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Large-scale testing of a sandwich shaft-sealing system at the Mont Terri rock laboratory

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Interdisciplinary research symposium on the safety of nuclear disposal practices

Large-scale testing of a Sandwich shaft sealing system at the Mont Terri rock laboratory

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The Sandwich sealing system

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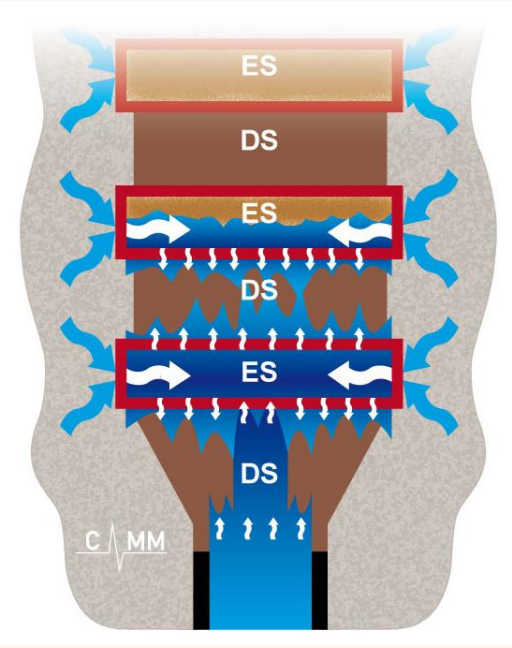
- Structure: alternating **sealing segments (DS)** of binary mixture of bentonite and **equipotential segments (ES)** for homogeneous hydration
- Advantage: seal bypass and fingering as well as high hydraulic loads are absorbed, seal element re-saturation is more homogeneous
- Patent 2002 (held by KIT-CMM)
- Functional demonstration in semi-scale experiments
- A **large-scale test** taking into account the interaction with the host rock was planned in an international pre-project (2017-2019)
- In-situ implementation was started at the **Mont Terri Rock Laboratory** in 2019 (project **Sandwich-HP**)



Sandwich-HP: objectives and organization

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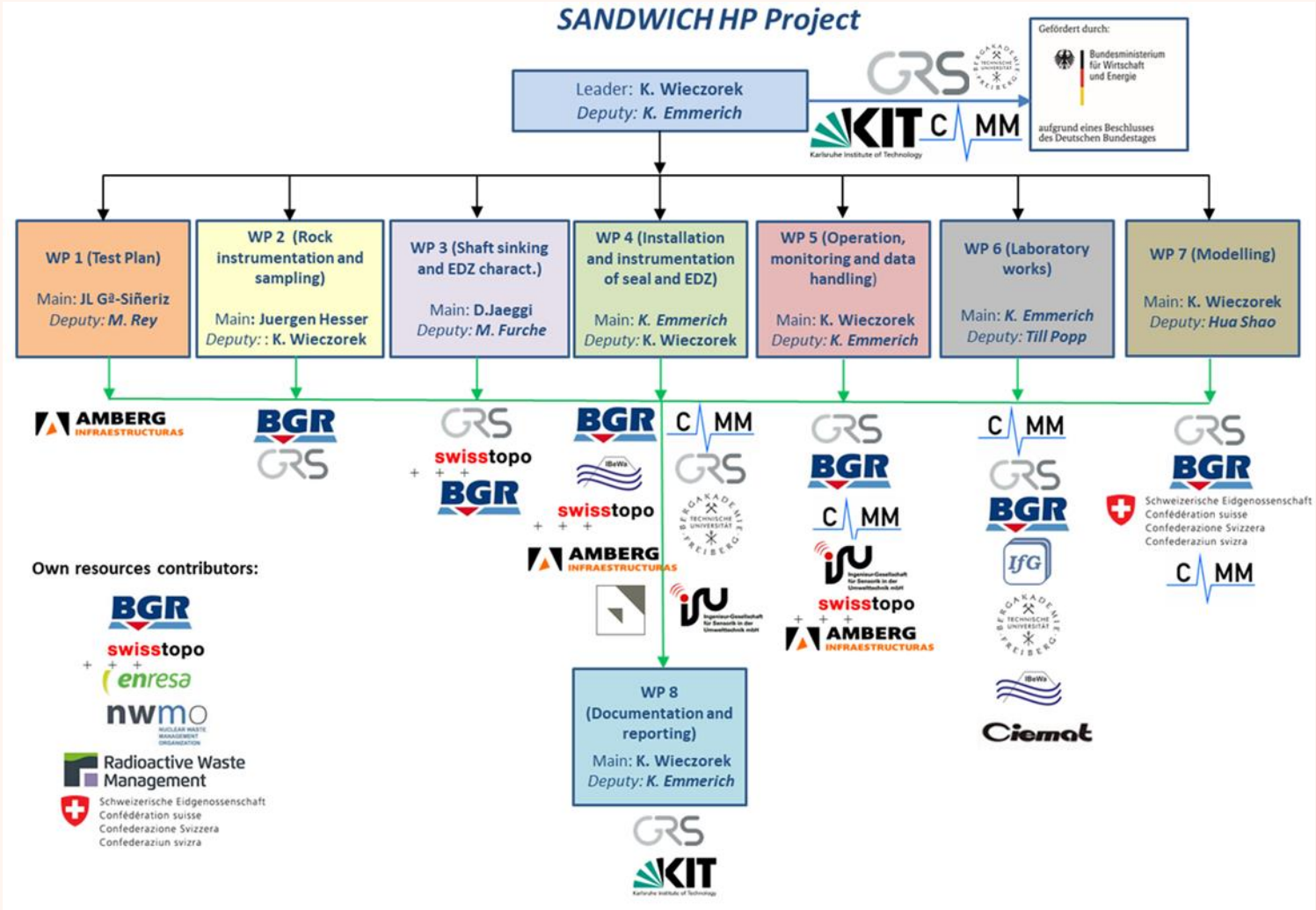
Objectives

