International Bentonite Longevity (IBL) project: recent results

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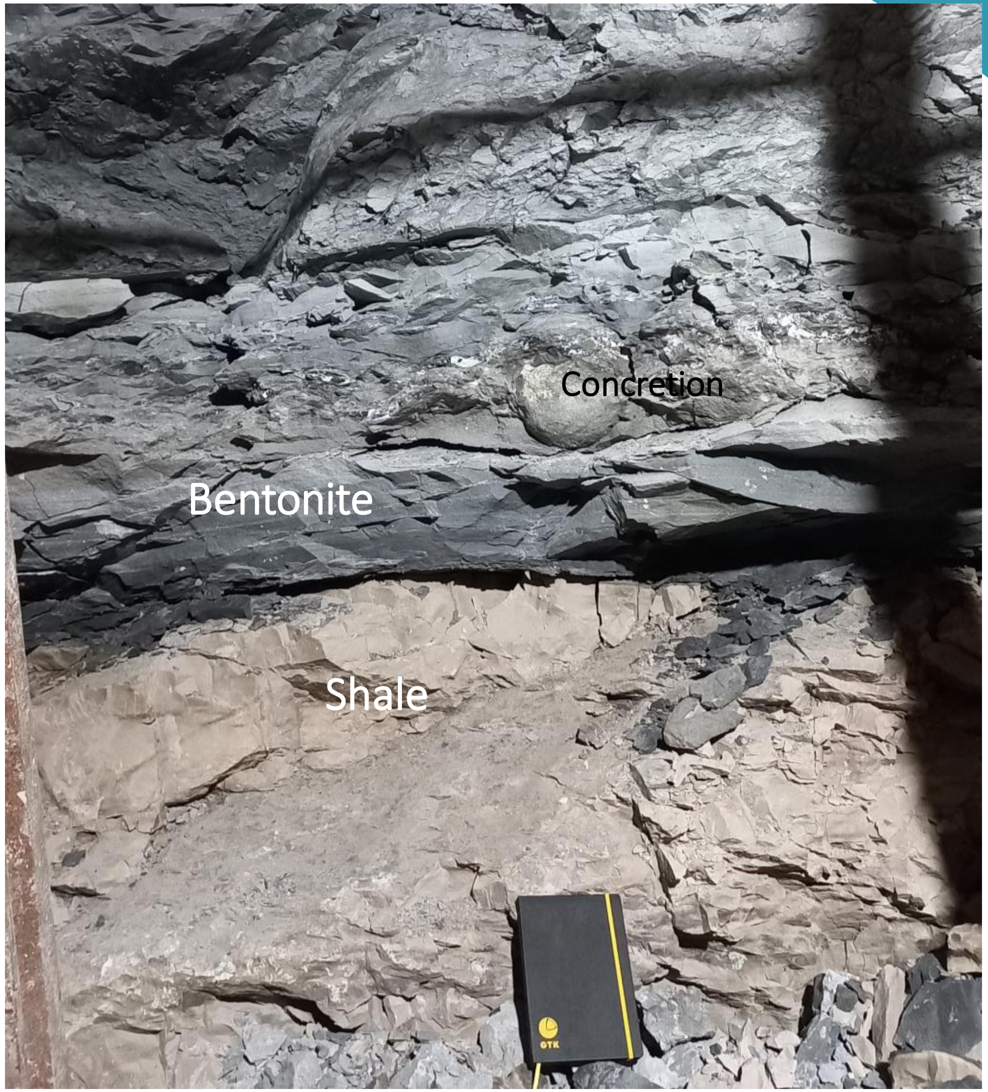
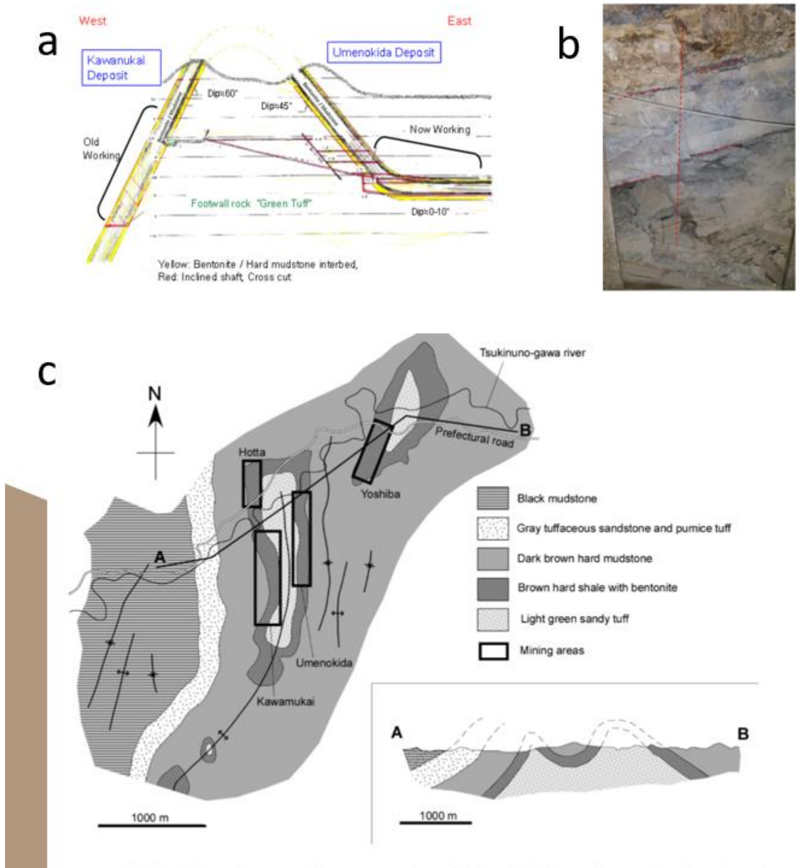
IBL-project

- Started in 2018
- Ongoing, project Phase B just finished sampling campaign at Tsukinuno, Japan
- Results of the Phase A reported in:
  - *Reijonen, H. & Alexander, W.R. 2022. Sealing deep site investigation boreholes: Phase 3 International Bentonite Longevity (IBL) project Report - Phase A. Jacobs Ref: 207314/R_05 Issue A. United Kingdom: RWM, 99 p. (in press)*
- Here, some recent results of further analyzing the drill core 1 from Phase A are presented
- Follow the project at www.ibl-project.com



Tsukinuno site and NA potential in IBL-project

Feature	Safety relevance	Examples of FEPs of interest
1. Bentonite occurs at various depths (0 – ca. 200m below ground surface) Fig 1 a and c.	Repository relevant depth (hydrostatic and lithostatic pressures)	Saturation, groundwater flow, groundwater diffusion…
2. Area has shearing and faults cutting bentonite bearing rocks Fig 1 b	Deformed bentonite	Faulting, bentonite deformation, host rock deformation, self-sealing, self-healing
3. Hosted by sandy silt stone Fig 1 b and c	Brittle host rock: fractures and water conducting features	Advection/diffusion, water-rock (clay) interaction
4. Some of the bentonite is dry Fig 1 b	Unsaturated bentonite	Saturation
5. Bentonite occurs as bands with varying thicknesses (from few cm to ca. 7 m) Fig 1 b	Repository relevant size, scale effects.	Clay – rock interaction. Clay based buffer and backfill designs
6. Bentonite deposit outcrops at the surface, including in nearby riverbed Fig 1 d	Potential to study freshwater bentonite interactions	Saturation, water-rock (clay)interaction, cation exchange, colloid formation, erosion…



Appendix 5 Plan figure and cross section of the Tsukinuno bentonite deposit after Kobayashi and Itoh (1992).

