

# Thermal alteration of bentonite (TAB): an overview

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# TAB: background

- in the case of thermal alteration of bentonite, e.g. cementation, caused by smectite/illite conversion where silica is released at higher temperature (and later reprecipitated) can occur
- currently, in many national programmes, the requirements for maximum bentonite temperatures are set around 100°C to avoid potential cementation (and other issues)
- in many cases, there would be interest in increasing this limit, so allowing, for example, the placement of waste packages more closely than is currently planned

Table 2-1. Summary of characteristics of repository concepts

| WMO           | CONCEPT                        | CLAY BUFFER TYPE        | THERMAL ASPECTS  | UNCERTAINTIES   |
|---------------|--------------------------------|-------------------------|--|---|
| ANDRA         | Cigéo                          | No                      | T<90°C in COx<br>No formation damage                                   | Non-linearity mechanical behaviour<br>Time-dependent behaviour  |
| BGE           | ANSICHT                        | Yes, sodium bentonite   | Preliminary cask surface<br>T <100°C                                   |   |
| ENRESA        | 2004-concept clayrock          | Yes, divalent bentonite | T <100°C in bentonite<br>ΔT<5°C upper aquifer<br>ΔT<0.5°C land surface |   |
| NAGRA         | HLW                            | Yes, sodium bentonite   | 130°C canister/buffer<br><90°C rock                                    |   |
| ONDRAF /NIRAS | Monoliths B and Supercontainer | No                      | <100°C overpack<br><25°C top clay formation                            | Large-scale response to heat<br>Anisotropy of THM properties<br>Changes in mineralogy/geochemistry (T, high pH)<br>Thermal reactivity<br>Gas role |
| POSIVA        | KBS-3V                         | Yes, sodium bentonite   | T <100°C in buffer   |   |
| RWM           | preliminary                    | Yes, sodium bentonite   |  |   |
| SKB           | KBS-3V                         | Yes                     | T <100°C in buffer   |   |
| SÚRAO         | preliminary                    | Yes, divalent bentonite | T <100°C in bentonite  |   |

Source: Villar et al., (2020) - HITEC.