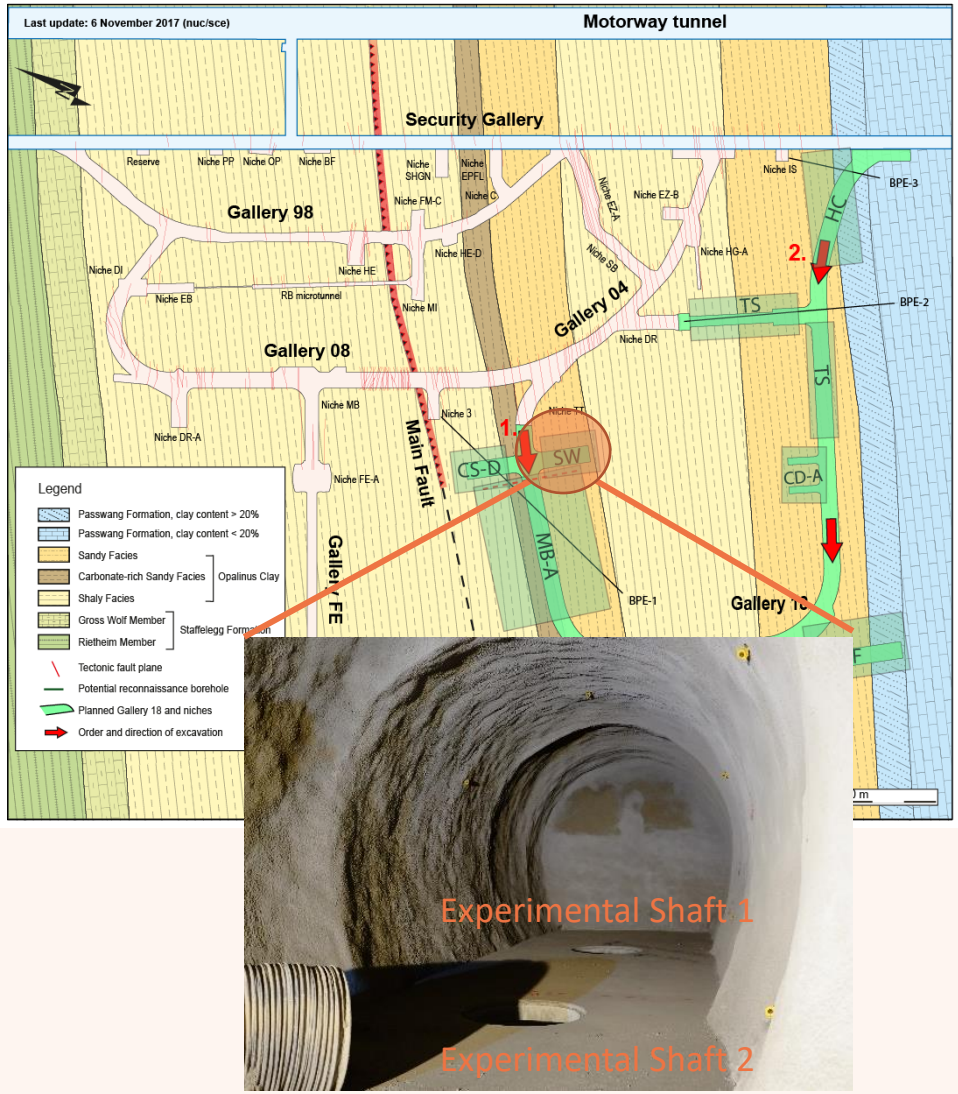
- Demonstrate the **feasibility of installation**
- Investigate the **re-saturation process**
- Qualify **measurement and monitoring** techniques
- Assess the **sealing effectiveness** (at a later stage of the experiment)

