Artur Meleshyn

Thermal compatibility of clay with regard to the disposal of highly radioactive waste

EUROSAFE 2016

Motivation

- A German Bundestag commission mandated the GRS in January 2016 to deliver expert opinion on thermal compatibility of salt, clay, and crystalline host rocks with regard to the disposal of high-level radioactive waste (HLW) and spent fuel (SF).
- The expert opinion was based on the results of the R&D projects
  - "VSG" (preliminary safety analysis Gorleben, 2010-2013) to assess suitability of the salt dome Gorleben to host a HLW/SF repository according to the German regulations, and
  - "AnSichT" (2011-2016) on the demonstration of the safety of a HLW/SF repository in clays according to the German regulations.*

* 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

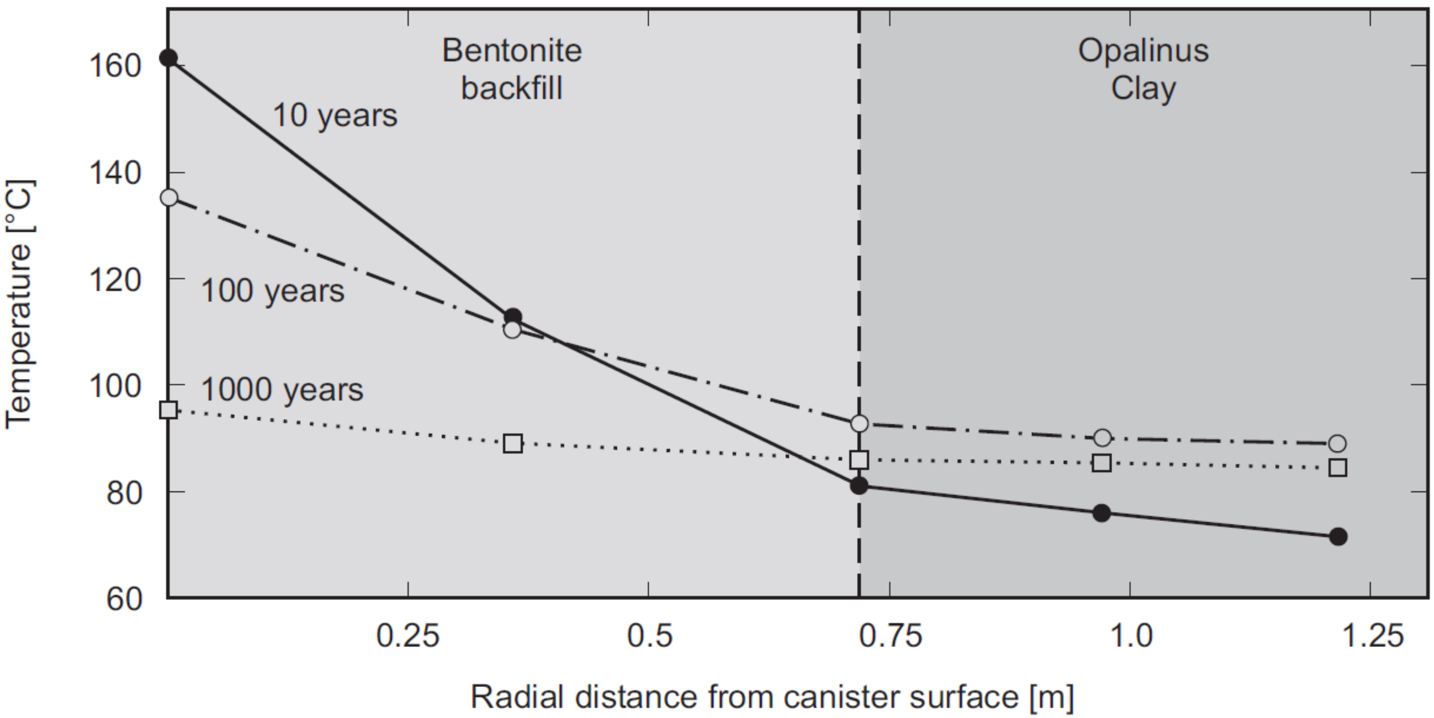
Outline

- The key topics of the commission's mandate were to give an overview on
  - the relevant thermally induced processes in the host rocks and geotechnical barriers that necessitate the limitation of the thermal impact of the emplaced waste
  - the corresponding temperature limits according to the international and national disposal projects.
- The responsibility of GRS Braunschweig was to overview these topics for clay host rock and clay-based geotechnical barriers in clay and crystalline host rocks, which is the subject of this presentation.
- It starts with an overview of the temperature limits and proceeds with a brief consideration of the most important identified processes.

International status

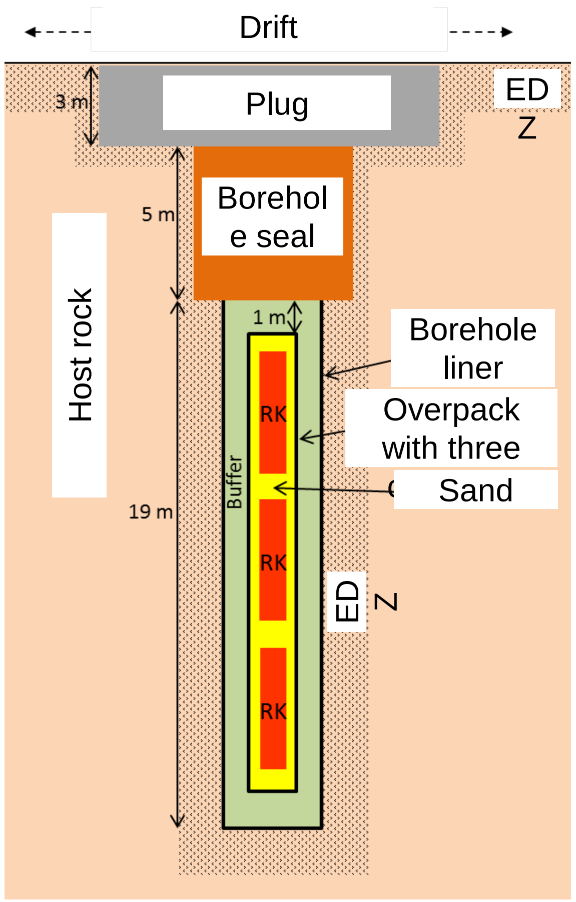
Country (WMO or "Project")	Host rock/buffer	Temperature limit in buffer	Reason
France (Andra, 2005)	COX clay/bentonite	100°C	mineral alteration
Belgium (Ondraf/Niras, 2005)	Boom clay/concrete	100°C	detrimental effects
Switzerland (Nagra, 2002)	Opalinus clay/ bentonite	125°C (outer half)	mineral alteration
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

