IGD-TP Exchange Forum 7 – Cordoba, 25-26 October 2016.

Working Group 3:

High Temperature Clay Interactions

→ High Temperature Consequences

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nagra.

Drivers for this session

- For the disposal of HLW assessing the consequences of the heat produced is important.

- While the heat pulse has no direct impact on the radionuclide transport it might affect the long-term performance of either the:
    - engineered clay barriers (bentonite)
    - natural barriers (COX, OPA, Boom Clay)

  with respect to fulfilling their safety functions.

- These impacts become more significant with increased temperatures. In several safety cases a maximum temperature of 100°C in the buffer has been formulated as an upper threshold, while in other safety cases it is conservatively assumed that part of the buffer will deteriorate partly due to thermal impacts.

Drivers for this session

- Being able to accommodate higher temperatures (above 100°C) while ensuring similar safety standards can have significant advantages with respect to:
  - disposing of higher enrichment/burn-up fuels,
  - interim storage requirements, (re)packaging of the waste, reducing the total numbers of canisters,
  - optimising tunnel spacing and canister spacing in the emplacement tunnels – repository footprint.
- Solid assessment of the impact of increased temperatures requires that the underlying scientific understanding at these higher temperatures is sufficiently established.
- This will form the basis of enhanced optimisation of the proposed repository concepts in terms of safety and cost and might also affect siting (required footprint).

Drivers for this session

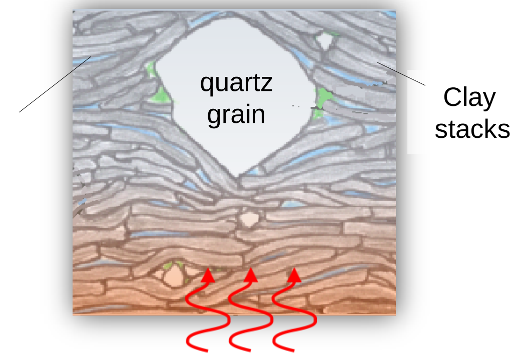
- Even if a higher design temperature is not considered, assessing the barrier behaviour at high temperature is worthwhile, because temperature increases the rate of many processes and helps to detect otherwise slow processes.
- This may help in the quantification of processes taking very long time at (lower temperature) repository conditions.

Where are the scientific issues – area 1

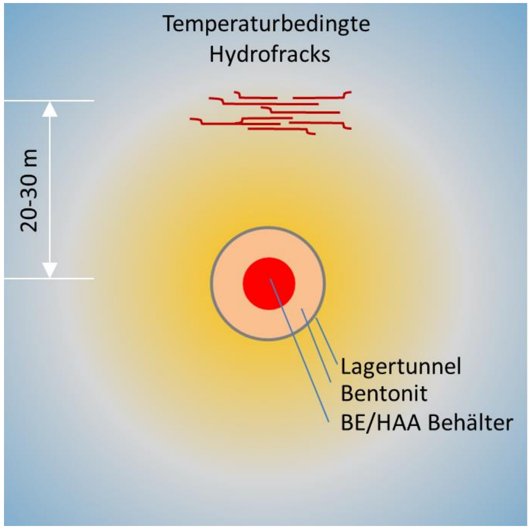
- Geochemical changes (e.g., cementation, illitisation, gas production) in the backfill/buffer and the host rocks might affect safety relevant properties such as swelling pressure and strength.
- Thermal impact on bentonite has been thoroughly assessed and characterised for temperatures up to 100°C. In the range between 100-150°C recent studies indicate that the impact is unlikely to be substantial although the characterisation is less advanced than at lower temperatures.
- At temperatures above 150°C more prominent geochemical changes are expected, but experimental evidence is scarce.
- Characterising the safety relevant properties at higher temperature (100°C-200°C) would be advantageous in that less conservative criteria would allow for optimisation in the canister loading and thermal output constraints.