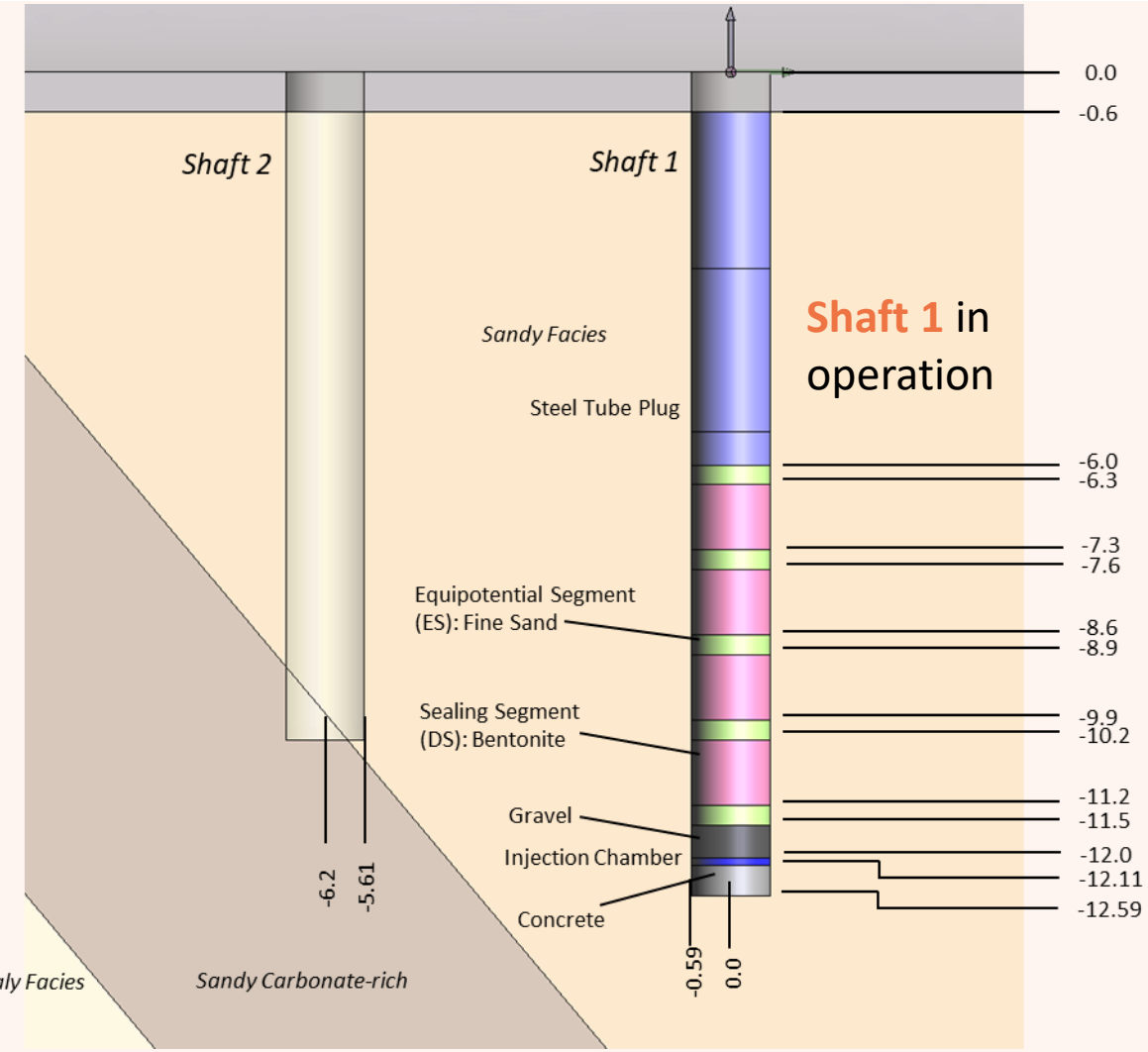
Partners: KIT-CMM, GRS, BGR, Swisstopo, Enresa, ENSI, NWMO, RWM, TUBAF

Contractors: Amberg, CIEMAT, ISU, IBeWa, IfG, SSKG, Schützeichel, Solexperts, Glötzl, VSH



