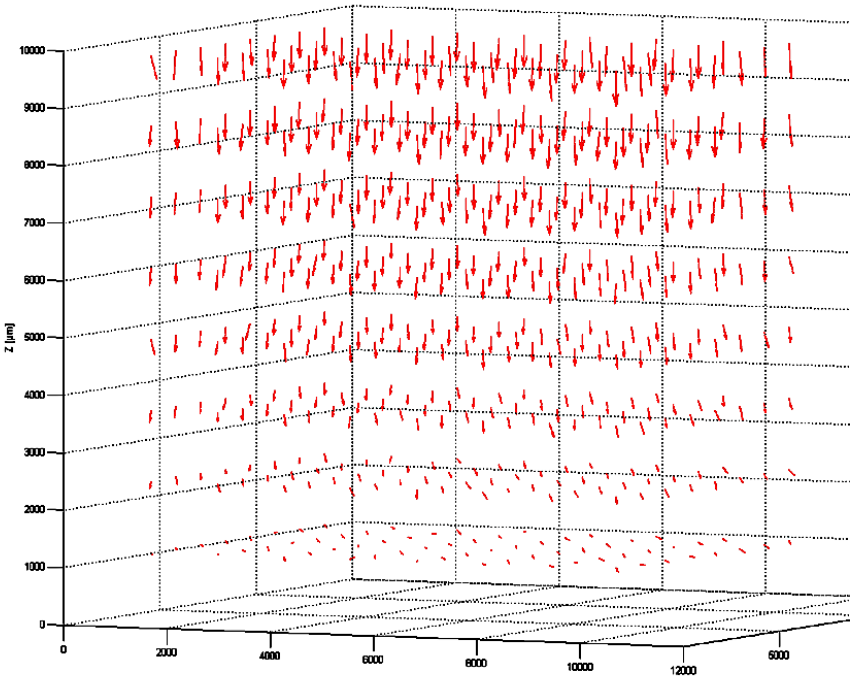
(Jarno Alaraudanjoki)

