Investigation of the bentonite barrier for radioactive waste repository

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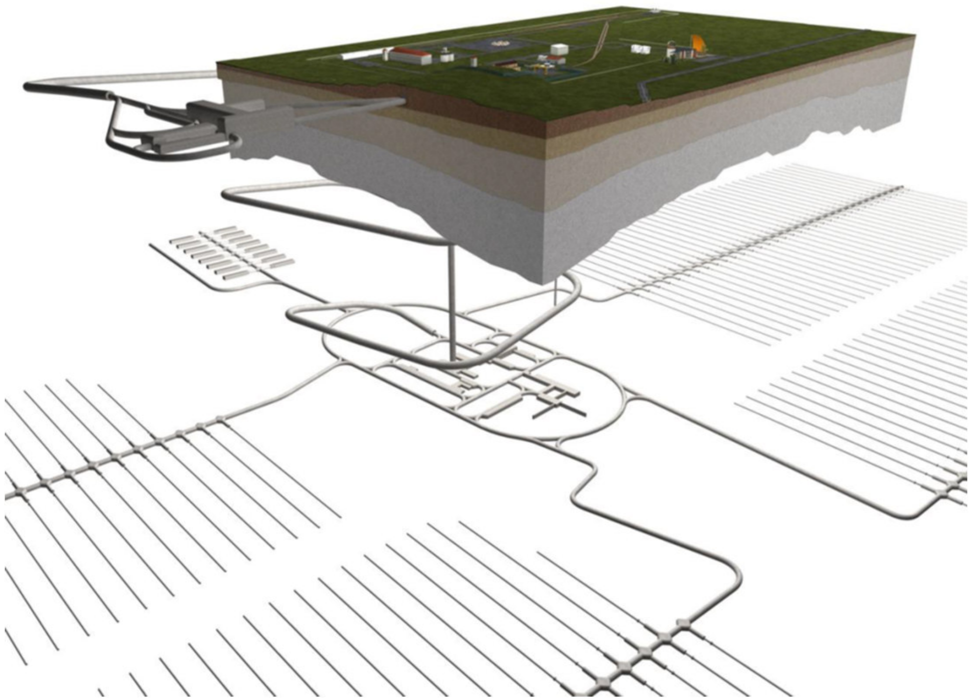
Outline

- Radioactive waste repository
- Bentonite and its role in repository
- Investigation of hydromechanical properties of bentonite
- Influence of temperature on bentonite behaviour
- Summary

Radioactive waste repository

- The purpose of constructing deep repositories is to provide a safe form of storage for highly radioactive waste (spent fuel from nuclear power plants).
- Nuclear power plants are currently operated in approximately 30 countries.
- The concept of deep geological disposal in a stable geological environment is (see, for example, the opinion of the International Atomic Energy Agency) the only acceptable method for the safe disposal of high-level radioactive waste.
- There are currently no operational repositories of this type in the world. Waste is currently stored in interim storage facilities at nuclear power plant sites.
- Deep geological repositories are unique structures in many respects (safety, service life).
- Extremely interesting area for research



Hausmannová et al. (2023)

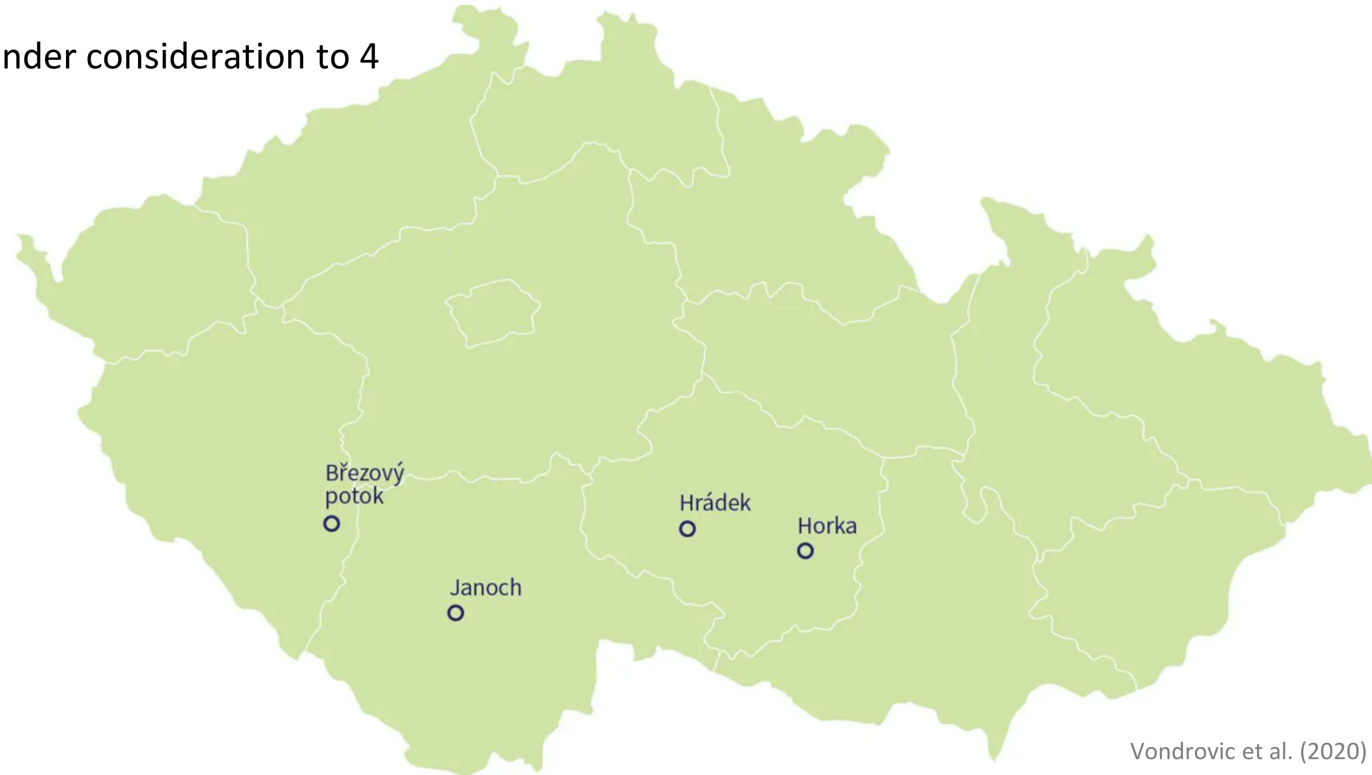
Radioactive waste repository

SITUATION IN THE CZECH REPUBLIC – CURRENT TIME SCHEDULE

According to the EU, nuclear power plants can be considered low-emission energy sources. However, one of the conditions is that disposal facilities must be operational by 2050.

