Research topics from the state of the art on THMCB aspects of thermal compatibility of clays

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Motivation

- GRS Braunschweig was mandated in January 2016 by a Commission of the German Bundestag to deliver expert opinion on thermal compatibility of clays with regard to the disposal of high-level radioactive waste (HLW) and spent fuel (SF). The expert opinion was largely based on the results of the R&D project “AnSichT” (2011-2016) on the demonstration of the safety of a repository for HLW and SF in clays according to the German regulations.*

- A special attention was given to
  - the relevant thermally induced processes in clays that necessitate the limitation of the thermal impact of the emplaced waste on the host rock and geotechnical barriers,
  - the corresponding temperature limits according to the international and national disposal projects.

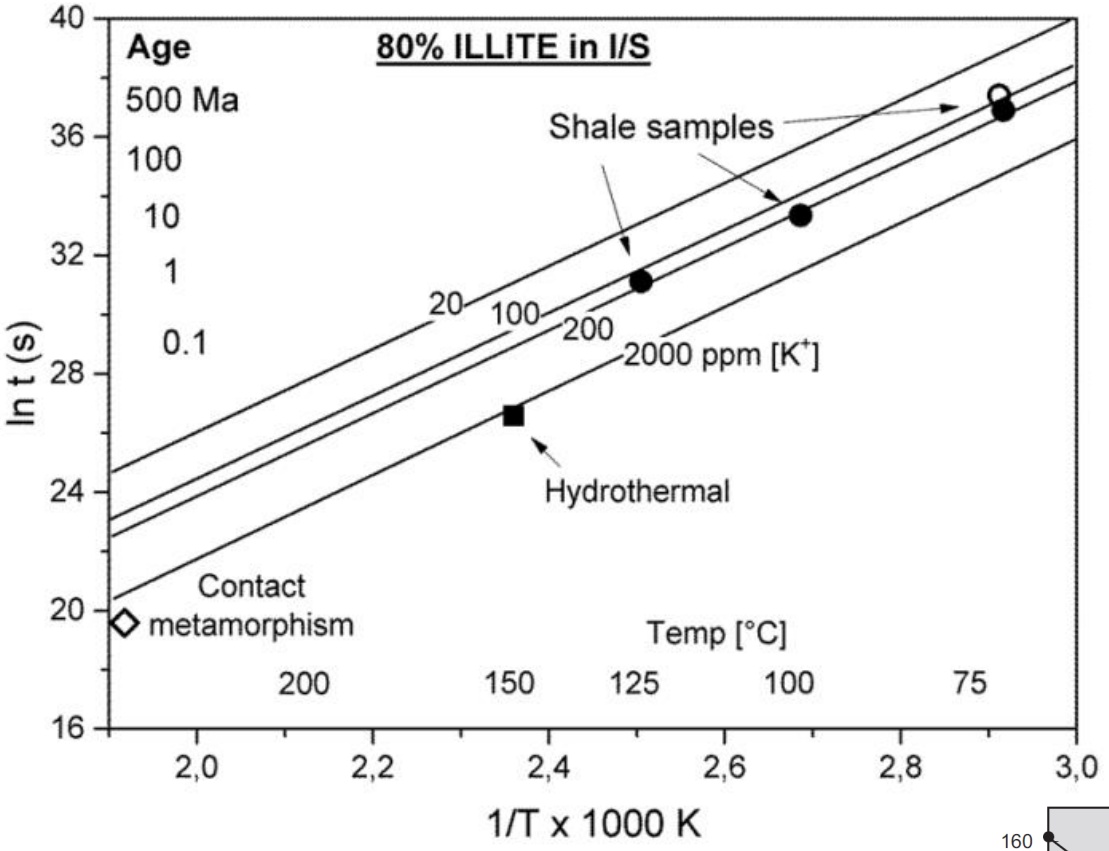
- This talk starts with an overview of the temperature limits and proceeds with a brief discussion on the most important identified processes and open questions.

* Jobmann & Meleshyn (2015): Evaluation of temperature-induced effects on safety-relevant properties of clay host rocks with regard to HLW/SF disposal, Mineralogical Magazine 79

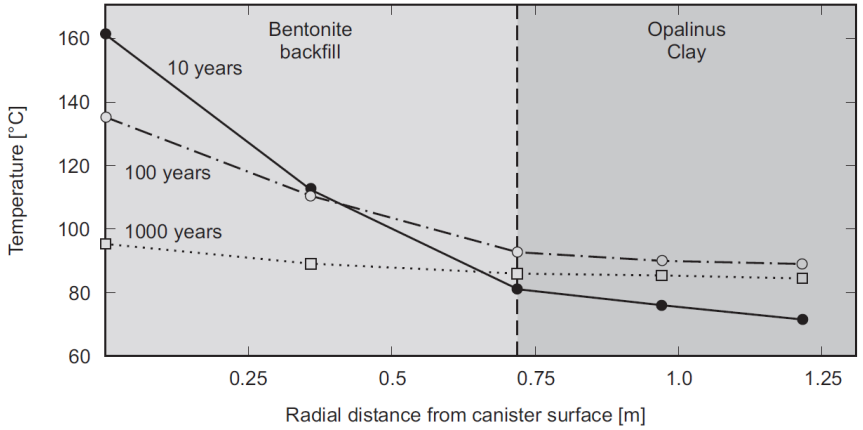
International status

Country (WMO or "Project")	Host rock/buffer	Temperature limit in buffer	Reason
France (Andra, 2005)	COX clay/bentonite	100°C	mineral alteration
Belgium (Ondraf/Niras, 2005)	Boom clay/concrete	100°C	detrimental effects
Switzerland (Nagra, 2002)	Opalinus clay/ bentonite	125°C (outer half)	mineral alteration
Sweden (SKB, 2005)	Crystalline/bentonite	100°C	mineral alteration
Finland (Posiva, 2013)	Crystalline/bentonite	100°C	mineral alteration
South Korea (KAERI, 2007)	Crystalline/bentonite	100°C *125°C wanted, 2016	mineral alteration
Germany ("AnSichT", 2016)	Lower Cretaceous (Opalinus) clay/ clay (+ bentonite)	150°C *proposal	scarce data for higher temperatures

