

A scenic landscape photograph of a misty forest at dawn or dusk. The sun is low on the horizon, casting a warm orange glow over the scene. The foreground is filled with tall green grass, and the middle ground shows a dense forest of evergreen trees partially obscured by a thick layer of white mist. The sky is a mix of orange, yellow, and blue.

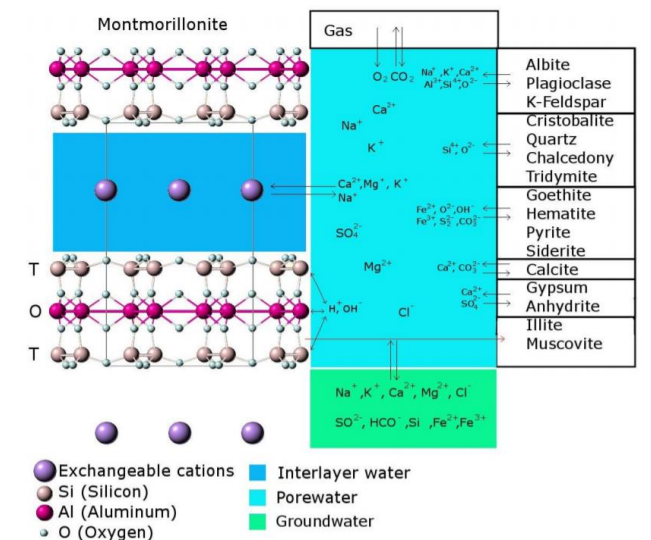
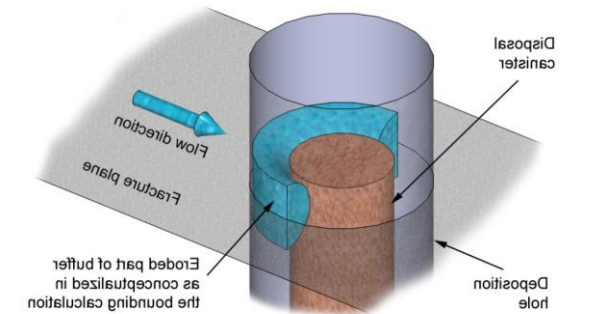
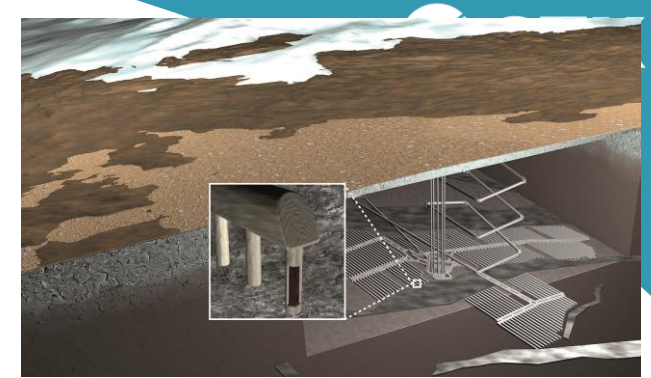
Fracture filling smectites as NAs for the bentonite buffer - case studies from Finland

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Natural Analogue Working Group workshop, Zadar, Croatia, 9.-11.5.2023

Background & objectives

- One of the scenarios that might affect bentonite barriers in the future is **chemical erosion of bentonite**
 - *Observed in lab tests when very dilute waters are used*
 - *Dilute waters possible during deglaciations in the future? Or due to continued meteoric water infiltration*
- Laboratory tests have been done, but
 - *No detailed studies have been made on the stability of smectites that occur naturally in the Finnish bedrock, until now*
- Here, some preliminary results from two projects are presented
 - BROCTIO: Nationally funded project 2018-2022 smectites from Olkiluoto and Hyykkölä
 - DILBI: Posiva funded study (ended 2022) on fracture minerals from Kivetty and Romuvaara



Background & objectives

Montmorillonite exists in bedrock fractures

Common mineral, including at sites where groundwater is naturally dilute e.g. Romuvaara, Kivetty and Hyrkkölä (shallow)