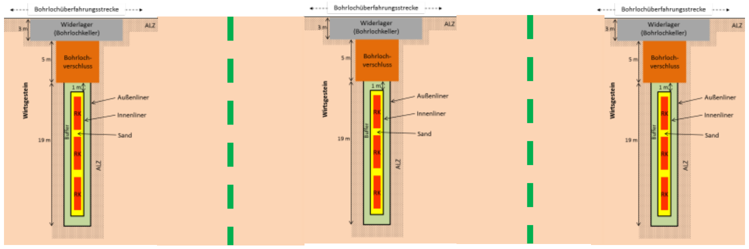
Temperature changes in space and time

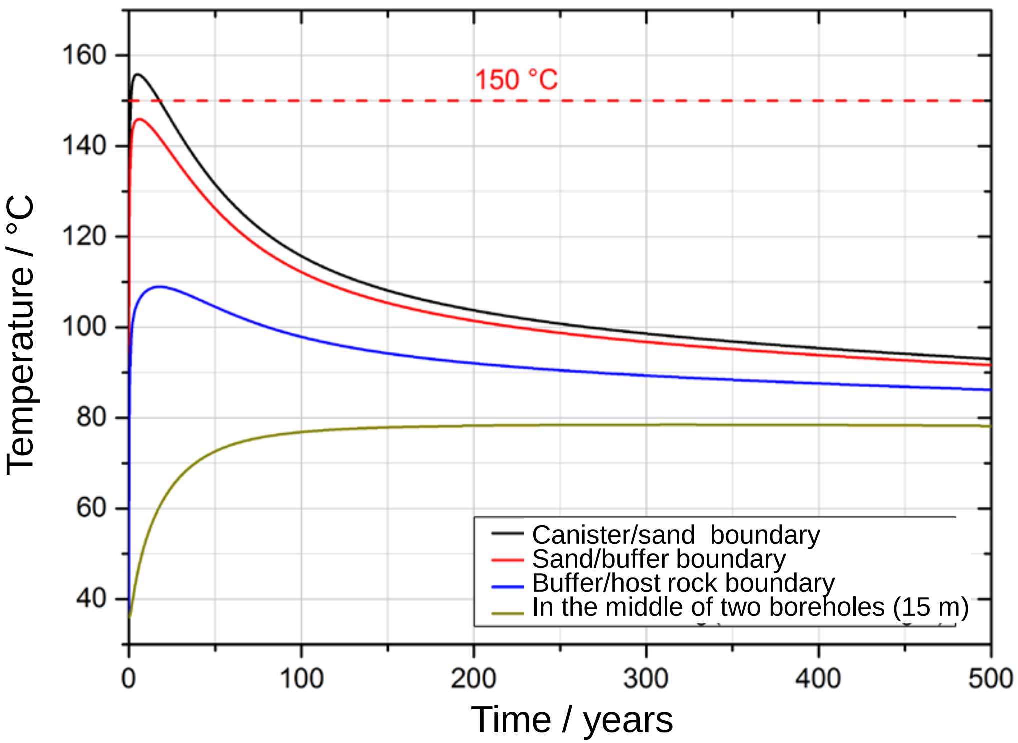


(Nagra, 2002)

“AnSichT” concept for the model site NORD



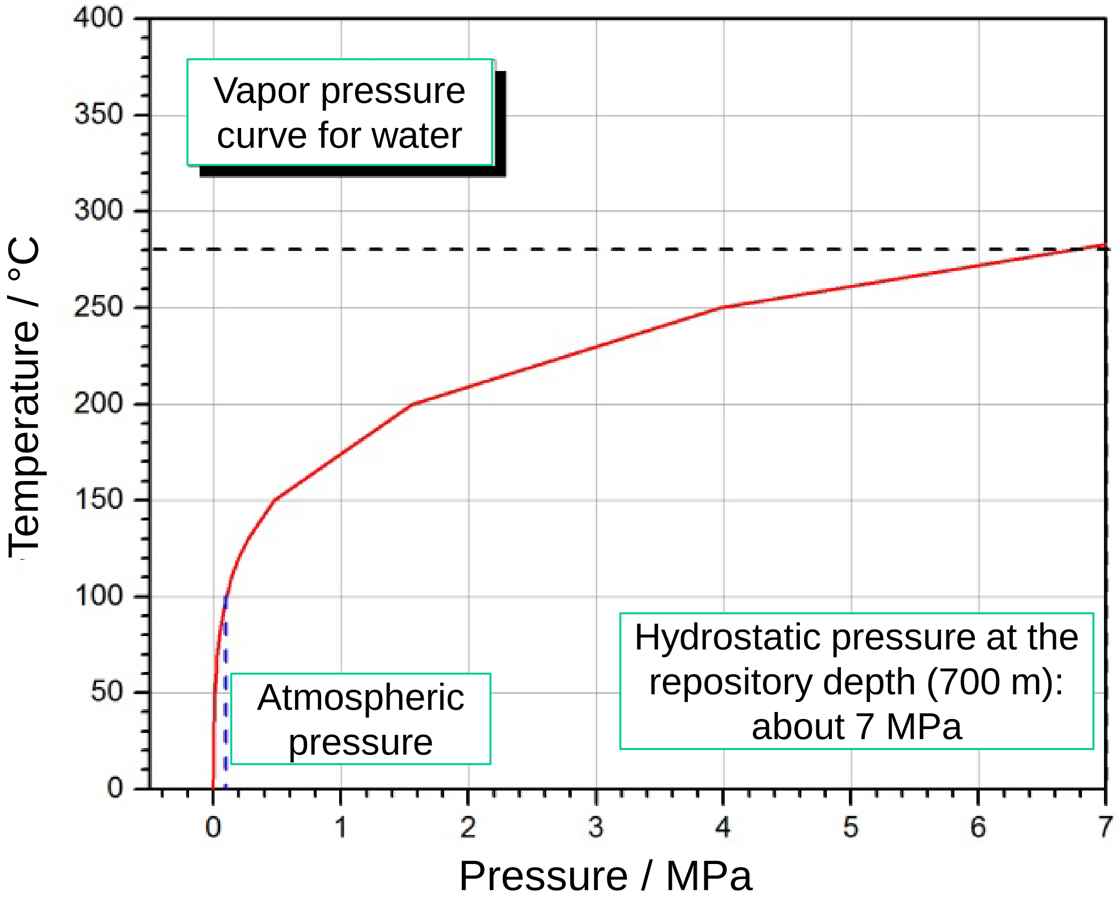




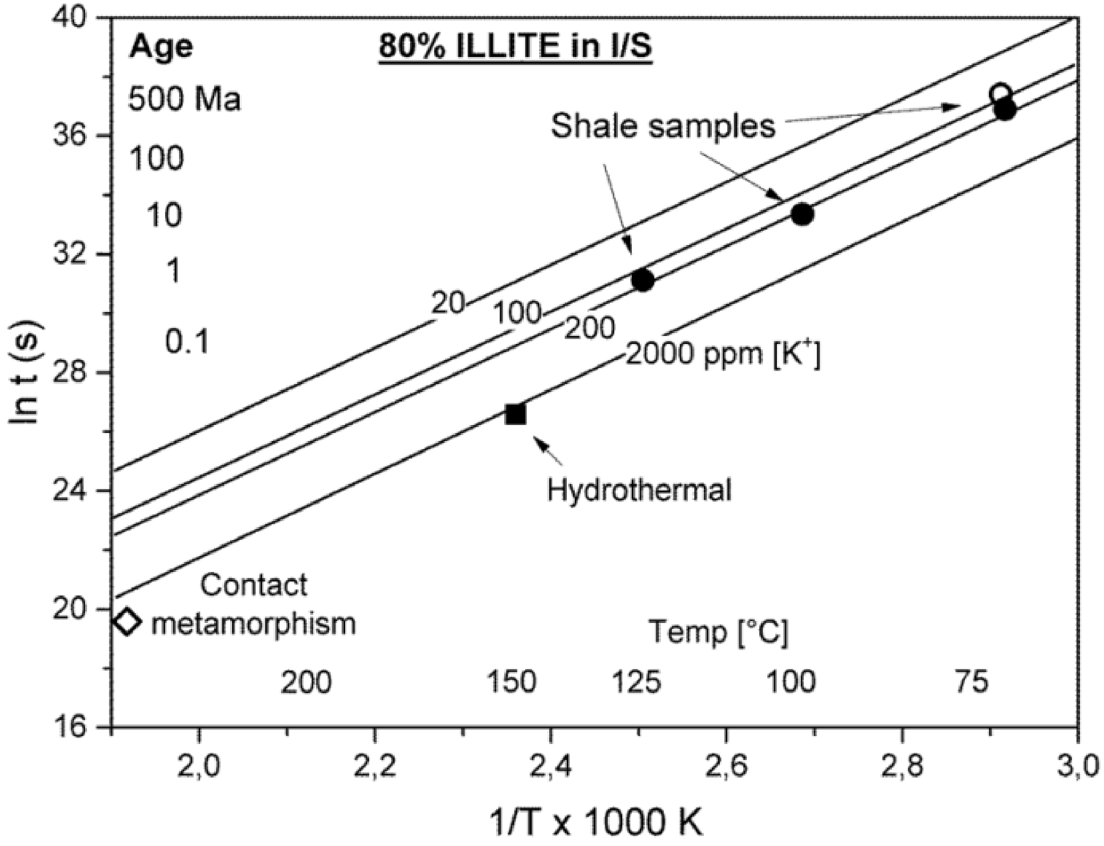
(Lommerzheim & Jobmann, 2015)

