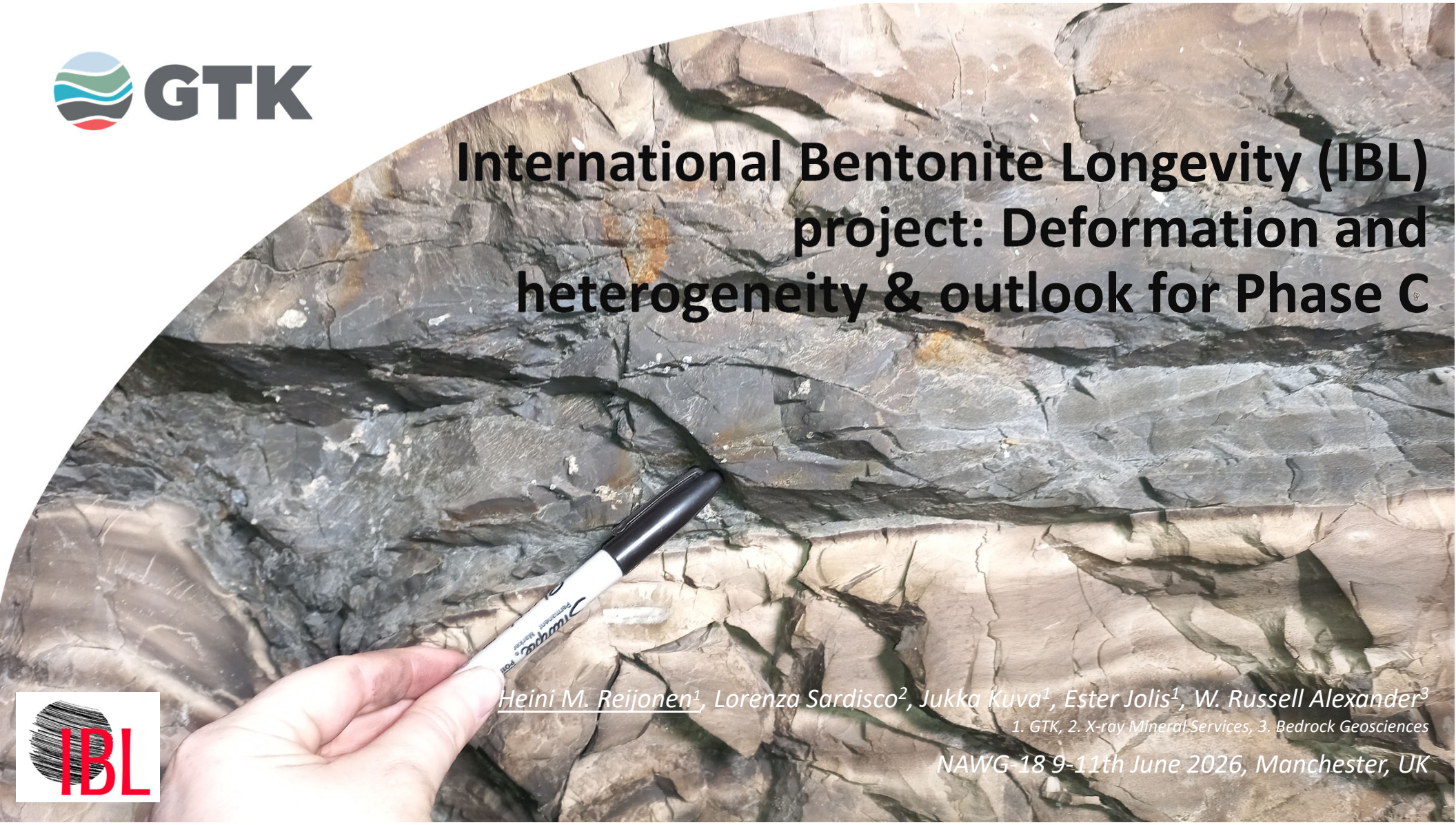

# International Bentonite Longevity (IBL) project: Deformation and heterogeneity & outlook for Phase C

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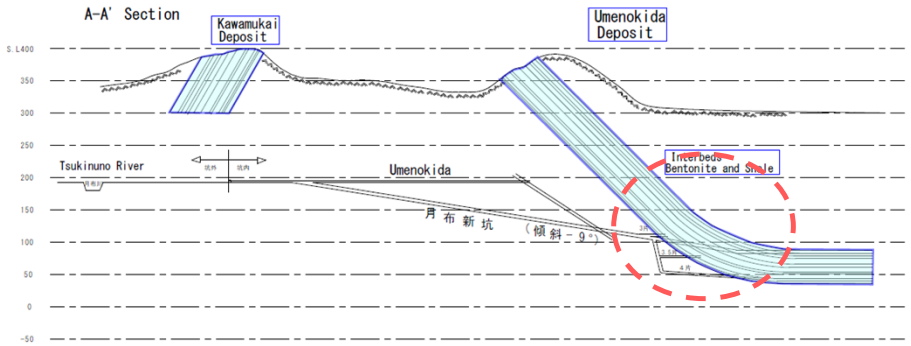
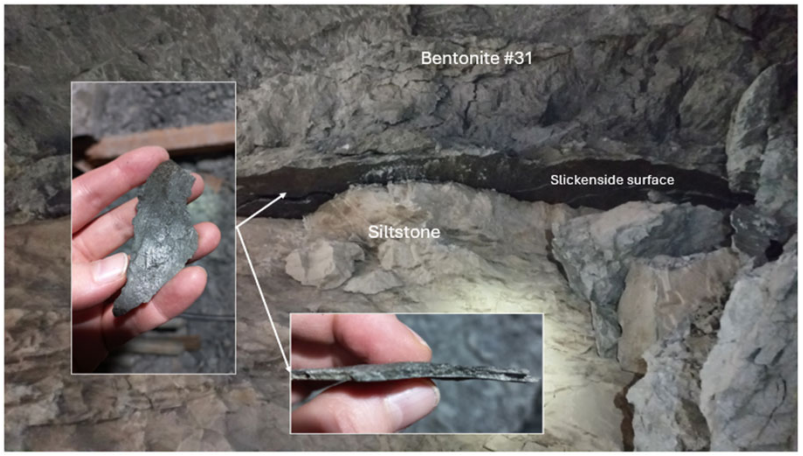