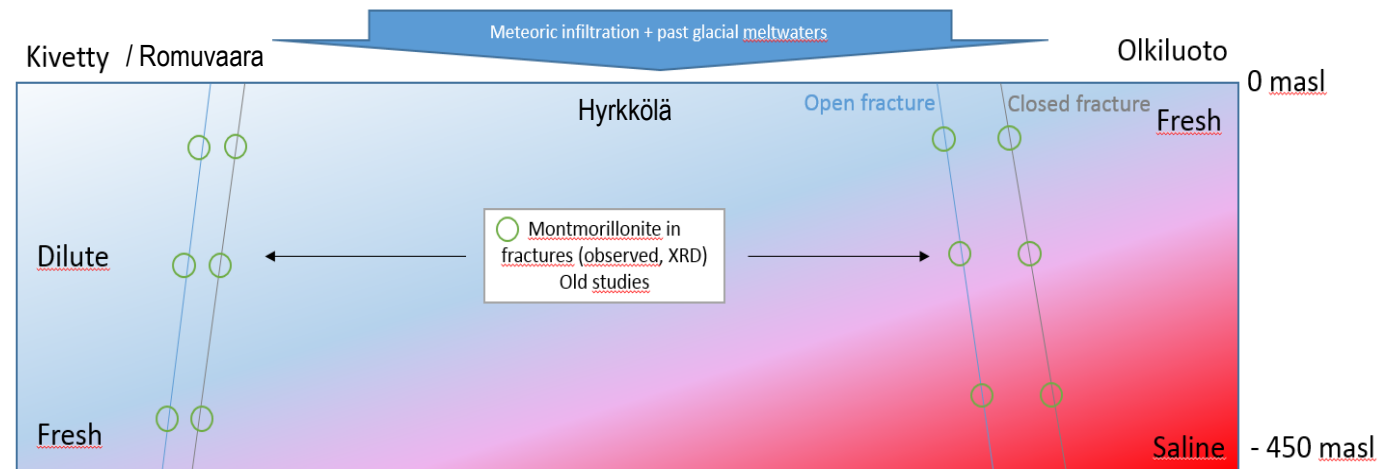
At Olkiluoto GW varies from fresh to brine (around 1000 m interval)

OBJECTIVE: better describe the montmorillonites and how they are related to gw system

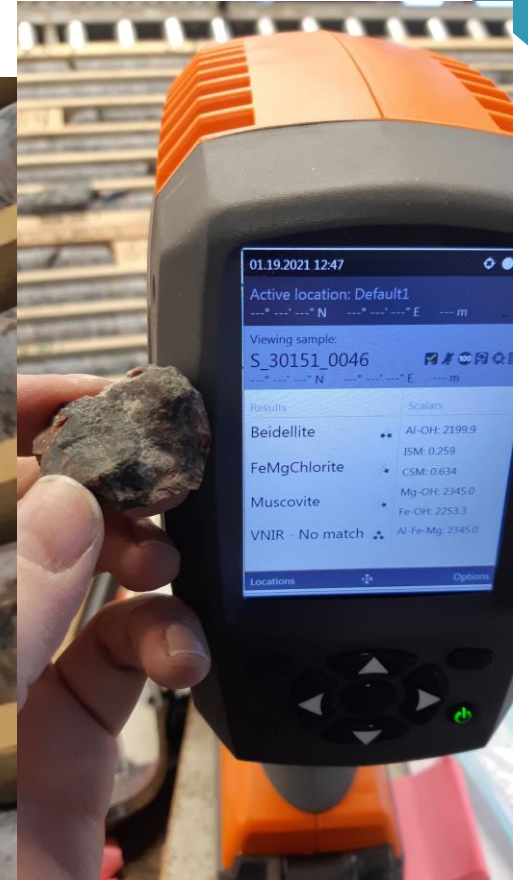
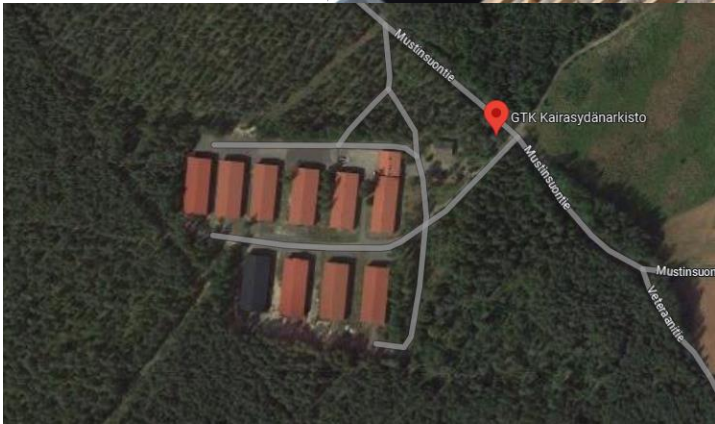
Relevant process: cation exchange, no information on the type of montmorillonites so far

Good set of samples available (Olkiluoto, Posiva's old site selection sites + Hyrkkölä, exploration site)

All drill core samples analysed here are archived at GTK drill core store at Loppi municipality.

