MIT EARTH RESOURCES LABORATORY
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Earth Resources Laboratory

Transmissivity and Deformation of Planar Fracture in Solnhofen Limestone during Cyclic Loading

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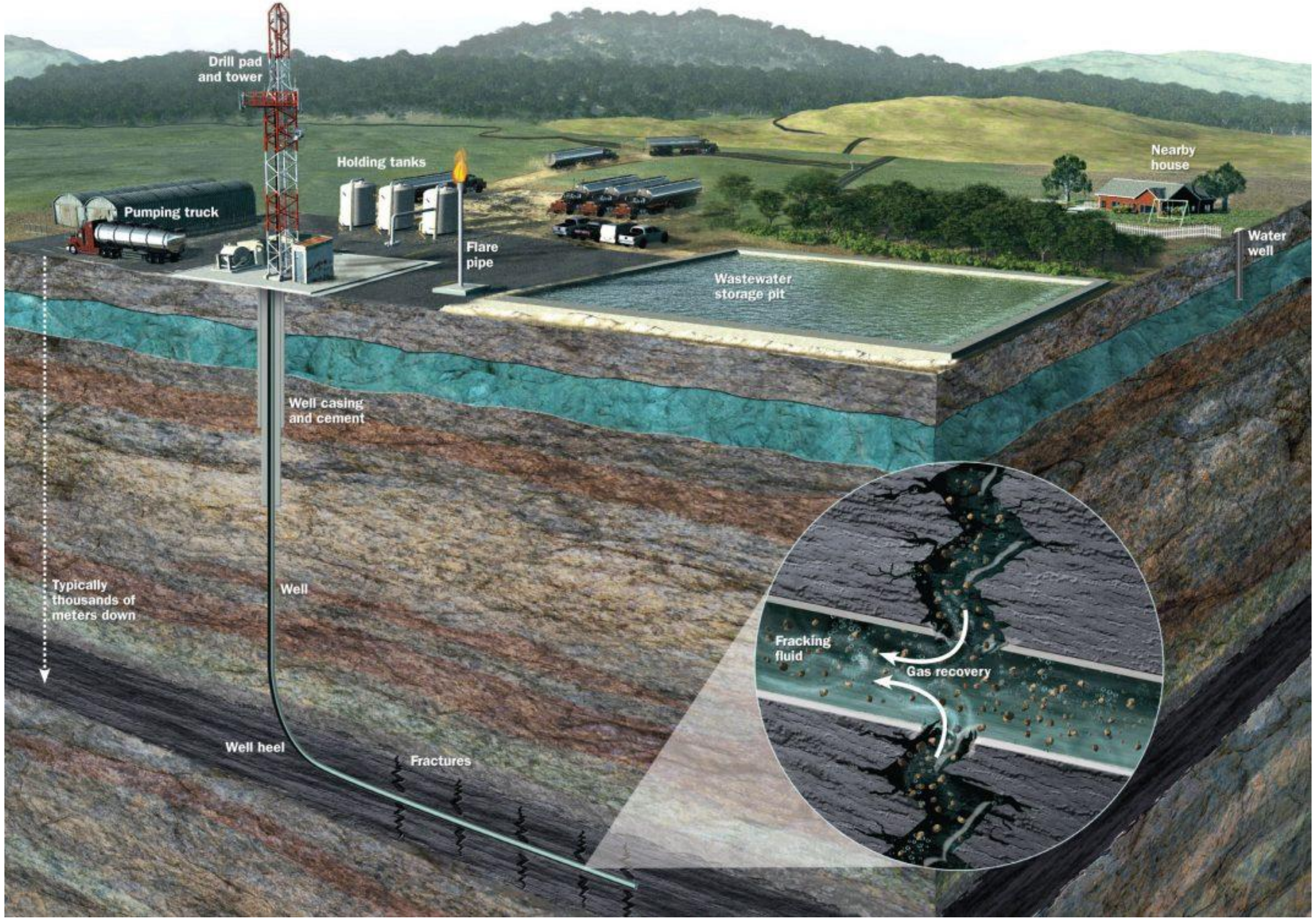
Motivation

Applications of fluid flow through fractures:

- Induced seismicity
- Groundwater circulation
- Hydrothermal vent
- Hydraulic fracturing
- Geothermal systems