Where are the scientific issues – area 2

- Higher T can impact the host rock hydrodynamically and geomechanically (deformation, fracturing).
- In low permeability clayey host rocks, thermal overpressures in the nearfield, reaching up to several MPa, need to be constrained
- Overpressures are being investigated at the URL scale for temperatures above 100°C (e.g. FE-experiment in Mont Terri URL) as well as using large scale numerical models.
- Hydraulic and geomechanical consequences in the farfield and the feedback to design is a topic of interest in terms of upscaling of the process understanding including coupled hydraulic-geomechanical behaviour



thermal expansion of porewater 10 x higher than the thermal expansion coefficient of solid skeleton



What is available for resolving the issues

- Both tested and new experimental techniques and setups
  - constant volume/constant pressure cells
  - special transparent oedometer cells allowing x-ray tomography
  - Small angle X-ray scattering (SAXS), nuclear magnetic resonance (NMR)
- New interpretation approaches
  - dynamical swelling models
- Enhanced modelling tools
  - THCM coupled codes
  - Large-scale modelling using geodynamic approaches
- Underground laboratories for medium/large-scale testing

Experimental techniques and setups

200 L. Massat et al. / Applied Clay Science 124–125 (2016) 197–210

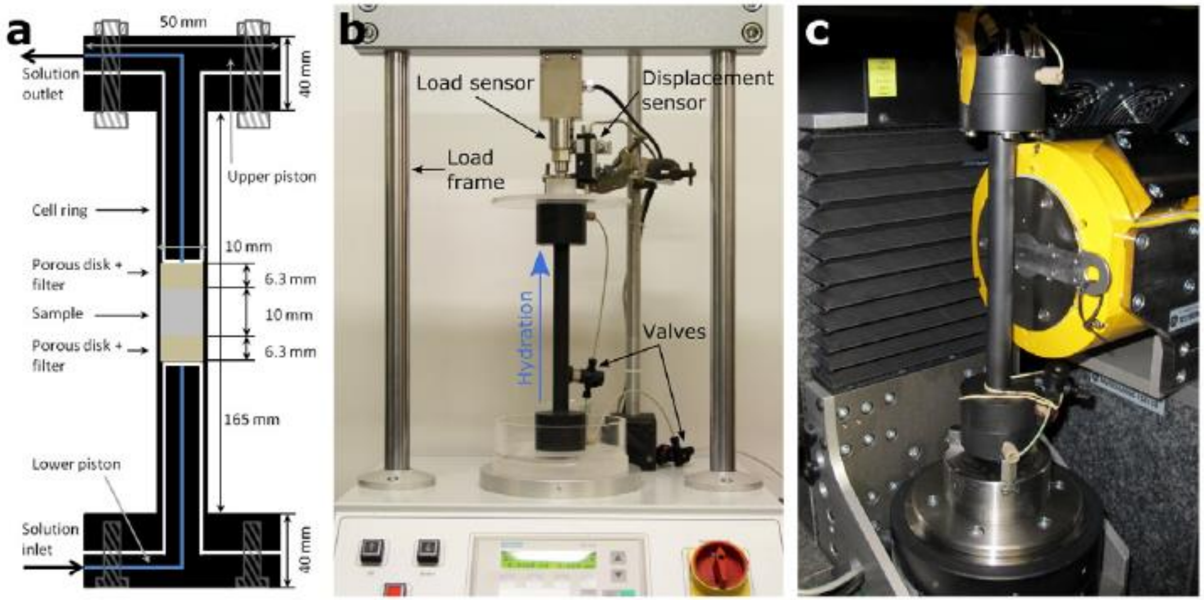
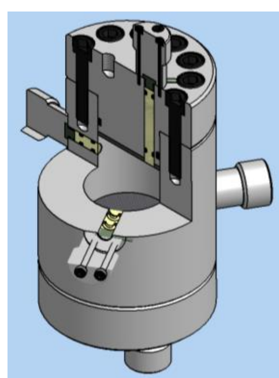


Fig. 3. Representation of the new designed oedometer cell at constant volume: (a) schematic layout, (b) cell with upper piston unscrewed into load frame and (c) cell with upper piston screwed and installed into X-ray tomograph.

Transparent oedometer cell (BRGM)



Constant volume cell (BGS)