Thermally induced processes

Water evaporation

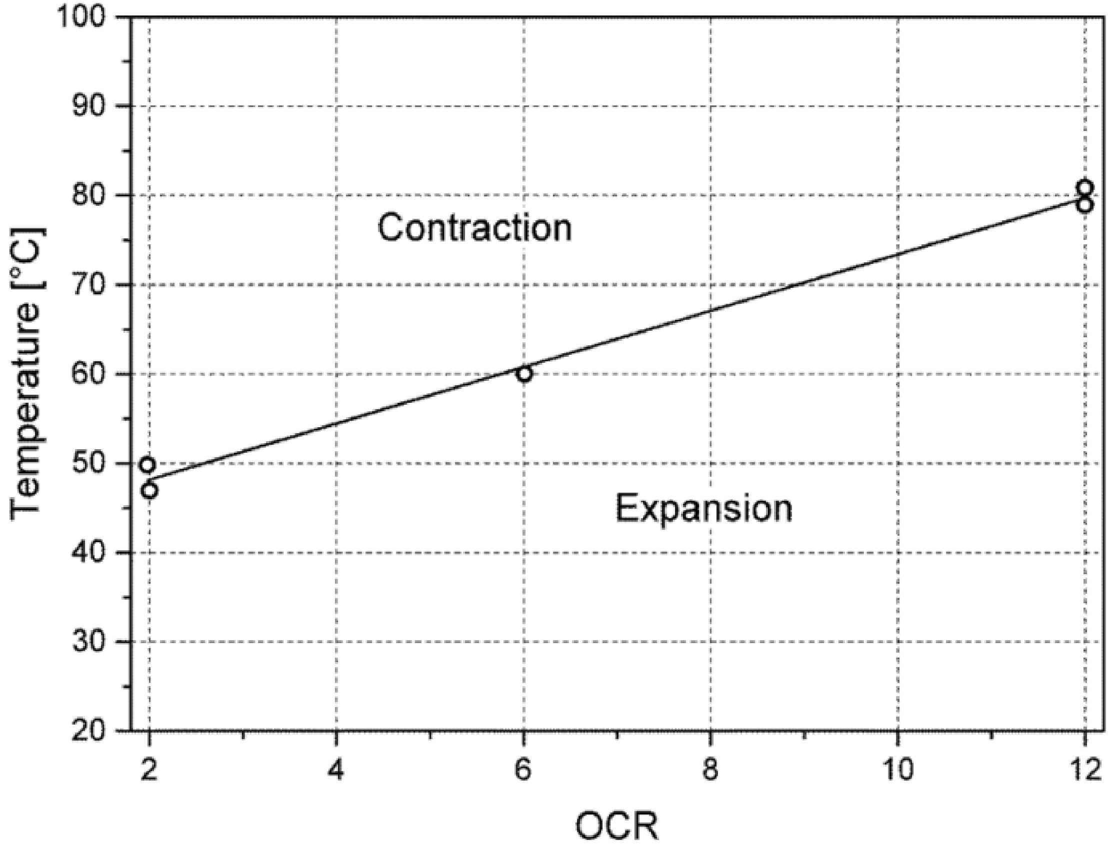


Illitisation of smectites



(Huang et al., 1993)