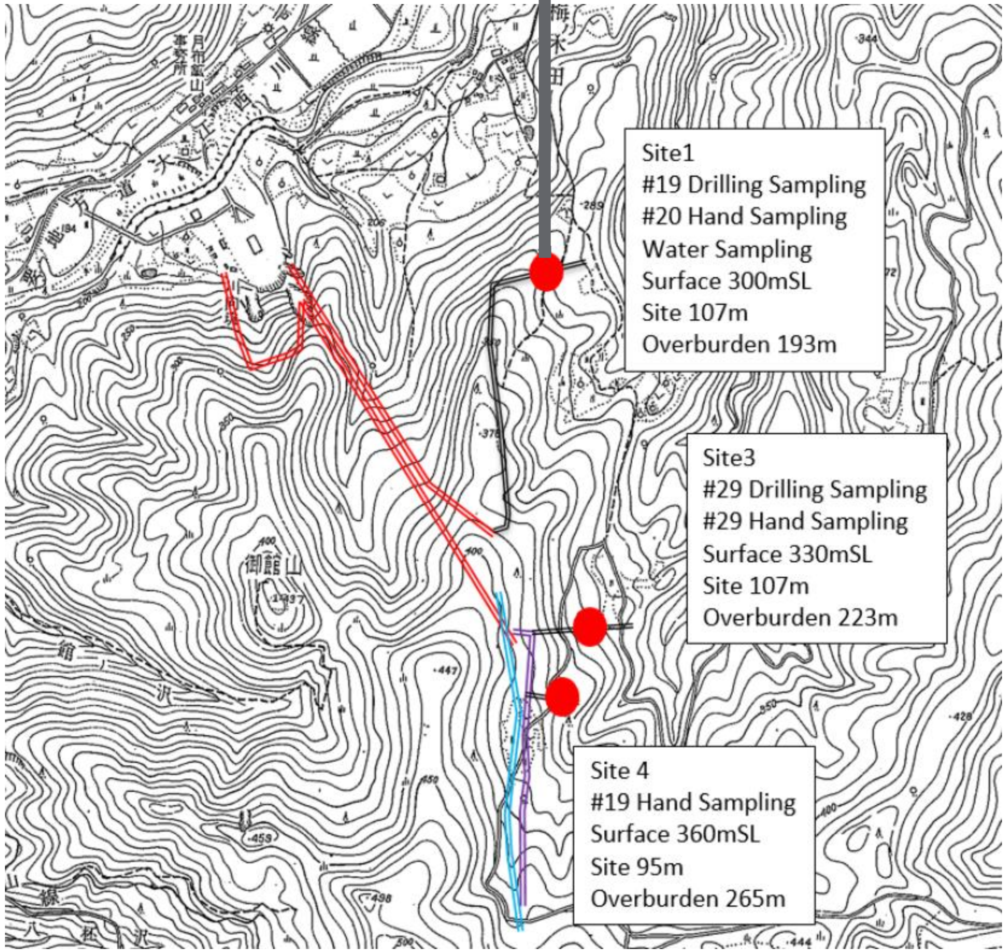
Source: Reijonen et al. 2022. International Bentonite Longevity project (IBL) – Overview. Poster at 8th International conference on clays in natural and engineered barriers for radioactive waste confinement, 13-16 June 2022, Nancy, France.

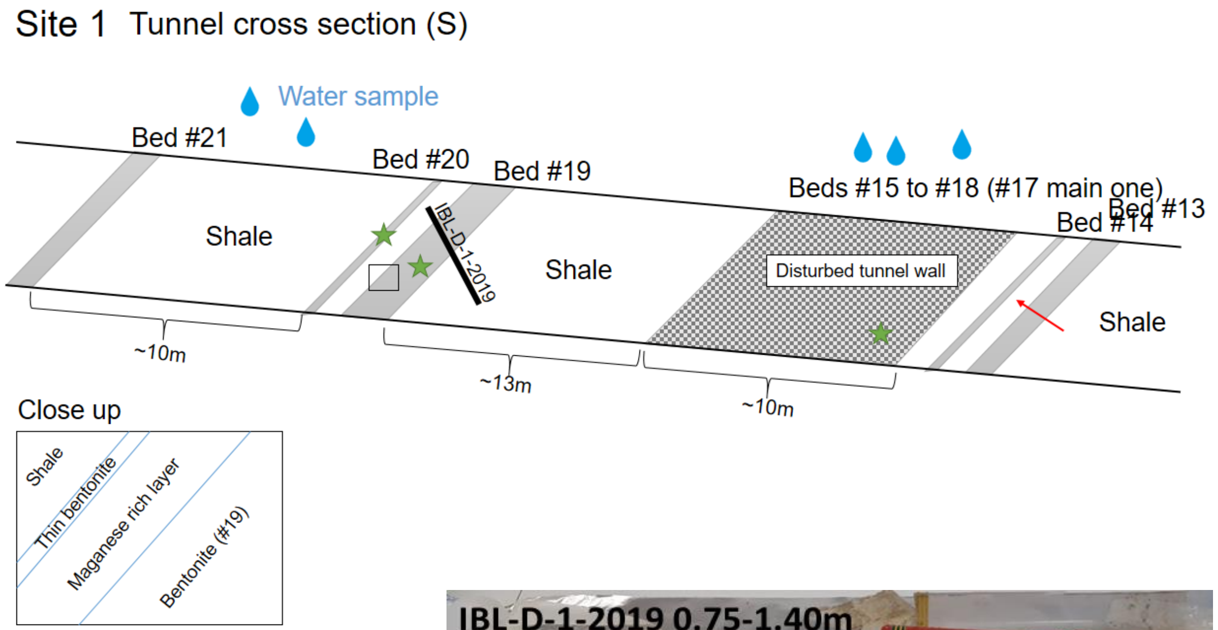
IBL-project Phase B goals and status

- Further development of bentonite sampling methods (done in April 2023)
- Assessment of bentonite durability
- Natural saturation state of bentonites (sampled in April 2023)
- Bentonite faulting (sampled in April 2023)
- Potential bentonite erosion
- Bentonite cementation (Hokkaido University)
- Microbial suppression in bentonites (sampled in April 2023) (Waterloo University)
- Production of engagement and communication materials
- Phase A report in press

New results on IBL-D1 drill core

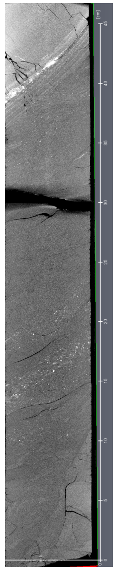
Site and IBL-D-1-2019



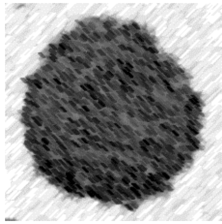


Methods

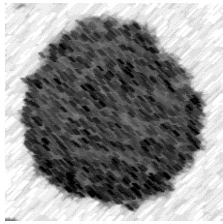
X-ray tomography
- Before opening the Perspex tubes
- GTK, Finland
- Reported in Phase A



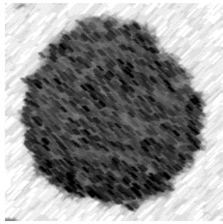
Analysis of CEC and exchangeable cations
- Powdering of the samples
- Labtium, Finland
- Reported in Phase A



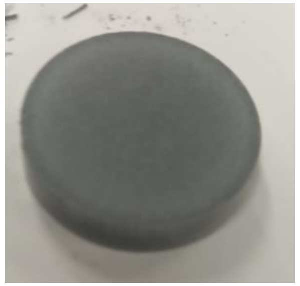
Quantitative XRD
- From powders
- X-ray mineral services UK



XRF
- From powders
- X-ray mineral services UK



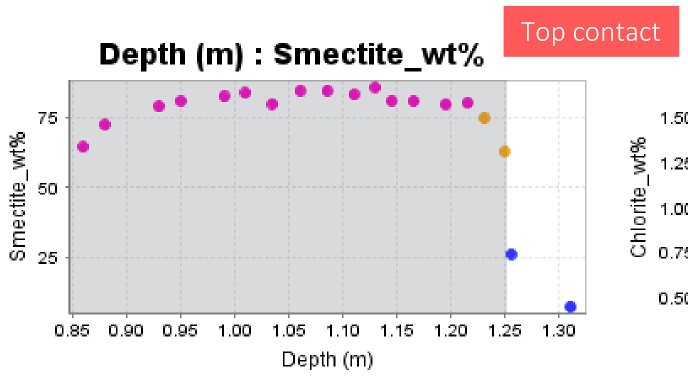
Hyperspectral measurements
- From compressed powder buttons
- VSWIR and FTIR
- Wavelenght ranges covered 400 – 14000
- GTK