1. Illitisation of smectites

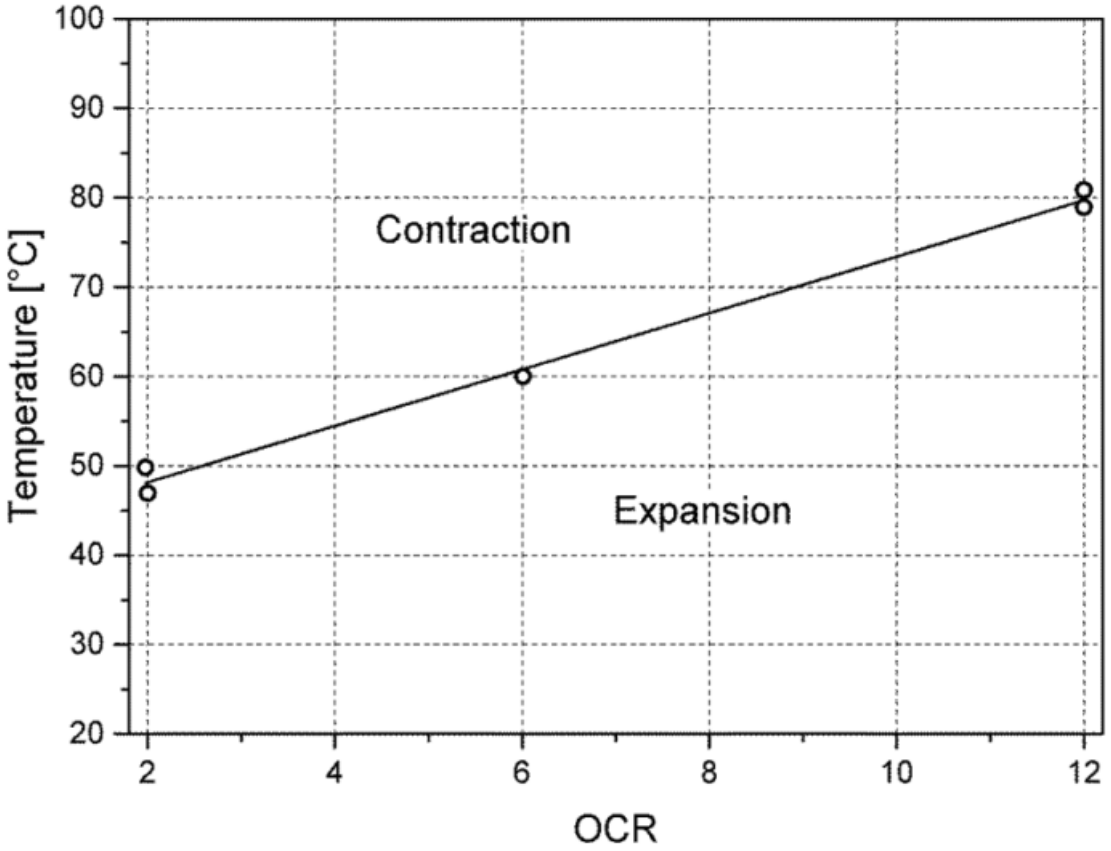


(Huang et al., 1993)



(Nagra, 2002)

2. Expansion-contraction of clay



OCR, a ratio of the pre-consolidation and current vertical effective stresses

(Sultan et al., 2002; Baldi et al., 1991)

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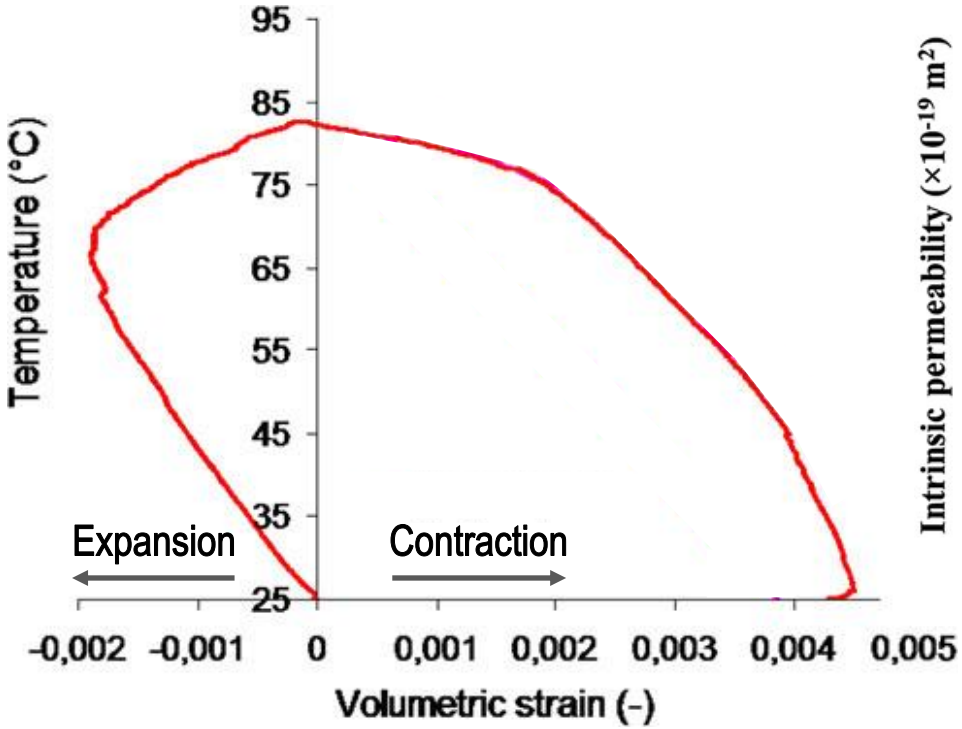
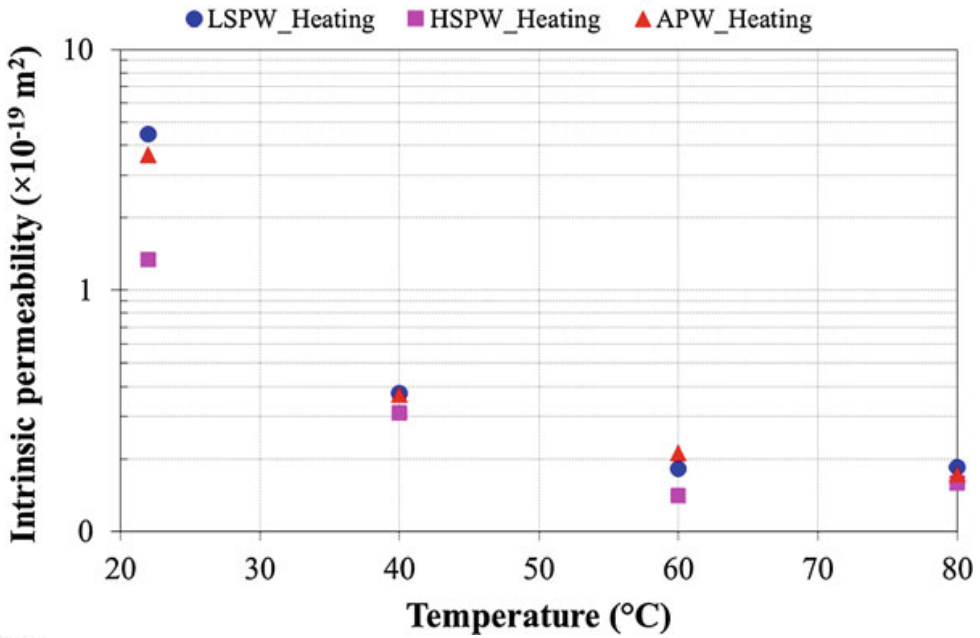