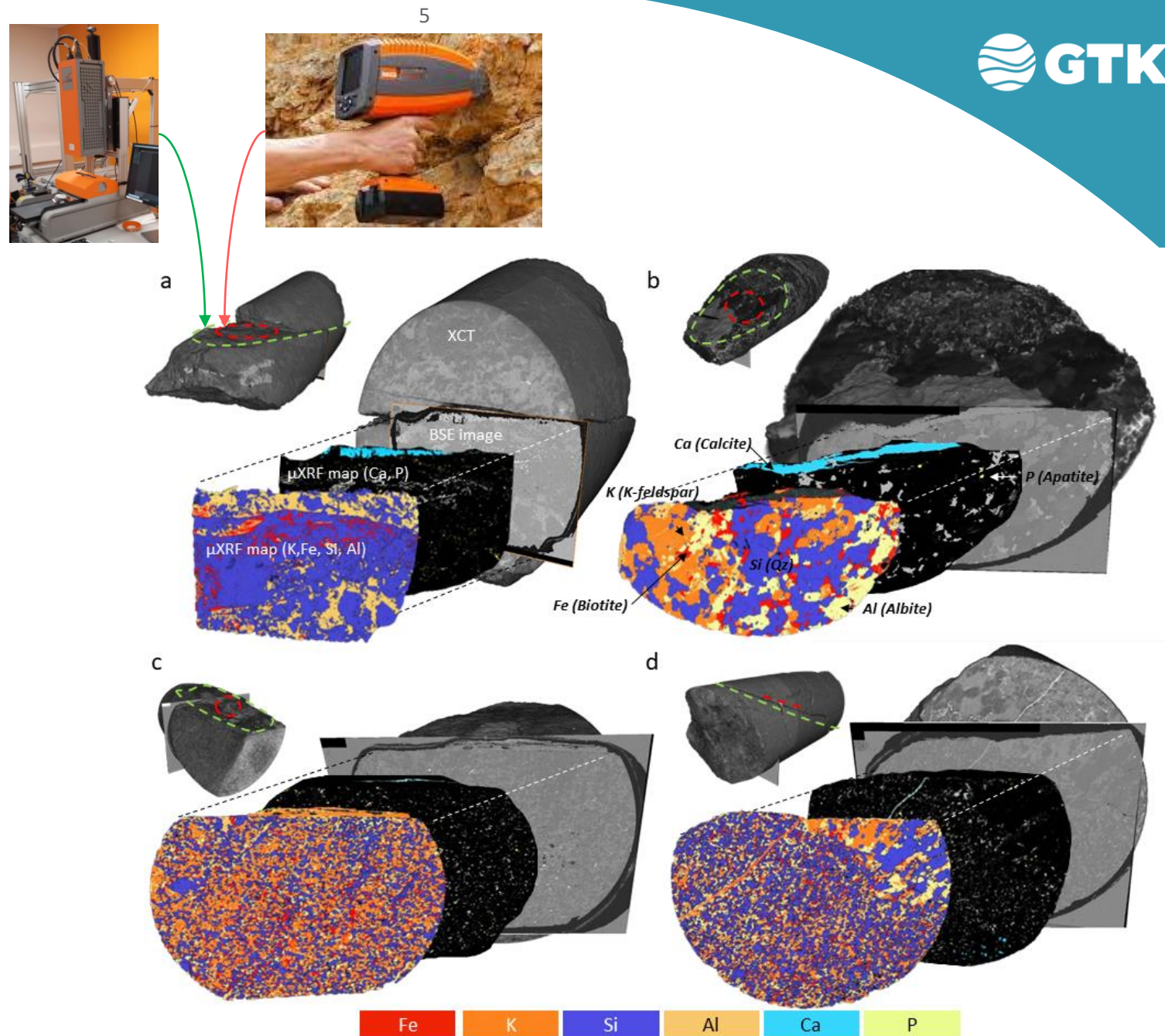


Few pictures from GTK drill core archive Loppi



Methods

- X-ray tomography
- Hyperspectral imaging and pointwise measurements (SWIR range)
- XRD
- Micro-XRF
- SEM-EDS (thin sections and rock cuts)
- Modelling (not discussed in this presentation, PhreeqC)