3D Displacement field computed by correlating two tomographic images

Thresholded image
(marker particles only)
Compressed state 1



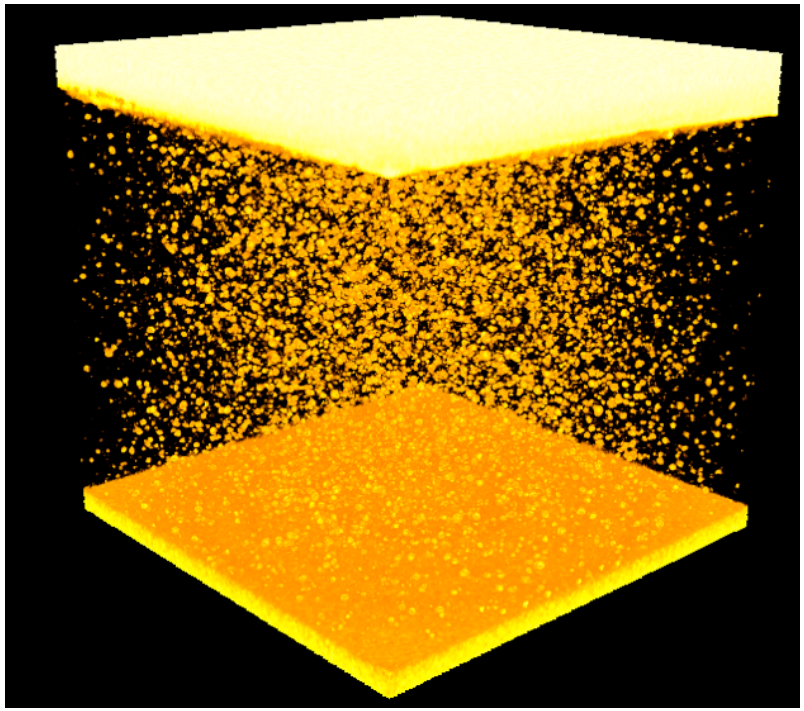
Displacement field



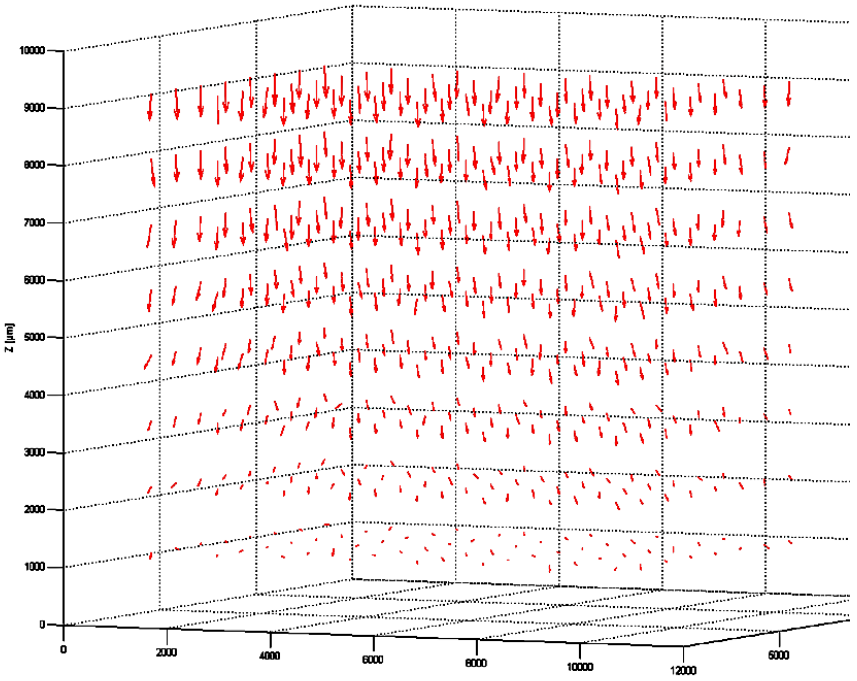
(Jarno Alaraudanjoki)