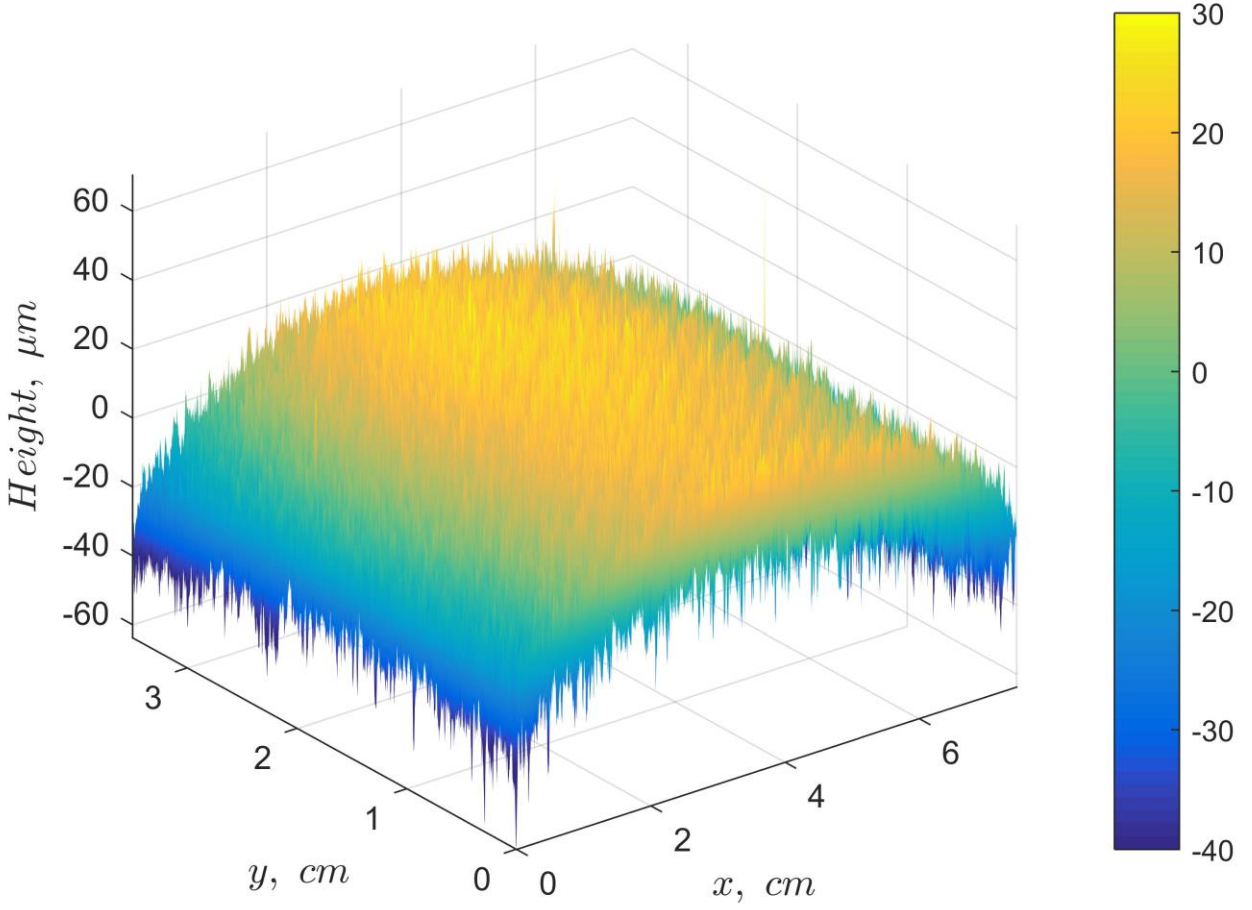
Fracture properties

Mechanical properties
(Fracture closure, Stiffness)

Roughness
(Contact area)

Aperture
(Void space)

Hydraulic properties
(Permeability)



Sample

Material - Solnhofen limestone is composed of weakly dolomitized calcite grains (about 95%). Porosity is 5% or less (Milsch et al., 2016).

Saw cut fracture roughened with # 80 polishing grit (Figure 2).