Test site and configuration





Shaft 2 installed 1-1.5 years later: pronounced EDZ, modified configuration

Rock mass instrumentation and response to shaft sinking

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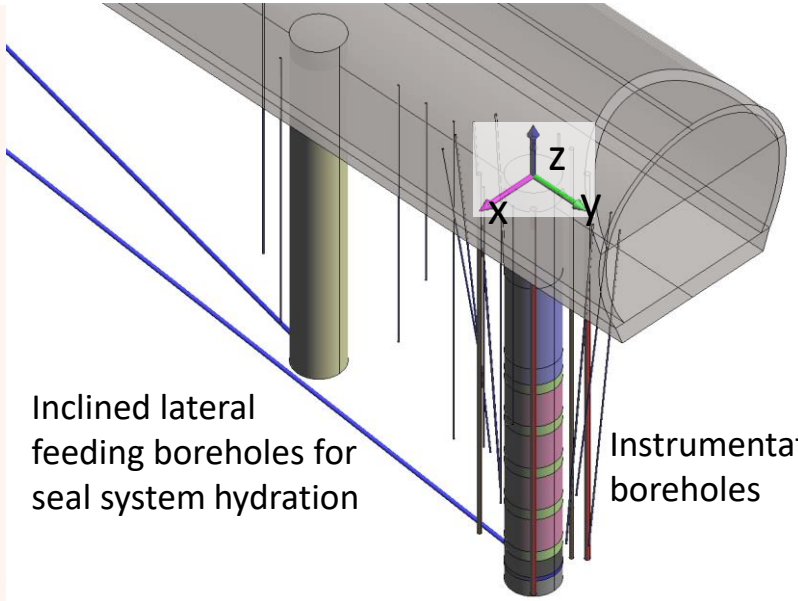
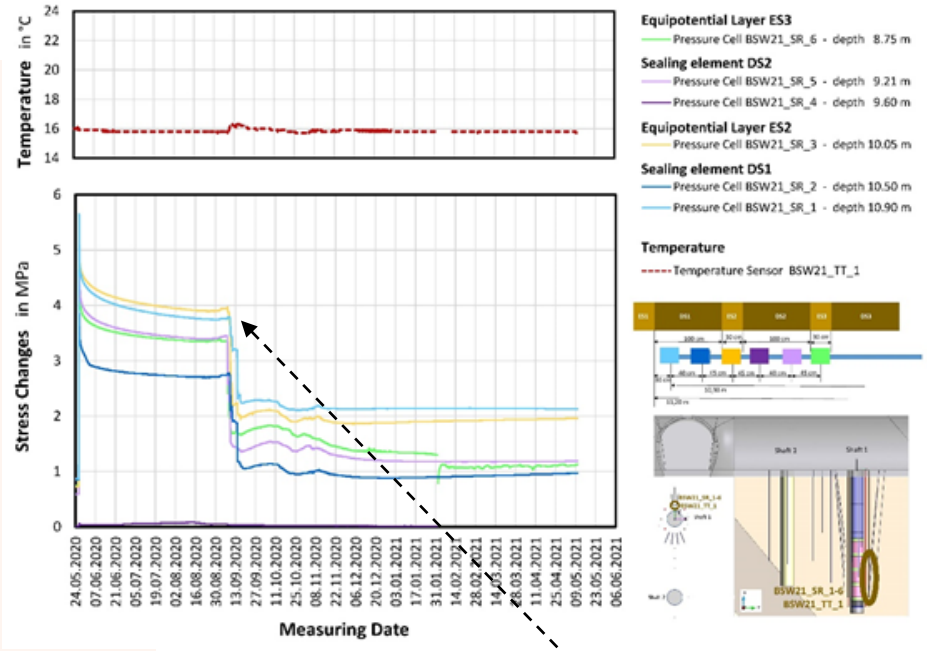
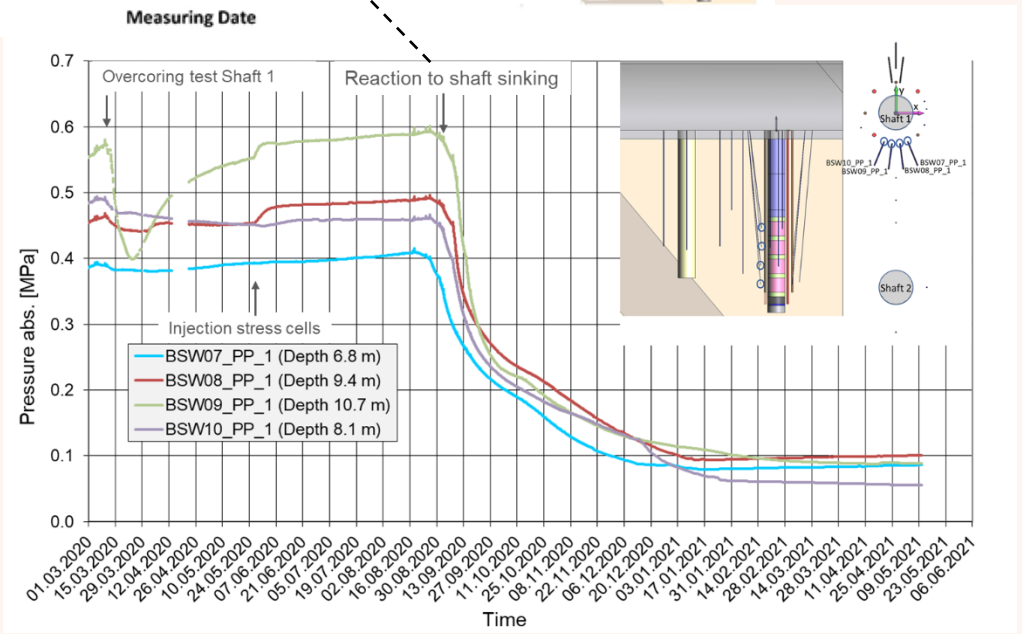




Rock mass instrumentation was performed between August 2019 and March 2020.

- Minipiezometers for pore pressure measurement
- Flat cells for stress monitoring
- Boreholes for seismic and geoelectric measurements



Shaft sinking and related work

August – November 2020

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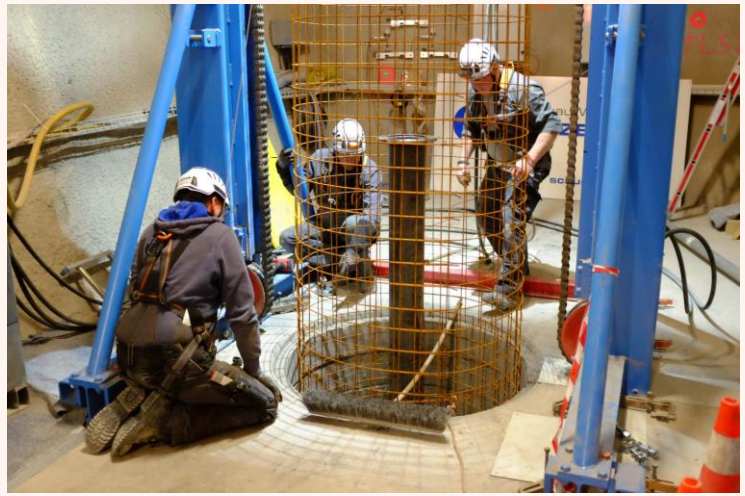
- Drilling and lining of inclined feeding boreholes
- Shaft sinking by core drilling : Drilling of both shafts within 11 weeks
- Installation of wire mesh support and ladders
- Installation of pressure chamber at shaft bottom
- Permeability measurements on shaft contour (surface packer), seismic measurements
- Installation of electrodes for electric resistivity tomography (water content)



