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

Working Group 3:

High Temperature Clay Interactions

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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)

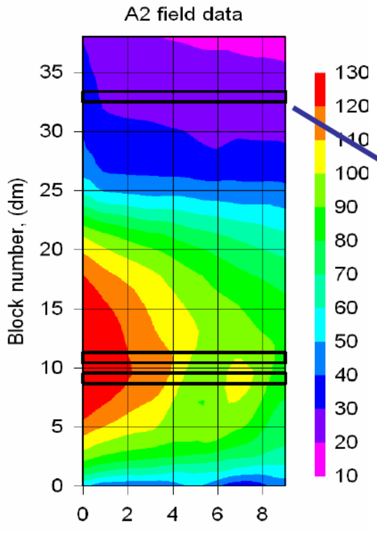
Where are the scientific issues – area 1

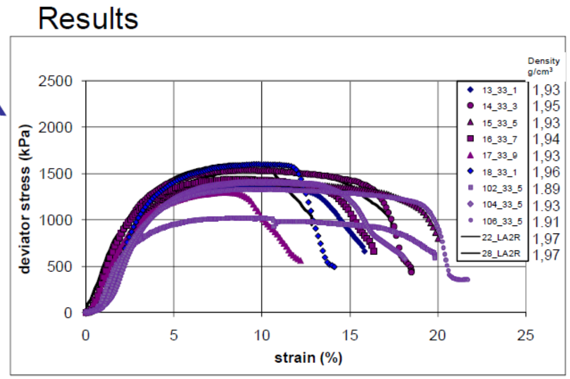
- Geochemical changes in the backfill/buffer and the host rocks might affect safety relevant properties such as swelling pressure and strength.
- Thermal impact on bentonite has been thoroughly assessed and characterised for temperatures up to 100°C. In the range between 100-150°C recent studies indicate 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.

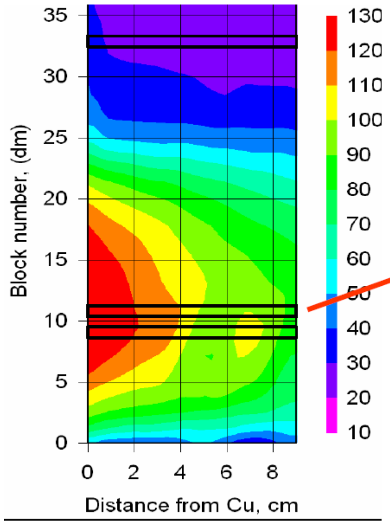
PEBS: Remaining uncertainties 1/2

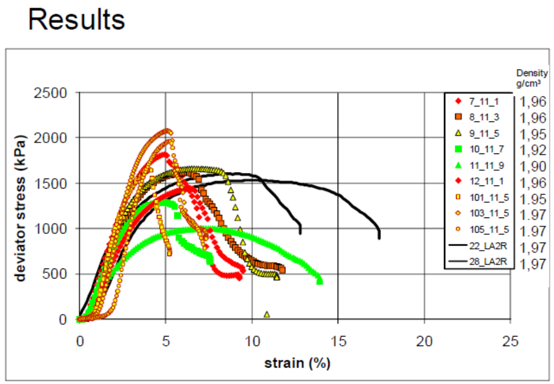
- There is no overall supported view on the relatively small impact of vapour on bentonite properties under repository relevant conditions.
- A comprehensive view on the impact of T up to 150°C on swelling pressure and hydraulic conductivity (although not dramatic) is not yet in place
  - Results from several long-term heater-buffer experiments show minor thermal transient effects:
    - Decrease in plasticity of bentonite
    - Slight decrease in hydraulic conductivity
    - Slight decrease in swelling pressure
  - Thermally-induced mineralogical transformation of bentonite likely to be very limited

Example THM Impacts at T>100°C - Cementation - decreasing plasticity (URL)