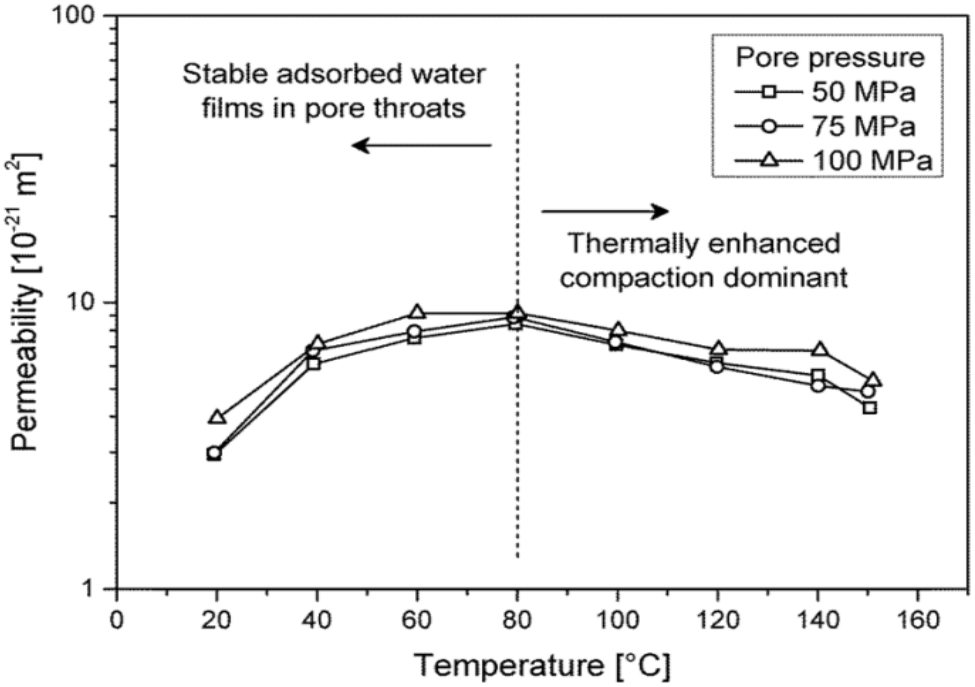


Drained heating test on Opalinus clay
(under in-situ stress)

Opalinus clay with artificial fractures
LSPW (HSPW): low (high) salinity pearson water,
APW: alkaline pearson water

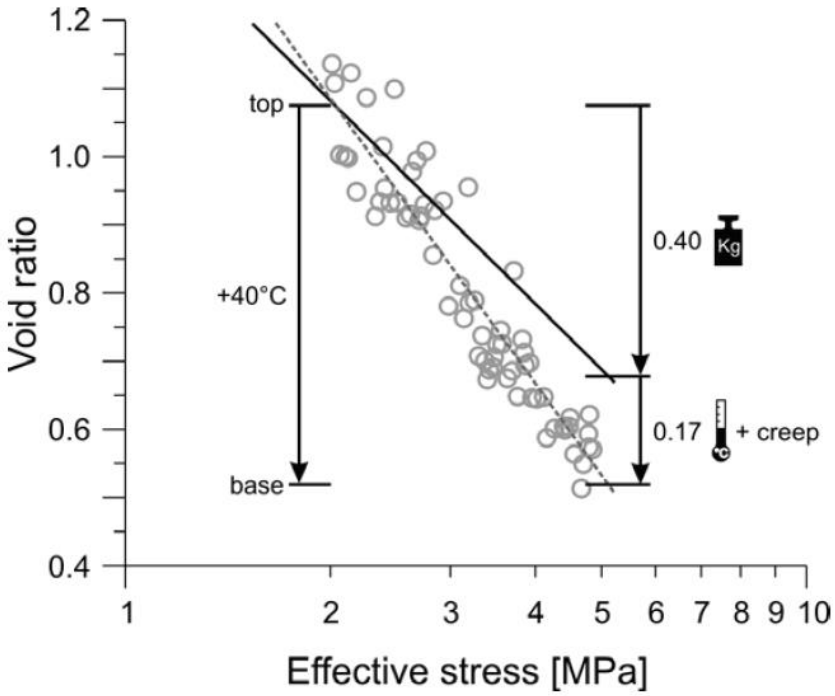
(Yu et al., 2014)