Emplacement of sealing system and shaft instrumentation

November – December 2020

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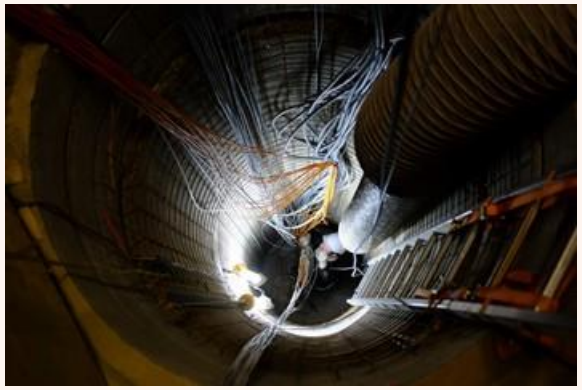
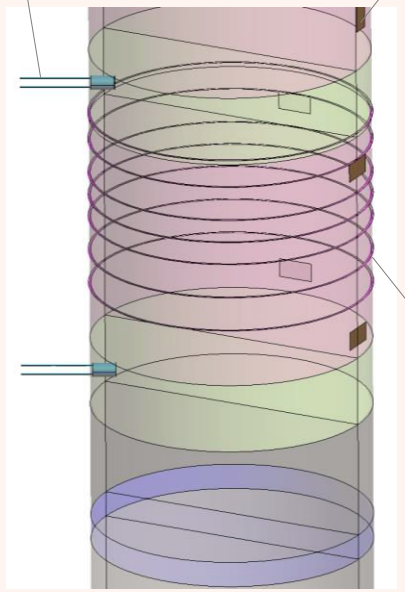
Materials emplaced in about decimeter layers and compacted

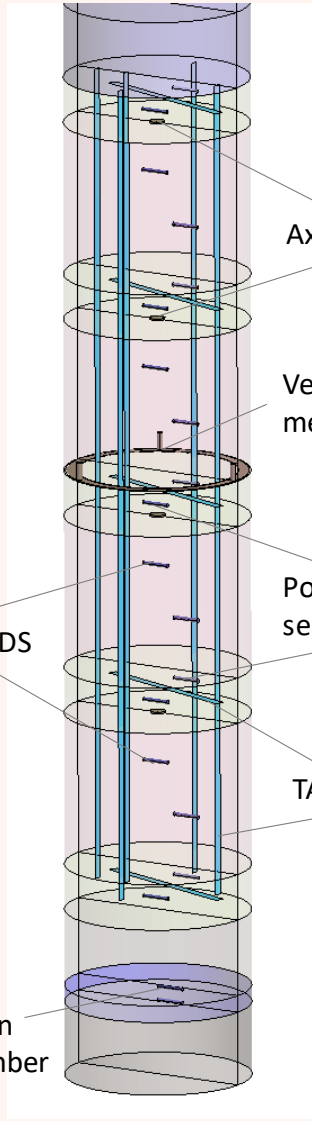
- Sealing segments: pillows and crushed pillows of Calcigel (German Ca-bentonite)
- Equipotential segments: fine-grained quartz sand

Instrumentation and cables embedded in the material

- ERT electrode rings / rod TDR (shaft wall)
- TAUPE TDR (water content)
- Water pressure
- Relative humidity / temperature
- Radial stress (shaft wall) and vertical stress
- Axial displacement







Installation of plug and hydration system

January – May 2021

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Start of hydration (May 18, 2021)

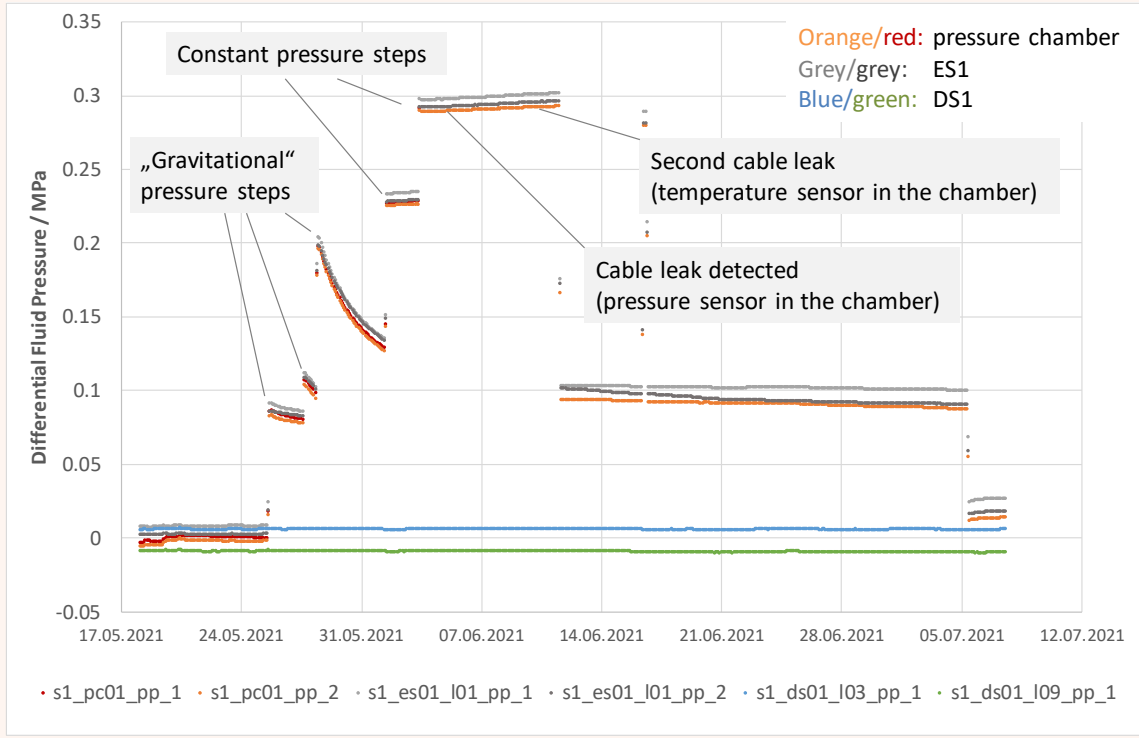
Hydration with artificial pore water (Pearson water type A3)