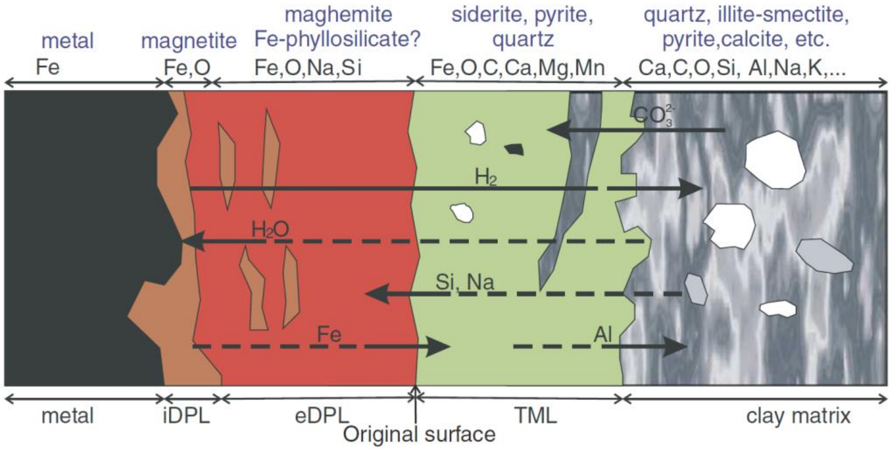
- The strain at failure is less (increased brittleness) for all the drilled specimens taken from the warm section of the field exposed material compared to the references taking the density into account.
- The special behavior of the specimens from the warm section of the field exposed material is emphasized by the occurrence of a qualitatively different course of shearing involving a more pronounced failure. In addition a nearly vertical failure surface is seen on some of these specimens after failure but not seen on specimens exposed to short time heating in the laboratory.
- The increased brittleness and pronounced failure seen on these drilled specimens from the warm section of the field exposed material is destroyed when the specimens are dried, milled and re-compacted.
  - ○ *Ann Dueck, 2008; clay technology*

Example Reduction of structural Fe and diffusion of Fe^{2+} into the bentonite

The interaction of corrosion-derived iron and bentonite deserves particular attention, not only because this may influence corrosion rates but because this may jeopardize the safety functions of the bentonite buffer. Such adverse effects include:

(1) local cementation of the bentonite via precipitation of Fe(II)/(III) oxides and hydroxides,
(2) destabilisation of the dioctahedral smectite structure (Lantenois et al. 2005),
(3) transformation of the montmorillonite to a non-swelling iron phyllosilicate, such as berthierine (Mosser-Ruck et al. 2010),
(4) dissolution of the montmorillonite via pH increase (Kumpulainen et al. 2010), or even
(5) direct interaction of H_2 with structural Fe in the smectite (Didier et al. 2012). The mechanisms leading to these adverse effects are still poorly understood. Moreover, their relevance for long-term safety is unclear.

ABM Block 7; picture by U Mäder (NAB 11-19)



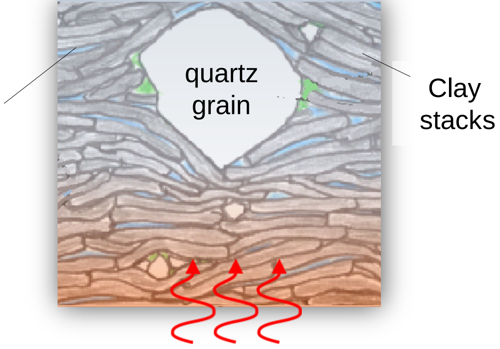
- Schlegel, M. L.; et al. Metal corrosion and argillite transformation at the water-saturated, high-temperature iron-clay interface:; Appl. Geochem. 2008, 23 (9), 2619-2633.

PEBS: Remaining uncertainties 2/2

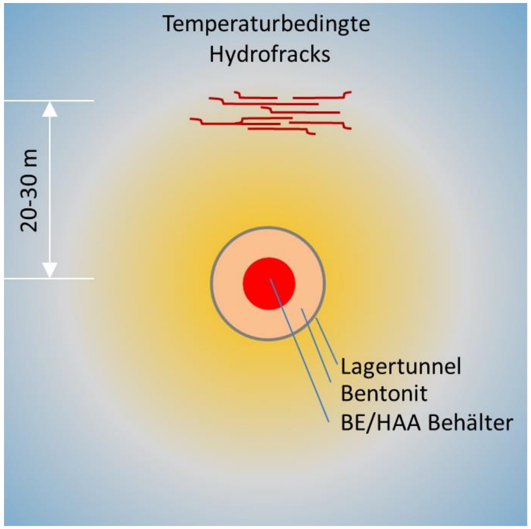
- Iron-bentonite impacts remain uncertain
  - Potential to reduce swelling and cause cementation
- The impact of chemistry induced by reactive gases in partially saturated bentonite under suction (potentially causing changes in underlying thermodynamic laws) has not been investigated and has not been constrained (potentially relevant for long unsaturated time periods at elevated temperatures).
- The relation between thermal conductivity and degree of saturation needs further data support and upscaling, its correlation with retention curves could be further investigated to support the assessment of the resaturation time and progress