3D Displacement field computed by correlating two tomographic images

Thresholded image
(marker particles only)
Compressed state 2



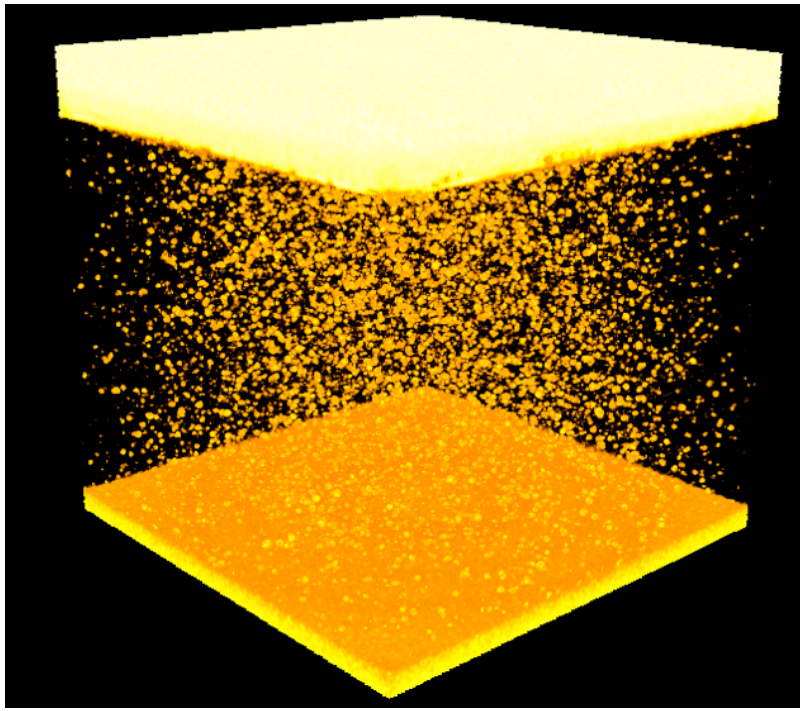
Displacement field



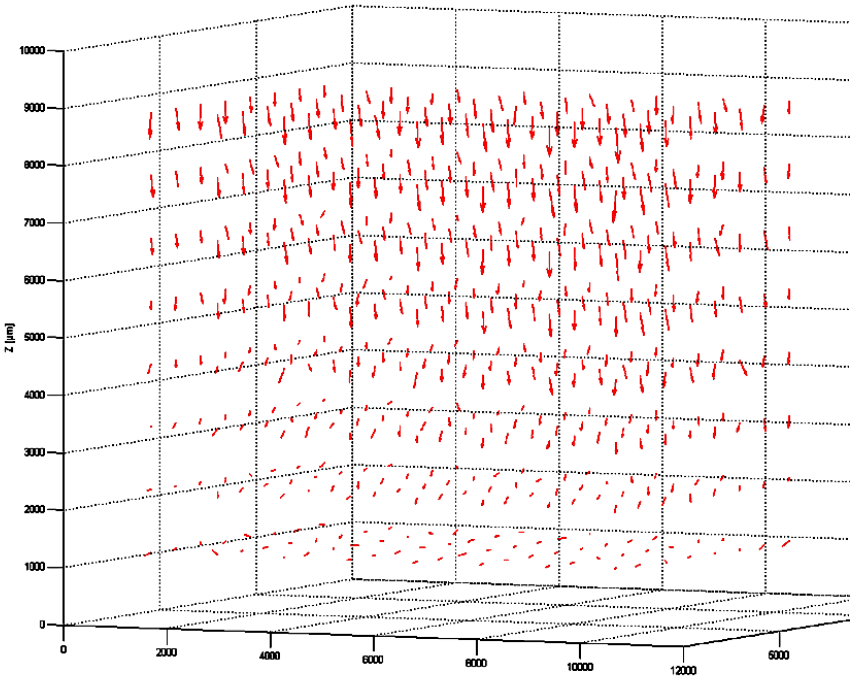
(Jarno Alaraudanjoki)

3D Displacement field computed by correlating two tomographic images

Thresholded image
(marker particles only)
Compressed state 3



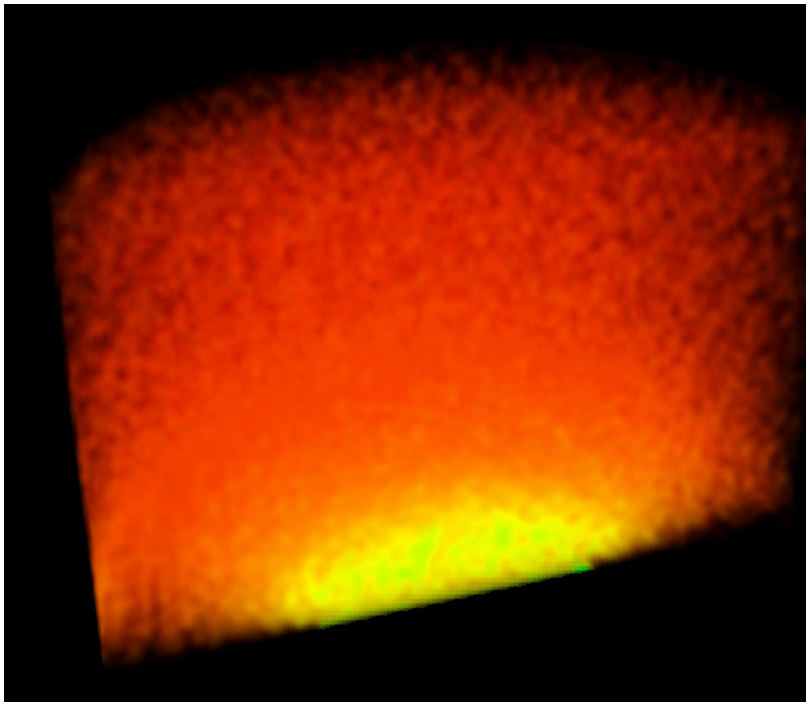
Displacement field



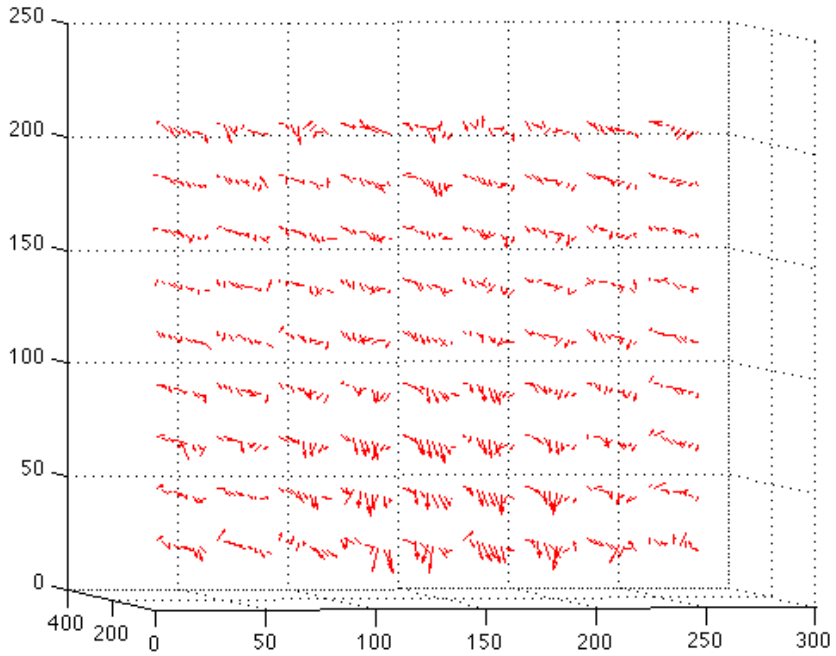
(Jarno Alaraudanjoki)

Simultaneous monitoring of wetting and deformation.