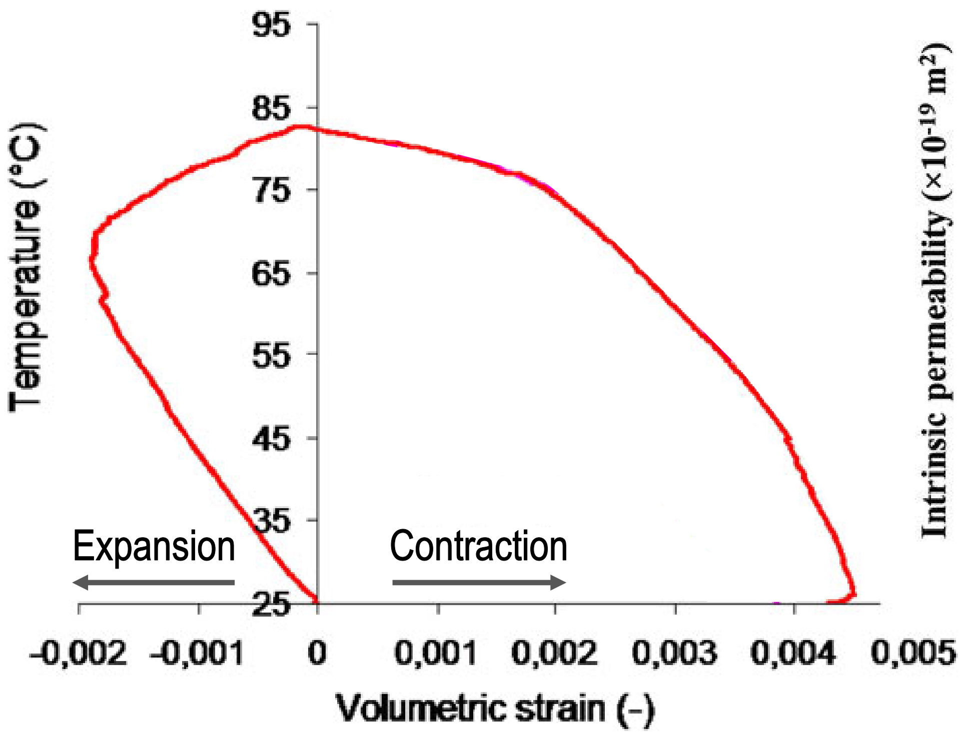
Expansion-contraction of clay

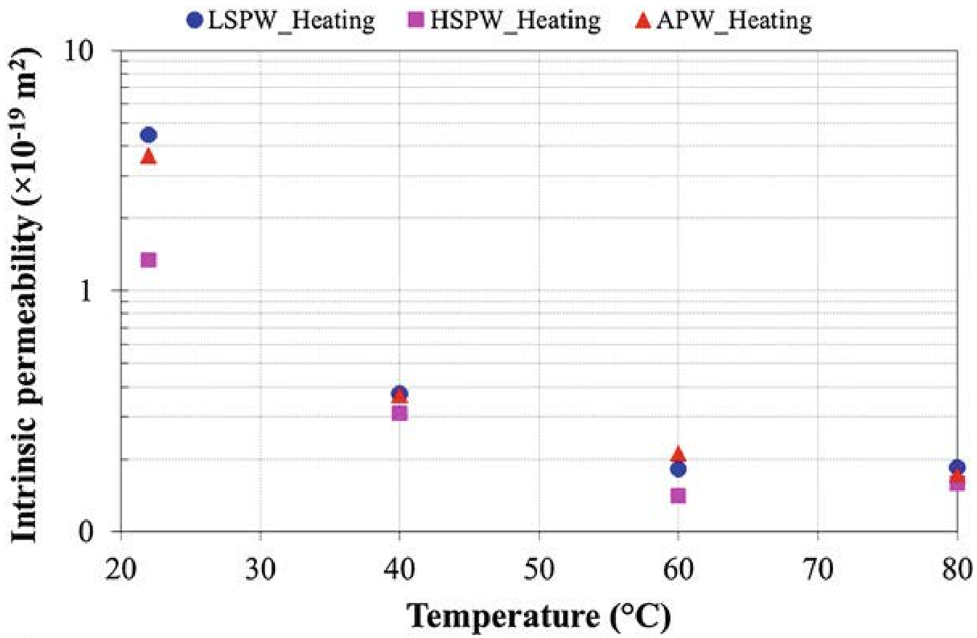


OCR, a ratio of the pre-consolidation and current vertical effective stresses

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

Expansion-contraction of clay



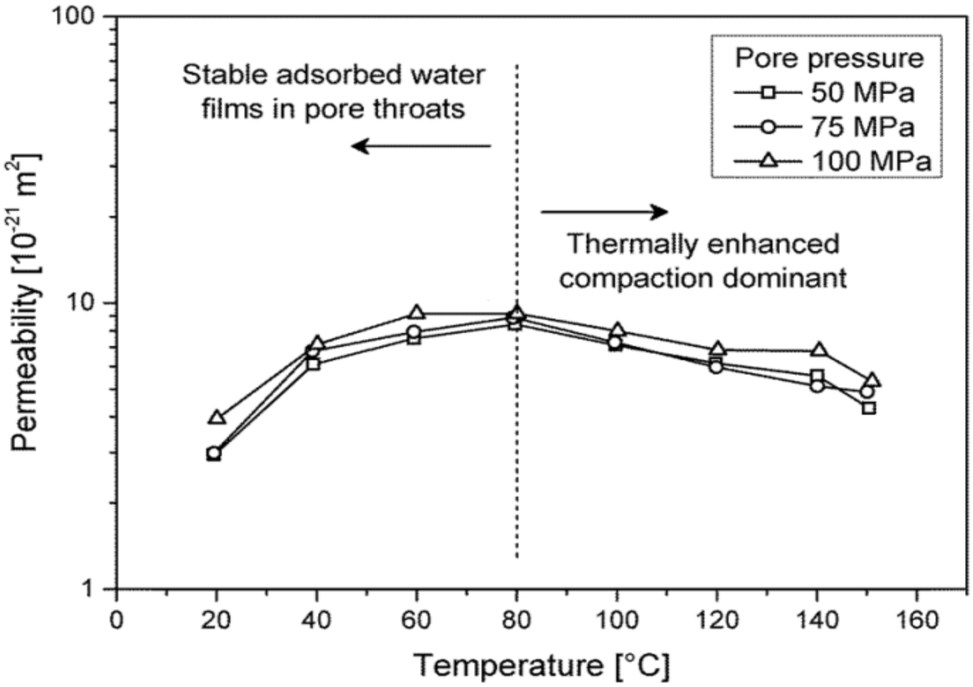


Drained heating test on Opalinus clay
(under in-situ stress)

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

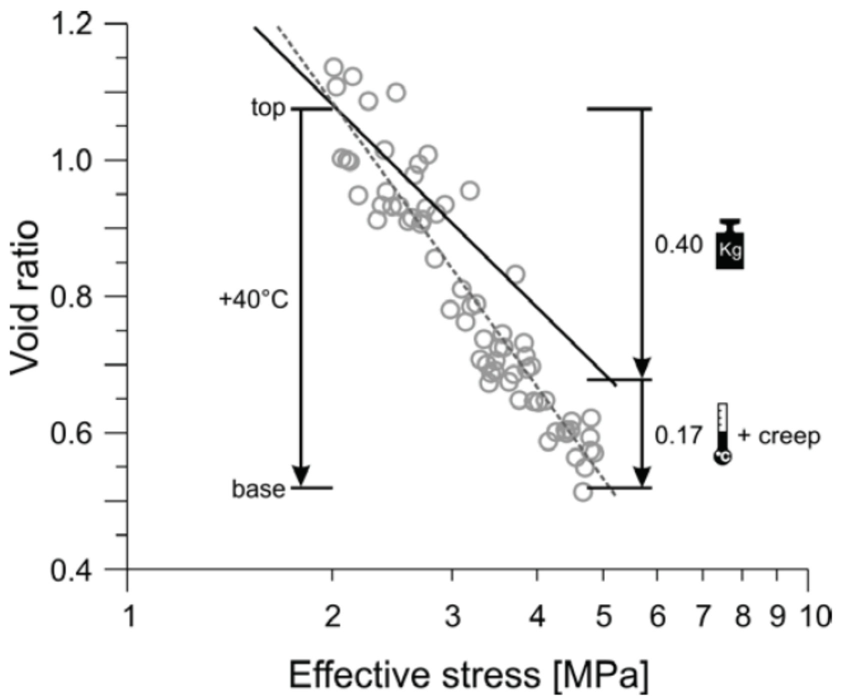
(Yu et al., 2014)

Expansion-contraction of clay



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

(Faulkner & Rutter, 2003)