# Contents

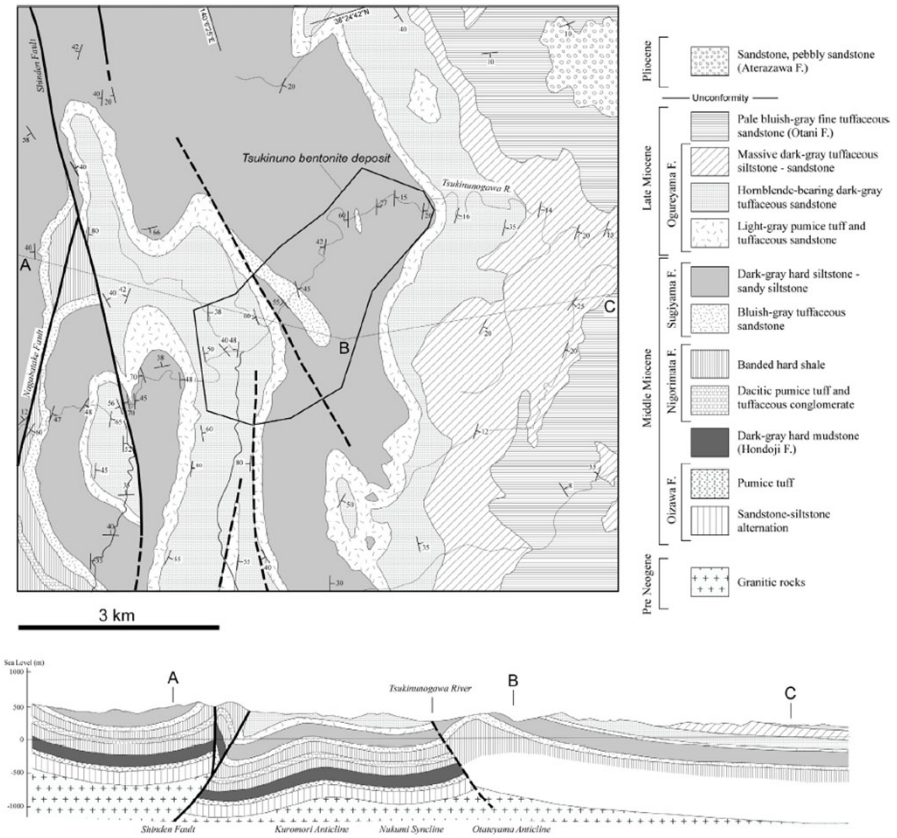
- The faulted site (C) at Tsukinuno mine, Umenokida Deposit (~125 m depth)
- Samples and analytical results
- Consideration of the analogue (Theme in IBL overview: bentonite response to fracturing and faulting)
- What next?
- Overview of proposed Phase C contents