# TAB: background



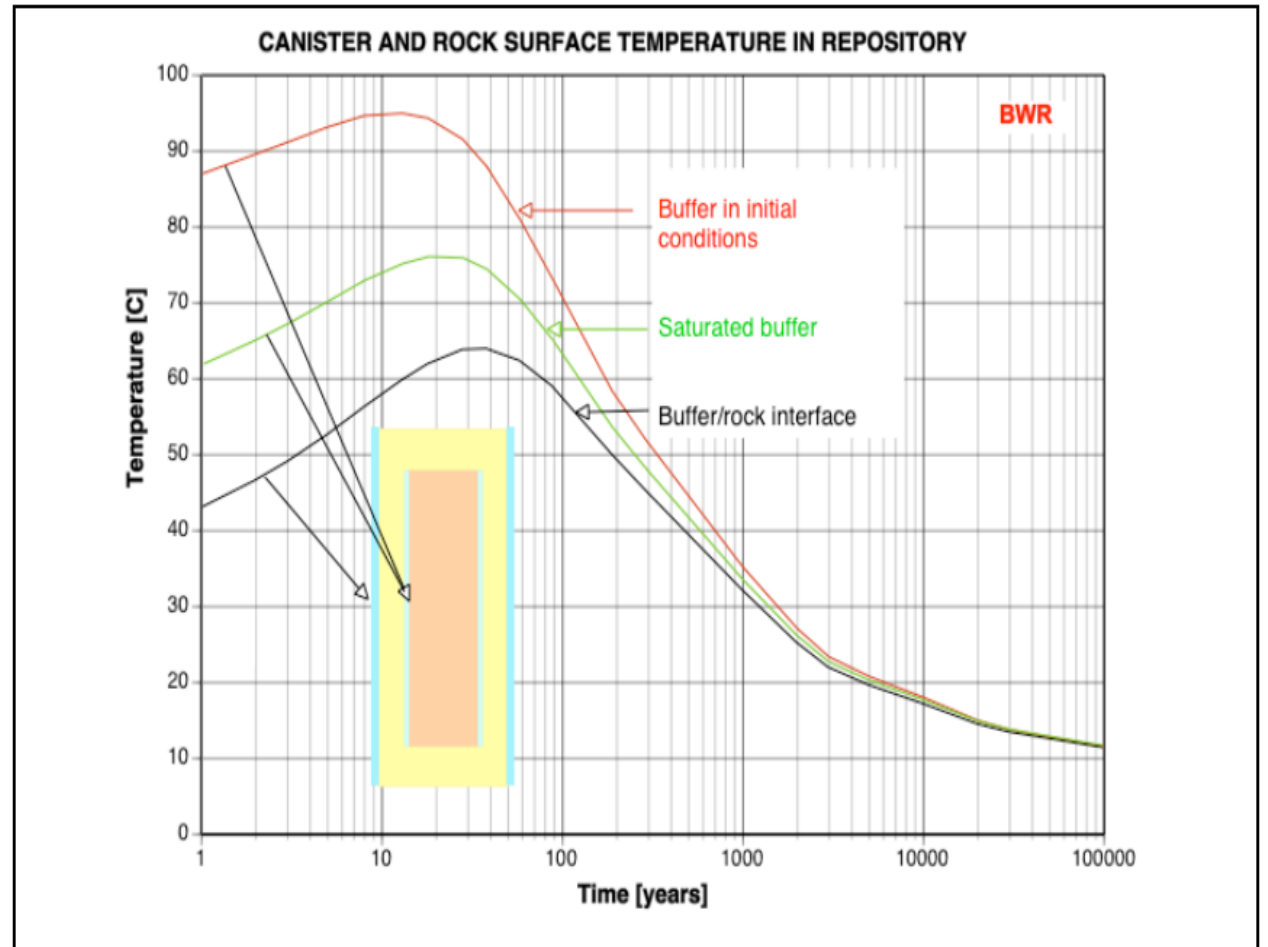
# TAB: background

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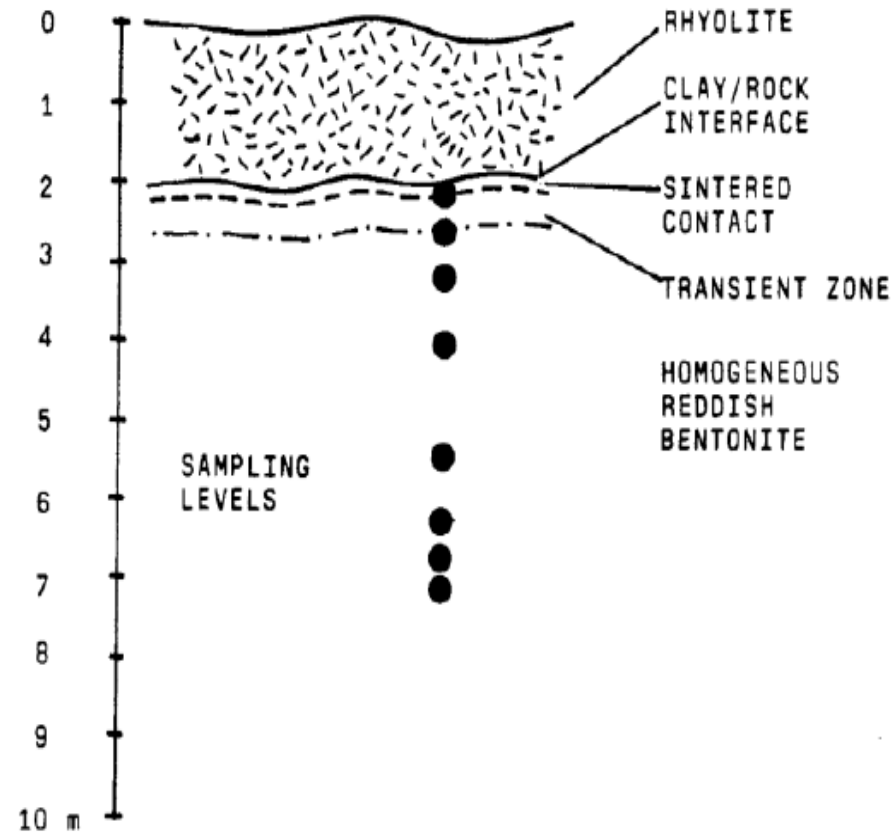
- but this would require more stringent justification than currently exists (NB EURAD-HITEC 2019-2024 project is currently examining this)
- although a significant number of NA papers on this theme are available, critical re-analysis of the data (Posiva, 2013, 2023) showed that most examples suffer from the same problem: **the conditions are not truly representative of a repository**
- As such, the conclusions reached in such NA studies to date are misleading