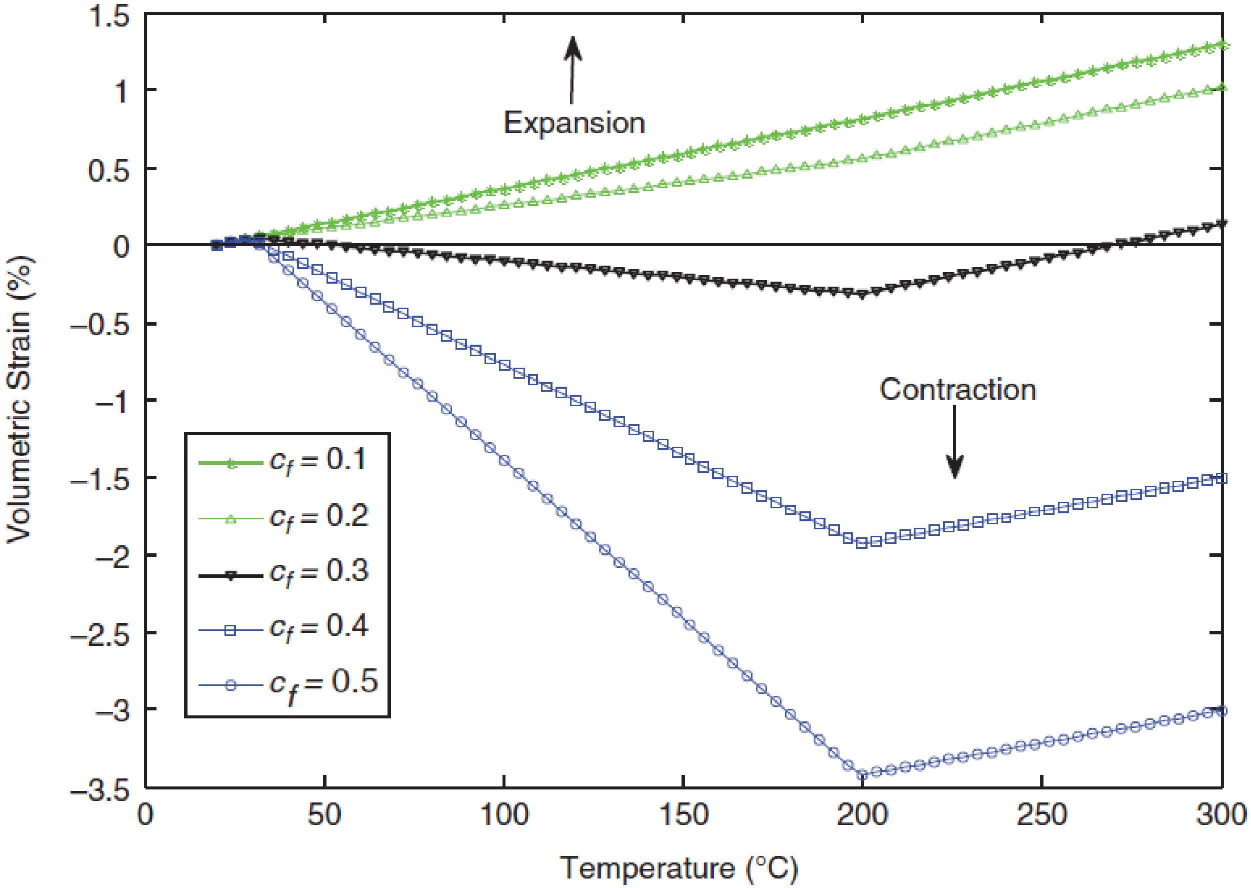


Porosity change with depth in Nankai Trough off Japan (~250-650 mbsf)

(Hüpers & Kopf, 2009)

EUROSAFE 2016

Expansion-contraction of clay



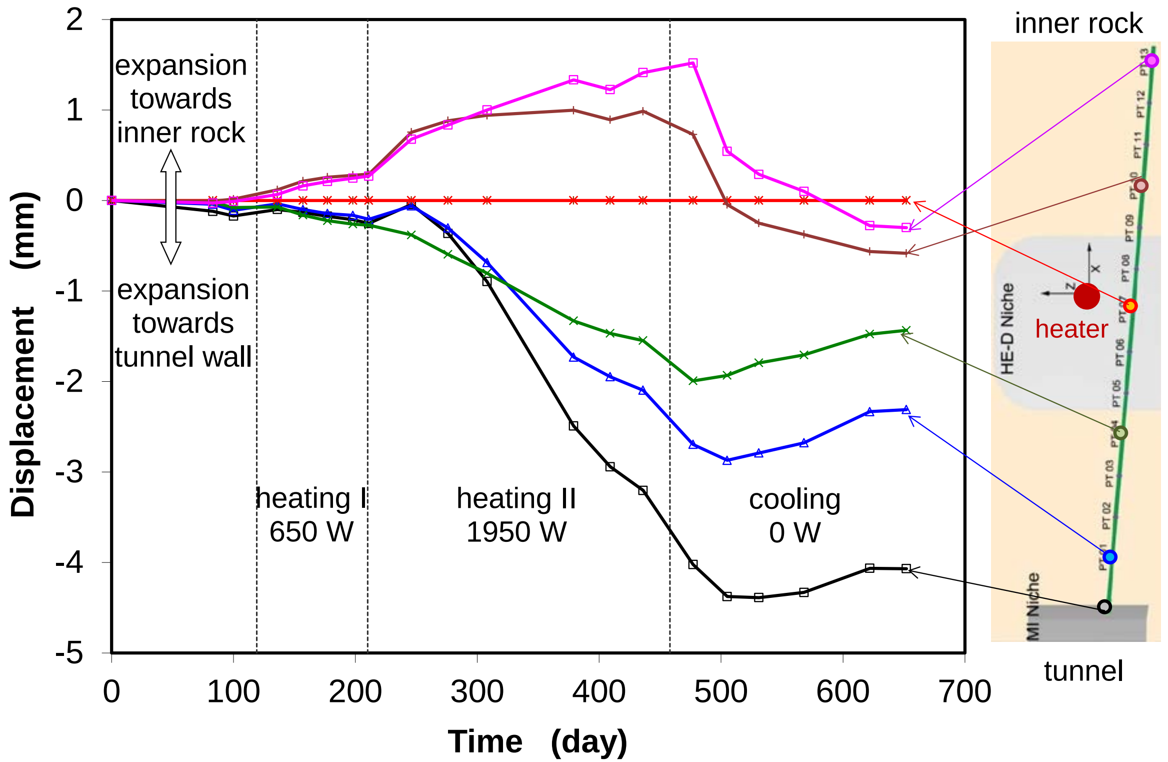
Clay formation with porosity of 0.3
and different clay fractions

(Li & Wong, 2015)

Open question

Expansion-contraction behavior and permeability of compacted bentonites and crushed clays at high temperatures

Expansion-contraction: In-situ scale



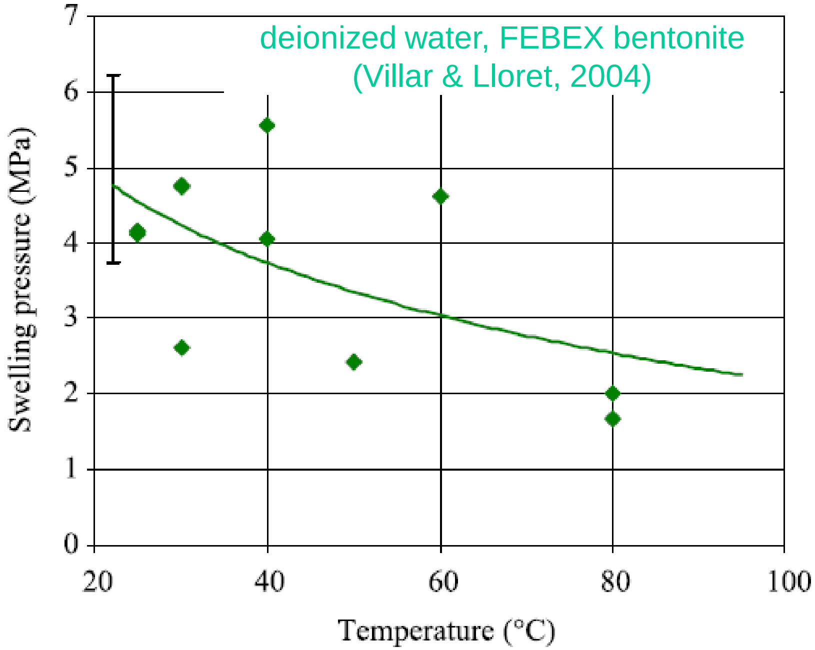
In-situ experiment HE-D in Opalinus clay,
URL Mont Terri

(Zhang, 2010)