2. Expansion-contraction of clay



Permeability of clay samples taken from clay-bearing fault gouges (confining pressure = 200 MPa)

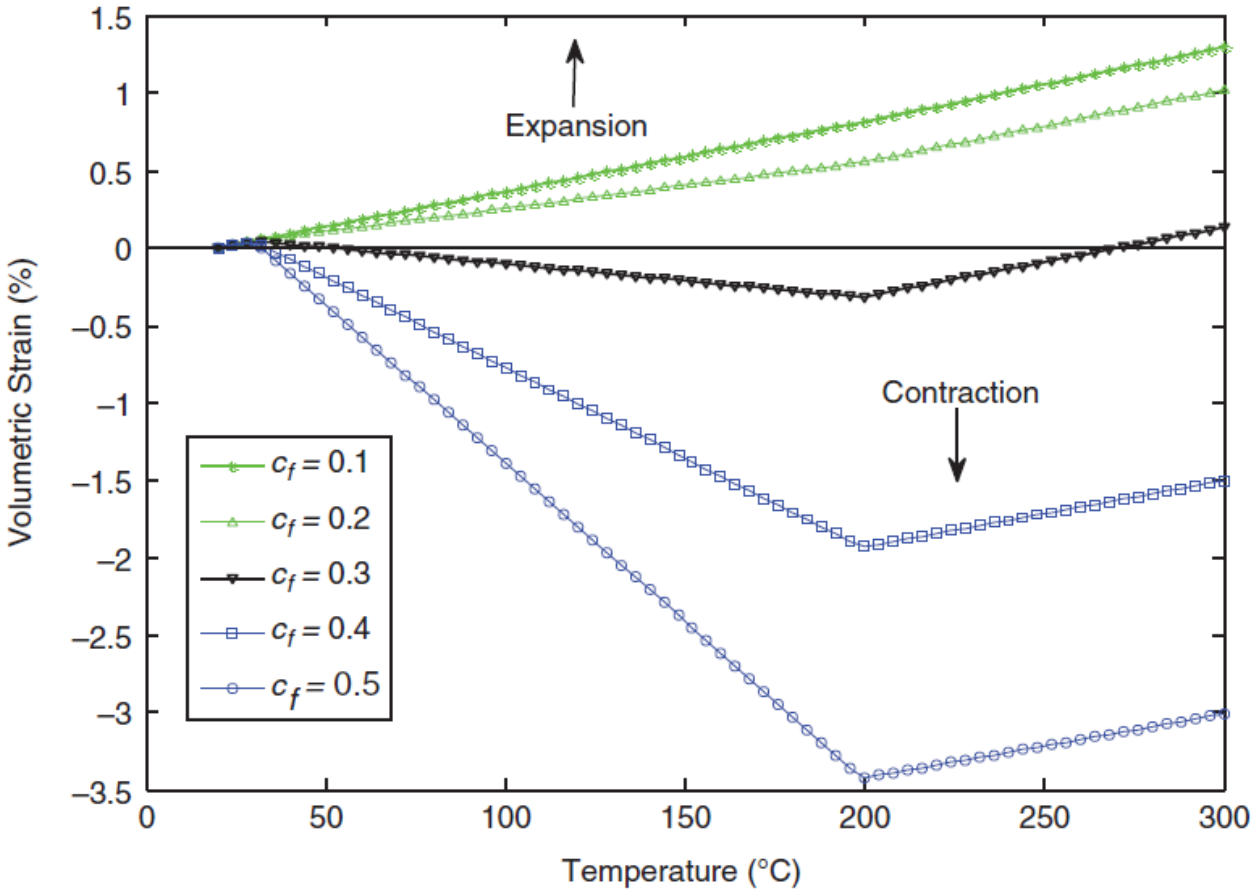
(Faulkner & Rutter, 2003)



Porosity change with depth in Nankai Trough off Japan (~250-650 mbsf)

(Hüpers & Kopf, 2009)

2. Expansion-contraction of clay



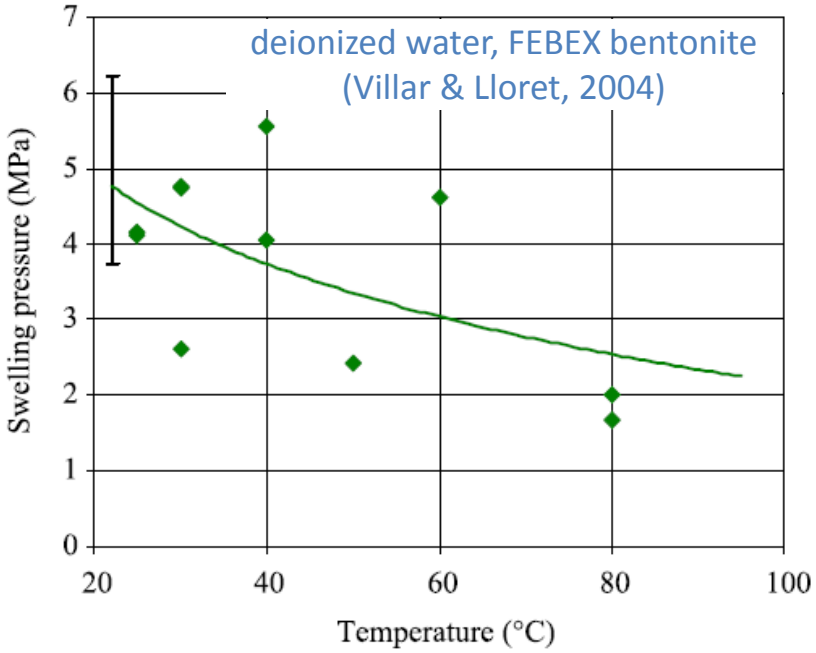
Clay formation with porosity of 0.3
and different clay fractions