⟶ acceleration of the original schedule for the construction of the repository:

- 2020 - reduction of the number of locations under consideration to 4
- 2028-30 - selection of the final site
- cca 2040 - construction
- cca 2050 - start of operation



Vondrovic et al. (2020)

Radioactive waste repository

MULTI-BARRIER SYSTEM OF DEEP REPOSITORY

1. Canister

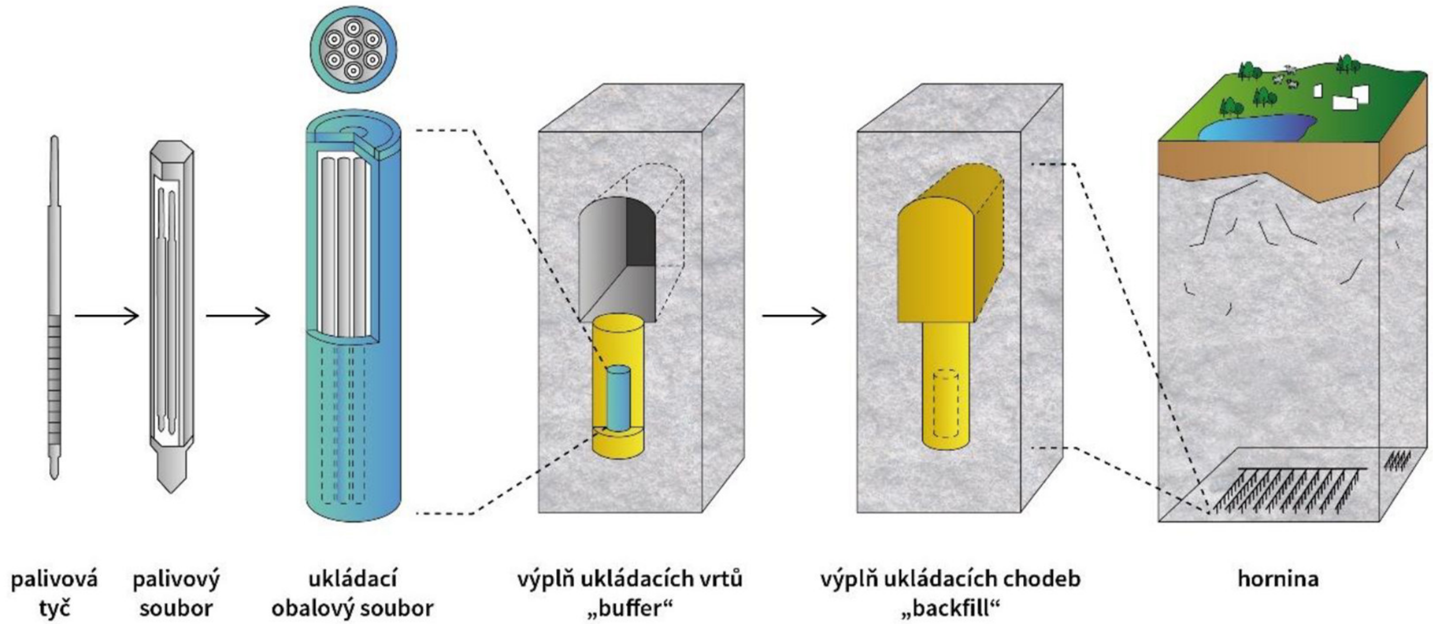
- Isolation from the environment
- Made of steel/copper, cylindric shape
- lifetime of tens of thousands of years

2. Bentonite buffer

- Sealing and stabilizing the waste package
- Backfill of tunnels
- Form of compacted blocks or pellets

3. Geological formation

- Stable and compact rock (crystalline rock, clay, salt)
- Low permeability
- Depth 500-1000 m



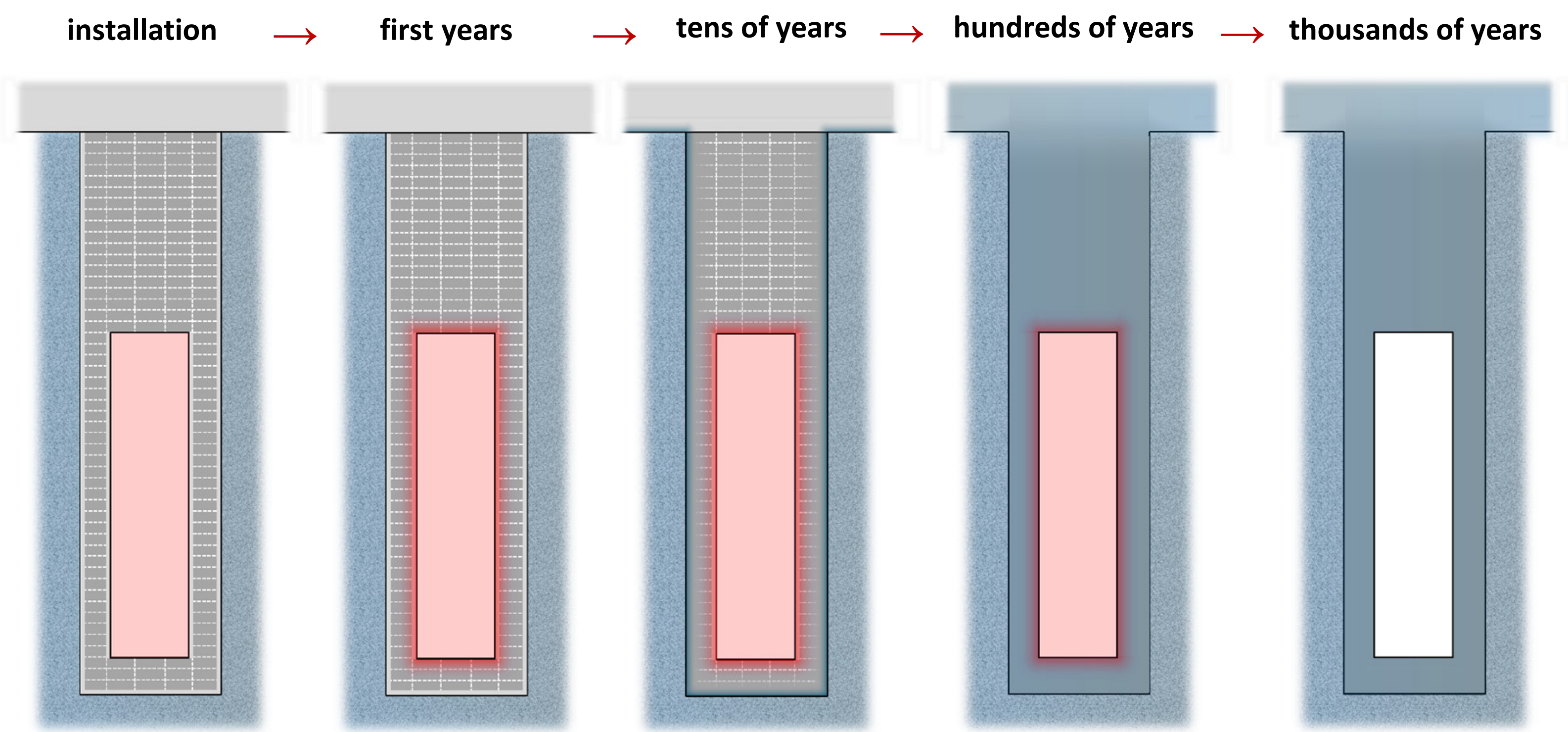
Hausmannová et al. (2023)

Bentonite and its role in repository

Why bentonite?