Open question

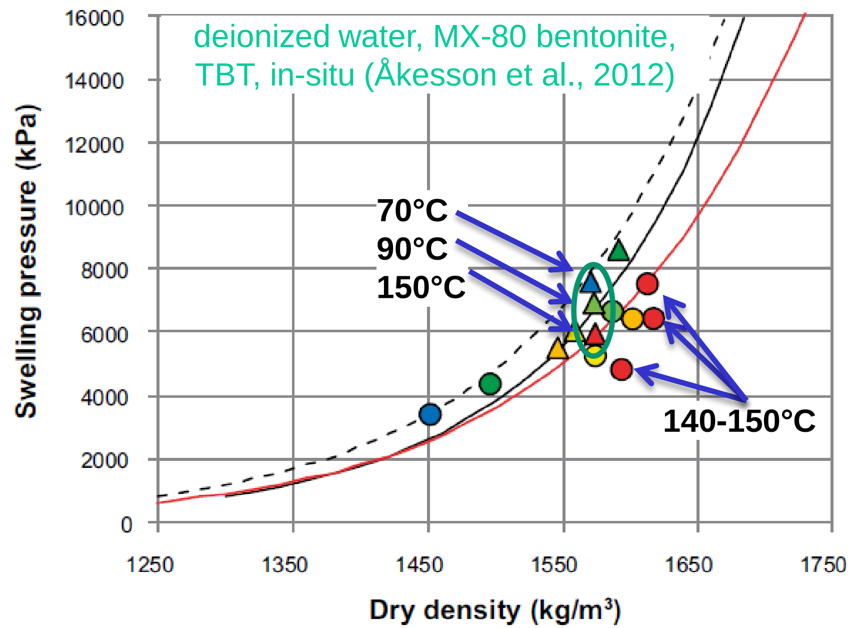
Quantification of the thermally induced drainage and of the influence of inhomogeneities at in-situ scale

Swelling of clay

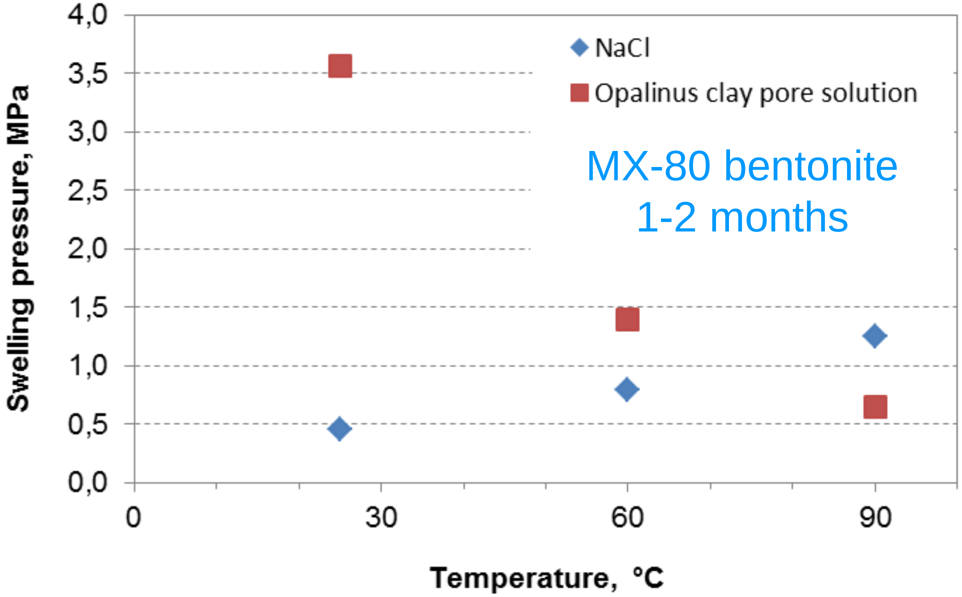


Effect of a short temperature treatment

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

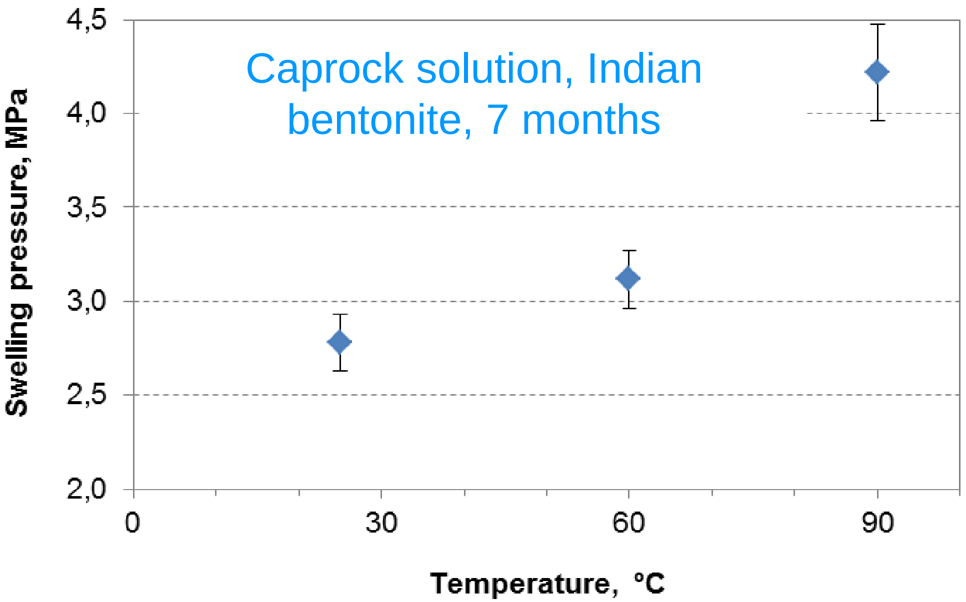


Swelling of clay



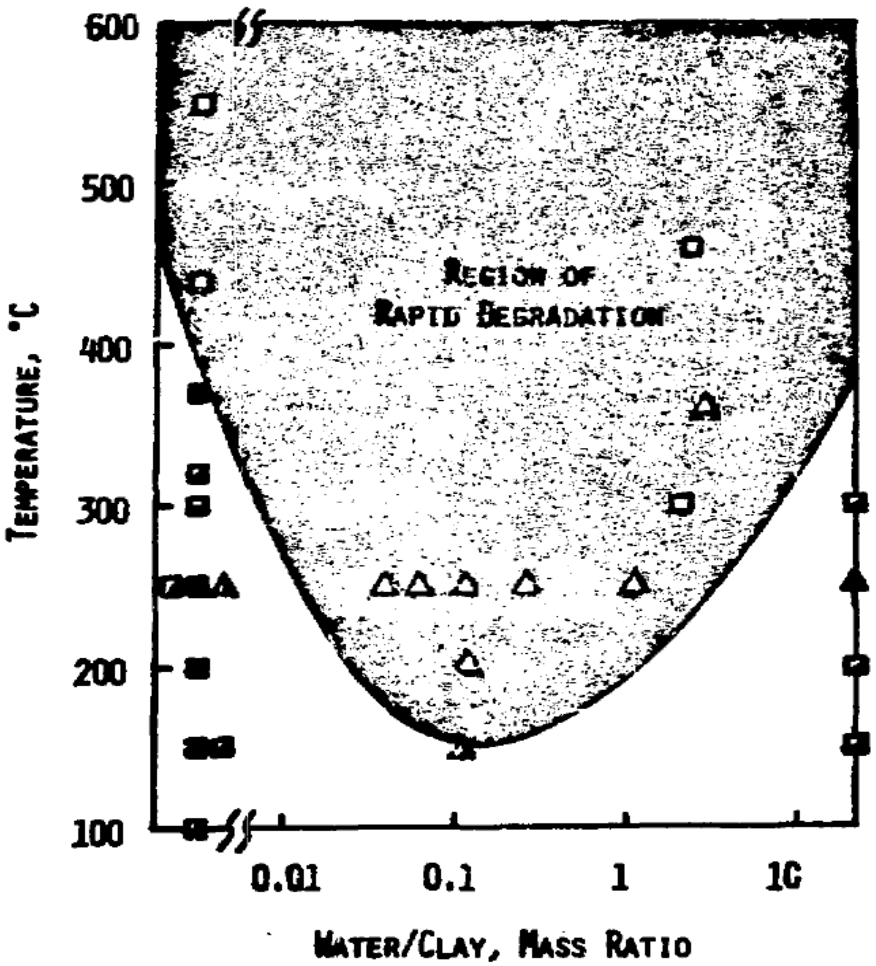
Effect of a prolonged temperature treatment (mineral alteration)