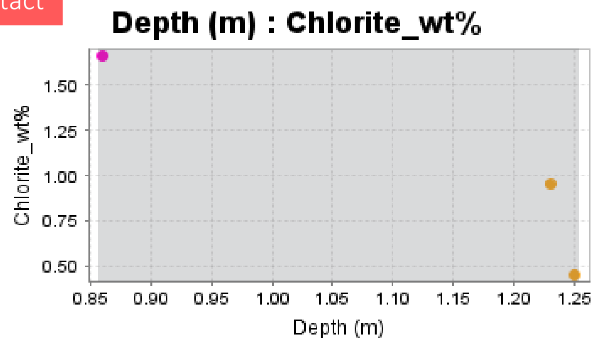


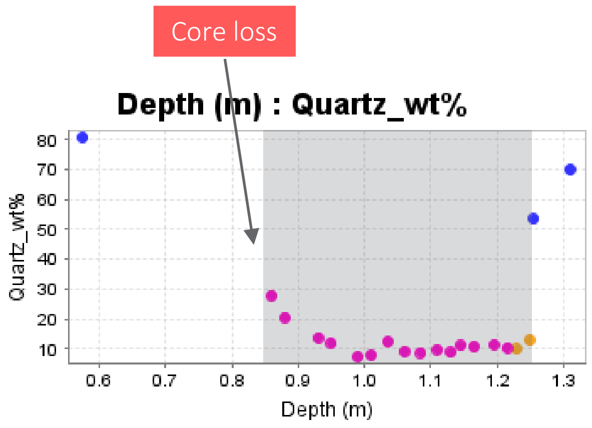
Combined results in this presentation

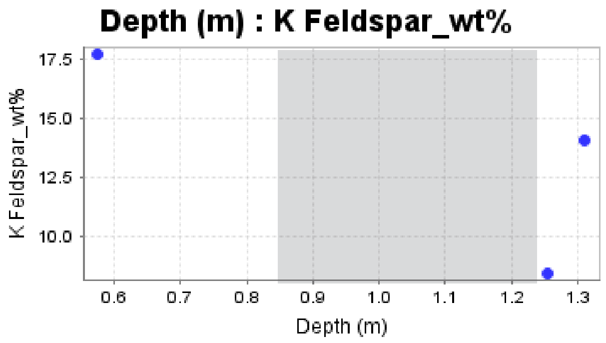
Software used The Spectral Geologist and IoGAS