# TAB: background

The degree of saturation of the EBS affects the thermal conductivity of the bentonite, the highest temperatures being met in the “dry” case, i.e. bentonite water contents being as installed (e.g. in Posiva’s reference design, the initial water content of the buffer is assumed to be 17%)

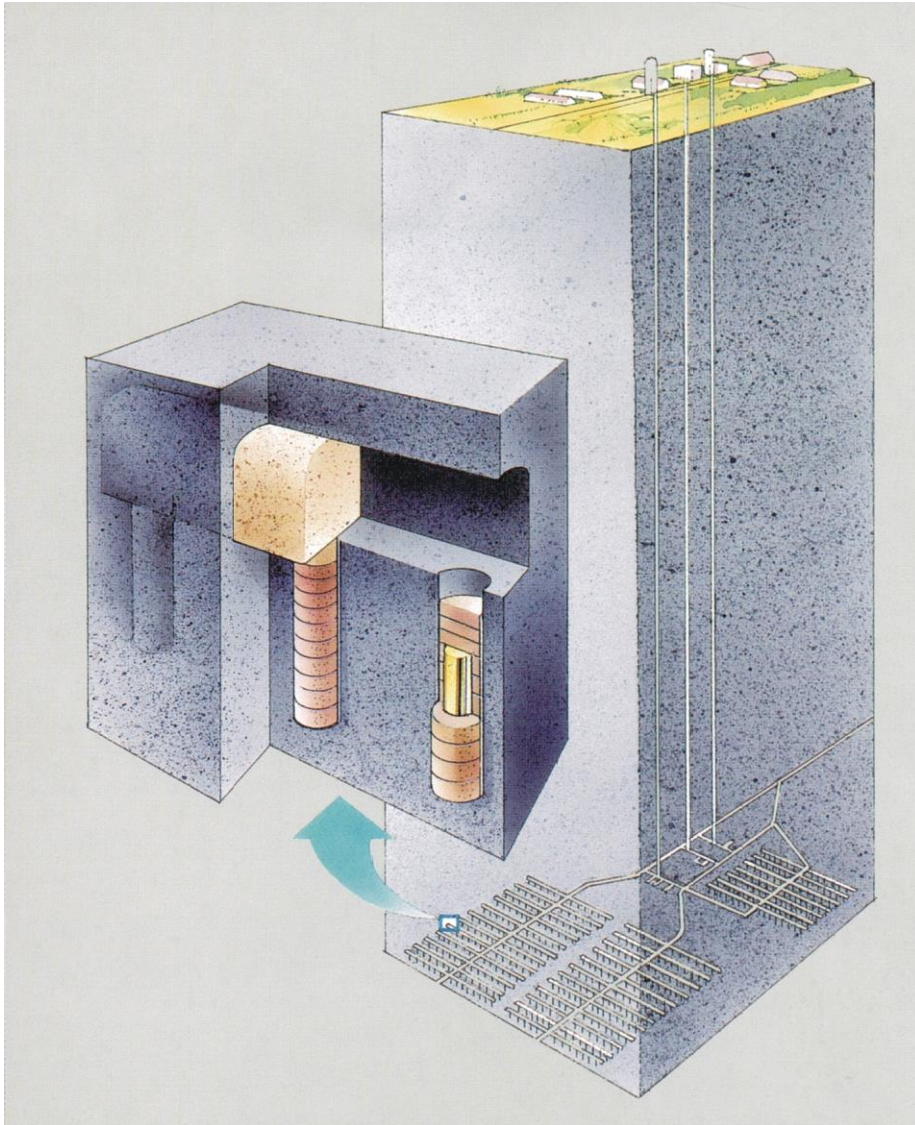


# TAB: previous work (Busachi)



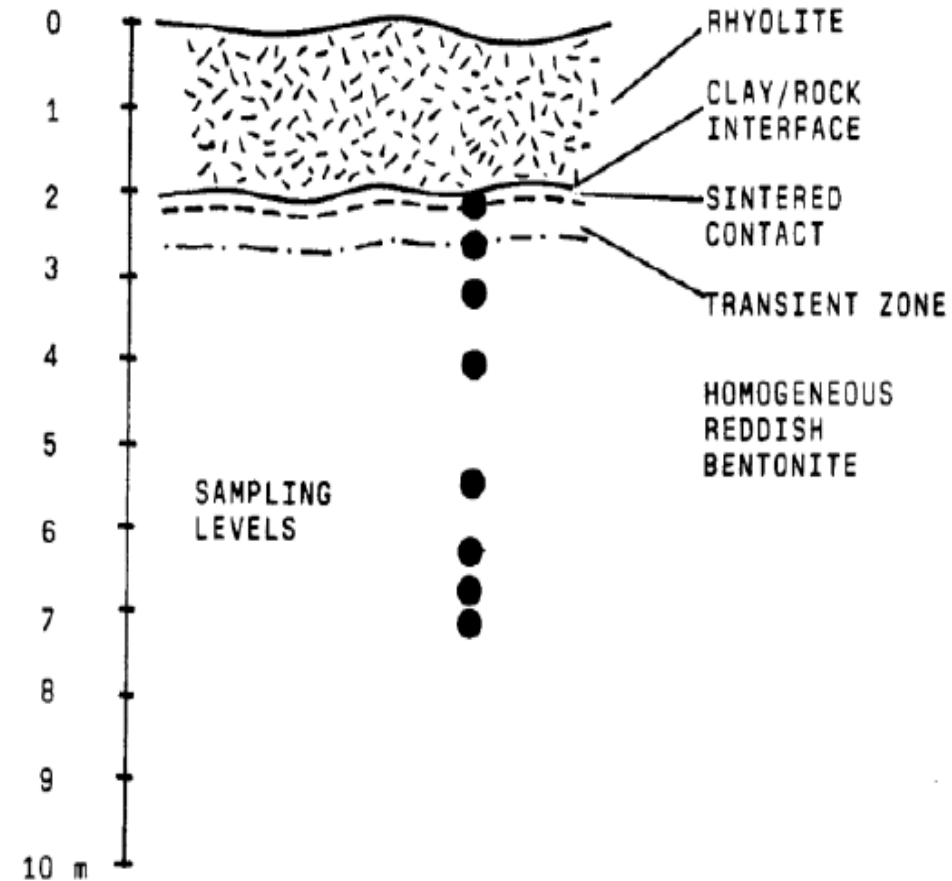
- numerous studies where smectite-bearing clays which had been penetrated by dykes/sills have been reported
- mineralogical changes were generally associated with subsequent fracturing of the cemented clays as the interstitial waters were driven out

# TAB: previous work



- While these mechanisms are of relevance to various repository designs (e.g. disruption of the bentonite by the movement of interstitial waters), in most cases of contact metamorphism studied, the temperatures have been much too high (**800-900°C**)

# TAB: previous work



- **In a few rare cases, attempts have been made to sample far enough away as to be in a more appropriate temperature field**

# TAB: previous work

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- *unfortunately, even these observations cannot be applied directly to the safety case because the full thermal, chemical and pressure histories experienced by these clays were not adequately characterised (if examined at all)*
- *no information on the degree of saturation is available in any of the reported studies*