(Herbert et al., 2011)



(Meleshyn, 2015)

Swelling of clay

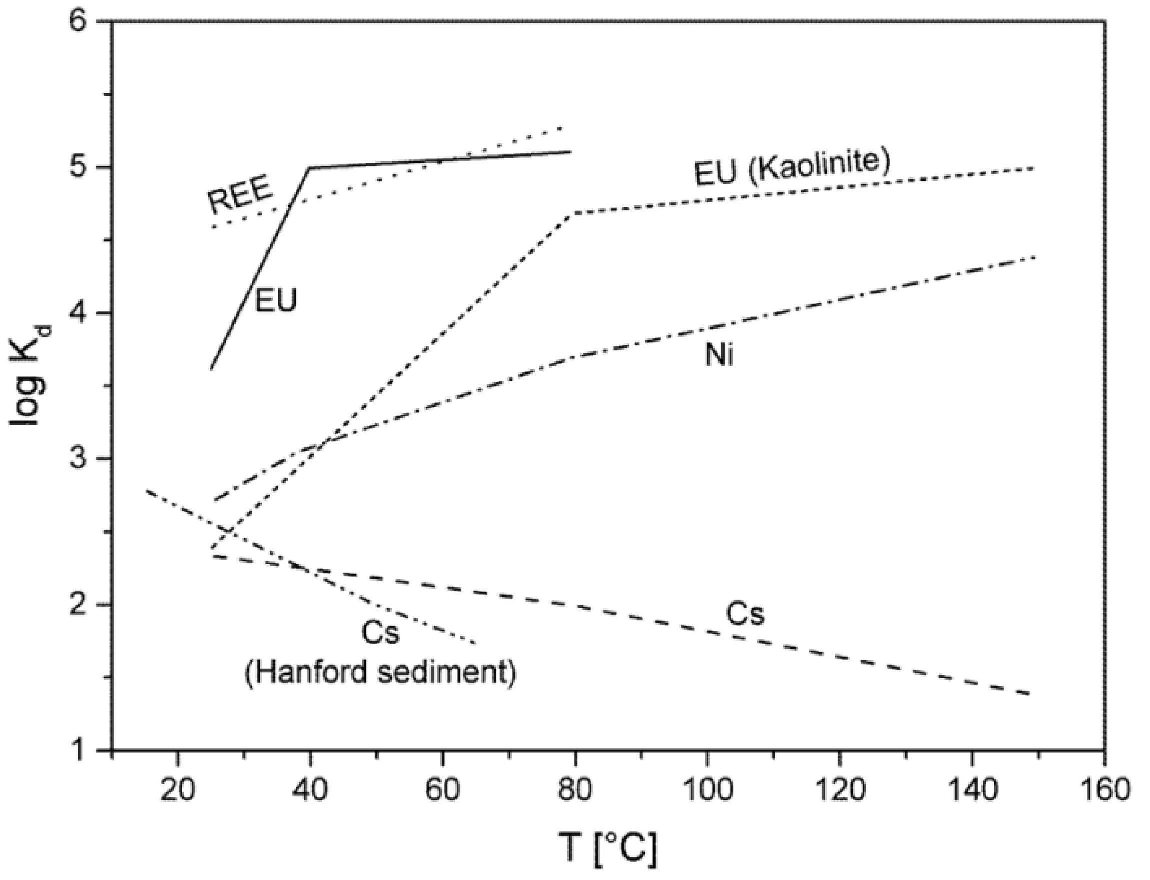


Hydrothermal degradation of the osmotic swelling ability of bentonite by water vapor within one week (Couture, 1985)

Open question

The effect of high temperatures on swelling ability and swelling pressure of clays

Sorption capacity of clay



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

Open question

The effect of high temperatures on sorption capacity of clays

Microbial survival in clay

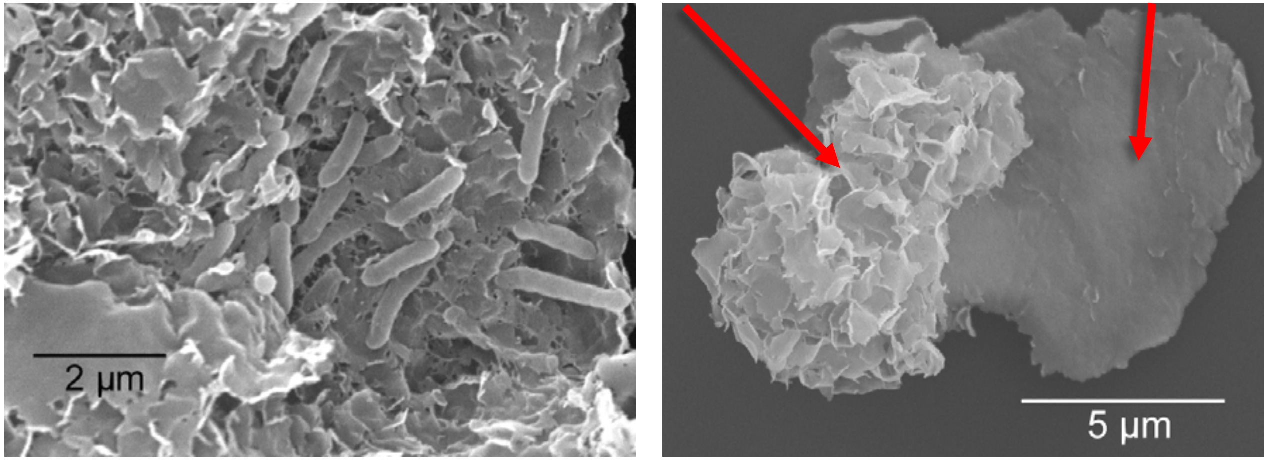
Microorganisms	Temperature limit of activity	Endospore survival
Sulfate-reducing	95-110°C	~ 125-140°C*
Fe(III)-reducing	121°C	~ 150°C*
Methanogenic	122°C	-