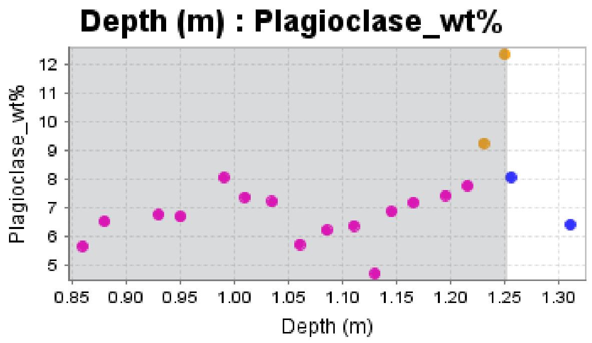
Mineralogy – bulk qXRD

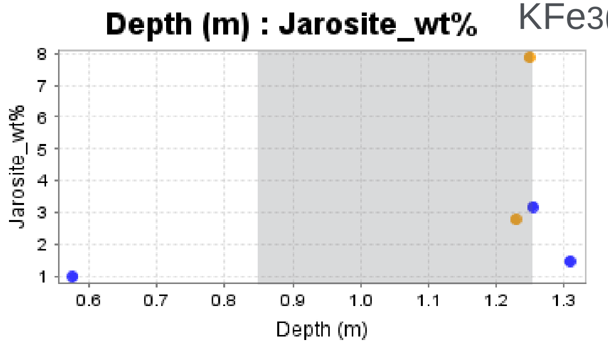




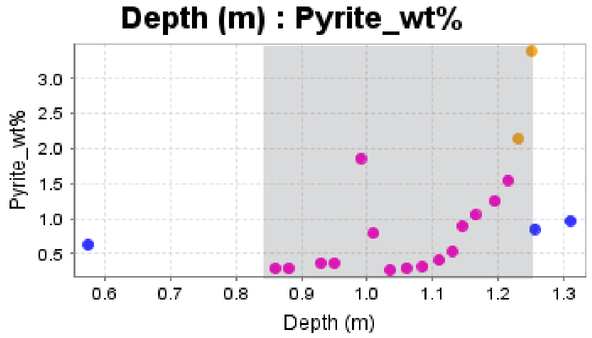








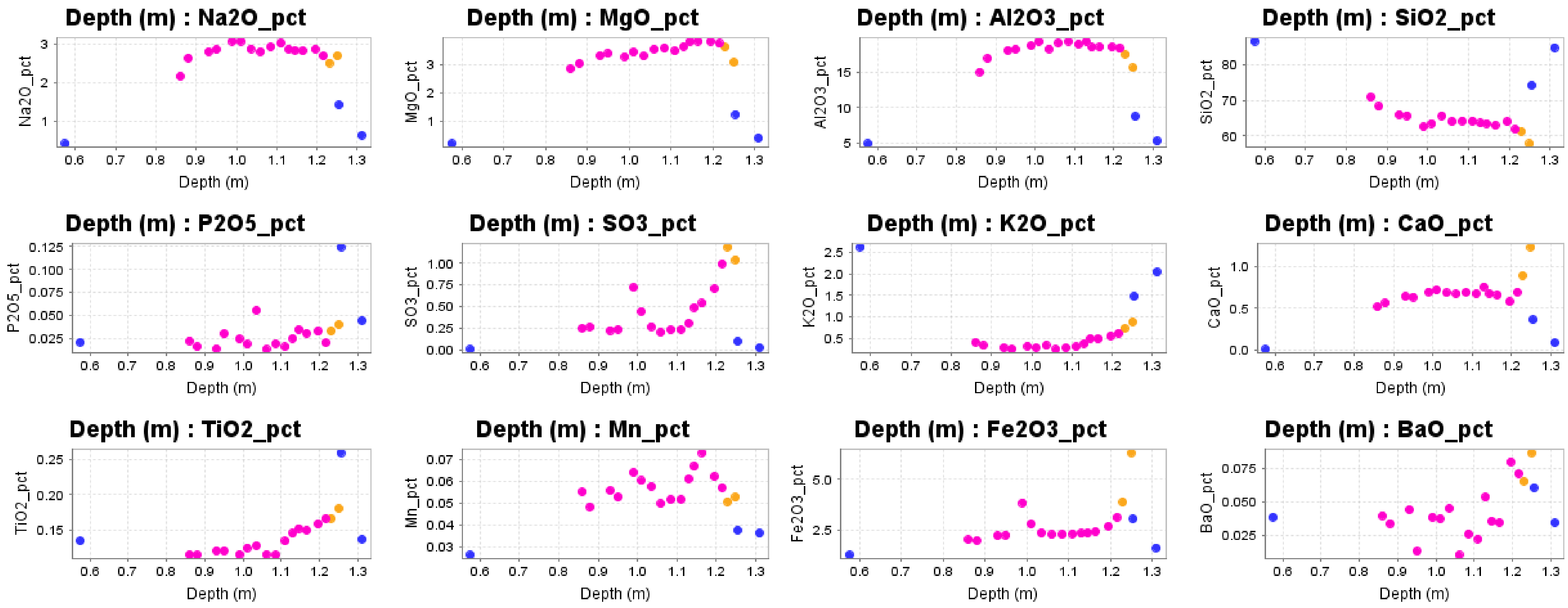
$KFe_3(SO_4)_2(OH)_6$

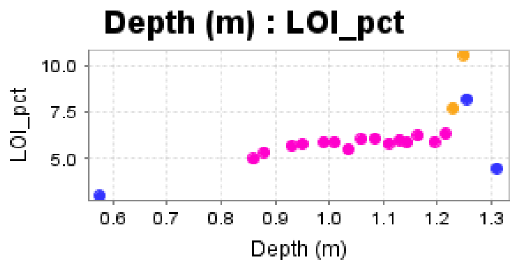


Lithology
- Bentonite
- Bentonite_l
- Shale

Bentonite area marked with gray

Geochemical characteristics – major elements + LOI

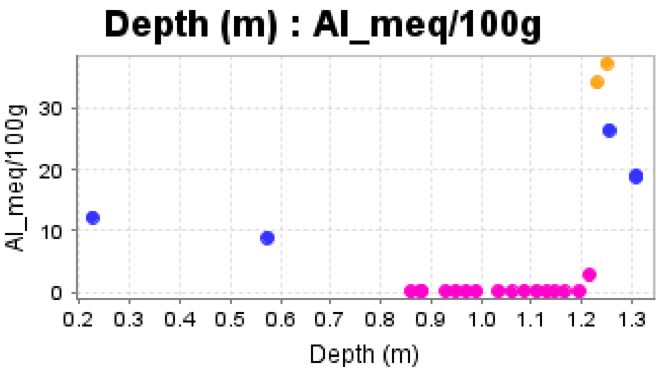


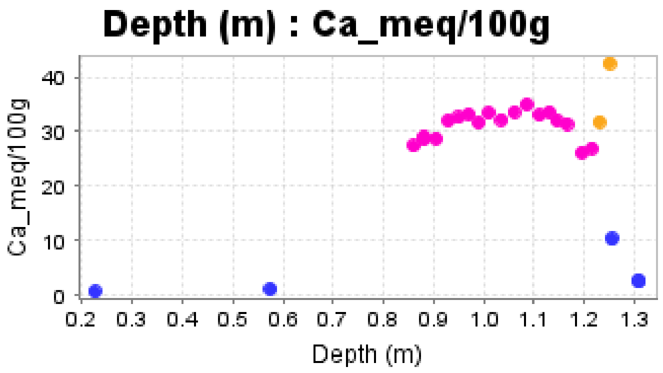


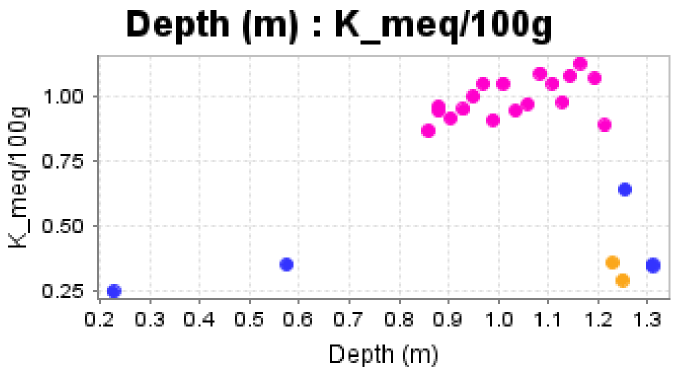
Pyrite reflected in SO3 and Fe2O2 results (also jarosite K,Fe,SO)
Increase in Cao and K2O reflect plagioclase (K also Jarosite)
Linear trends in bentonite for MgO, SiO2, K20, TiO2

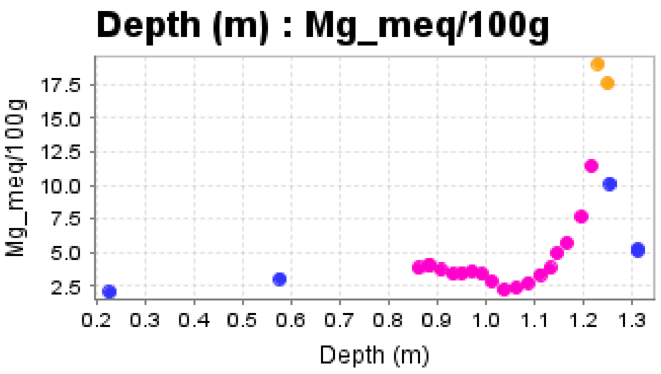
Lithology
- Bentonite
- Bentonite_l
- Shale

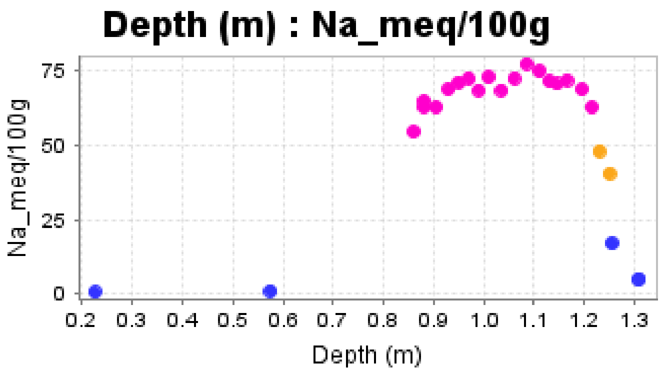
Cation exchange capacity and exchangeable cations

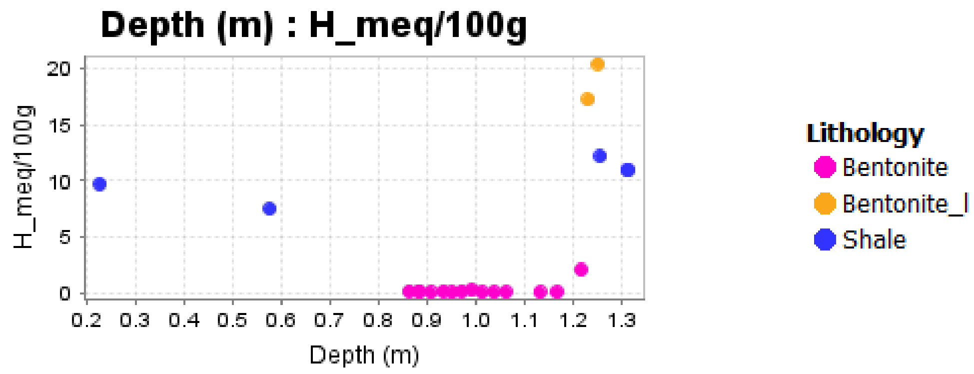


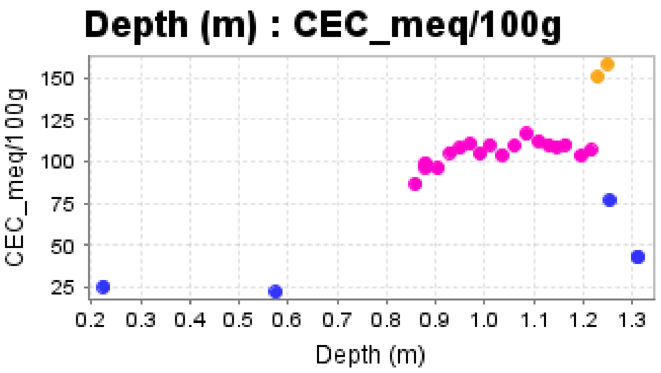












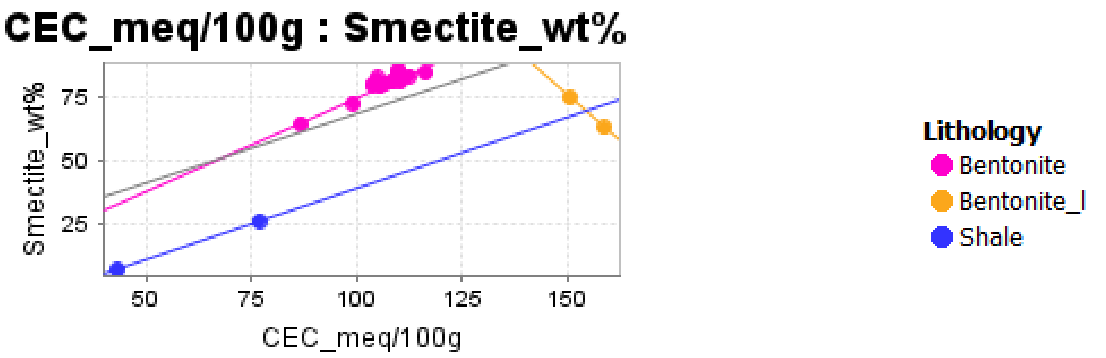
Within one 40 cm bentonite we see significant variation in the composition of exchangeable cations → show case of bentonite internal variation

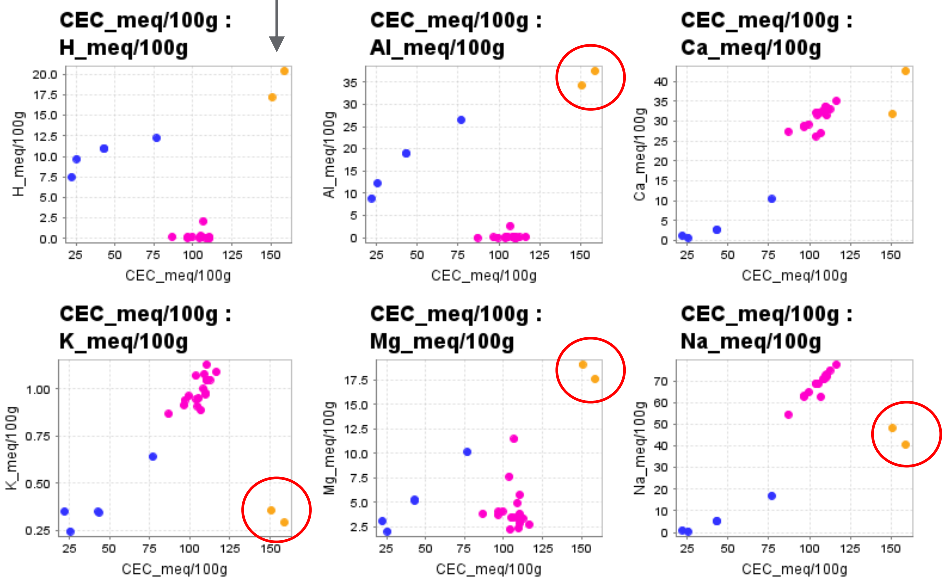
Some of the variation can be explained by cation exchange processes (the upper contact