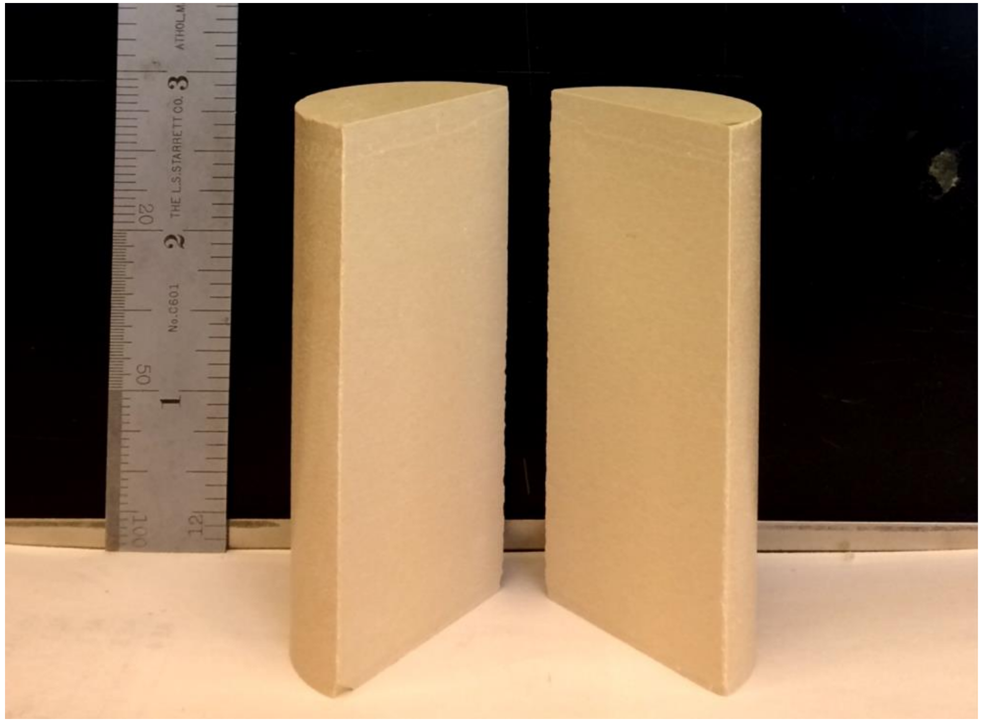


Figure 1. Two halves of the cylinder

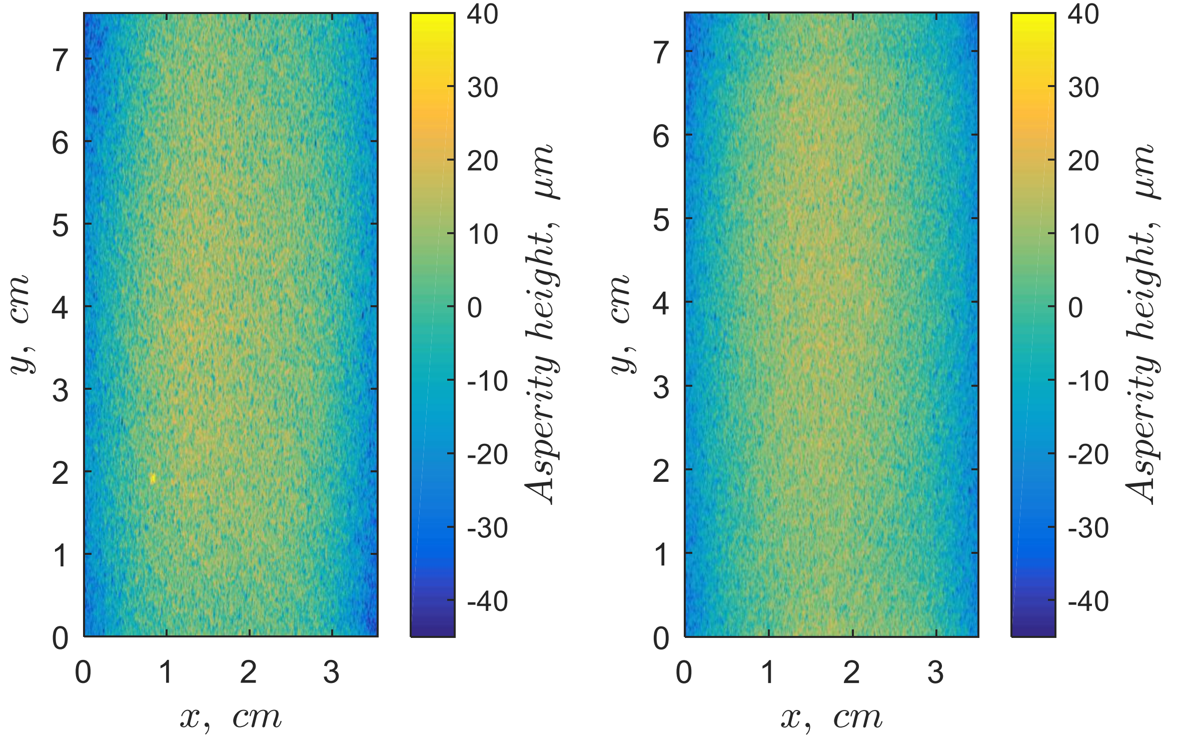


Figure 2. Roughness profiles

Sensors

- Strain gauges (across fracture and on intact sample);
- Acoustic sensors (p-wave, s-wave);
- 2 acoustic sources (Figure 2).