(Li & Wong, 2015)

Open question

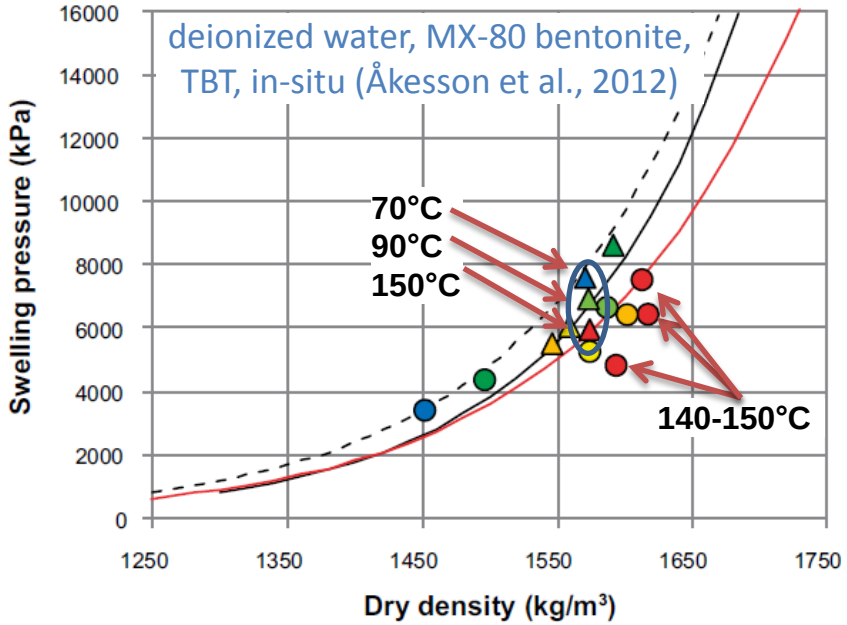
What is the expansion-contraction behavior and permeability of compacted bentonites and crushed clays at high temperatures?

3. Swelling of clay



Effect of a short temperature treatment

„A temperature increase to 70°C reduces the swelling pressure to approximately 50% of the value at 20°C“ (Pusch, 1980).



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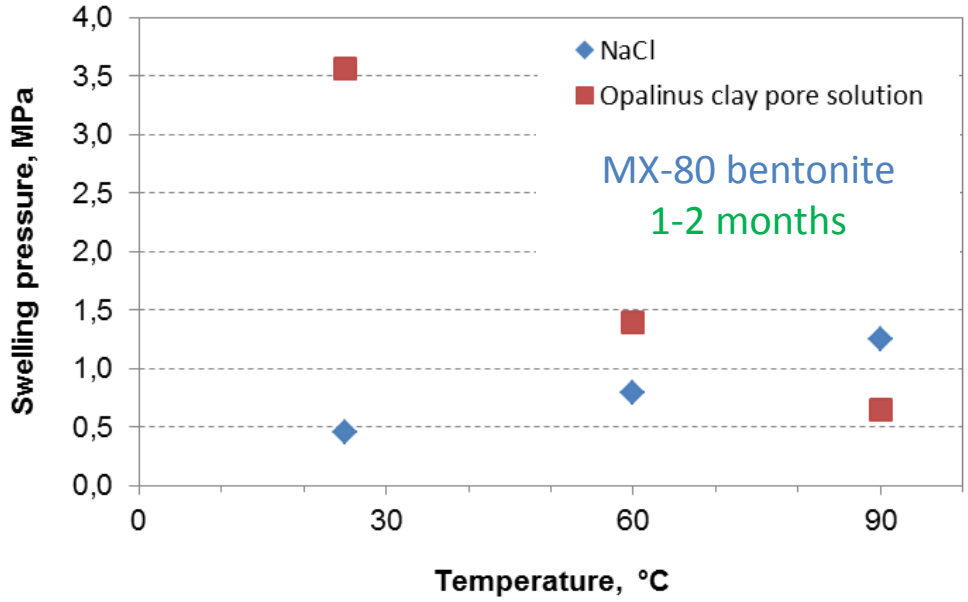
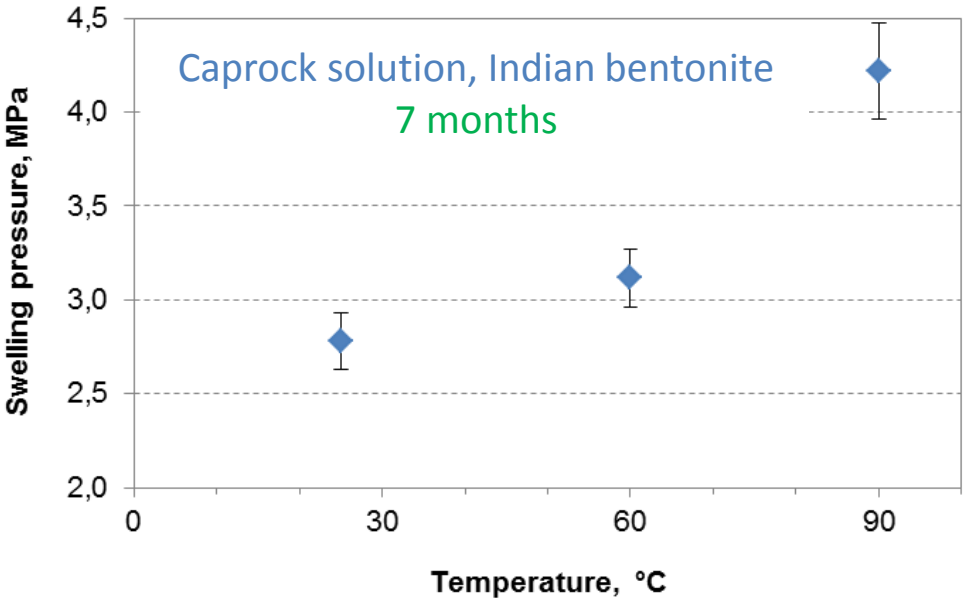