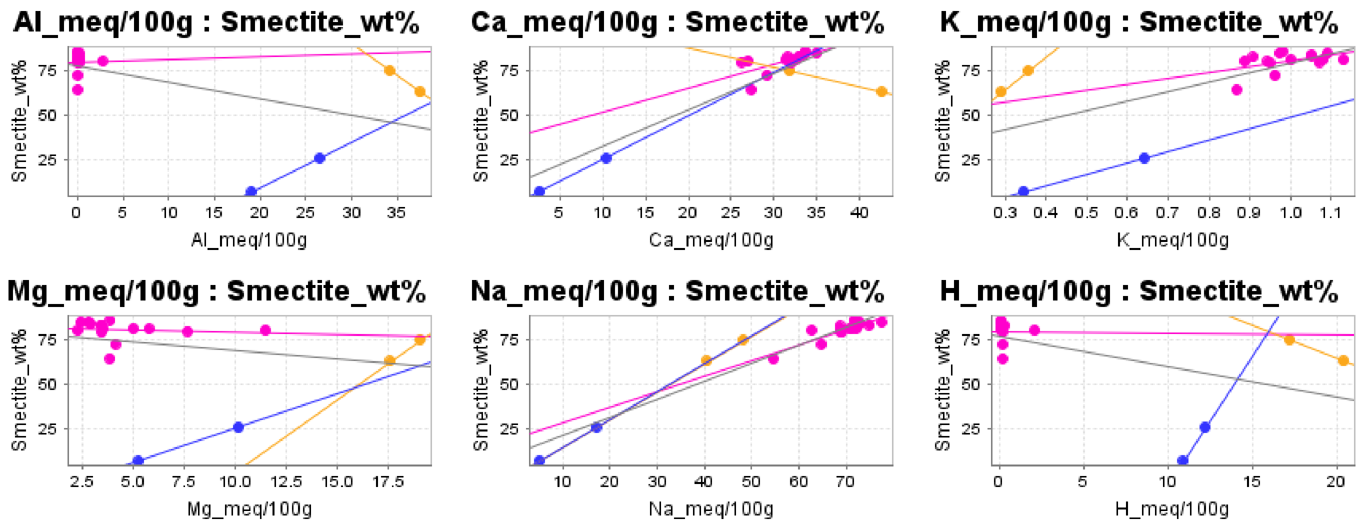
Ca, Na, contribute the most to overall CEC

Cation exchange capacity and exchangeable cations

- CEC follows smectite contents (also Na and Ca except the samples closest to top contact)
- → Hydrogen has significant input to CEC in bentonite_l samples (layered)







Interim results

- Still to address which features are depositional, and which later alteration
    - *Current hypothesis: exchange for Mg over Na and K (and Ca except bentonite_I) close to top contact → cation exchange process*
    - *Oxidation event at the top contact*
        - *Hydrogen increase at the contact (Grim & Güven, 1978)*
        - *Jarosite formation; hydroxylated oxidation product of sulfides (Deer et al., 1992)*
        - *However, pyrite remains (increasing content towards the top contact) indicating original deposition in acidic conditions*
        - *Pyrite rich layer occurs also in the middle of bentonite → no indications of oxidation*

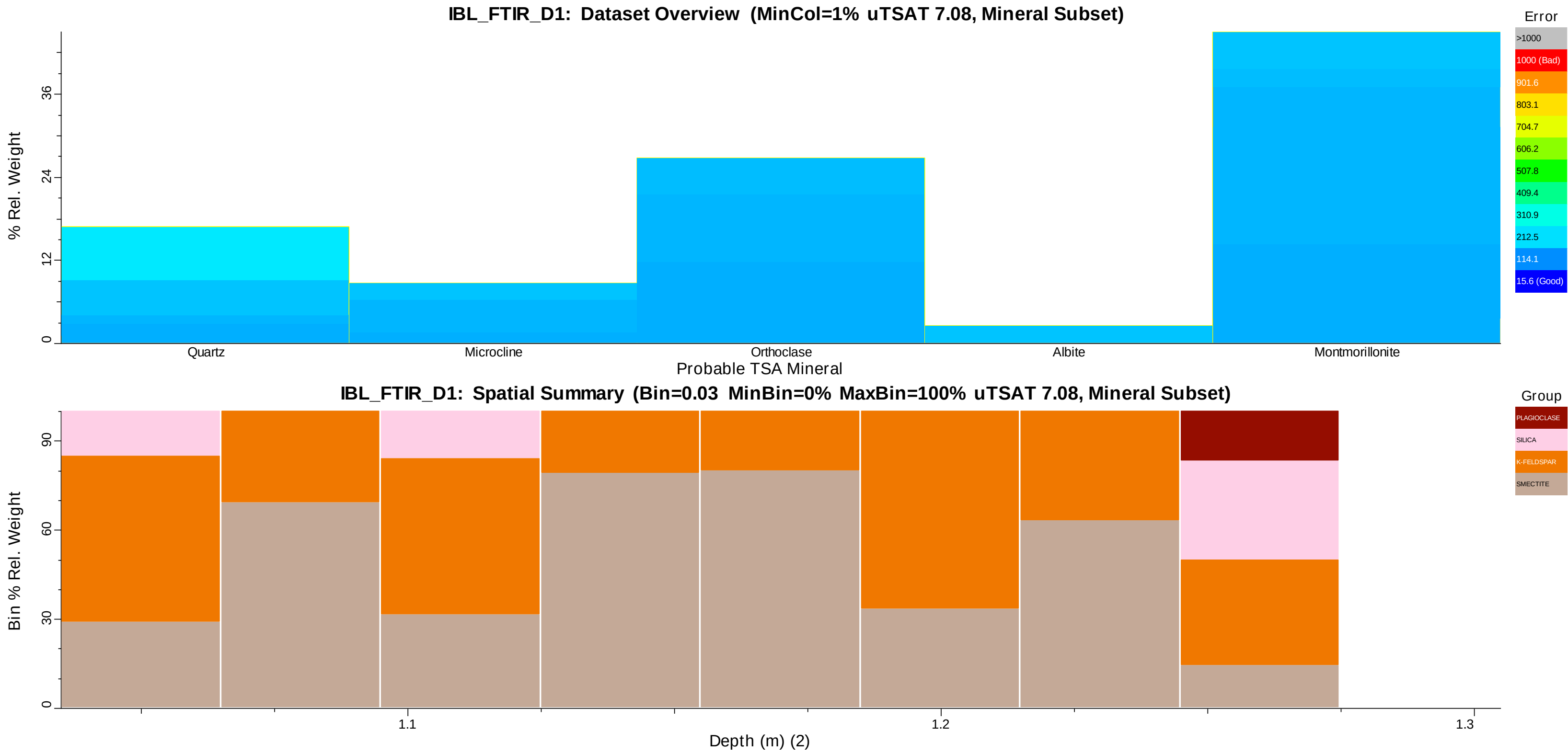
→ The reactions are limited to contact zone

→ Based on **limited** GW analysis in Phase A, the current groundwater does not explain these reactions → likely ancient

- Full analysis of the data (including also trace elements) is still ongoing and will be reported in Phase B (some further analysis yet to come, such as NDS)