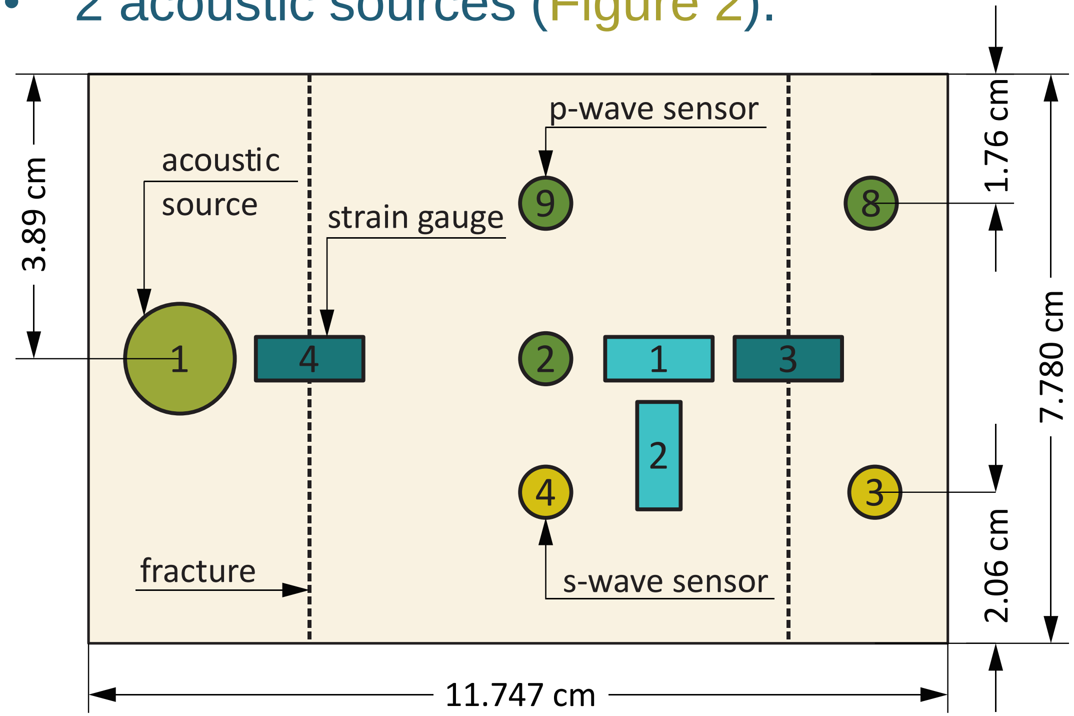


Figure 3. Sample surface unwrapped

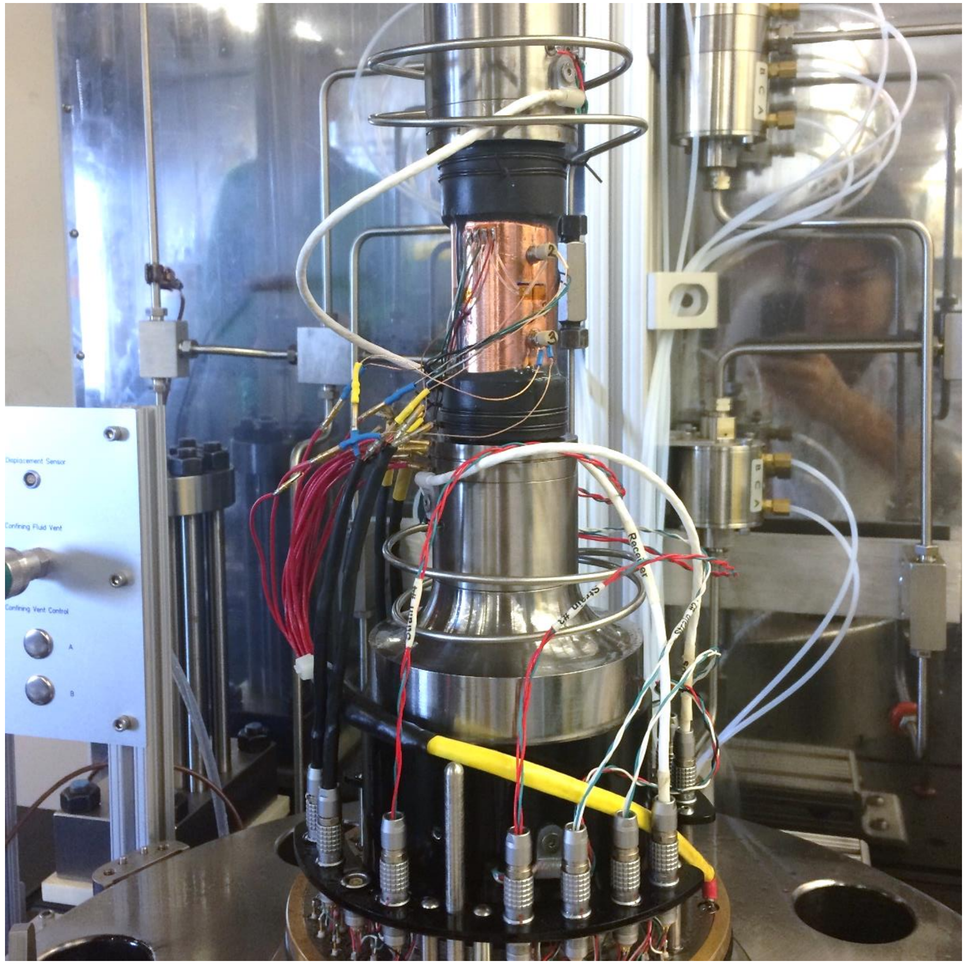


Figure 4. Sample assembly inside the vessel

Experimental procedure

- NER Autolab 3000 under cyclic loading and isostatic condition;
- Pore fluid – gas argon;
- Strain was measured continuously;
- Permeability measured and acoustic data was recorded at each "step" of the cycle (Figure 5).