- Gravitational filling of feeding borehole, pressure chamber (and gravel) and ES1
- Low / high pressure hydration (up to 0.9 MPa / 2.5 MPa) by applying gas pressure on respective water tank, injection pressure is increased stepwise

Two cable leaks detected in June 2021, both concerning sensors located in the pressure chamber

- Injection pressure removed and water level in the feeding borehole lowered
- Both cables sealed with sheaths reaching into the uppermost ES5

Hydration resumed on 12 July



Water ingress / cable leakages (August 2021)

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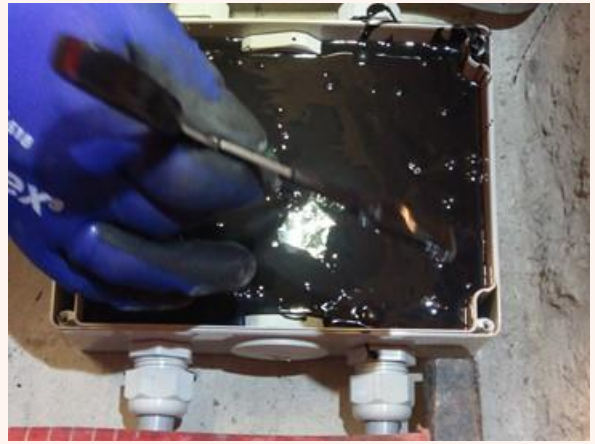
- 11 August (after injection pressure increase from 5 to 8 bar): the water tank emptied into the shaft and the pressure was lost
- Afterwards, water found in pore pressure sensor cables and ERT electrode cables
- Explanation: Water bypassed DS1 (possibly via contour) and reached sensors with untight cables
- Capturing bypassing water is just the functionality of the Sandwich seal!
- All ERT and pore pressure cables sealed using connection boxes filled with resin (effective if the cable insulation withstands the inside water pressure – has been tested)
- Hydration will be resumed in November 2021 with a first pressure step



Sensor reaction to water ingress

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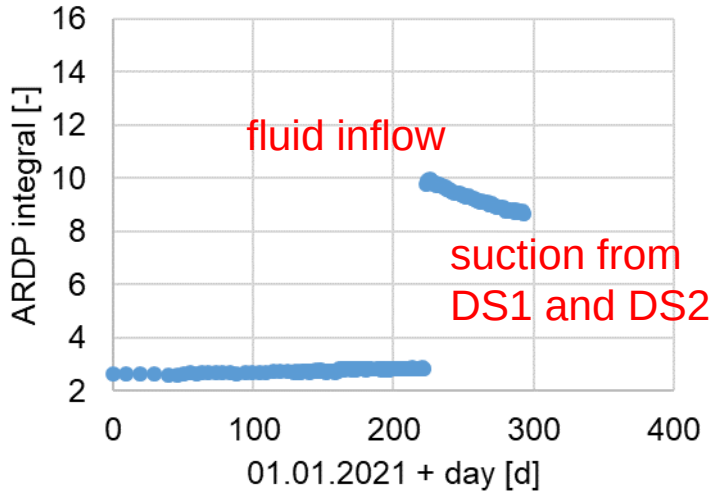
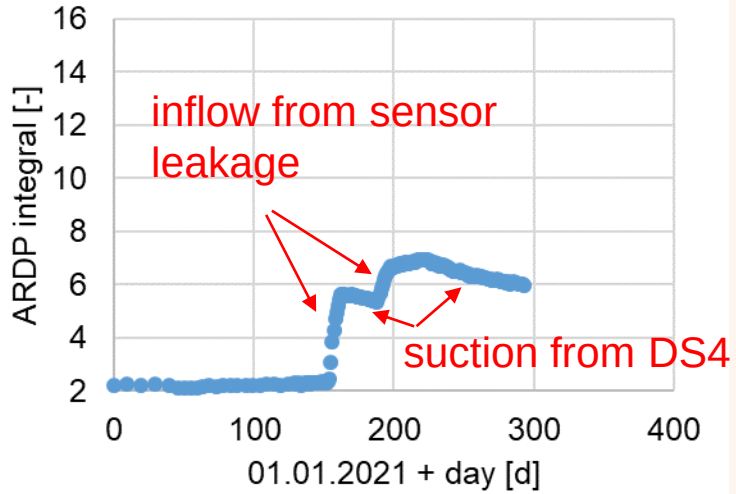
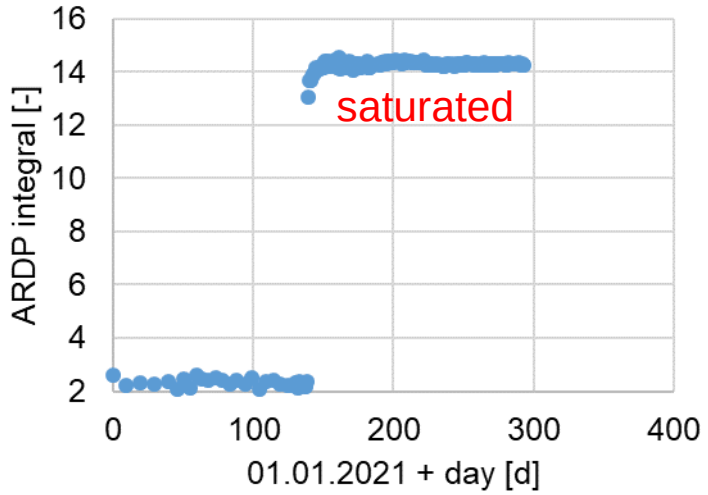
TAUPE TDR