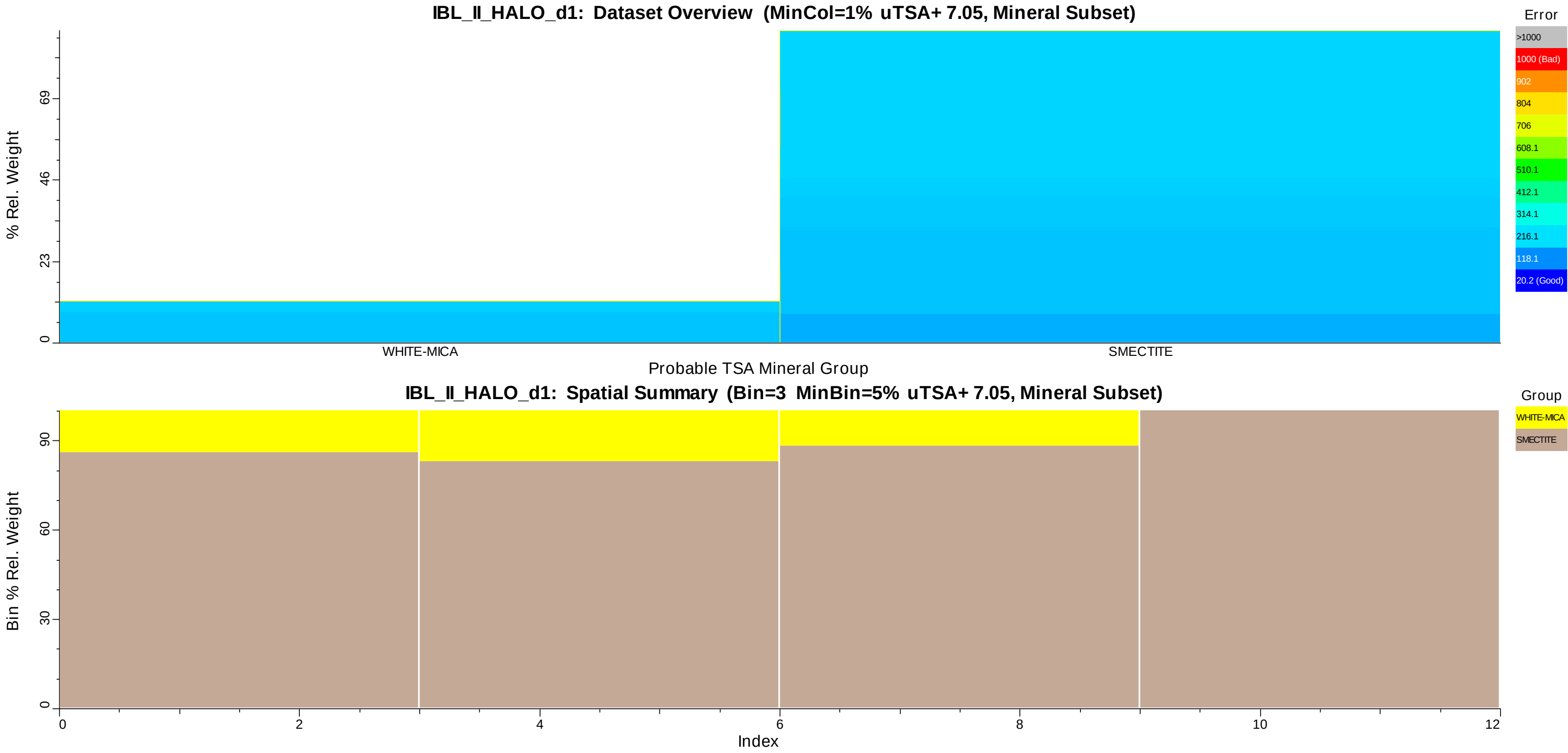
Hyperspectral results (FTIR) – automated XRD validated mineralogy

- FTIR active minerals such as Qz, Pl, Kfeld, smectite are detected after validation of data with XRD
- TSA gives relative weight %. But these are relative to minerals detectable, not quantitative
- Carbonates not detected → in agreement with XRD



Hyperspectral results (VSWIR) - automated XRD validated mineralogy

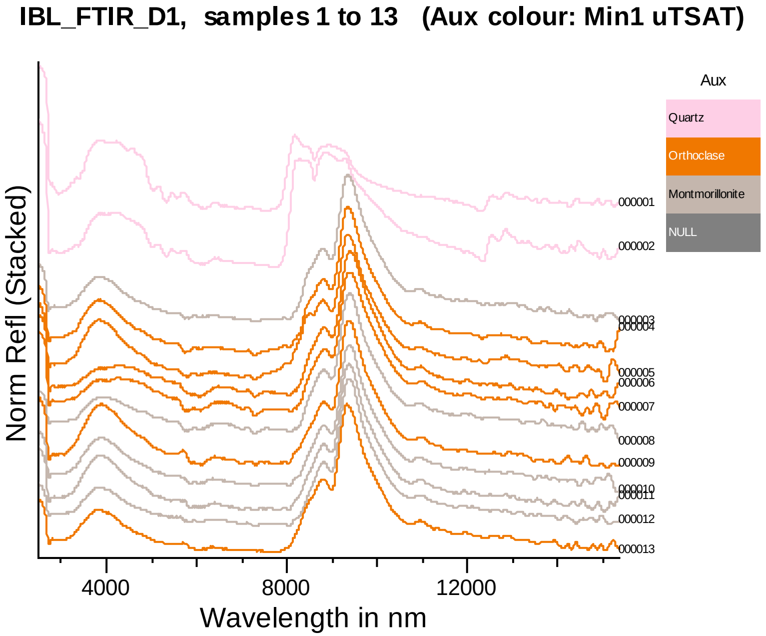
- VSWIR active minerals such as Smectite and white micas (muscovite- illite series) can be detected, but the TSA is not very useful
- TSA gives relative weight %. But these are relative to minerals detectable, not quantitative
- The spectral features give more information (next slides)
- Carbonates not detected → in agreement with XRD



Scalars used to examine spectral features

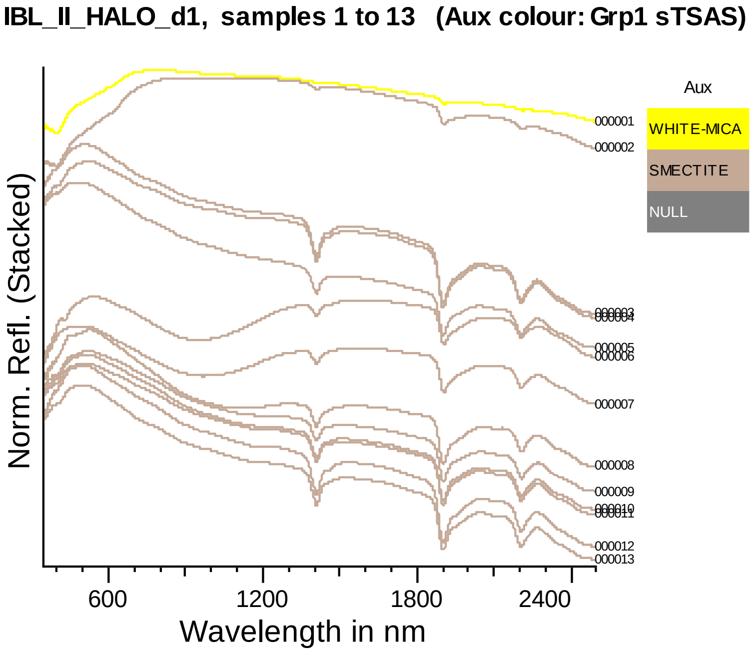
FTIR

- 4470D Quartz
- 4500D Jarosite
- 4500W Jarosite
- 5330D Quartz
- 6500P stretch CO3
- 8625D Quartz
- 9660P feldspar



SWIR (sheet silicates mainly)

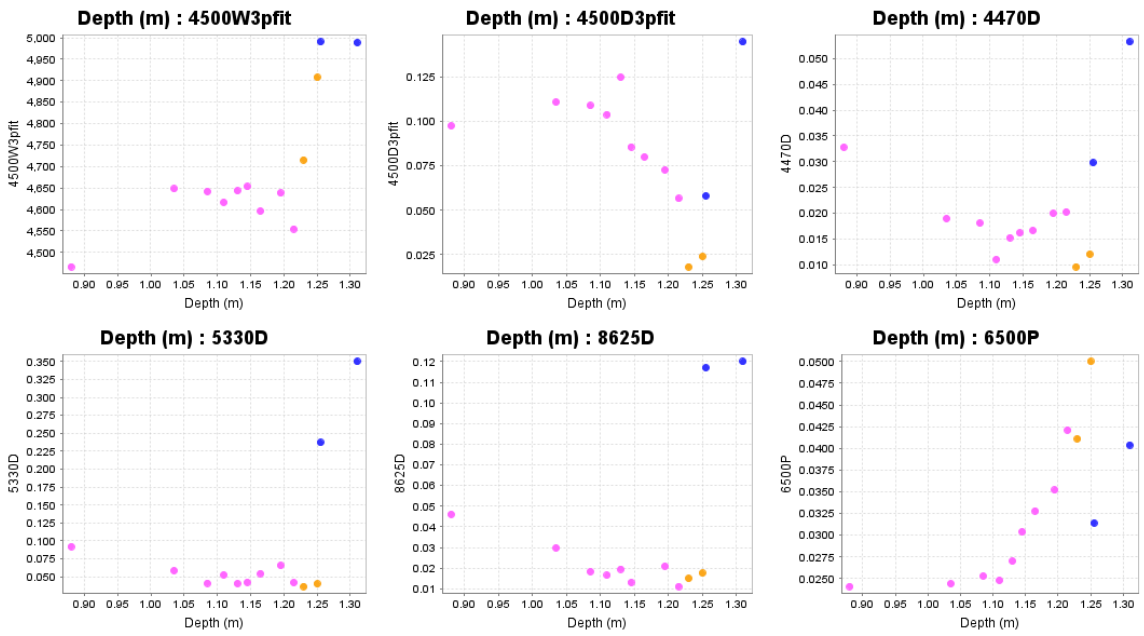
- 2200D
- 2200W
- 2250D
- 2250W
- 2350D
- ISM (H2O)
- ISM (ARvsD)