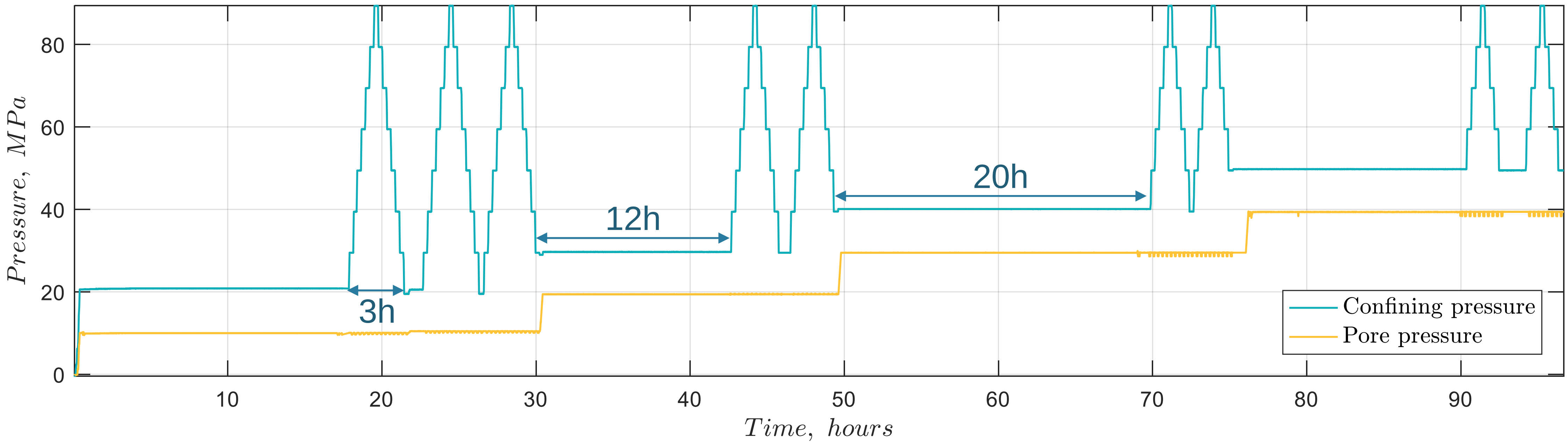


Figure 5. Cycles of confining and pore pressure

Strain Measurements

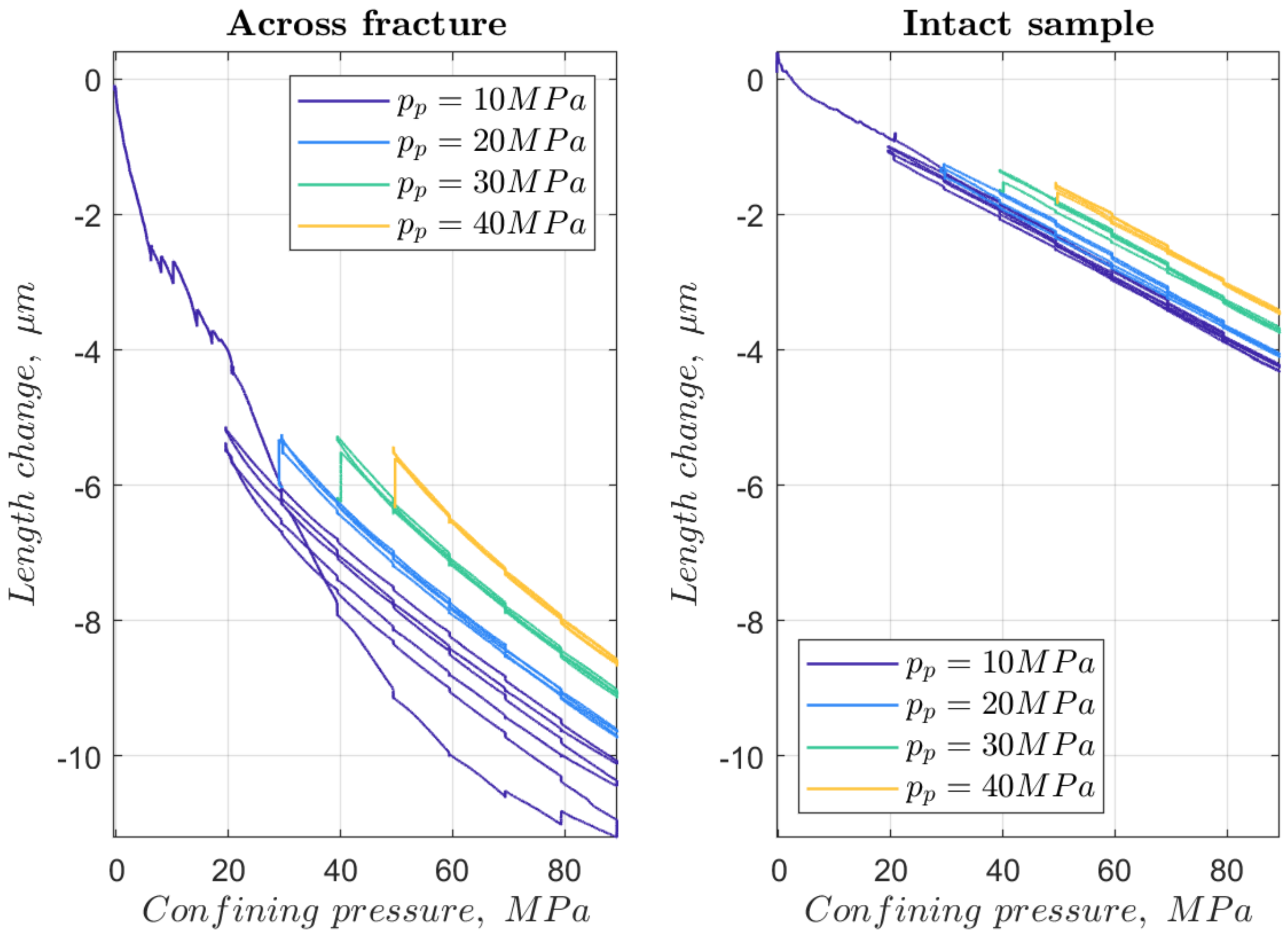


Figure 6. Strain measurements

- Strain measured continuously (Figure 6);
- Decreasing length – closure or contraction;
- Nonlinear deformation curve across fracture;
- Amplitude of change: ~ 6 μm – across the fracture; ~ 3 μm – intact part of the sample.

Fracture permeability

- Steady-state (Bernabe, 2008).
- Darcy's Law:

$$q = -\frac{k\ \delta p}{\mu\ \delta L}$$

where k is permeability, p is the pressure of pore fluid, and μ is dynamic fluid viscosity.

$k \sim 10^{-4}\ mD$ - matrix permeability.