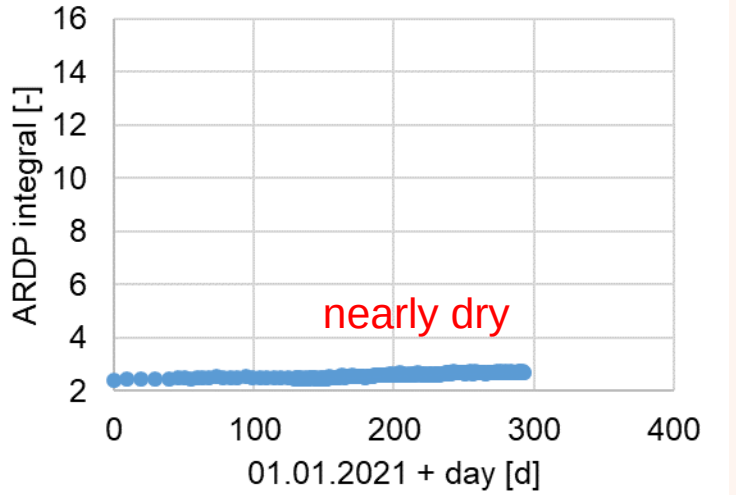
S7h
ES2



S10h
ES5
top



S6h
ES1
bottom



S8h, S9h
ES3, ES4

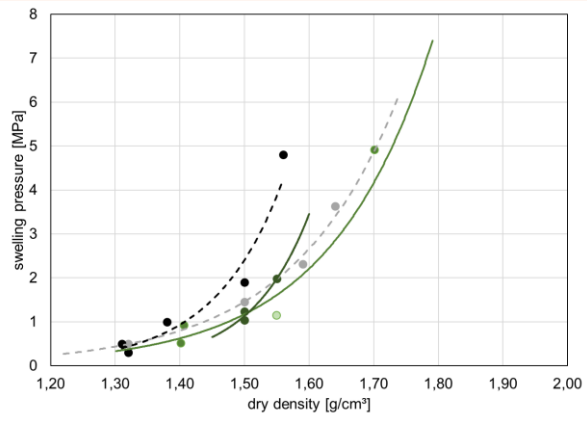
Lab testing (Scale transition)

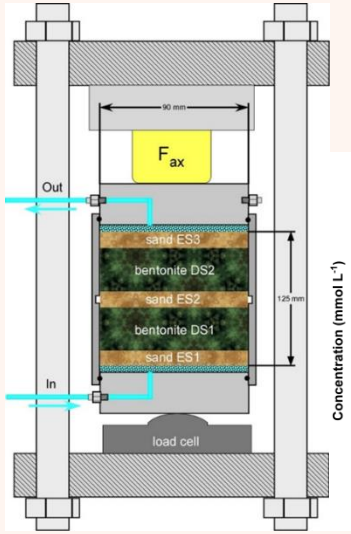
Semi-technical scale
d=0.8 m; h=1.45 m

Objectives

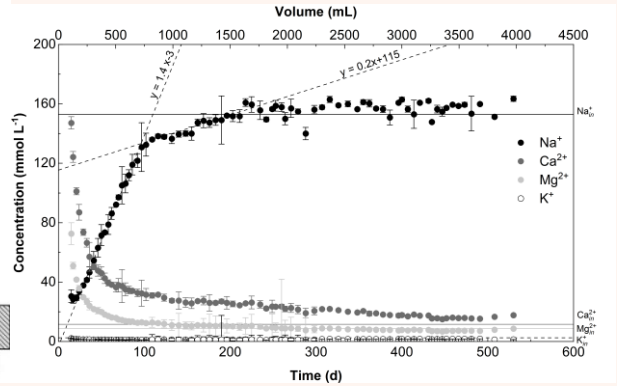
- Functionality under fluid inflow pressure up to 100 bar
- Development of binary mixture of bentonite pillows and granular bentonite material (GMB) for DS (pillow geometry, compaction method for powdered and granular bentonite, grain size distribution of GBM)
- Characterization of HMC behavior (hydration, swelling pressure, permeability, ion transport, cation exchange) of two national Ca-bentonites for different dry densities and initial hydration state