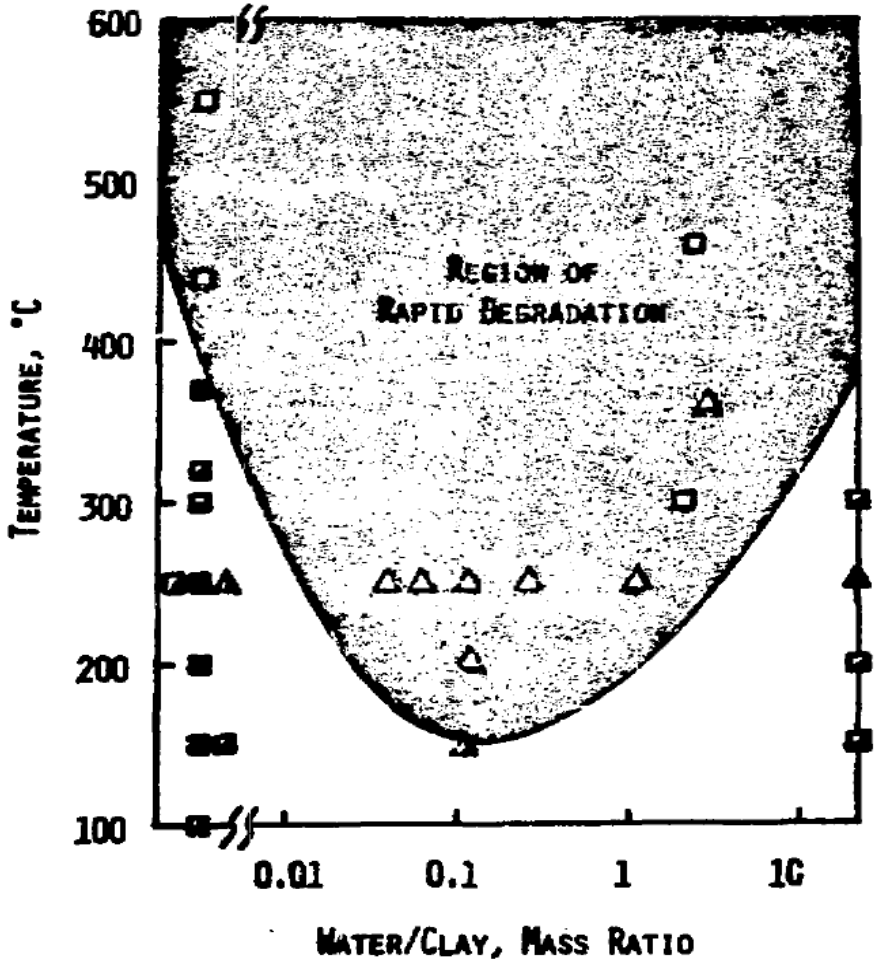
Effect of a prolonged temperature treatment (mineral alteration)

(Herbert et al., 2011)



(Meleshyn, 2015)

3. Swelling of clay

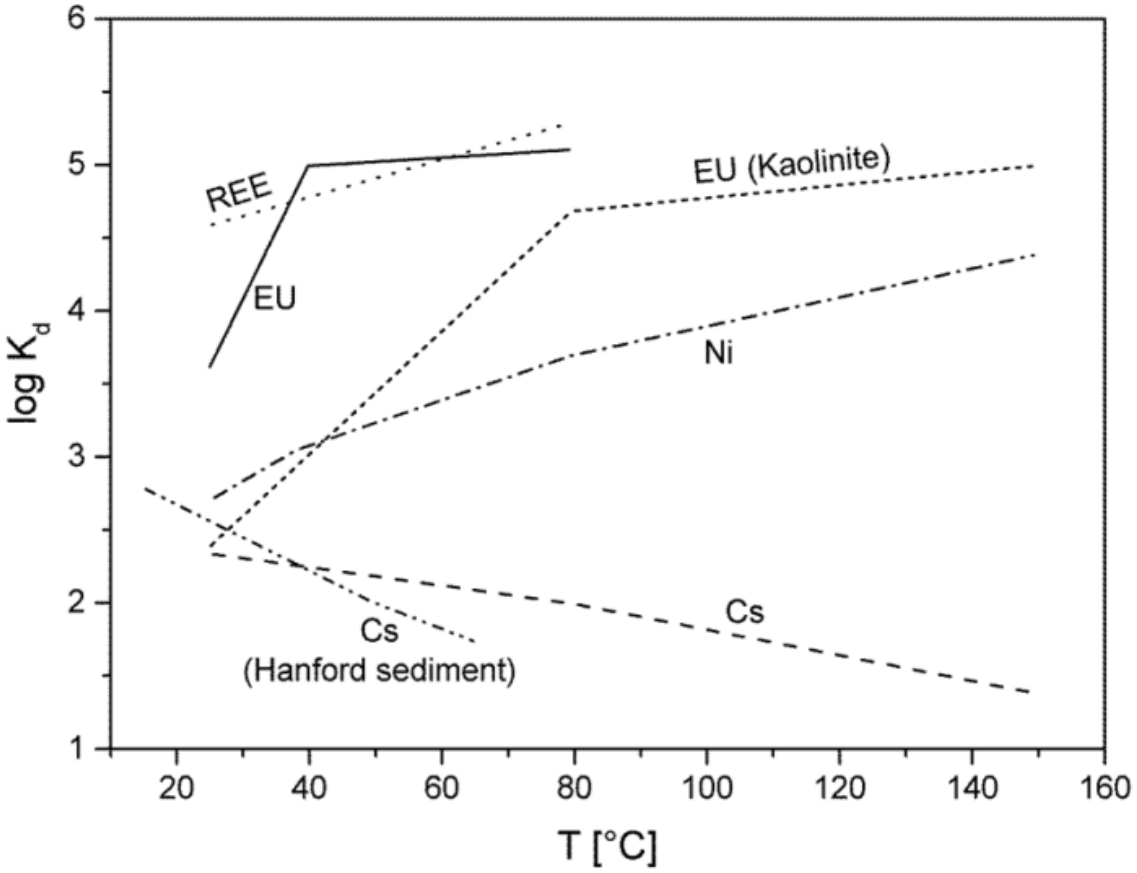


Hydrothermal degradation of the osmotic swelling ability of bentonite by water vapor within one week (Couture, 1985)

Open question

What is the effect of high temperatures on swelling ability and swelling pressure of clays?