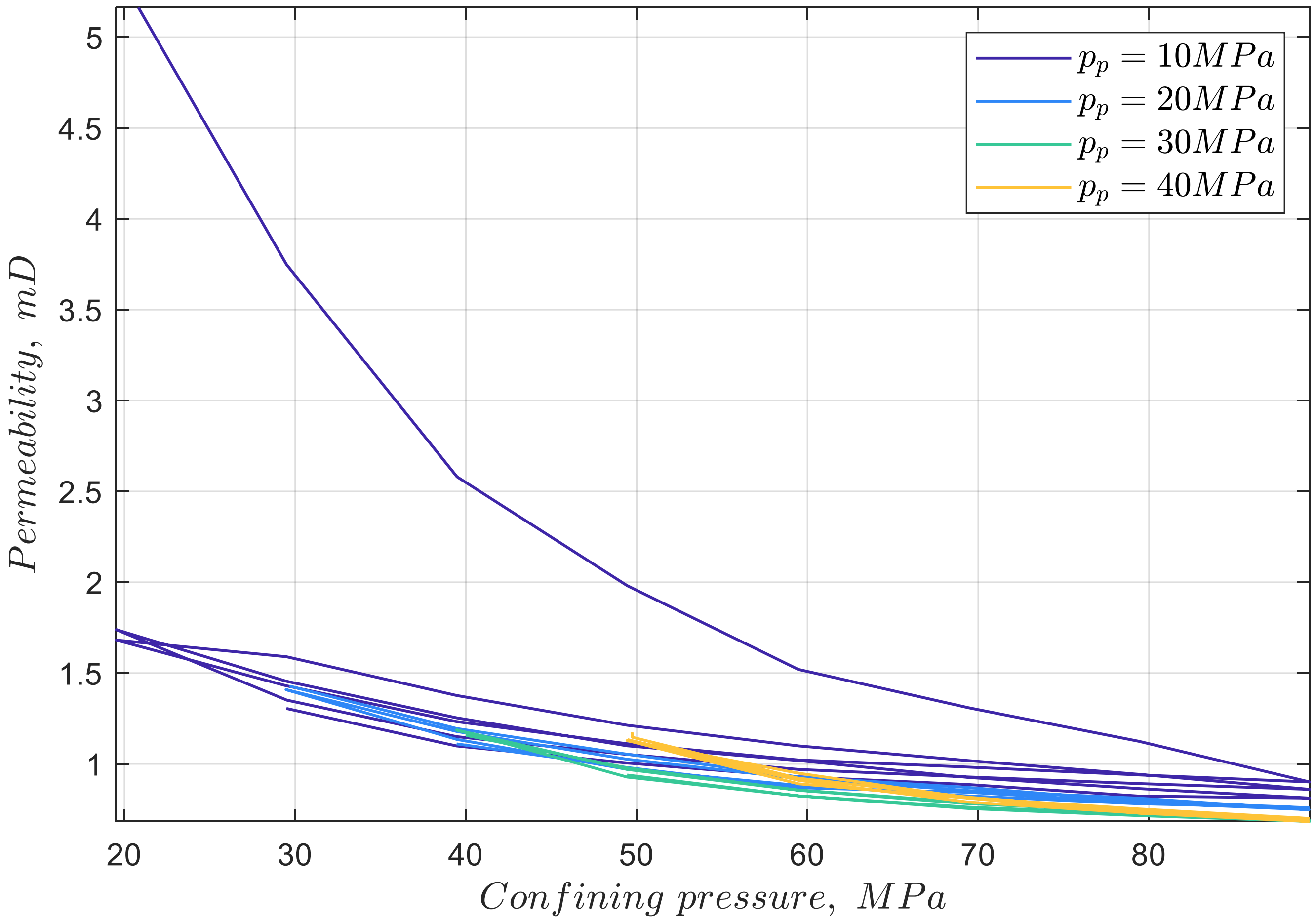


Figure 7. Permeability measurements

Mechanical and Hydraulic aperture

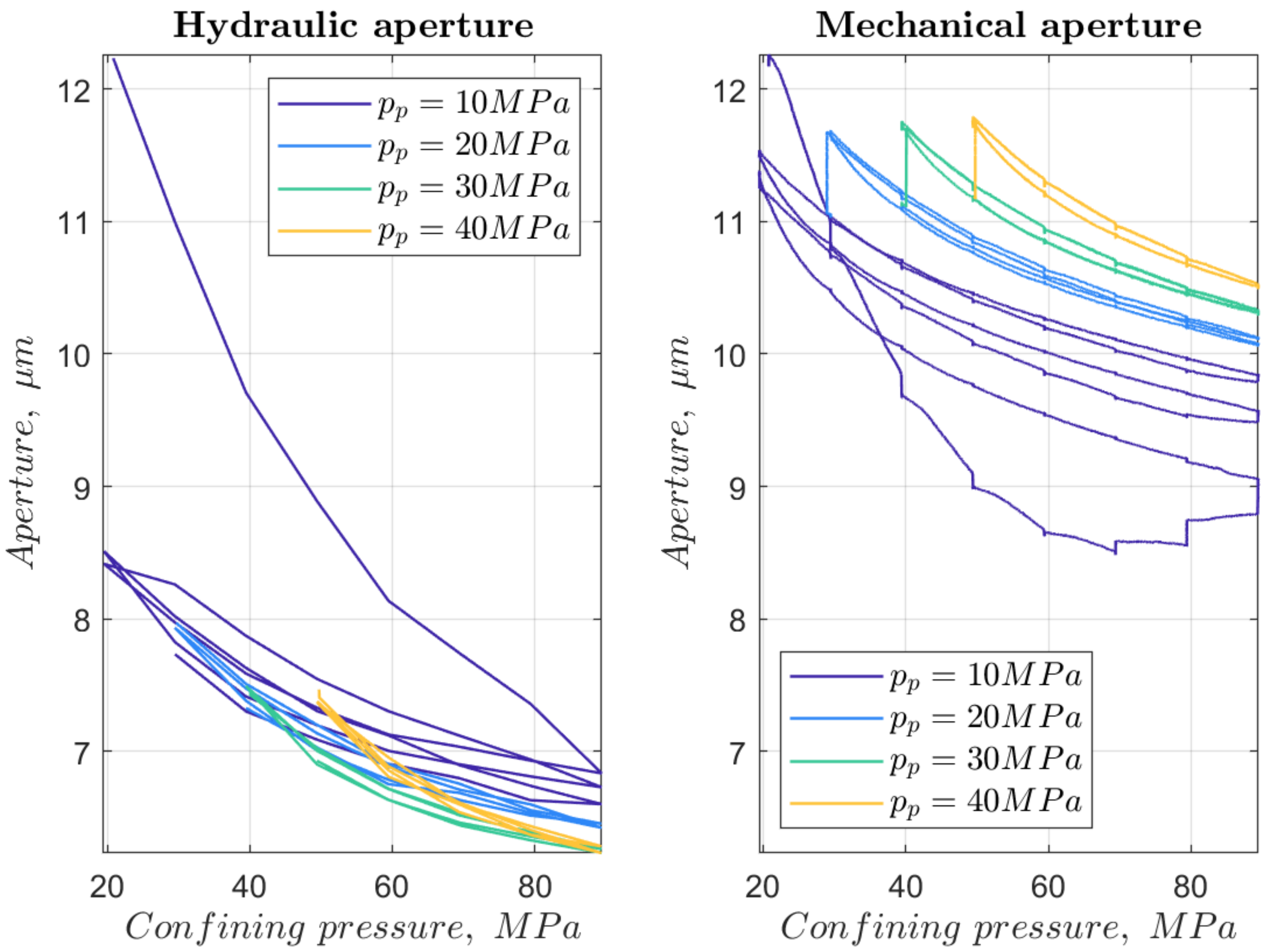


Figure 8. Mechanical and hydraulic aperture

- Mechanical aperture – difference in scaled strain measurements.
- Hydraulic aperture – the aperture between two parallel plates for the same flux rate.

Similar in the range of change, different in terms of hysteresis and absolute magnitude.