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

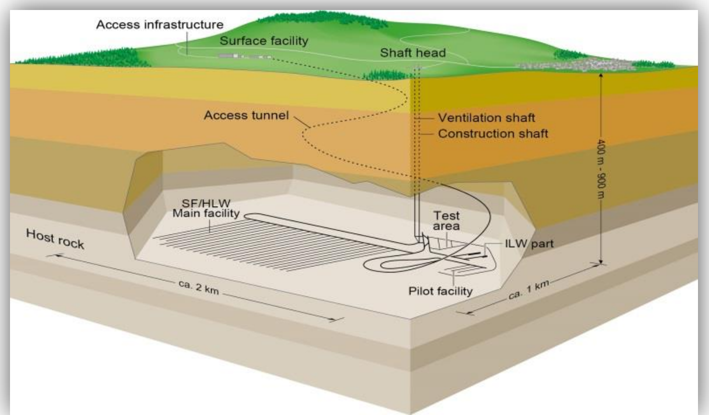


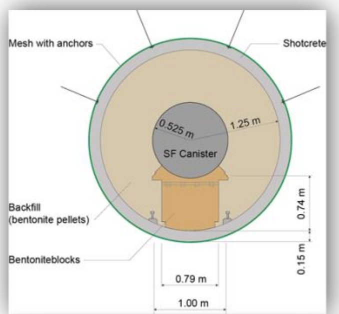
thermal expansion of porewater 10 x higher than the thermal expansion coefficient of solid skeleton

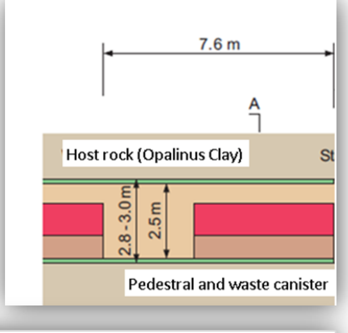


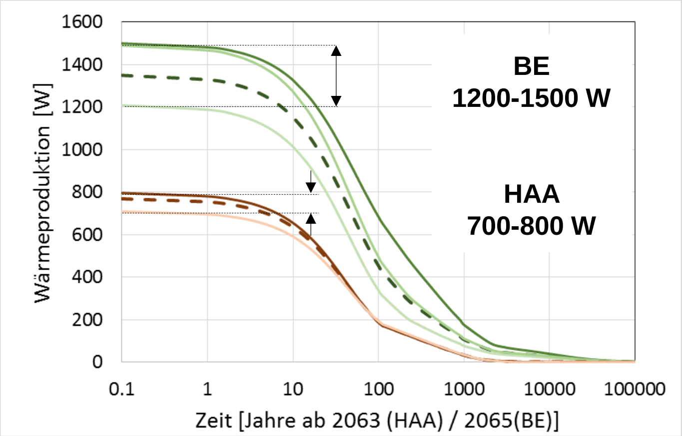
The Swiss example – what affects the thermal impact

- Thermal evolution of the repository near-field is governed by:
  - Geological setting of the siting region *(depth, thickness and tightness of the host rock formation)*
  - General repository layout with particular emphasis on the SF/HLW main facility *(tunnel length, separation distances)*
  - Design of the SF/HLW near-field *(canisters, bentonite buffer, compartmentalisation seals)*
  - Waste inventory and emplacement concept *(canister loading, date of emplacement, emplacement strategy)*