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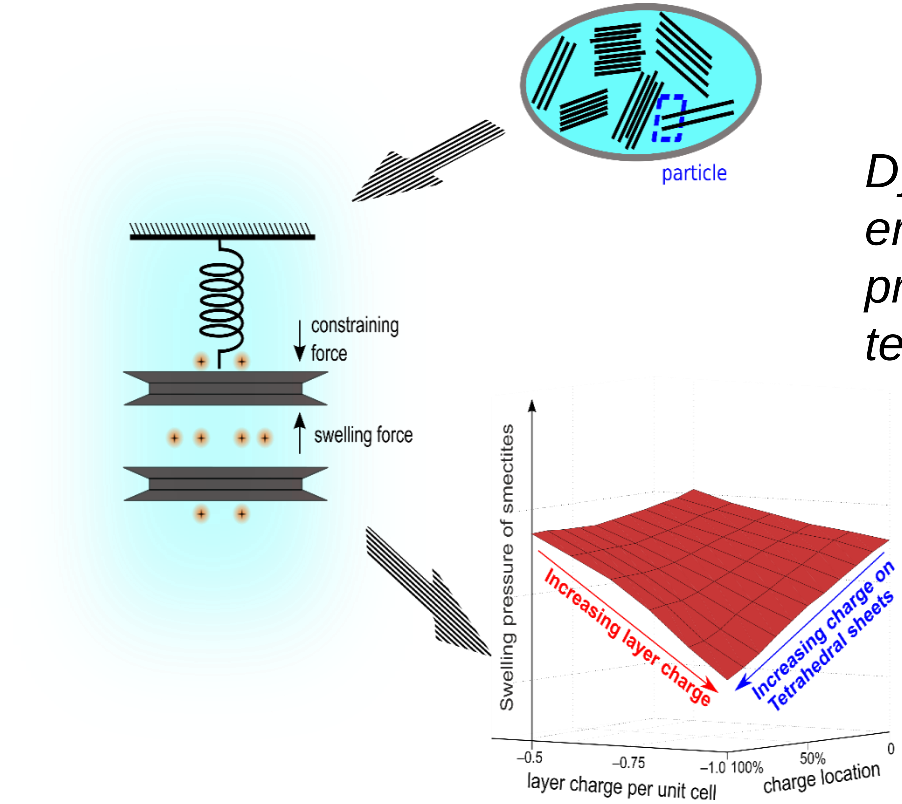
Dynamical swelling model



Dynamical swelling model, enables prediction of swelling pressure as a function of temperature (VTT)

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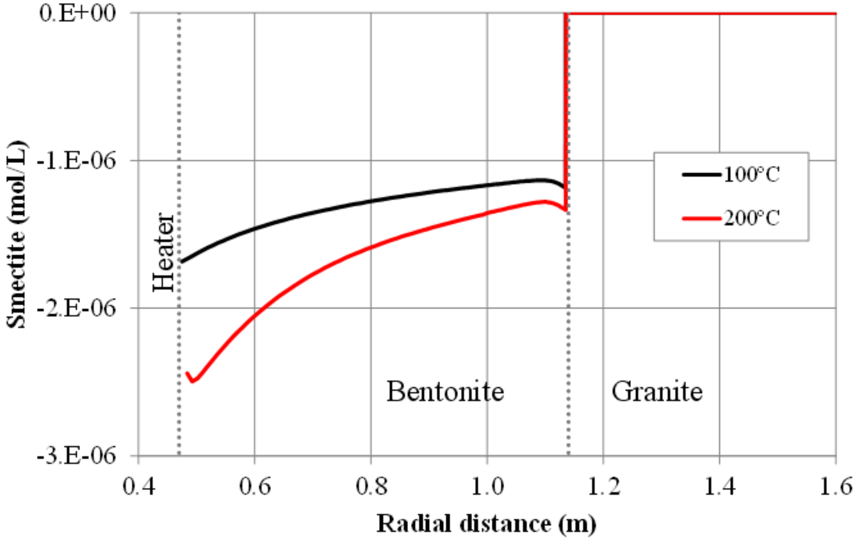
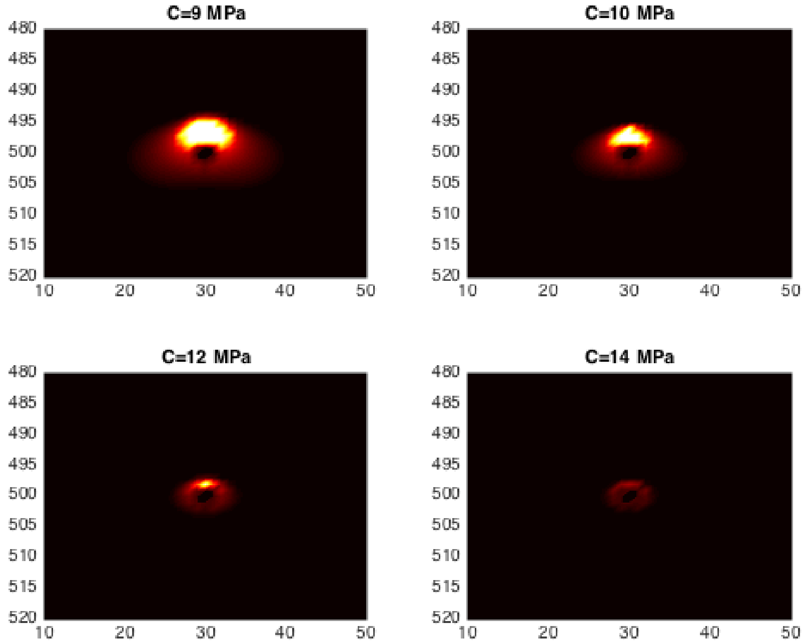
Enhanced modelling tools