Roughness analysis

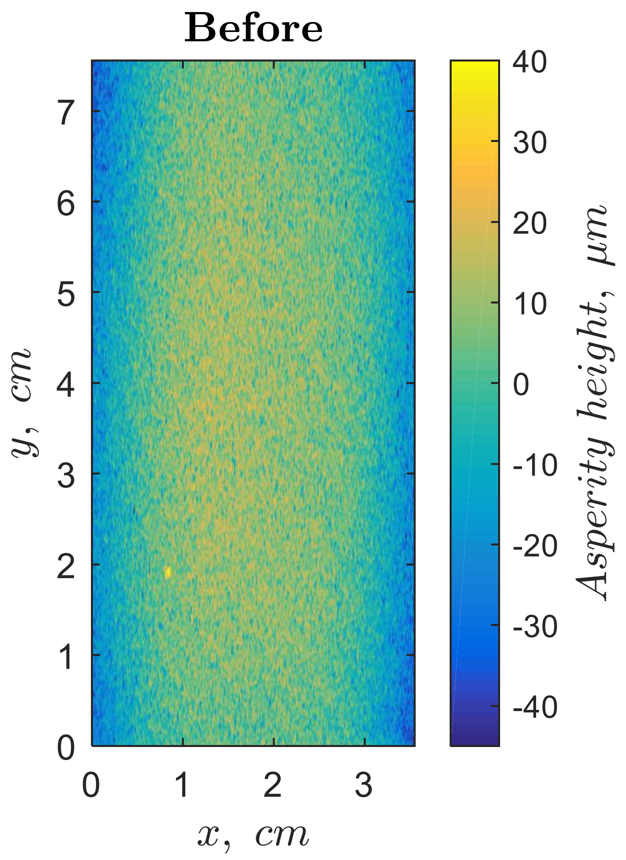


Figure 9. Roughness profiles before and after

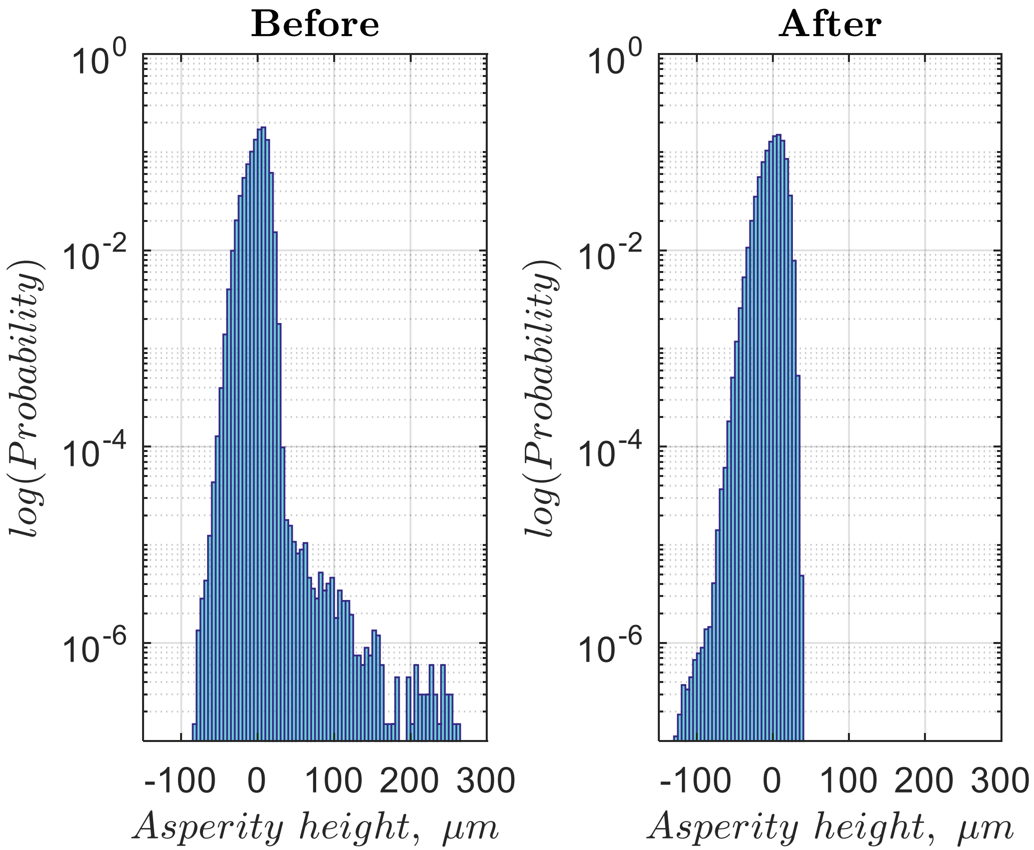


Figure 10. Asperity height distributions

Creep

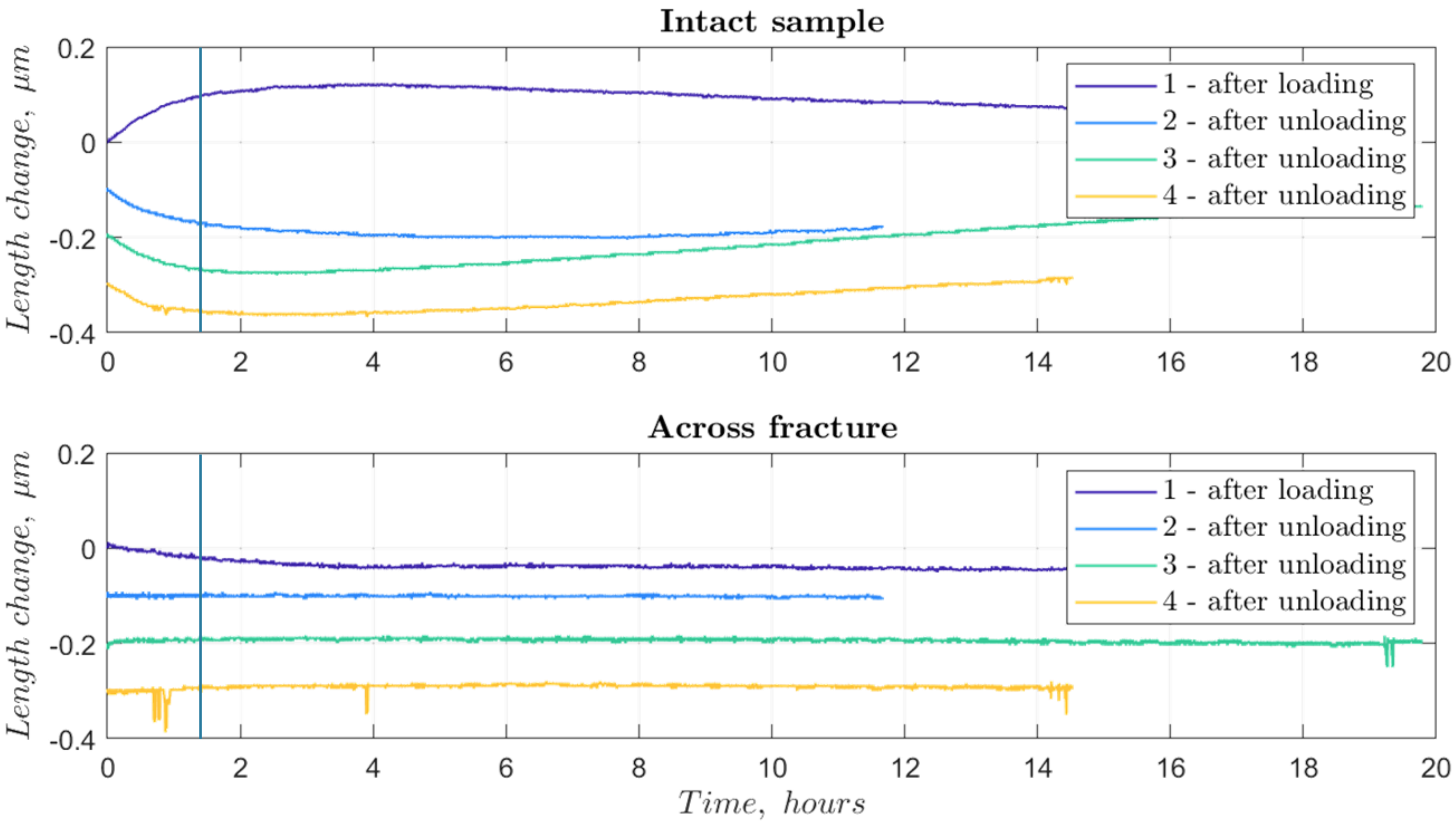


Figure 11. Strain measurements for creeping sections

Time of gas diffusion into the rock matrix:

$$t = \frac{R}{v} = R\frac{\mu}{k\,\Delta p}$$

$\Delta p = 10\ \mathrm{MPa}$ is the pressure gradient, $R = 20\,mm$ is the sample radius, and $\mu = 2.6 \cdot 10^{-5}\,Pa \cdot s$ is dynamic viscosity of argon.

$$t = 1.44\ hours$$

Results

Current state:

- First loading process – permanent deformation;
- Subsequent loading cycles – deformation and permeability repeatable;
- Stiffness – larger with loading;
- Time dependent behavior – elastic response + gas dissipation.

Future work:

- Different pore fluids and roughness;
- Time dependent behavior;
- Acoustic data analysis.

References

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Questions?

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