# TAB: previous work

- the Ishirini bentonite body (Libya) has been examined and the impact of a basalt dome and dykes on the bentonite was assessed
- minimum temperature experienced by the bentonite was probably  $>190^{\circ}\text{C}$  but bentonite from outwith this zone (i.e. in the lower temperature area) was *not* sampled, so the original condition of the bentonite is not known



# TAB: previous work

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- **In the case of diagenetic illitisation, a number of natural analogue studies have been carried out in the Gulf of Mexico (and elsewhere)**
- **However, these studies do not really represent the repository environment because the duration of heating is several orders of magnitude longer than would be the case in most repositories**
- **Nevertheless, these studies suggest the illitisation rate in the natural environment is considerably slower than that predicted by kinetic models, but this is often due to the fact that the process depends on the rate of supply of potassium, which may often be limited**

# **TAB: conclusions on existing work**

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**NA studies of thermal alteration of bentonite are legion (and only a few are noted above), but critical reviews (e.g. Laine & Karttunen, 2010, Posiva 2013, 2023) of the work carried out to date indicates that they are of little value in supporting the safety case because:**

- either the conditions are non-repository relevant**
- the background information obtained was too limited**
- inappropriate temperature range examined (e.g. Ishrini)**

# TAB: previous work

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- ***in conclusion, while the probable impact of raised temperatures is minimal (i.e. some local cementation occurs, but the majority of the bentonite remains unaltered), a truly repository-representative analogy has not yet been examined***

# TAB: conclusions on existing work

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- **inappropriate timescales for heating of the bentonite, they are usually way too long (e.g. Gulf of Mexico)**
- **ill-defined (e.g. 1999 EU study; Pellegrini et al., 1999) or assumed (e.g. Busachi; Pusch & Karnland, 1988) boundary conditions**
- **under-characterised physico-chemical parameters of the bentonite**
  - *use of modern analytical techniques can better define temperature zonation before assessing changes in the smectite*
  - *define more than just the smectite content (e.g. swelling pressure, saturation state etc)*

# TAB: what should we do now?

Certain aspects have never been properly addressed, for example:

- as surface/near-surface sites are normally studied, bentonite under a repository-relevant lithostatic load/hydralulic pressure has not been examined
- the saturation state of **a deep** bentonite has never been assessed in detail



Zoopigi bentonite quarry, Cyprus

# TAB: what next? Coupled projects

## URL

- to date, bentonite saturation studies have been highly artificial, with induced (relatively high) groundwater flow
- what is required is an approach where resaturation is studied under appropriate conditions, only then can we be sure that the scenarios (e.g. dry thermal pulse) are realistic/reasonable

Large-scale tests considered relevant in EURAD-HITEC:

Table 3-8. Summary of relevant large-scale tests characteristics

| Test            | Host Rock                | Duration         | Characteristics                | Temperature   | Buffer                            |
|-----------------|--------------------------|------------------|--------------------------------|---------------|-----------------------------------|
| ABM<br>SKB      | Granite<br>(Äspö)        | 1, 3, 5 years    | Reduced scale,<br>vertical pit | 130°C (250°C) | 11 different clays <sup>a</sup>   |
| LOT<br>SKB      | Granite<br>(Äspö)        | 1, 6, (20) years | Reduced scale,<br>vertical pit | Up to 130°C   | MX-80 (Na<br>bentonite)           |
| HE-E<br>NAGRA   | Opalinus<br>(Mont Terri) | >8 years         | Reduced scale,<br>gallery      | 140°C         | Sand/MX80 mixture<br>MX80 pellets |
| FE<br>NAGRA     | Opalinus<br>(Mont Terri) | >5 years         | Real scale, gallery            | 140°C         | MX80 blocks<br>MX80 pellets       |
| FEBEX<br>CIEMAT | Granite<br>(Grimsel)     | 5, 18 years      | Real scale, gallery            | 100°C         | FEBEX (Ca-Mg<br>bentonite)        |
| JOSEPH<br>SÚRAO | Mock-up (CZ)             | >7 years         | Reduced scale,<br>vertical     | 90-100°C      | B75 (Ca-Mg<br>bentonite)          |
| Ophelie         | Mock-up (BE)             | 4.5 years        | 1:1 scale                      | 170°C         | FoCa/sand/graphite<br>(60/35/5)   |

Source: Villar et al., (2020) - HITEC.