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

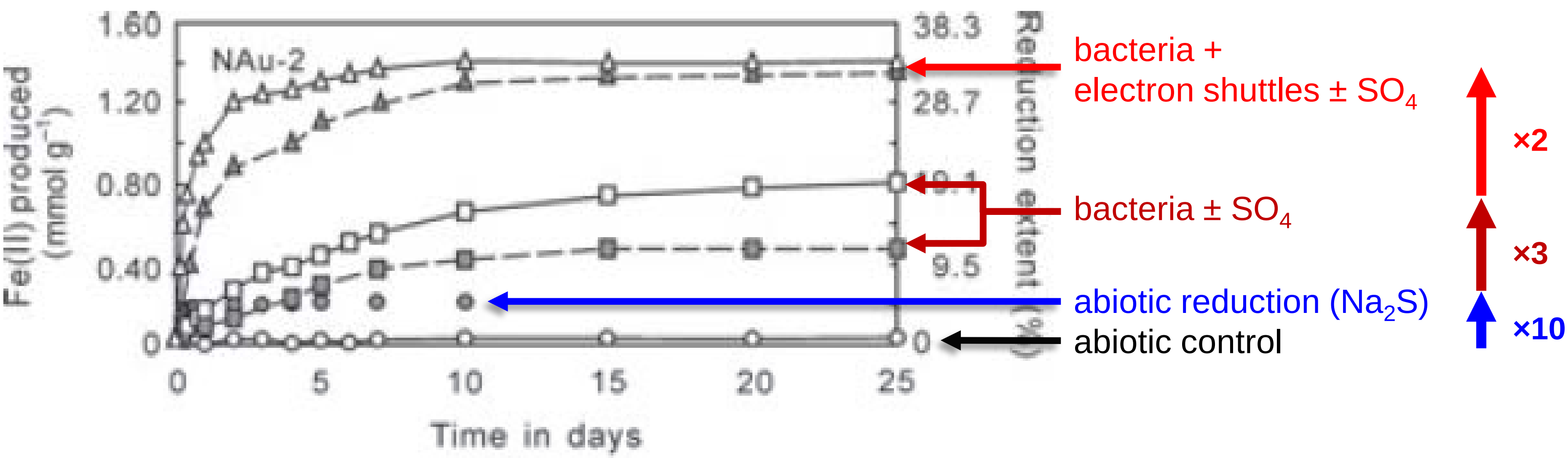
Sedimentary rocks exposed during their diagenesis to paleotemperatures of 140°C show only spurious and of 145°C no microbial biomass at all (Colwell et al., 1997)

Microbial transformation of smectites

microbially reduced smectite unaltered smectite

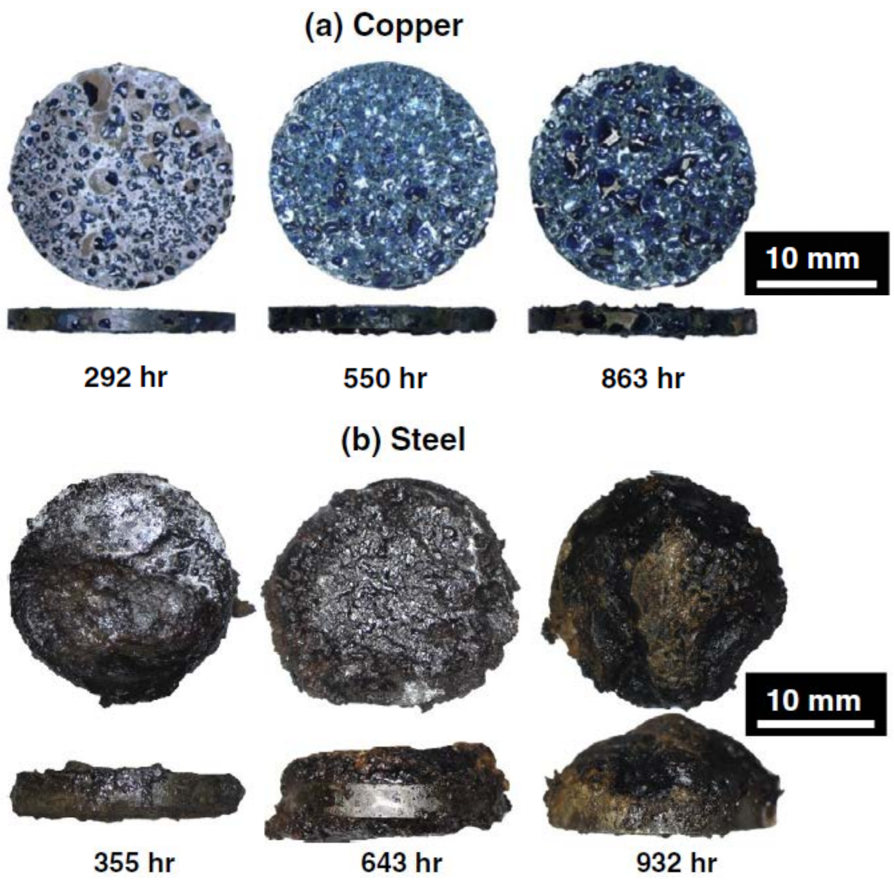


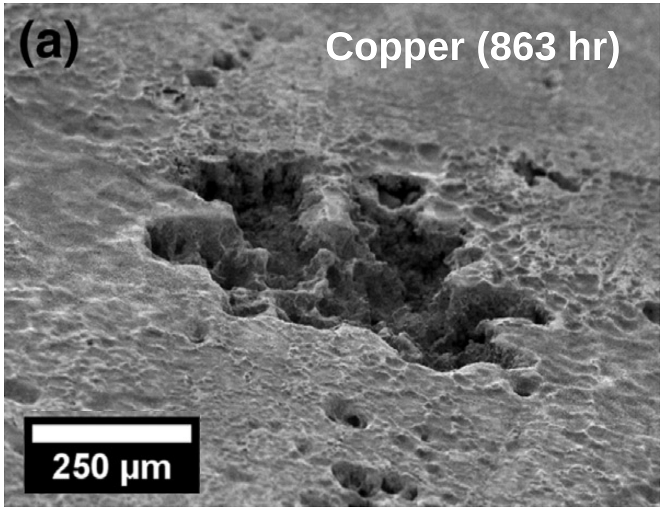
SWa-1 after 2 months with Fe(III)-reducing bacteria (Dong et al., 2003)

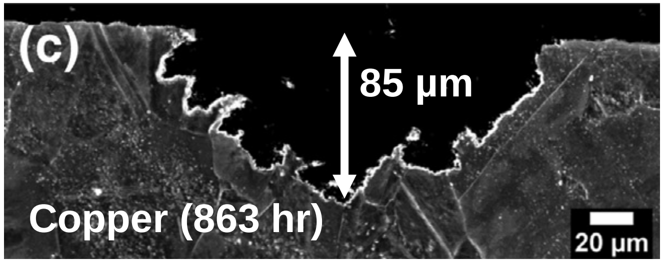


Nontronite NAu-2 + sulfate-reducing bacteria (Liu et al., 2012)

Microbially influenced corrosion







Pitting (general) corrosion:

Copper

0.88 (0.06) mm/a in vapor phase

0.40 (0.05) mm/a in liquid phase

Carbon steel

2.85 (1.10) mm/a in vapor phase

4.70 (0.06) mm/a in liquid phase

(Sowards & Mansfield, 2014)

Open question

Decline of the detrimental microbial activity in clay with increasing temperature

Summary of identified research topics

- Expansion-contraction behavior and permeability of compacted bentonites and crushed clays at high temperatures
- Quantification of the thermally induced drainage and of the influence of inhomogeneities at in-situ scale
- 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 you attention!