- soil formed as a product of volcanic rock weathering
- long-term stability
- extremely high: swelling capacity, plasticity, sorption capacity
- extremely low: hydraulic conductivity

Boundary conditions in repository:



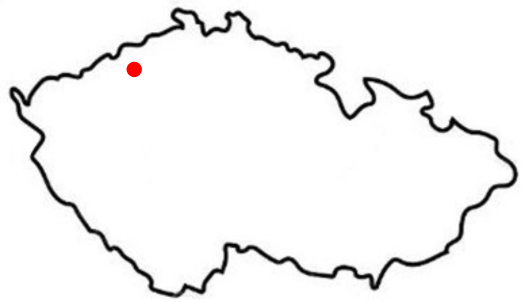
Bentonite and its role in repository

Laboratory research of bentonite:

- complex material with extreme properties, highly compacted samples
- special boundary conditions – variable saturation, high temperatures, constant volume conditions
- commercial equipment for soil testing is insufficient – development of special experimental equipment is necessary

Bentonite Černý Vrch (BCV)

- Ca-Mg bentonite from Černý Vrch deposit
- industrially produced by Keramost, a.s.
- reference research material in the Czech deep geological repository concept



www.keramost.cz

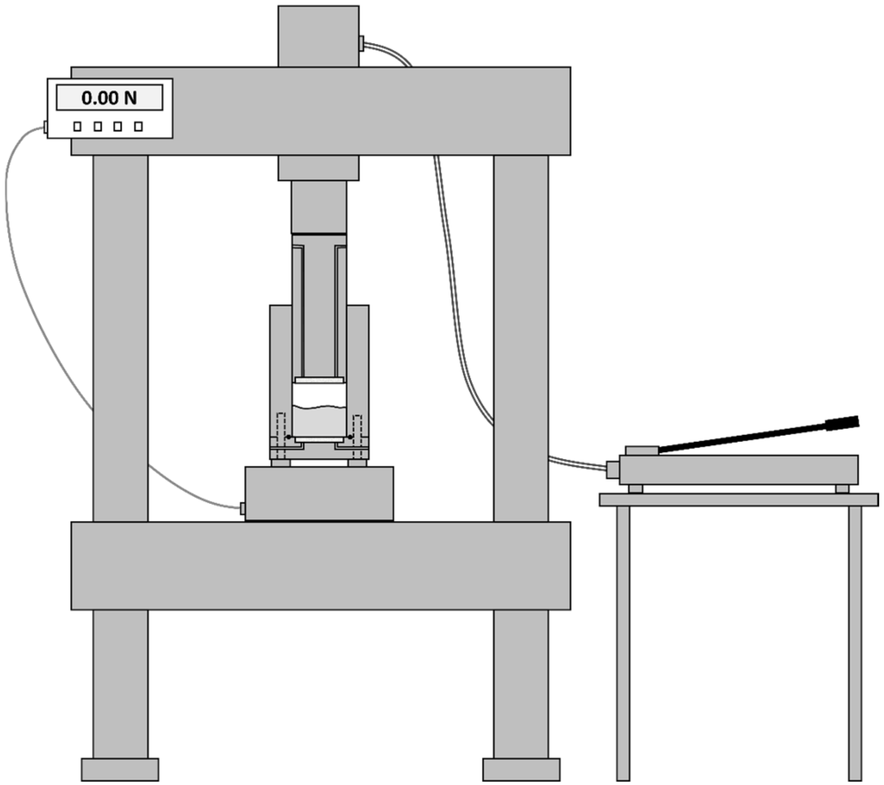
mineralogical composition:

Ca/Mg montmorillonite	70%
quartz	11%
kaolinite	5%
illite	4%
Mg-calcite	4%
goethite	3%

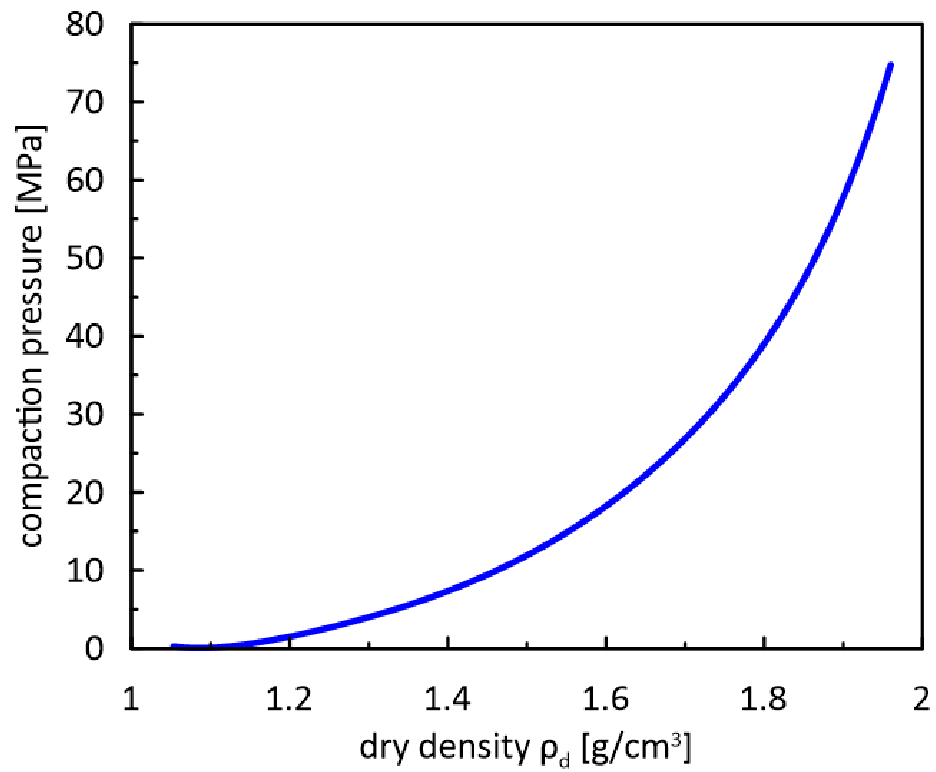
Investigation of hydromechanical properties of bentonite

PREPARATION OF SAMPLES

Uniaxial compaction in a press:



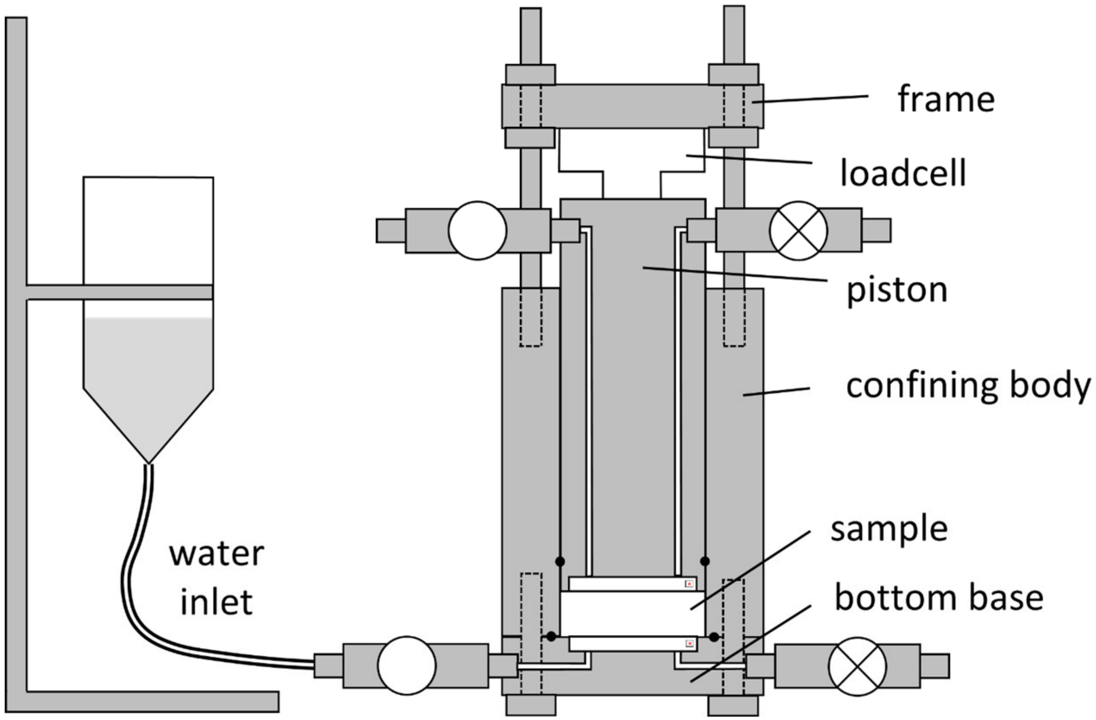
Dependence of compaction pressure on sample dry density:



Investigation of hydromechanical properties of bentonite

„MPC“ CELLS

Setup for determination of swelling pressure:



Investigation of hydromechanical properties of bentonite

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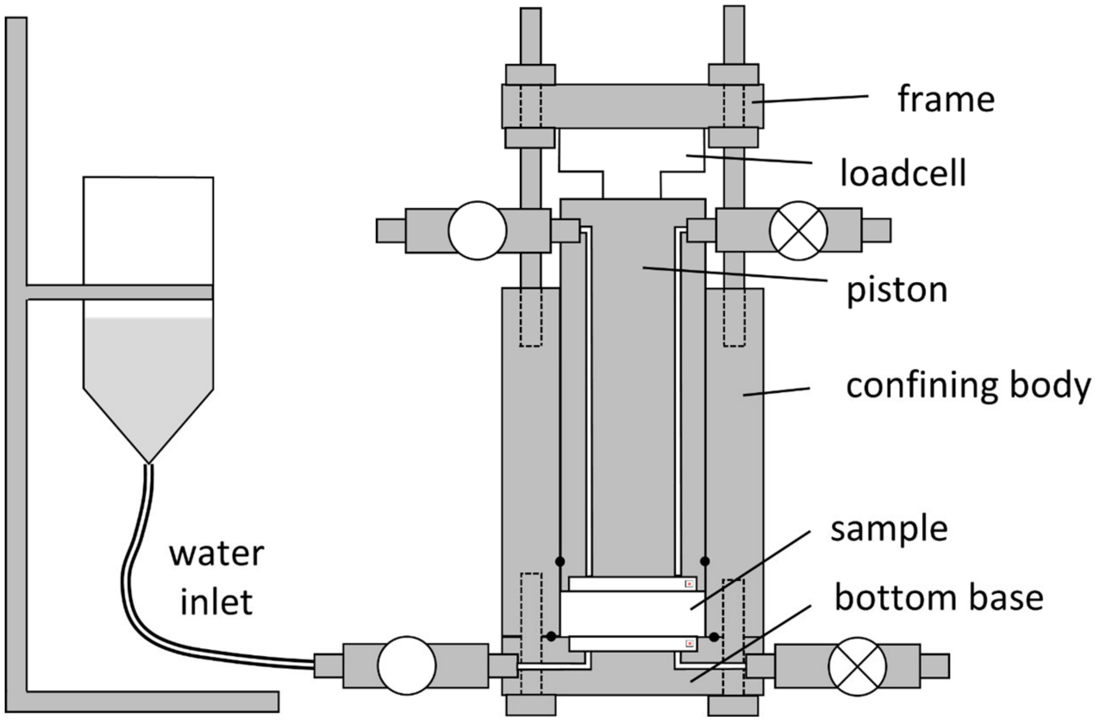
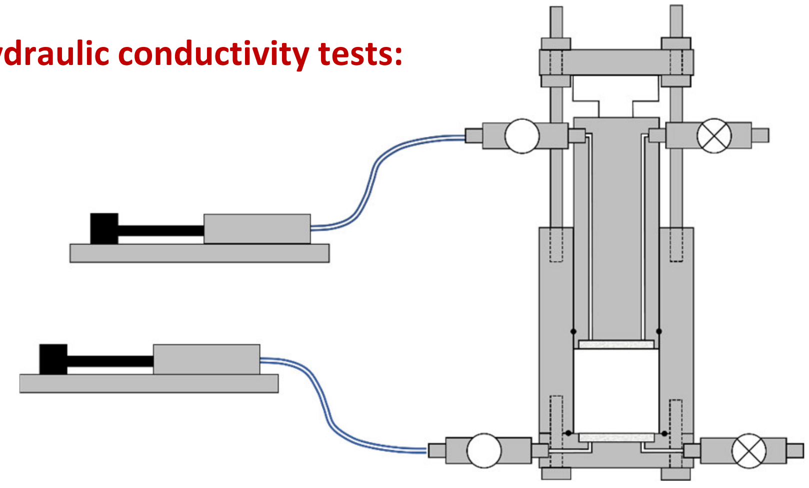
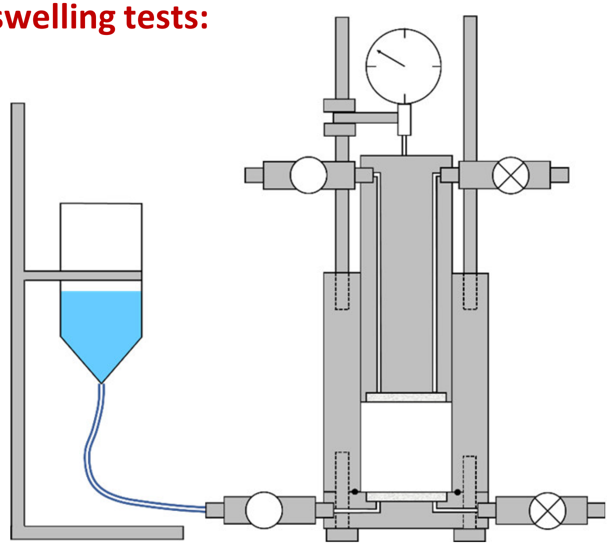