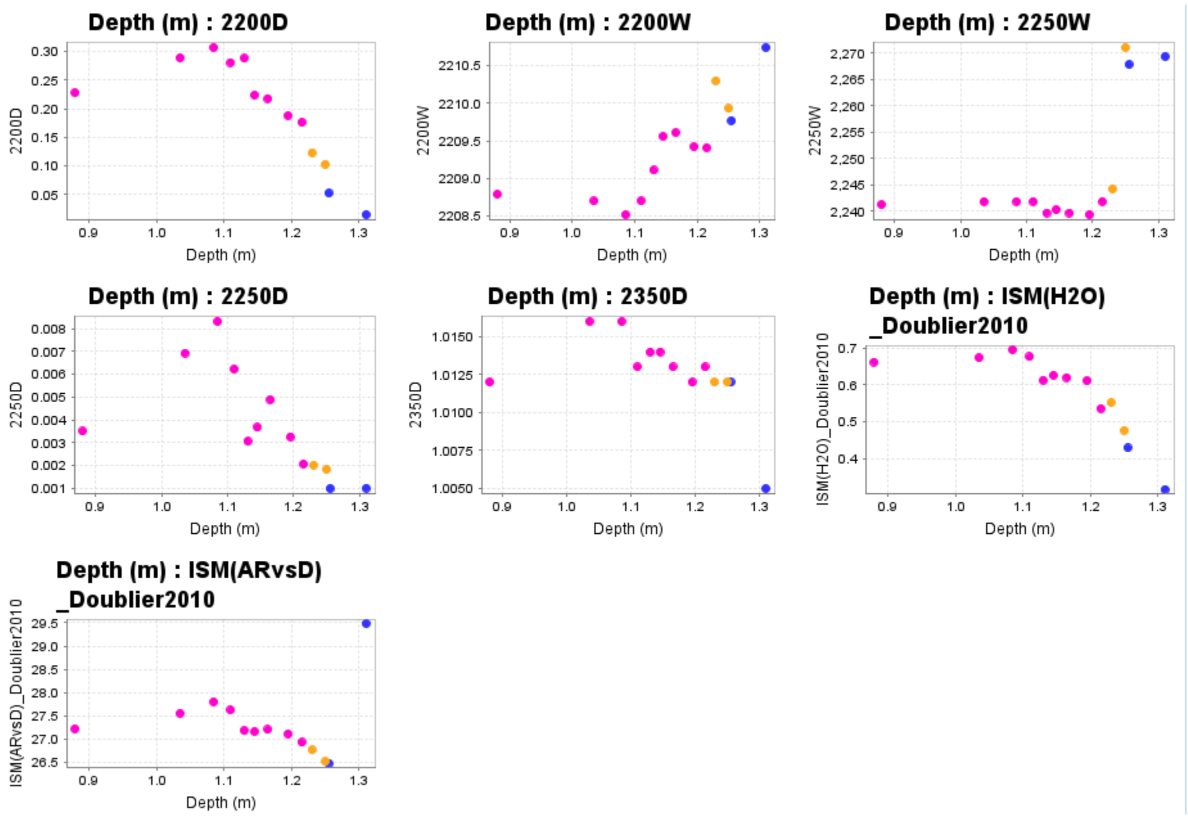
More details on scalars, see Laukamp et al. 2021