4. Sorption capacity of clay

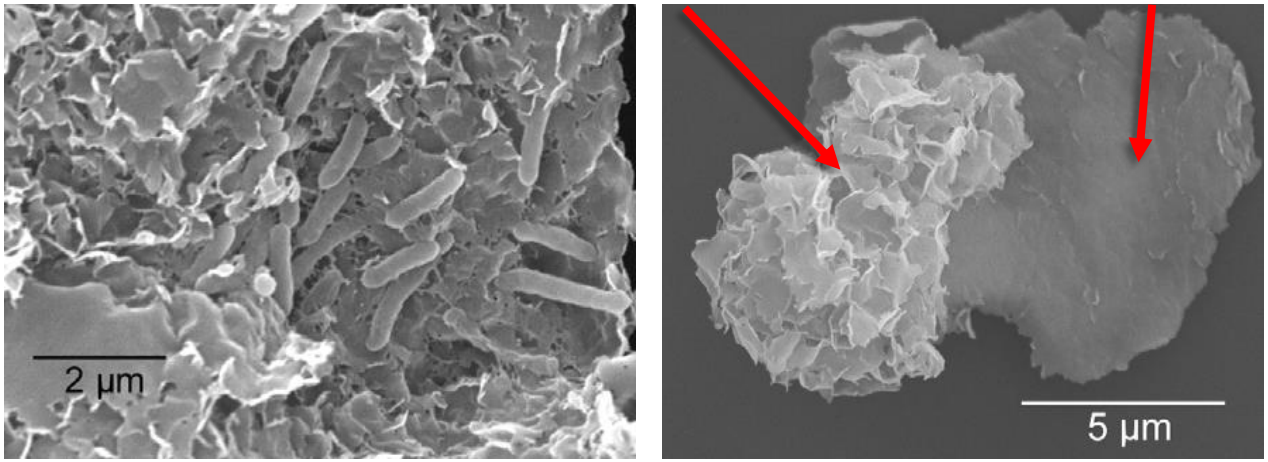


(Liu et al., 2003; Tertre et al., 2005, 2006)

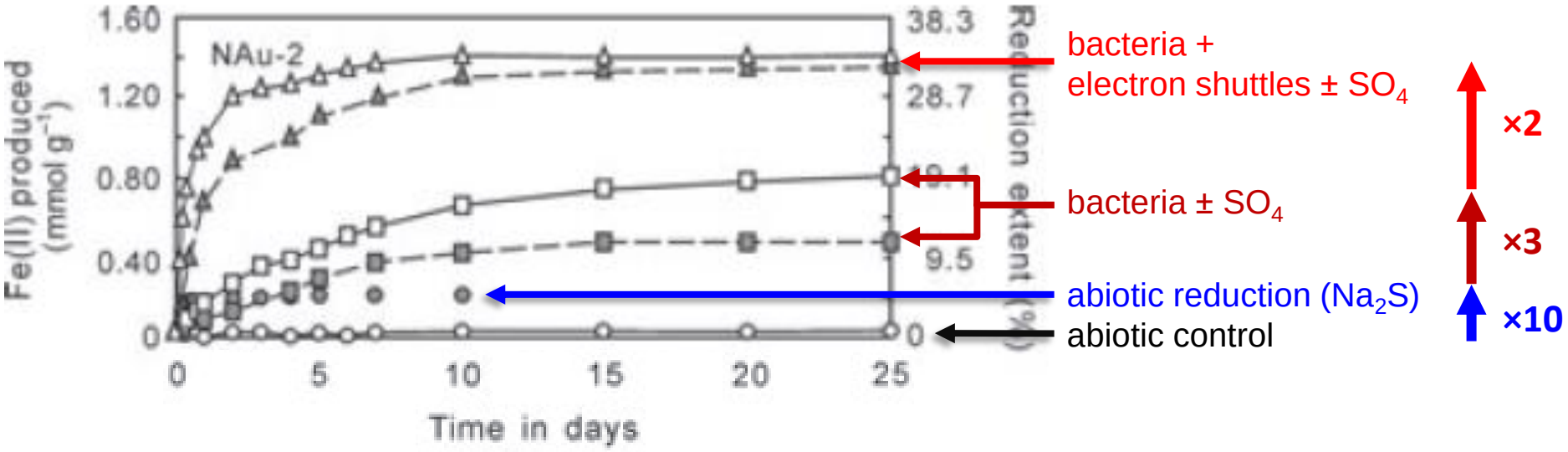
Open question

What is the effect of high temperatures on sorption capacity of clays?