Enhanced smectite dissolution and increased temperature (UDC)



Identified micro fracturing zones for different cohesion values (9-14 MPa), THM code adapted from plate tectonics (AF Consult)

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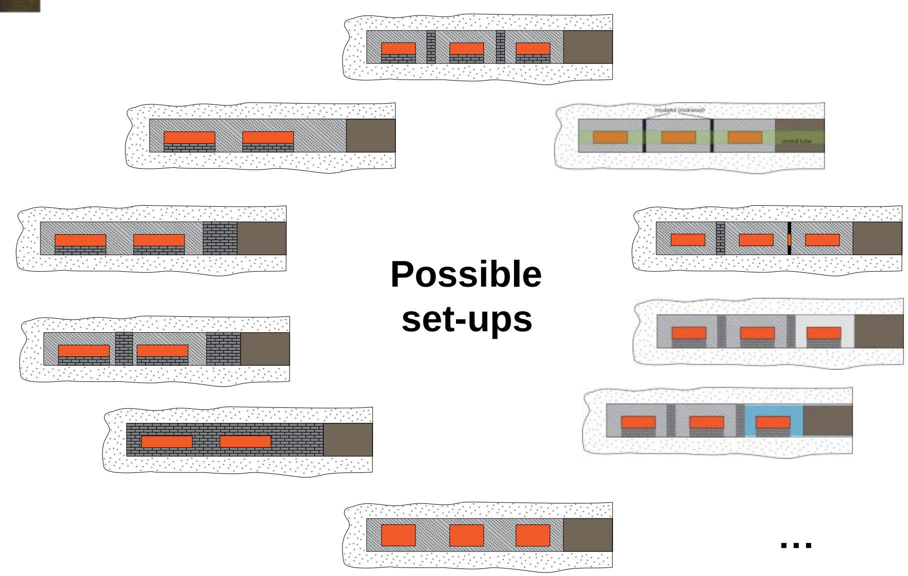
- Underground laboratories for medium/large-scale testing (separate funding)

Underground laboratories

Mock-up experiments at Josef Mine (CTU)

Possible configurations of HotBent at Grimsel (NAGRA)



Discussion results

- High temperature effects are important not only for clay-based engineered barriers and clay host rock, but also for other types of EB and host rock
- High temperature effects will be varying widely depending on other conditions (e.g., high T and low pore pressure <> high T and high pressure)
- Process understanding should go beyond the actual design conditions
- High T investigation may also develop arguments to justify optimisation limitations towards repository financers
- The high temperature topic has the potential for a joint progamme → clear interest from WMOs
  - SKB, POSIVA: optimisation of current concept
  - ANDRA, NAGRA, ONDRAF: THM in clayrock at higher T
  - Programmes facing site selection (RWM, Germany)

JP Structure: High Temperature Consequences (HiTeC)

Drivers
- Optimisation of repository lay-out
- Setting safety margins at high T
- Siting (repository footprint)

WMO

Analysis/sensitivity on which aspects are worth optimising
(concept/safety case specific, also FEP check)

Engineering considerations on practicability
(concept/safety case specific)

WMO

Bentonite barriers up to 200°C

THC consequences
- Illitisation
- Cementation
- …

THM consequences
- Swelling pressure
- Strength
- Permeabilty
- Vapour and boiling effects

THM impact on clay host rock

Constitutive models, upscaling in estimating overpressures

Thermal uplift and potential reactivation of faults

Integration of knowledge from other geo-domains

Cement barriers up to 200°C

Ettringite formation and cracking

…

…

WMO, RE, TSO

nagra

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Prioritization example

WMO, RE, TSO

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Outlook and next steps

- Discussion about the topic in the IGD-TP EG → tomorrow
- If integrated in strategic research agenda (by JOPRAD) for joint programming:
  - Development of the framework (detailing the topics and assigning the priorities by the WMO's) --> long-term vision
  - Working out 1-2 topics in a 2-3 pager to be included in the next call for joint programming (expected Dec 2017)

Thank you for your attention

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and special thanks to the WG3 participants!