Samples

- Olkiluoto (19) (hyperspectral analysis included)
- Hyrkkölä (3) (hyperspectral analysis included)
- Romuvaara (15) (hyperspectral analysis used to locate smectite samples from drill cores)
- Kivetty (23) (hyperspectral analysis used to locate smectite samples from drill cores)
- Non-destructive analyses were performed first (XCT and hyperspectral), followed by XRD and thin sections and SEM-EDS (micro-XRF was done on thin sections)

Examples of inspecting fractures in the drill core prior thin sectioning:

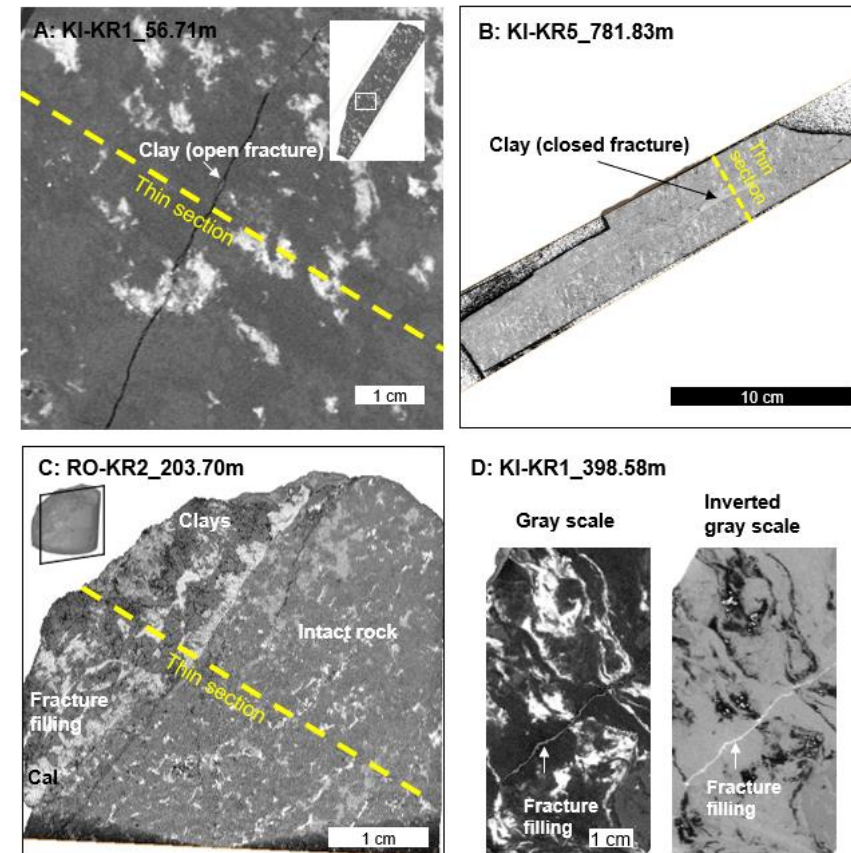
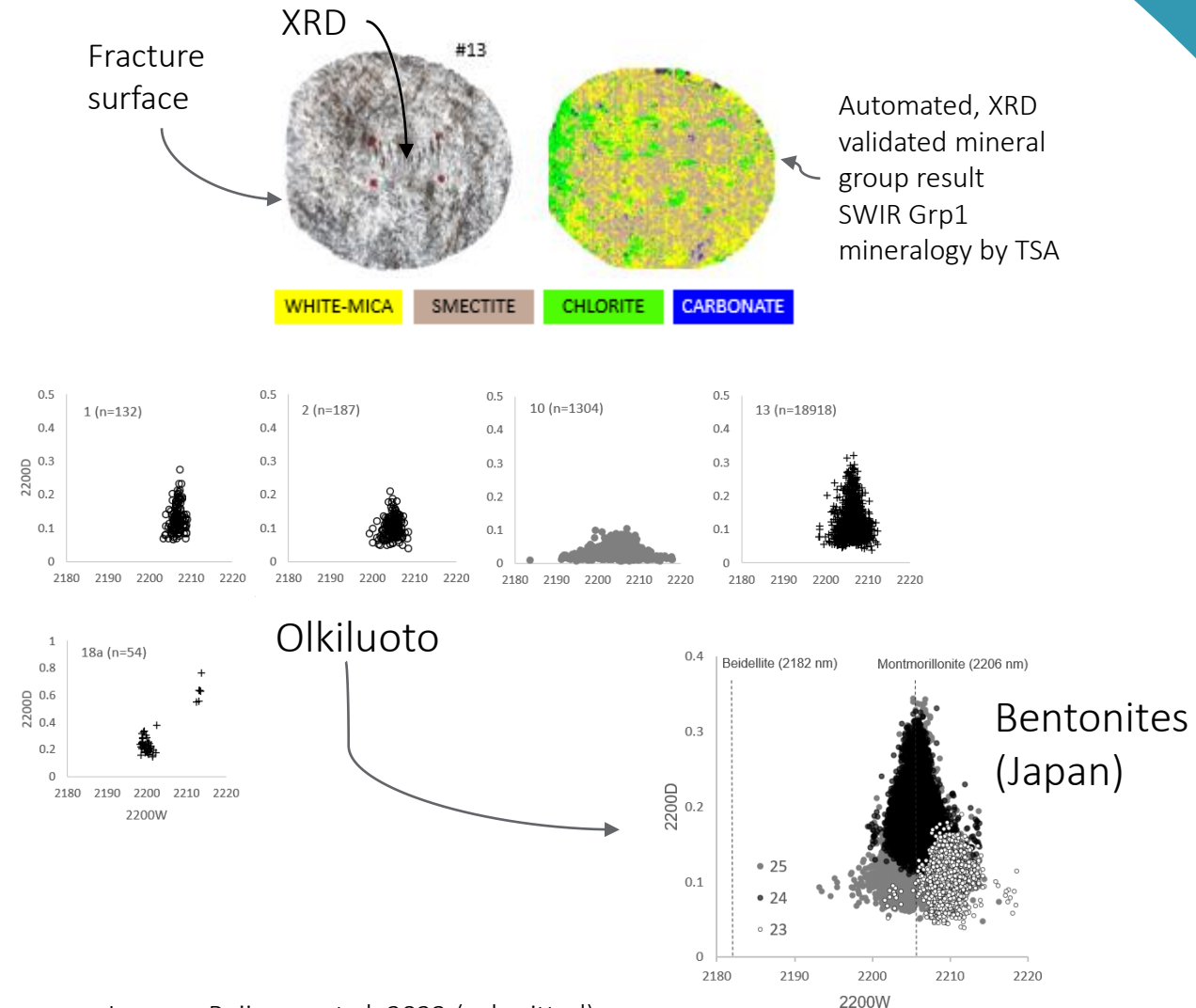