Wetted zone after one day of wetting



Displacement field due to wetting

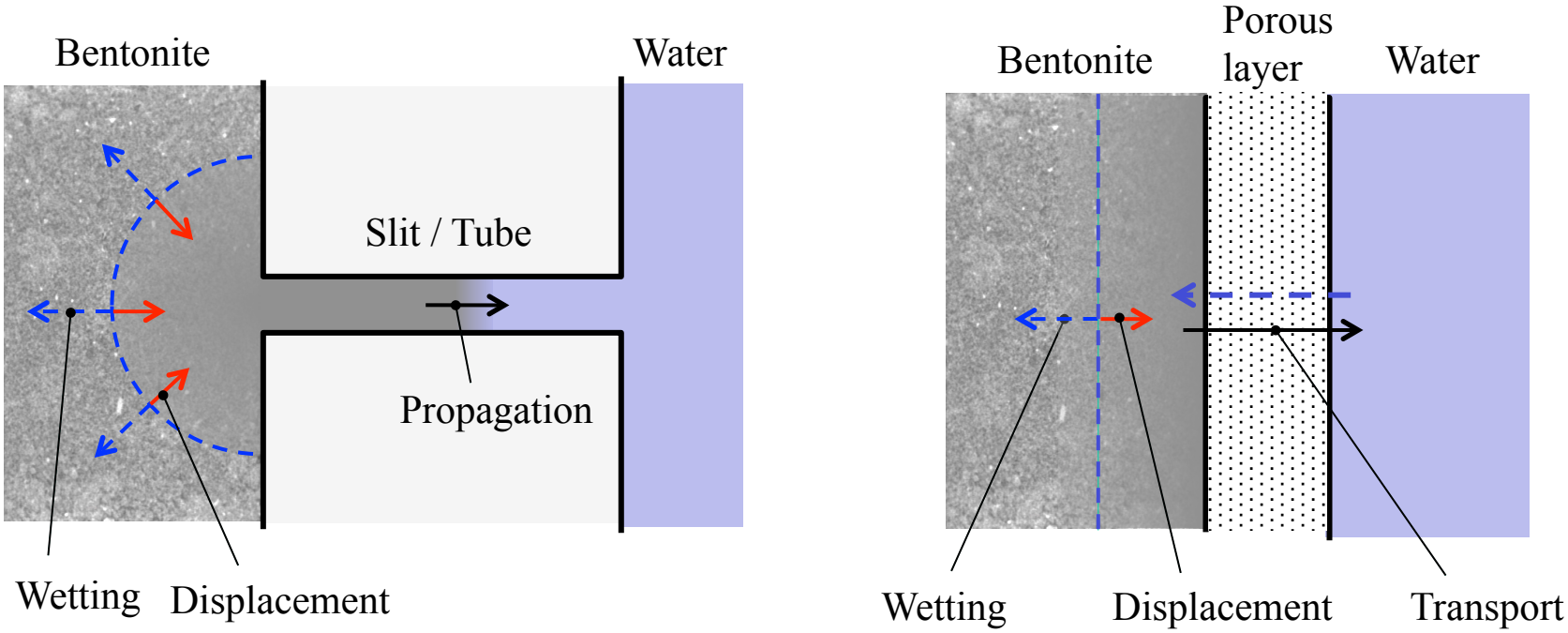


Notice: the measured deformation indicates contraction due to wetting (initial softening of bentonite near water inlet)

Plan for BELBaR WP2:

1. Develop methods for 3D monitoring of erosion process using X-ray micro- and nanotomography.
2. Apply the methods in selected erosion processes <u>to support modeling and model validation</u>

<u>Examples of possible types of experiment (schematic)</u>



Another idea: 3D geometry of a crack in a rock sample
=> numerical simulation and experiments in the **same** geometry?