# TAB: what next? Coupled projects

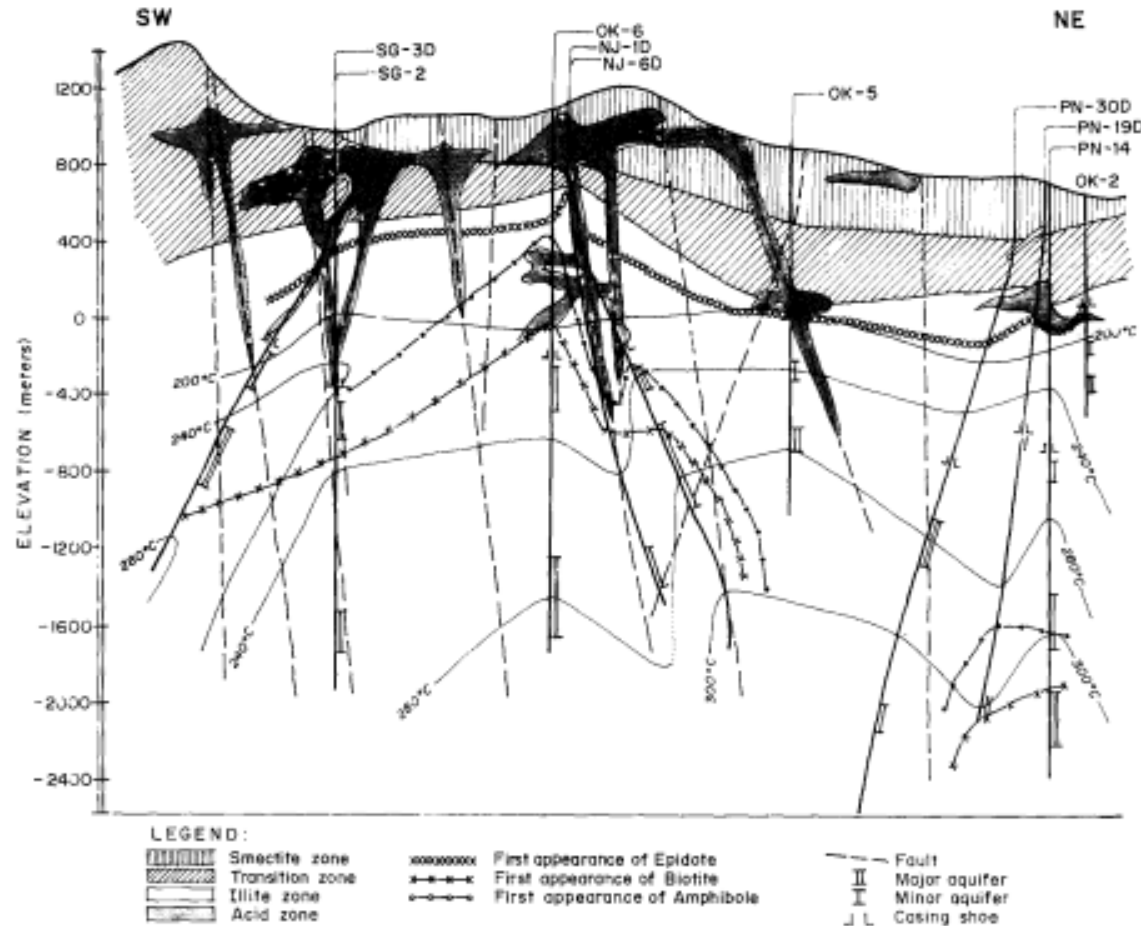


Fig. 9b. The distribution of alteration zones and measured isotherms in the Palimpinon geothermal system, Southern Negros.

## NA

- no more surface sites, time to look at bentonite mines or deep borehole samples where the bentonite is under appropriate hydrostatic loads
- and is under repository-relevant saturation states
- fully characterise the material using modern methods

# TAB: references

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