Image: Reijonen et al. 2023 (in prep)

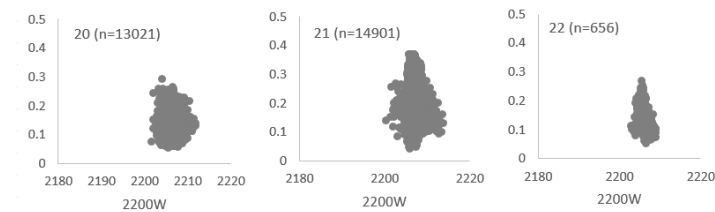
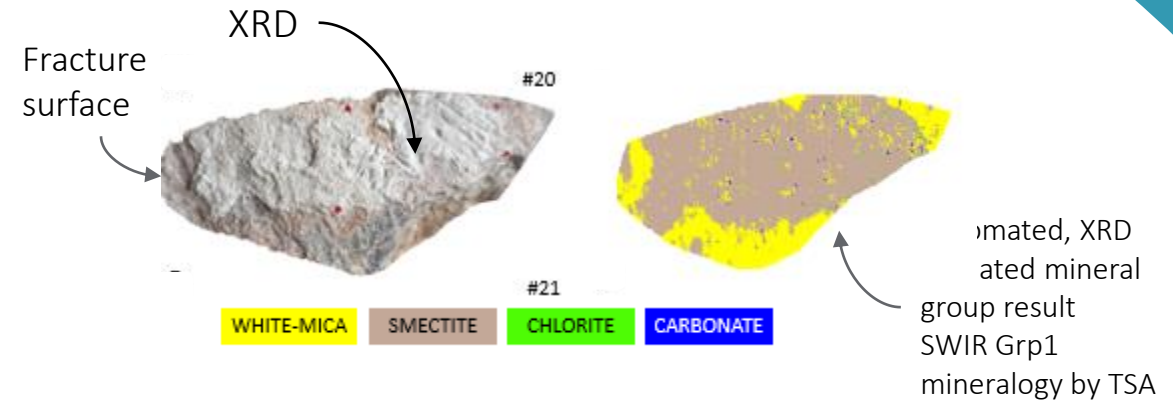
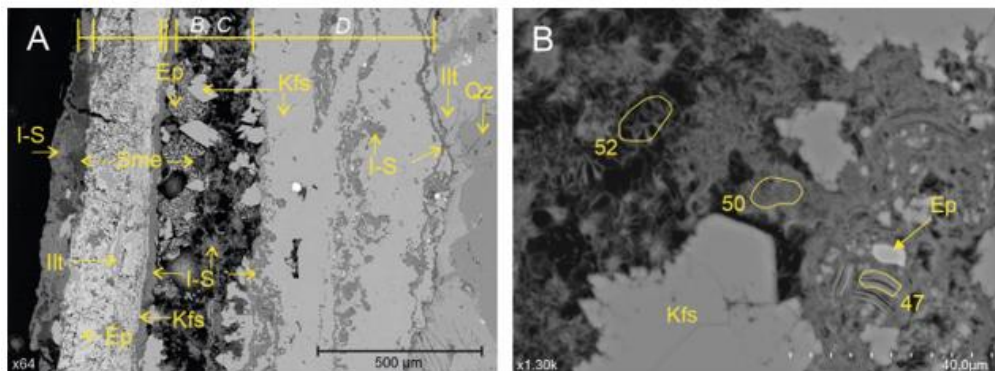
Examples of mode of occurrence - Olkiluoto