Setup for hydraulic conductivity tests:

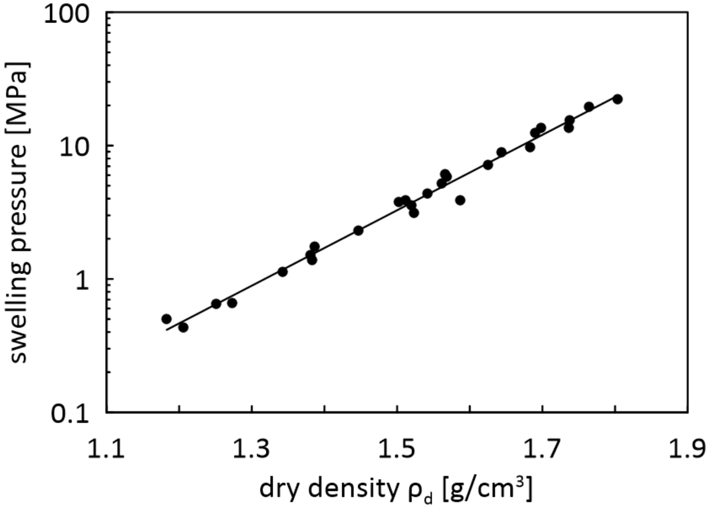


Setup for free swelling tests:

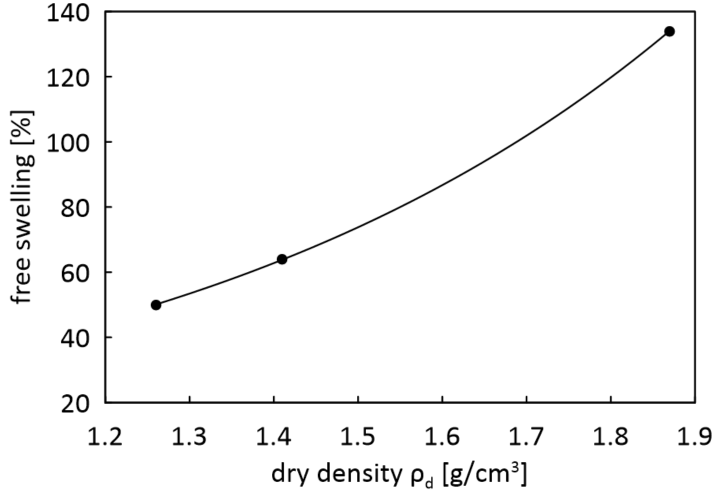


Investigation of hydromechanical properties of bentonite

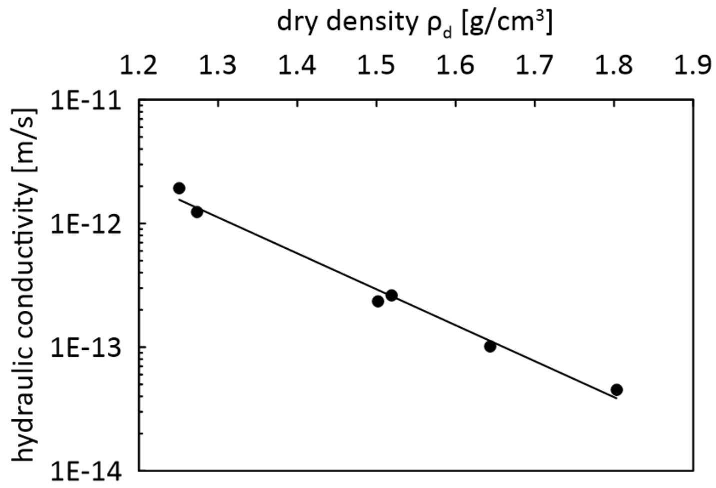
swelling pressure:



free swelling:

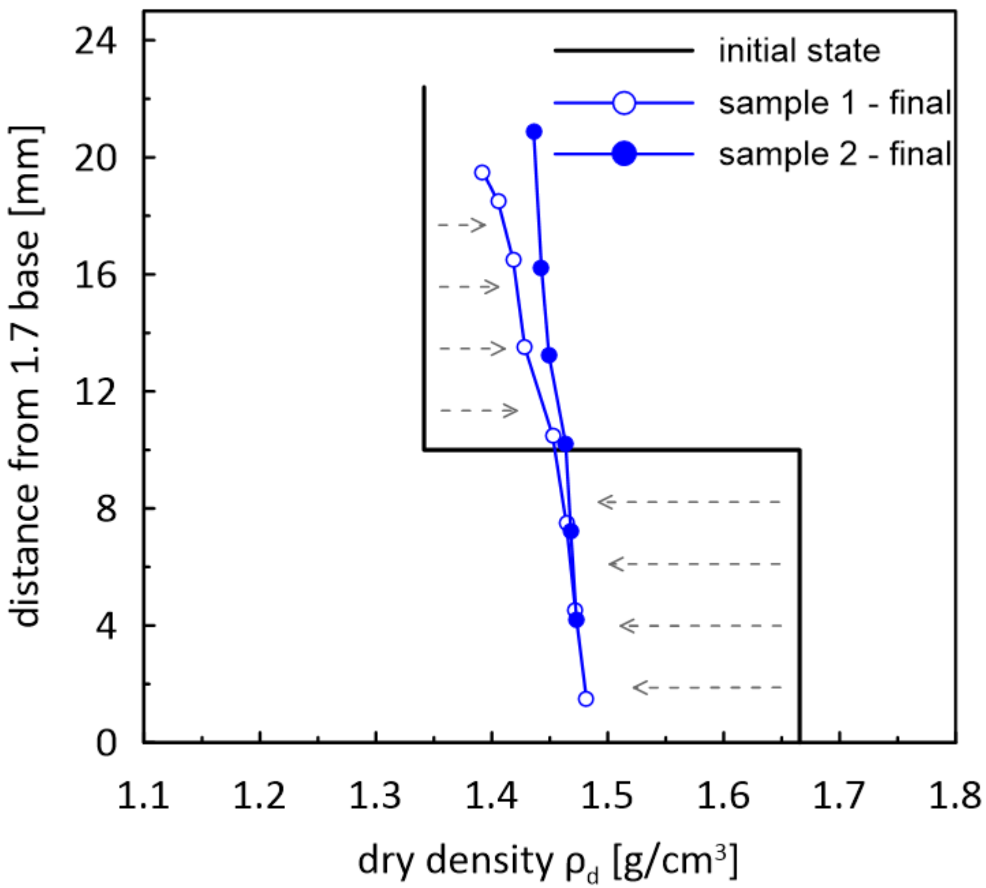


hydraulic conductivity:

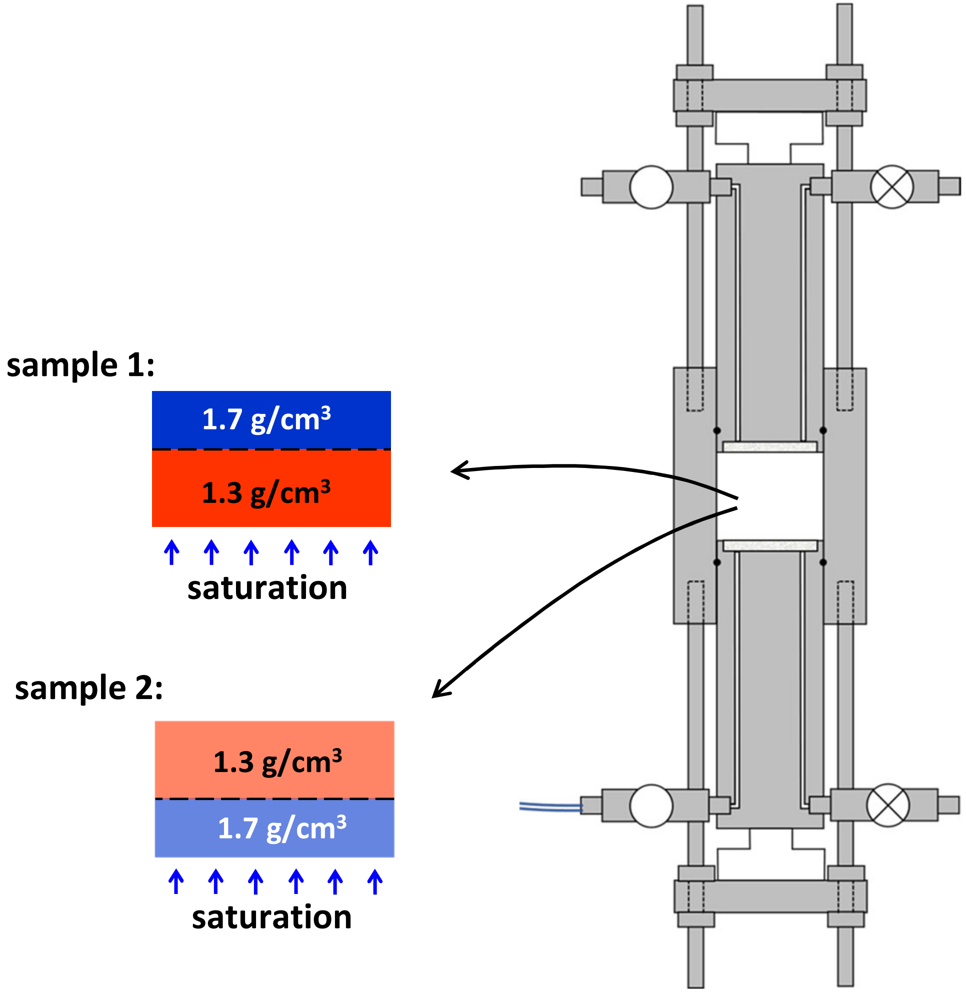


Investigation of hydromechanical properties of bentonite

HOMOGENIZATION BEHAVIOUR



Test setup for homogenization tests:



Influence of temperature on hydromechanical behaviour

TWO DIFFERENT APPROACHES

1. Testing of thermally treated samples at lab temperatures

- no effect on swelling capacity
- small effect on hydraulic conductivity
- some structural changes (mostly reversible)

→ no significant impact on hydromechanical behaviour

Influence of temperature on hydromechanical behaviour

TWO DIFFERENT APPROACHES

T-MPC cells for high-temperature tests:

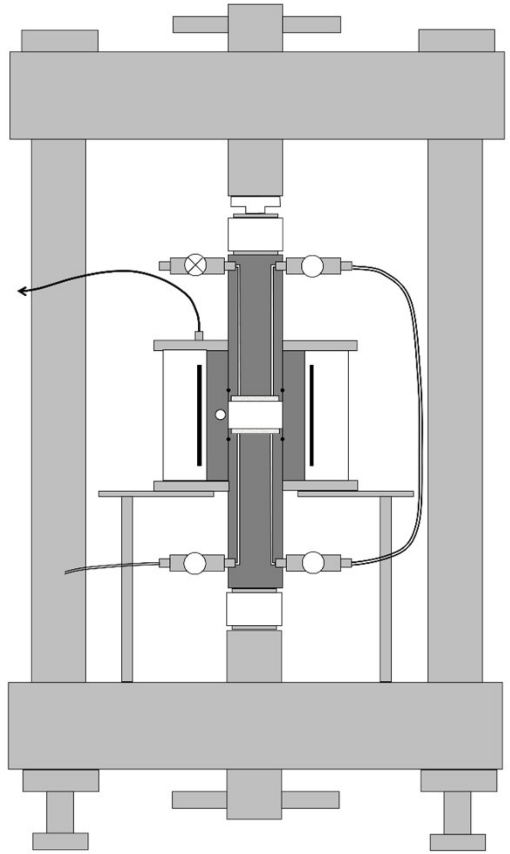
1. Testing of thermally treated samples at lab temperatures

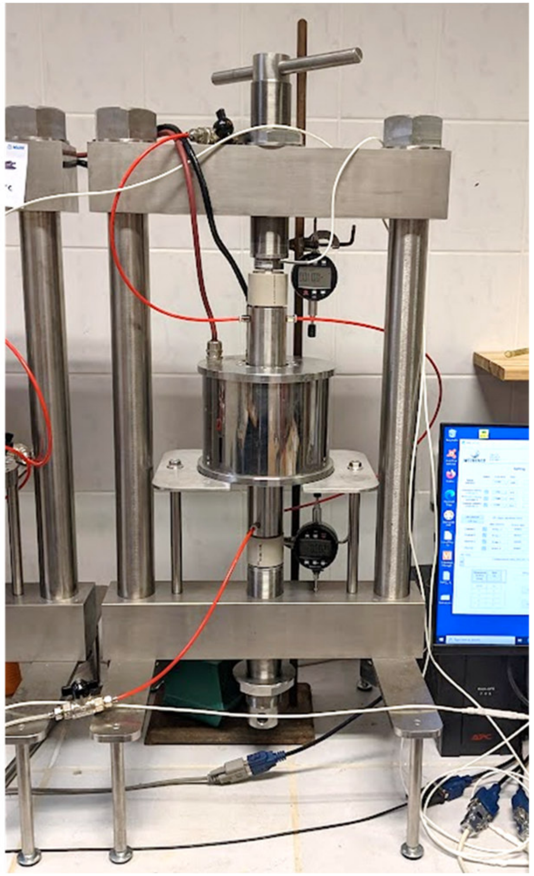
- no effect on swelling capacity
- small effect on hydraulic conductivity
- some structural changes (mostly reversible)