Oedometer
d=0.036-0.10 m; h=0.012-0.02 m

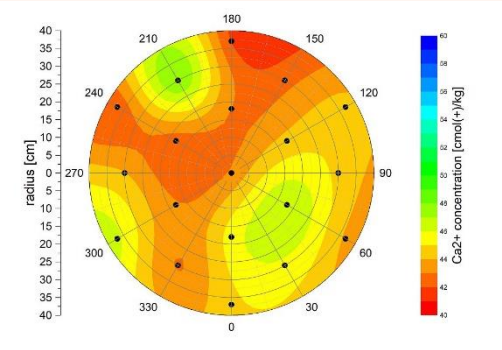




MiniSandwich
d=0.09 m; h=0.12 m



Mineralogical/chemical analyses



Rölke et al. 2019 / Emmerich et al. 2021

Model simulation

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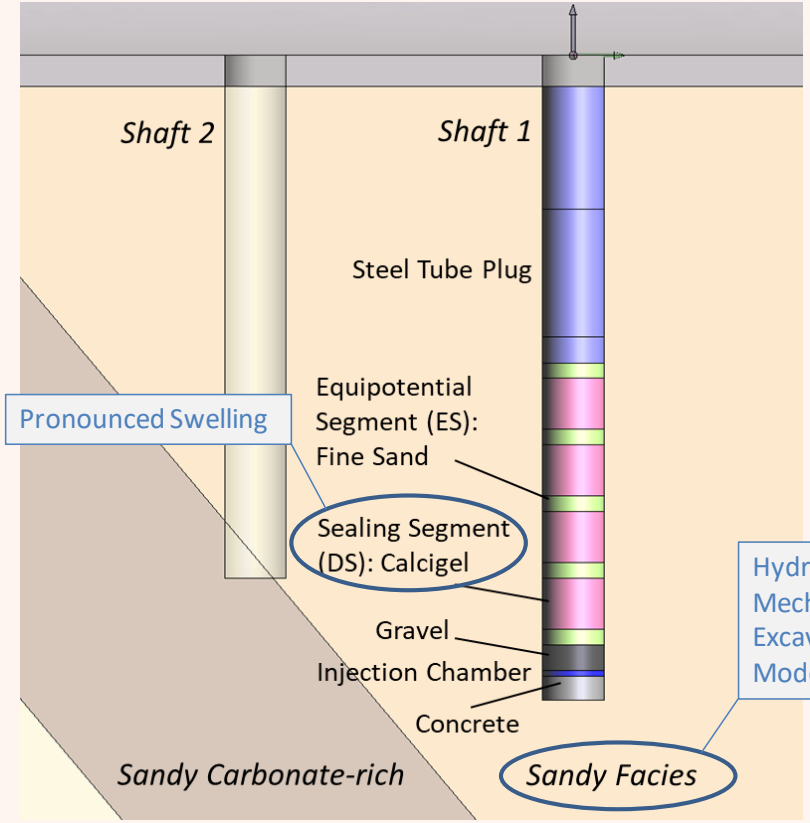
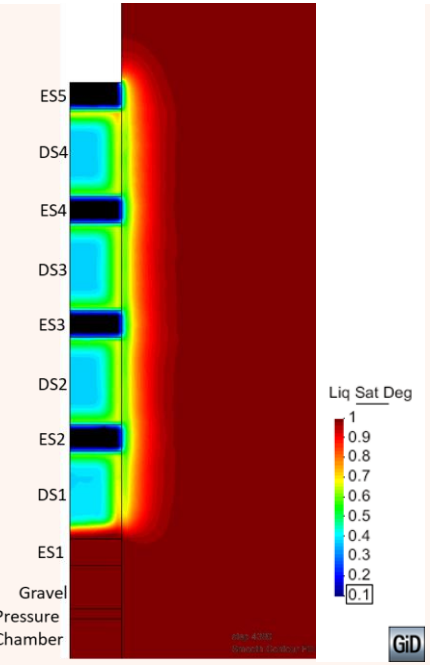
Three teams (BGR, ENSI, GRS) performing comparative and complementing simulations

Scoping calculations (already performed in the pre-project)

Interpretative hydromechanical (HM) simulations

- Needed for the evaluation and interpretation of the in-situ experiment
- Require suitable calibrated material models, good knowledge of boundary conditions, and an adequate geometrical representation
  - Model calibration using existing lab tests (e.g., MiniSandwich, swelling pressure tests)
  - In-situ measurements to obtain actual conditions (e.g., stress state, pore pressure)
  - Geometry and model complexity adapted to specific question





Simulation of liquid saturation distribution after 100 days of hydration

Current status and next steps

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Status

- In-situ experiment is about 1 year delayed, due to Covid and cable tightness issues
- Laboratory experiments and modelling run as planned

First results

- Shaft sinking and sealing system installation proved successful
- Sandwich sealing system shows expected function, sensors work satisfactorily
- Special care required with respect to sensor cable tightness – testing instead of producer information

Next steps

- Resume hydration in Shaft 1 with stepwise pressure increase
- Plan Shaft 2 installation
- Proceed with lab experiments and modelling

Thank you!

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Any questions?

Supported by:

Federal Ministry of Economics and Energy

on the basis of a decision by the German Bundestag

The Sandwich experiment is funded by the German Federal Ministry for Economic Affairs and Energy under contract 02E11799 A+B.