- Based on XRD both smectite and interstratified smectite/illites observed
 - I/S* mainly at depth > -500 m
 - Smectite 0-450 m (but more samples were taken 0-200 m)
- Hyperspectral imaging was proven feasible to assess fracture surface mineralogy
- Based on SWIR analysis, smectite closer to montmorillonite composition than beidellite
- No smectite was observed in thin sections but this is likely due to the small amount (3) of samples and some problems in thin section making

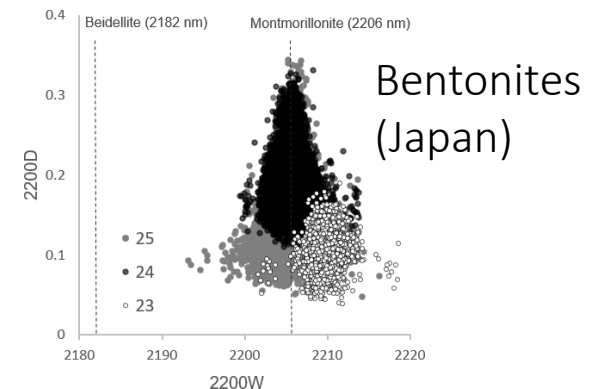


Examples of mode of occurrence - Hyrkkölä

- Based on XRD smectite observed
 - I/S* mainly at depth > -500 m
 - Smectite 0-450 m (but more samples were taken 0-200 m)
- Hyperspectral imaging was proven feasible to assess fracture surface mineralogy
- Based on SWIR analysis, smectite closer to montmorillonite composition than beidellite
- In thin section, also *I/S* is observed
- SEM suggests Mg-smectite



Hyrkkölä

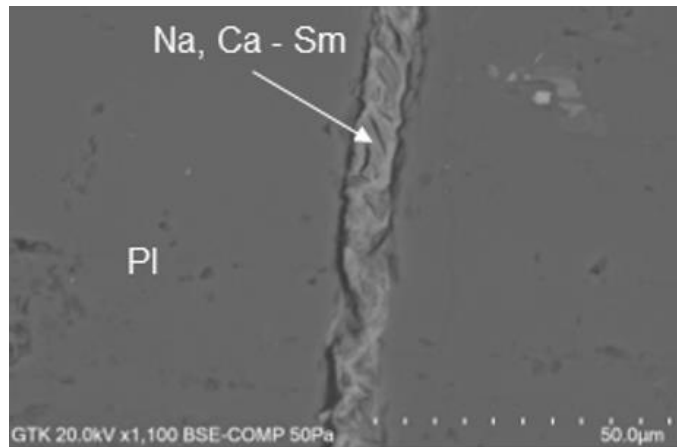


Images: Reijonen et al. 2023 (submitted)