Hyperspectral results - Trends along the drill core

Some **FTIR** range indexes

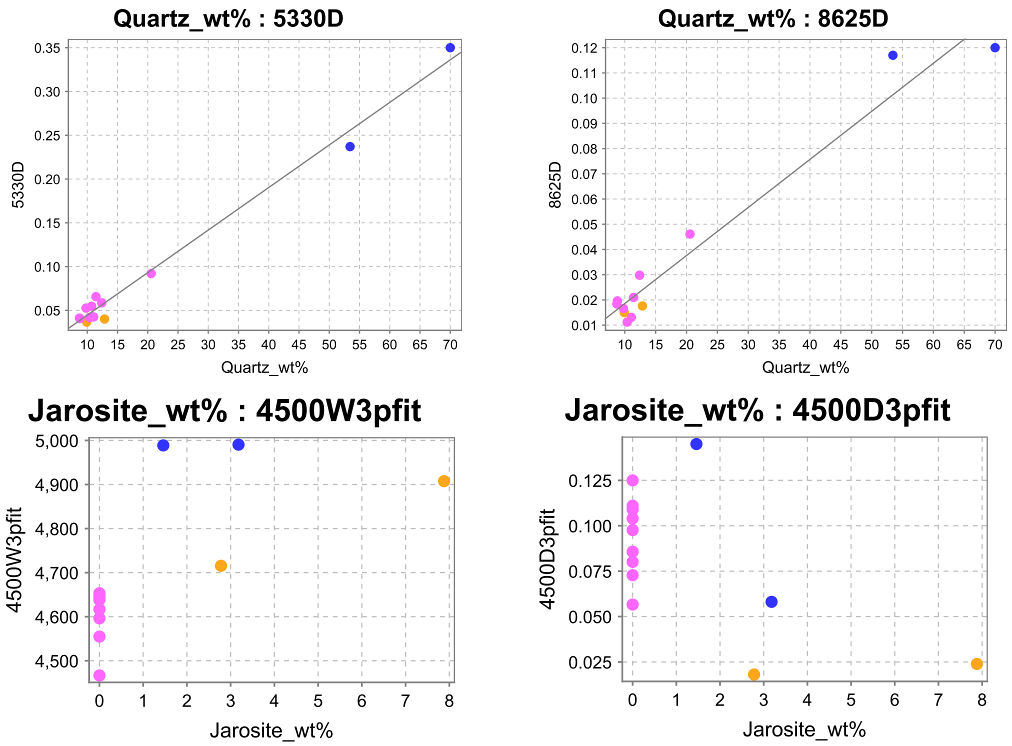


Some **SWIR** range indexes

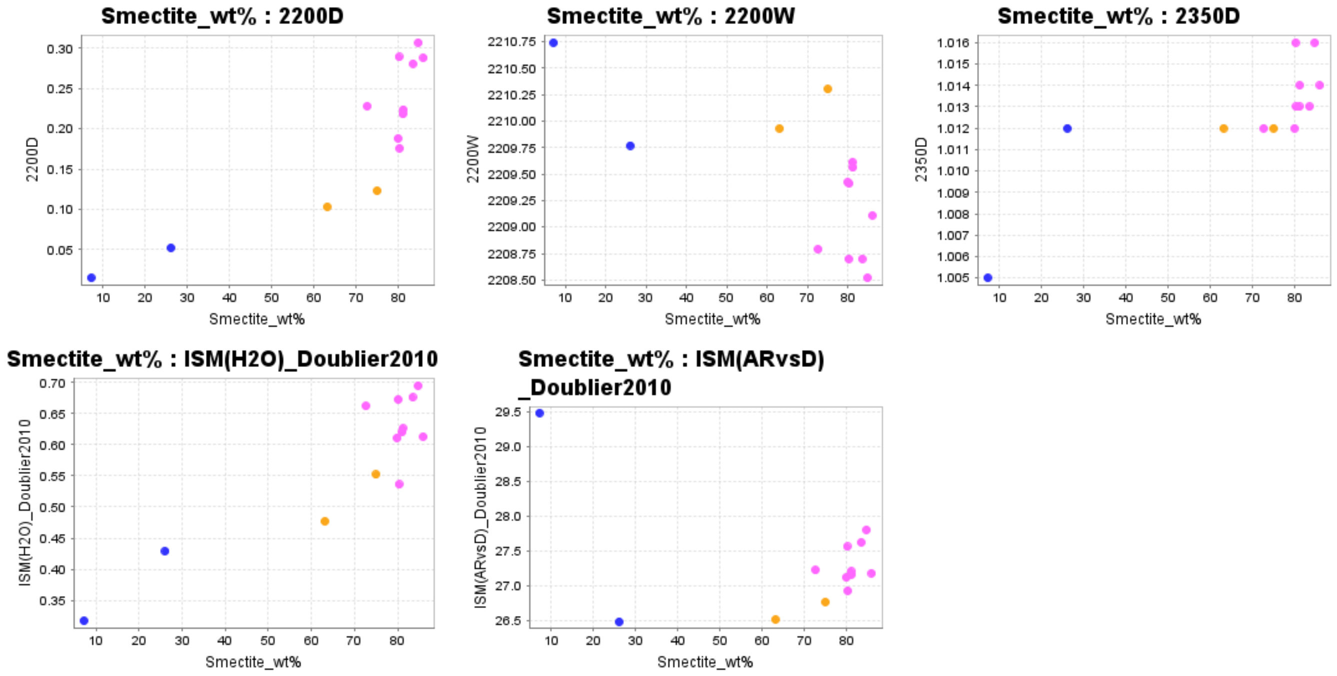


Hyperspectral results – examples of scalar vs XRD mineral %

Some **FTIR** range indexes



Some **SWIR** range indexes

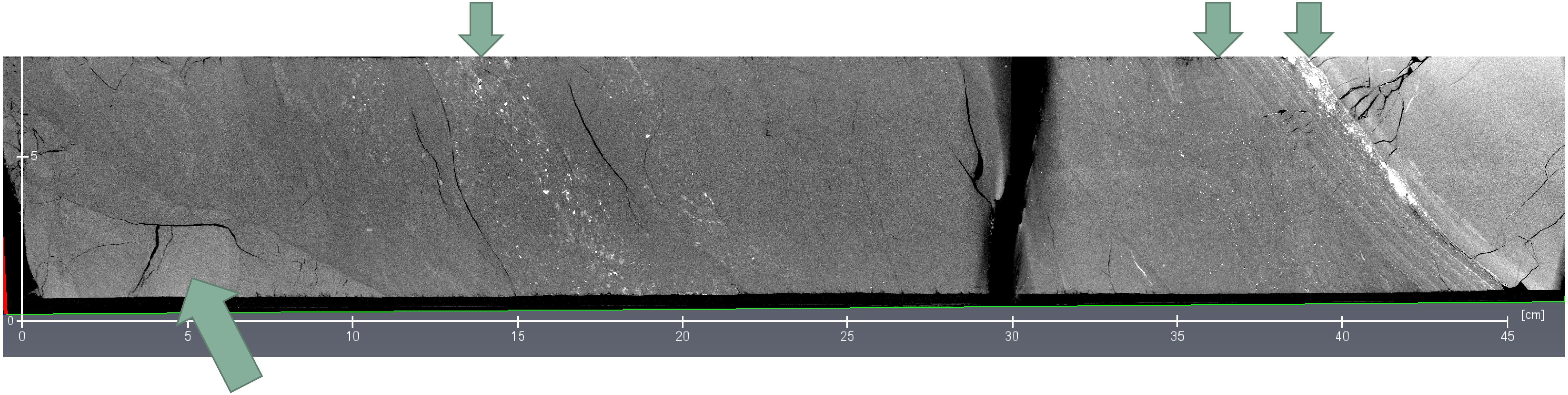


Potential of hyperspectral analysis

- More detailed statistical analysis is needed to fully examine the proxies for mineral abundance
- Some scalars are promising, especially for smectite content and quartz / potentially feldspars
- The samples do not contain much carbonate and only little sulphate minerals → in general these would be detectable with the methods used
- The benefit lies in the ease and speed of the analysis → further studies to be done on direct measurements (now powders were used as compressed buttons)
- Comparison to other bentonites would be useful, similar analyses being conducted on some Cypriot bentonites
- In areas less vegetated, remote sensing can be utilized

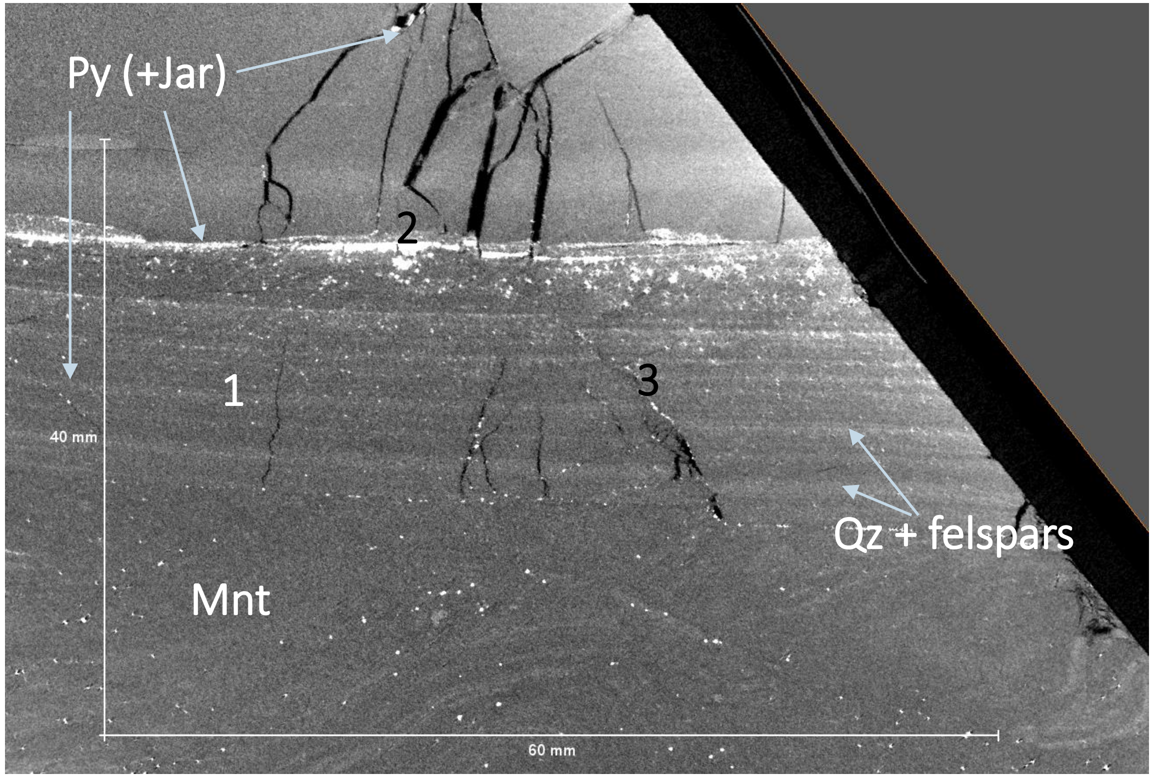
Getting more out of tomography

Can be seen in tomo:
- Pyrite + plagioclase + Qz concentration in the middle of the sample
- Layered structure, increase in plagioclase, pyrite and jarosite



Can't be seen in tomo (at this resolution):
- Gradual decrease of Qz and increase of Sm close to bottom contact

Top contact details



1. Primary layering
2. Precipitates at the top contact
3. Fracturing (faulting), precipitates in shale and bentonite fractures (youngest)

→ Two oxidation events? Primary layering + precipitation in fractures?

With additional thin or thick section work or micro XRF full mineralogical mapping is possible

Densities of different minerals: Qz 2.65 g/cm³ Plag 2.61 - 2.76 g/cm³ Kfs 2.5g/cm³ Jar 3.09 g/cm³ Py 5 g/cm³ Mnt 2.35 g/cm³

Conclusions

- Mineralogical results aid in the interpretation of XCT
- The variation seen in composition of this very narrow bentonite showcase the importance of detailed investigations needed to assess the relevance of the analogy of natural bentonites to repository bentonites in respect to homogeneity and overall mineralogy of the material being studied
    - *Definition of the analogue type (e.g. in this case effects of oxidation events on bentonite)*
- Hyperspectral analysis
    - *can be useful in following e.g. smectite content in bentonites, but it needs careful case by case calibration*
    - *As a field measurement for NA studies, the use is limited, but for deposit scale studies t is promising (e.g. for QA purposes)*

Thank you for listening!

GTK

Acknowledgements

IBL-project organisations from Phase A (NWS, Jacobs, BG, GTK) and B (NWMO, NUMO, BG, GTK) are acknowledged for making this research possible. Associated labotaories are mentioned in the presentation. Special thanks goes to Kunimine Industries (KIC) and M. Ito, Dr. S. Norris (NWS), W.R. Alexander (BG), E. Kremer (NWMO) and M. Yamada (NUMO).

IBL | GEOSCIENCES multidisciplinary consultancy BEDROCK | nwmo | NUMO 原子力発電環境整備機構 | KUNIMINE INDUSTRIES | Nuclear Waste Services | GTK