5. Microbial alteration of clay

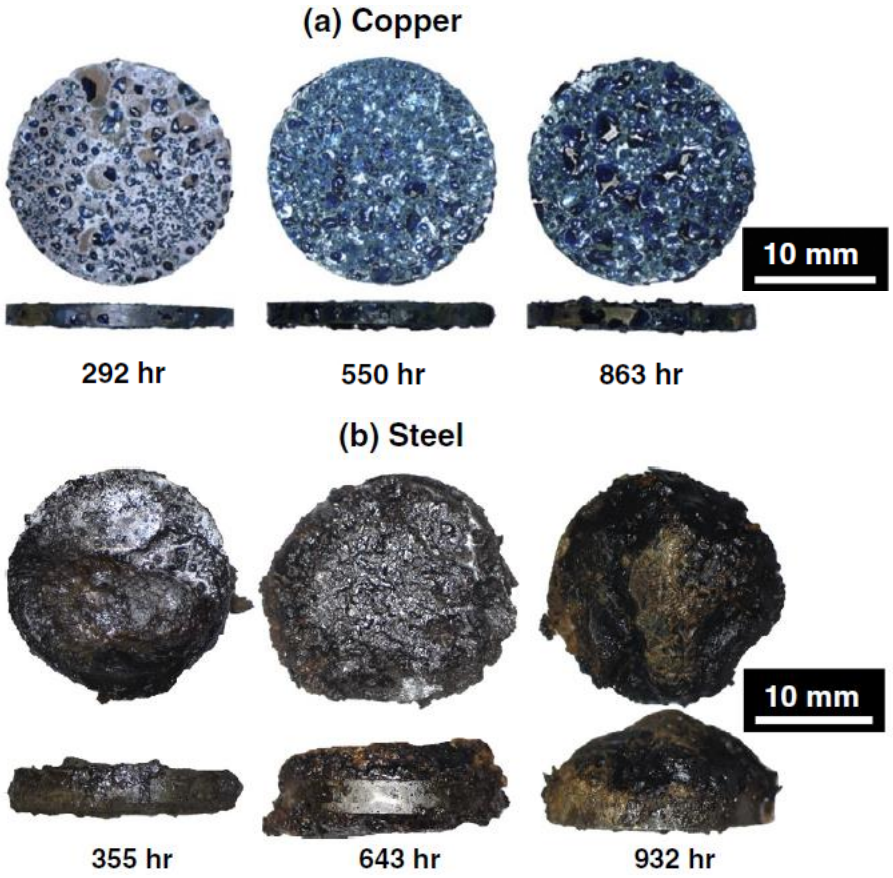


SWa-1 after 2 months with Fe(III)-reducing bacteria (Dong et al., 2003)

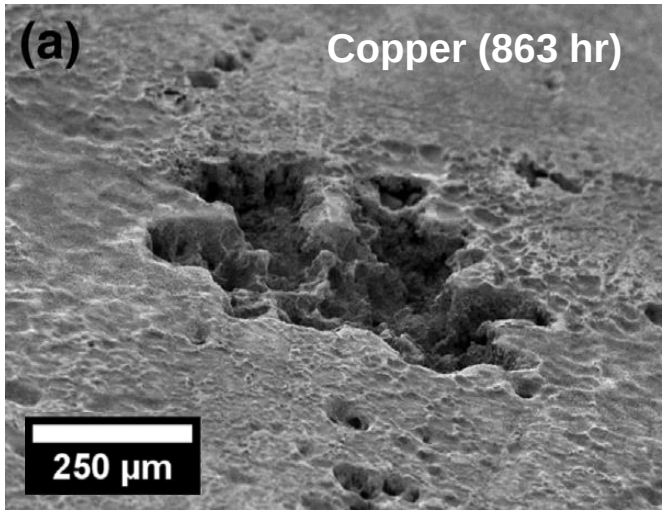


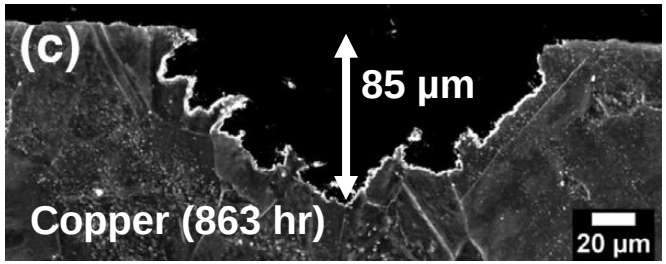
Nontronite NAu-2 + sulfate-reducing bacteria (Liu et al., 2012)

5. Microbially influenced corrosion



(Sowards & Mansfield, 2014)



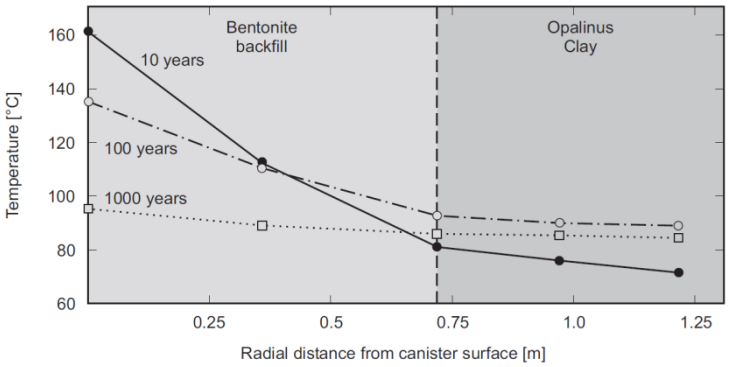


Copper pitting (general) corrosion:
0.88 (0.06) mm/a in vapor phase
0.40 (0.05) mm/a in liquid phase
Carbon steel pitting (general) corrosion:
2.85 (1.10) mm/a in vapor phase
4.70 (0.06) mm/a in liquid phase

5. Microbial survival in clay

Microorganisms	Temperature limit of activity	Endospore survival
Sulfate-reducing	95-110°C	~ 125-140°C*
Fe(III)-reducing	121°C	~ 150°C*
Methanogenic	122°C	-

* possibly only for several months to years at the highest temperatures



(Nagra, 2002)

Sedimentary rocks exposed during their diagenesis to paleotemperatures of 140°C show only spurious and of 145°C no microbial biomass at all (Colwell et al., 1997)

Open question

How does detrimental microbial activity in clay decline with increasing temperature?

Summary of research topics

- Expansion-contraction behavior and permeability of compacted bentonites and crushed clays at high temperatures
- Effect of high temperatures on swelling ability and swelling pressure of clays
- Effect of high temperatures on sorption capacity of clays
- Decline of microbial activity in clay with increasing temperature

Acknowledgements

- Deutscher Bundestag for the financial support (AG 3726)

Thank you for your attention!