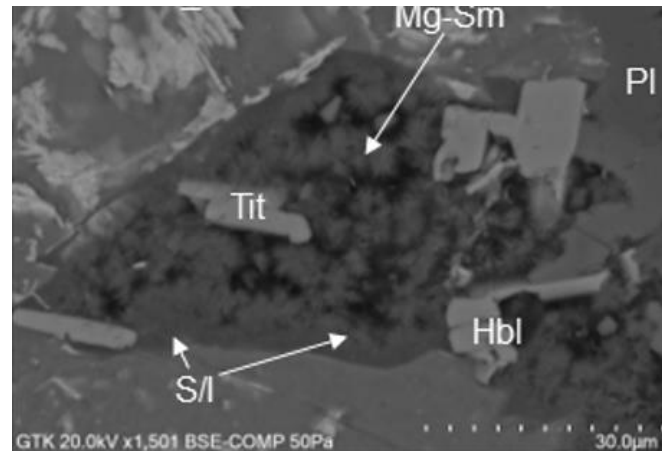
Examples of mode of occurrence - Kivetty

- Based on XRD smectite observed in most samples (not that sampling was aided with SWIR handheld measurements)
- Main types of (in situ) alteration observed:

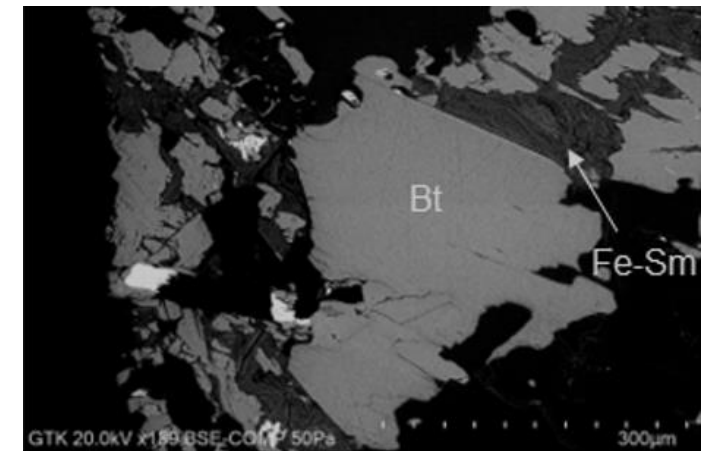
**Feldspars or Amphibole →
Na, Ca Smectite**



Amphiboles → Mg Smectite



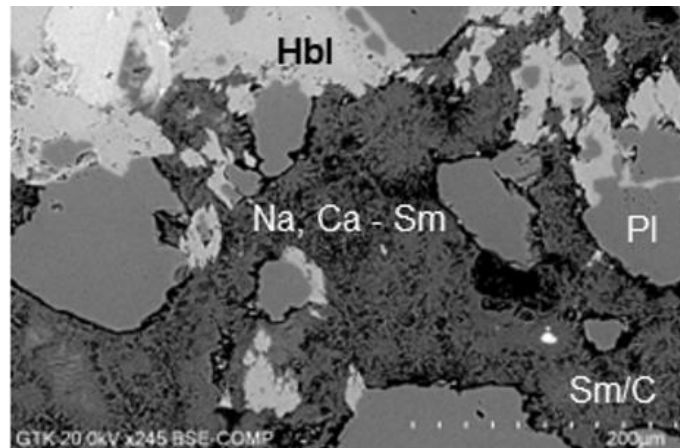
**Biotite → Fe Smectites
(least common type)**



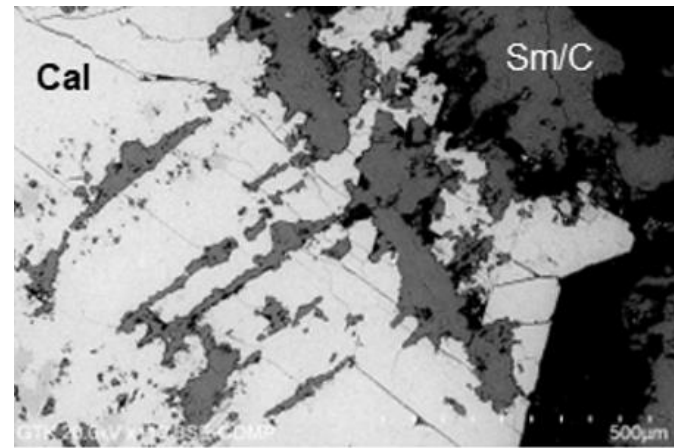
Examples of mode of occurrence - Romuvaara

- Based on XRD smectite observed in most samples (not that sampling was aided with SWIR handheld measurements)
- Main types of (in situ) alteration observed:

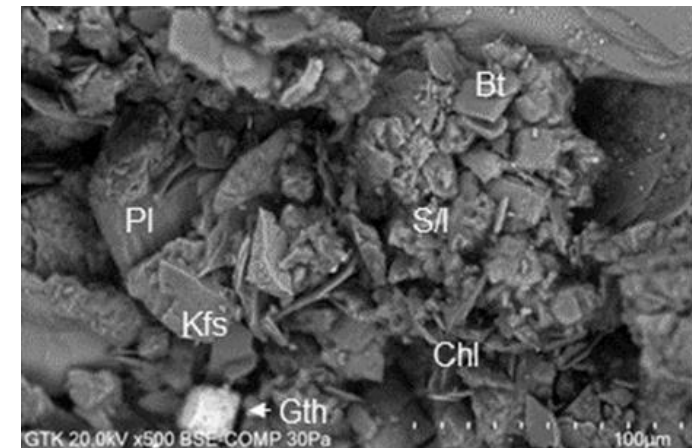
**Feldspars or Amphibole →
Na, Ca Smectite**



Calcite & Chlorite → Sm/C



**Biotite → chlorite → Fe
Smectites**



Smectite bearing fractures vs. bentonites

- Fracture mineral textures are much more heterogenous than homogenised bentonite microscopic composition (e.g. layering is quite common), but,
- The same minerals can be found in the smectite bearing fractures as in bentonites
 - *smectite, muscovite, quartz, plagioclase, K-feldspar and pyrite*
 - *some minerals that are trace in bentonite (cf. Wyoming examples; other bentonites may have much more of these): **calcite** and **illite**, are also present in variable amounts in fracture fillings*
 - *abundant **chlorite** is the most significant difference compared with the buffer bentonite overall mineralogy (although chlorite can be a component in bentonites in general)*

Results - what is the analogue?

- From all sites studied, **various types of smectites were observed in situ in the fractures** (both open and closed), including Na-, Ca-, Mg- smectites (Na and Ca types montmorillonite) and in some cases Fe-smectite
- The overall mineralogical assemblage comparable to bentonite mineralogy
- Analogues for dilute water – clay interaction: Hyrkkölä, Romuvaara and Kivetty data provides analogue to **chemical erosion scenario**
- Results from Olkiluoto confirm the observations made from the site, with additional sample deeper than previously reported (**fresh - saline conditions**)
- Uncertainties:
 - *samples with more clay and direct GW information would be useful for assessing the stability in conditions where more GW flow is expected → would require new drilling and luck in locating such fracture*
 - *Some clays may have been affected by original diamond drilling*
 - *Ages of smectites are not known very well (minimum age for Hyrkkölä based on previous studies suggests > 300 000 Ma, but could be much older)*

Conclusions

- Natural analogues
 - **SAFETY CASE:** *Fracture filling smectites provide a **natural analogue** for bentonites used in geological disposal facilities for radioactive waste*
 - *Both site analogues and regional analogues could be located in Finland*
 - *Analogue could be strengthened by studying other relevant sites and attempting dating of the smectites (worth comparing also to KINA results?)*

Conclusions

- Other uses
 - **SITE DESCRIPTIONS:** *Fracture filling mineral analysis using short wave infrared spectroscopy for site characterization is **non-destructive** providing an **efficient** method for investigating **large sample sets***
 - **ROCK ENGINEERING:** *Fast data collection and interpretation from field for rock engineering can **indicate swelling minerals (sometimes better than XRD)***
 - **QUALITY CONTROL:** *Hyperspectral methods hold potential for bentonite quality assurance development: e.g. **Bei vs. Mnt, smectite vs. white mica (illite) detection***

Publications

- BROCTIO results have been submitted:
 - *Reijonen, H., Elminen, T., Heikkilä, P., Kuva, J., Jolis, E. 2023. Enhanced identification of fracture smectites and other alteration minerals via short wave infrared reflectance at two Finnish crystalline sites, Olkiluoto and Hyrkkölä. (submitted)*
- DILBI results are in prep for journal publication
 - *Reijonen, H., Al-Ani, T., Kuva, J., Heikkilä, P., Elminen, T., Muniruzzaman, M., Issukka, K., Lamminmäki, R. 202X. Fracture smectite in bedrock as natural analogues for repository buffer in Kivetty and Romuvaara sites, Finland.*

Thank you – Kiitos!

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Acknowledgements

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