→ no significant impact on hydromechanical behaviour

2. Testing at high temperatures

Direct measurement of swelling pressure and hydraulic conductivity at temperatures up to 150°C

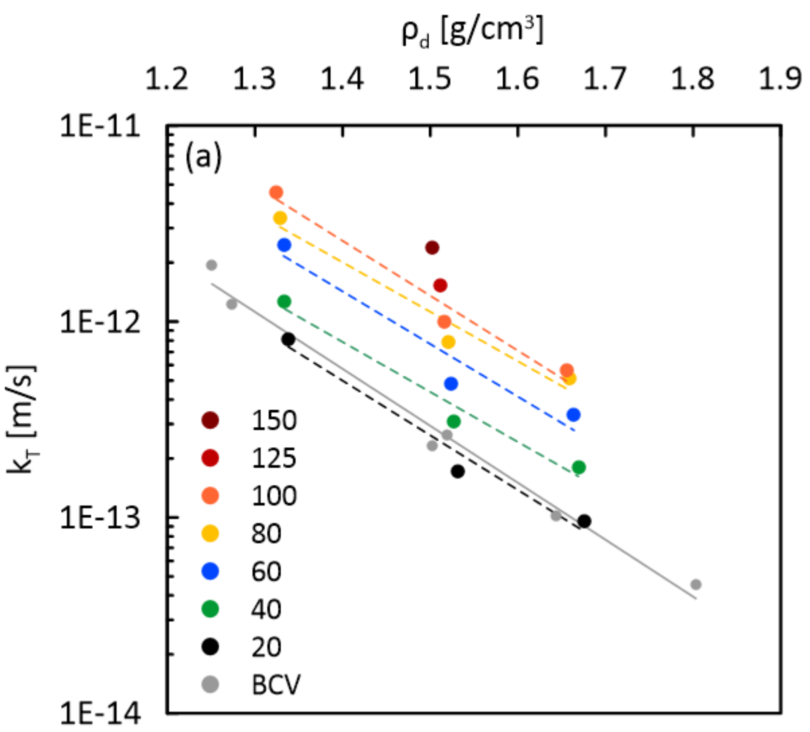




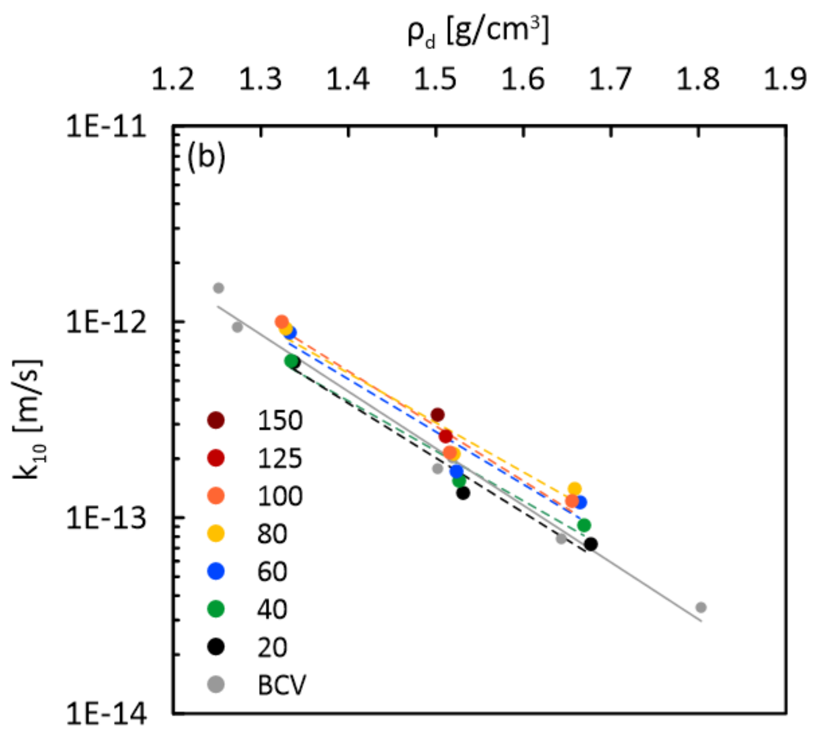
Influence of temperature on hydromechanical behaviour

HYDRAULIC CONDUCTIVITY AT HIGH TEMPERATURES:

Including changes of physical properties of water:

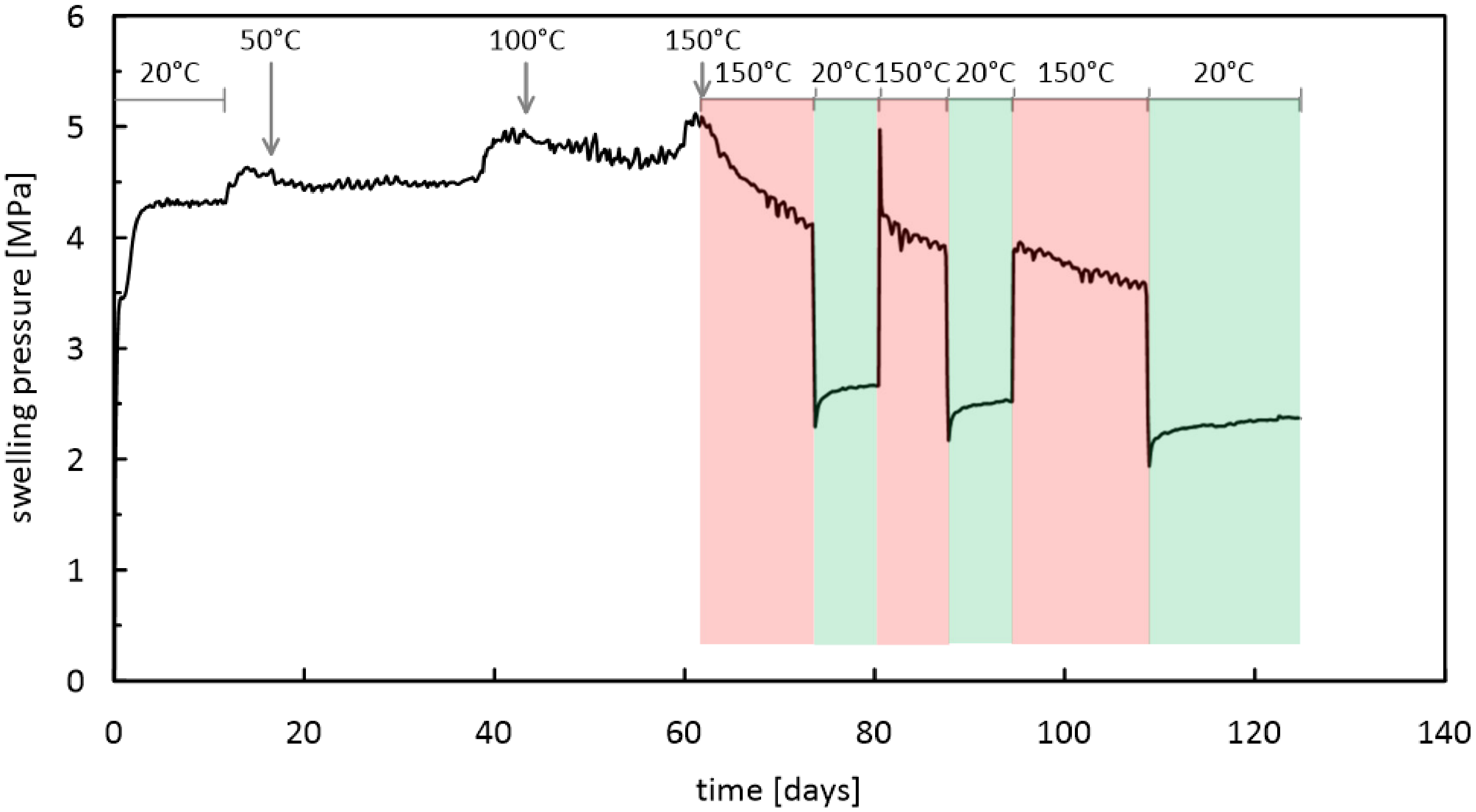


Excluding changes of physical properties of water:



Influence of temperature on hydromechanical behaviour

SWELLING PRESSURE AT HIGH TEMPERATURES:



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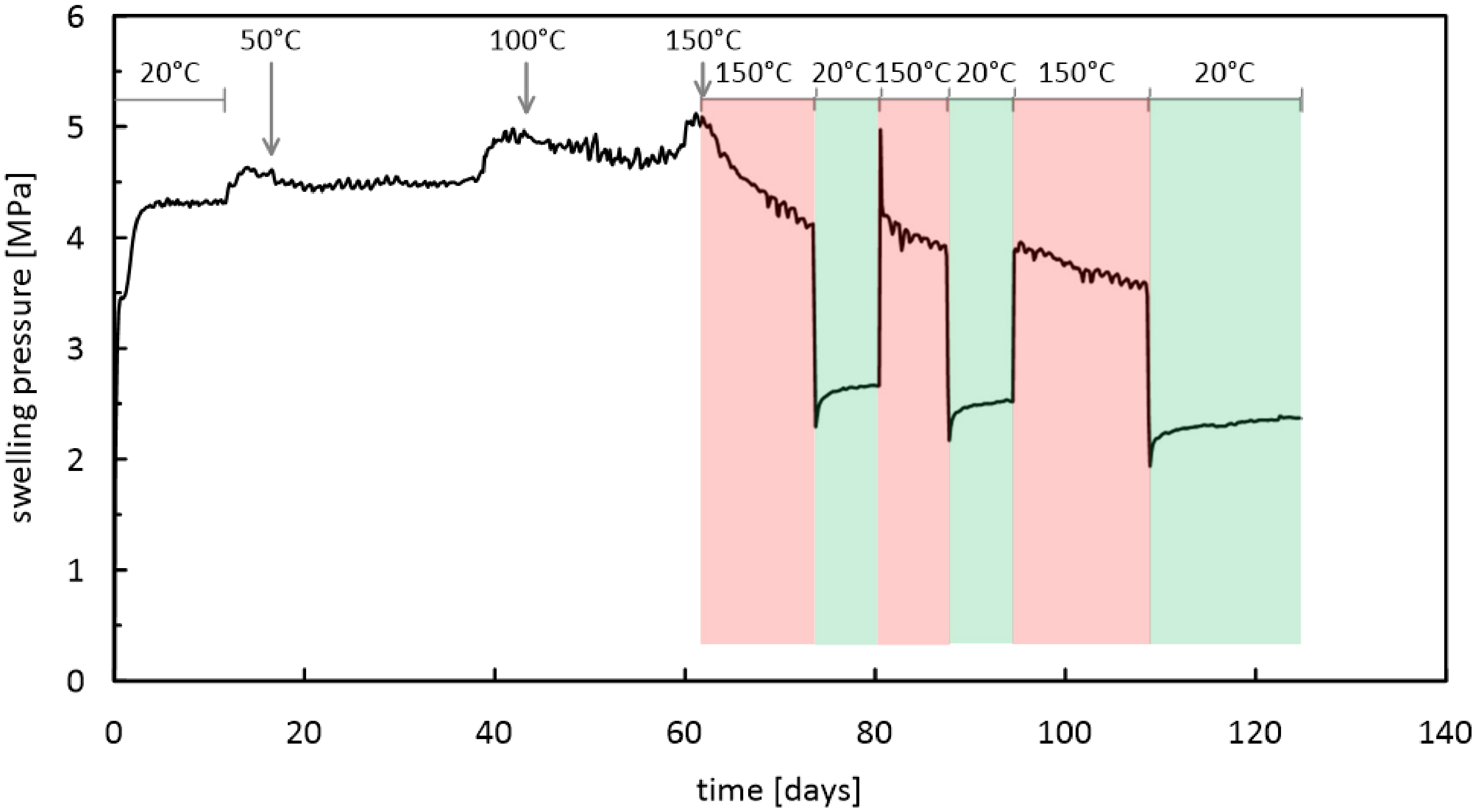

- effect of thermal relaxation identified
- rate of decrease depends on temperature and slows down in time
- decrease of swelling pressure has permanent effect (remains after cooling)
- no dramatic impact on bentonite barrier performance is expected but it needs to be quantified by numerical modelling

Summary

- A new laboratory for THM characterization of bentonites was built at Charles University in connection with the planned radioactive waste repository.
- A comprehensive hydromechanical characterization of BCV bentonite was performed.
- The very good homogenization capability of BCV bentonite during saturation was demonstrated.
- The effect of temperature on the hydromechanical properties of BCV bentonite does not significantly limit its use in deep repository barriers.
- The thermal relaxation of bentonite has been newly identified and described through the conducting of advanced high-temperature tests.

Thank you for your attention