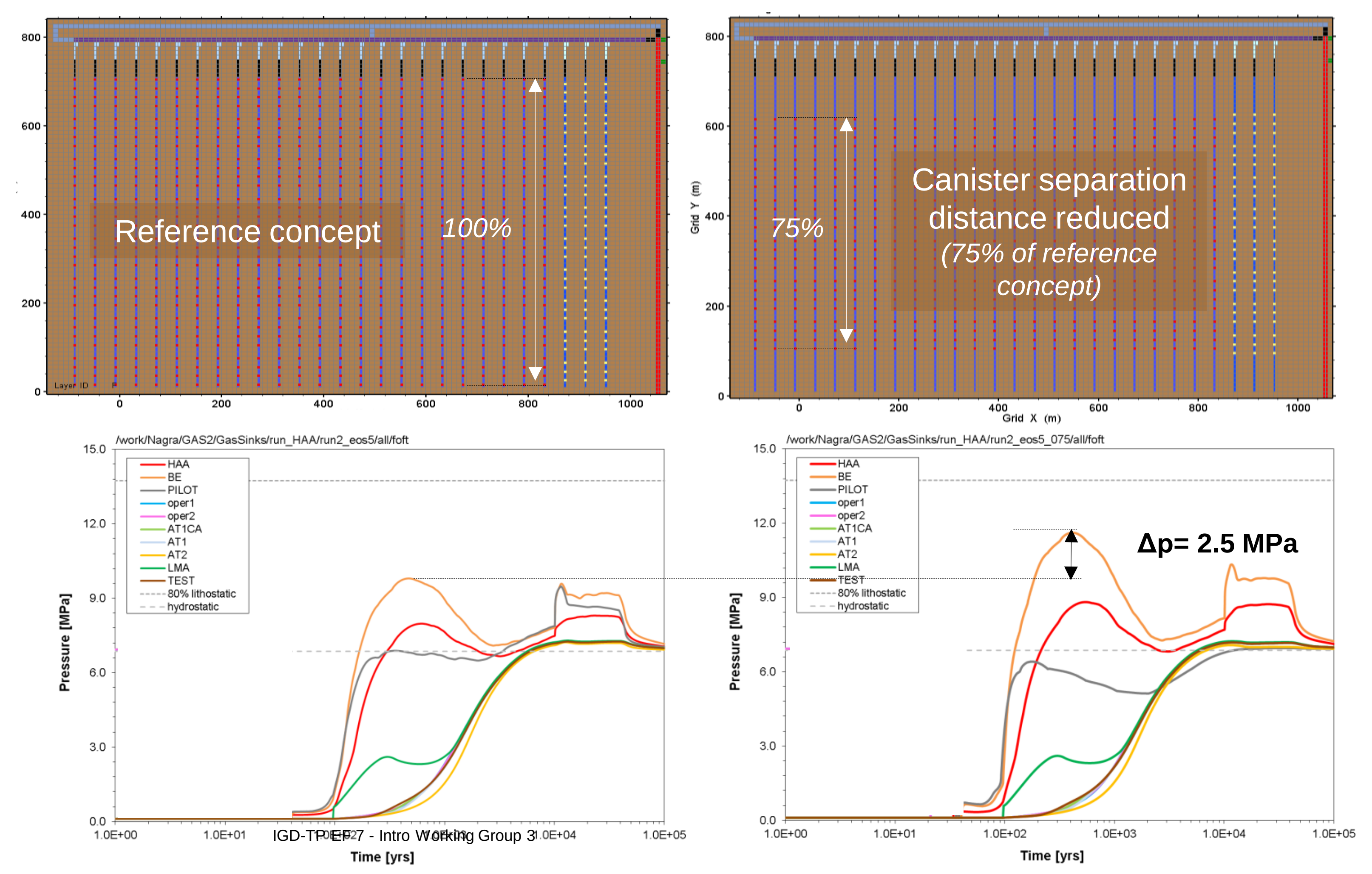






An example of thermal induced overpressures

- THM-related Sensitivity studies on the repository / near-field scale
  - Effect of separation distance between canisters



Reference concept

100%

75%

Canister separation distance reduced *(75% of reference concept)*

Δp= 2.5 MPa

This session – changes to the agenda

14:00 – 14:20	**Welcome and motivation of this session**	**I. Gaus**
14:20 – 14:35	Discussion on the motivation and possible outcomes of the session	I. Gaus, All
Topic 1: Progress in understanding up to 100°C		
14:35 – 14:55	Effects of elevated temperatures on the EBS in clay formations	T. Schäfer, KIT
14:55 – 15:15	Clay interactions at high temperature by molecular dynamics, thermodynamic modelling and lab analysis	M. Olin, VTT
15:15 – 15:25	Discussion	K. Wieczorek, All
Topic 2: Progress in understanding above 100°C		
15:25 – 15:45	Research topics from the state of the art on THMCB aspects of thermal compatibility of clays	A. Meleshyn, GRS
15:45 – 16:00	Coffee Break	
16:00 – 16:20	Coupled THMC interactions at temperature beyond 130 °C : experimental investigations and modeling of materials alteration, swelling processes and overpressure build-up	F. Claret, BRGM
16:20 – 16:40	Contribution to numerical modelling of high temperature clay interactions	J. Samper, UDC
16:40 – 16:45	High temperature THM	C. Daniels, BGS
16:45 – 17:00	Discussion	K. Wieczorek, All
Topic 3: Assessing THM consequences in clay host rocks for high T		
17:00 – 17:20	Thermo-Hydro-Mechanical Effects of a Geological Repository at Macro-Scale – A Novel Modeling Approach Adapted from Plate Tectonics	,N. Hubschwerlen, AF Consult
17:20 – 17:30	Discussion	I. Gaus, All
17:30	Close of day 1	

This session – changes to the agenda

Wednesday 26th Oct, Working Groups part 3

Topic 4: In-situ experiments regarding high T		
09:00 – 09:20	Hot Mock-ups at Joseph URL	J. Svoboda, CTU
09:20 – 09:40	HotBENT - High Temperature Bentonite Project Ideas	F. Kober, Nagra
09:40 – 09:50	Discussion	K. Wieczorek, All
Topic 5: Conclusions		
09:50 – 10:30	Final discussion conclusions and next possible steps	I. Gaus, K. Wieczorek, All

Thank you for your attention, let this be a good session…