# Deformation features in Tsukinuno mine

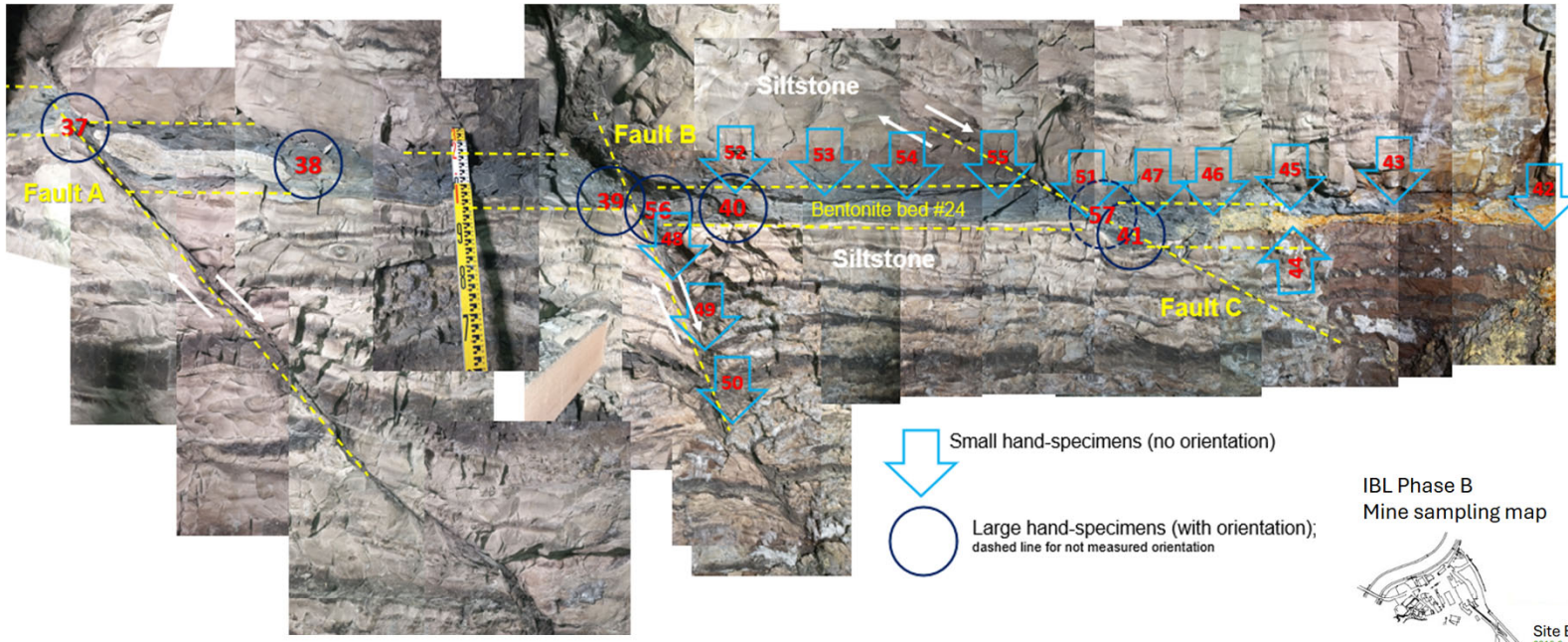
- Faults are known to occur around the mine (large scale structures and bentonite bed scale observations)
- Slickenside / faulting surfaces are observed at
  - the bentonite-siltstone contacts (not all beds)
  - internal to bentonite samples
- In IBL phase B, the focus was set on the faulted site C (next slide)



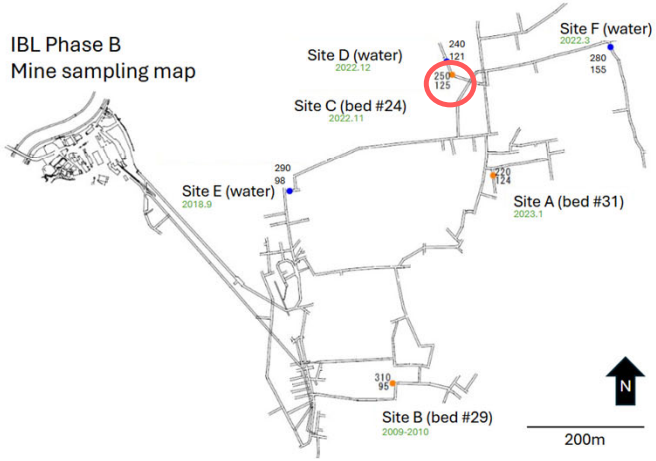



# The faulted site (C)

Mosaic picture of the tunnel wall looking NE



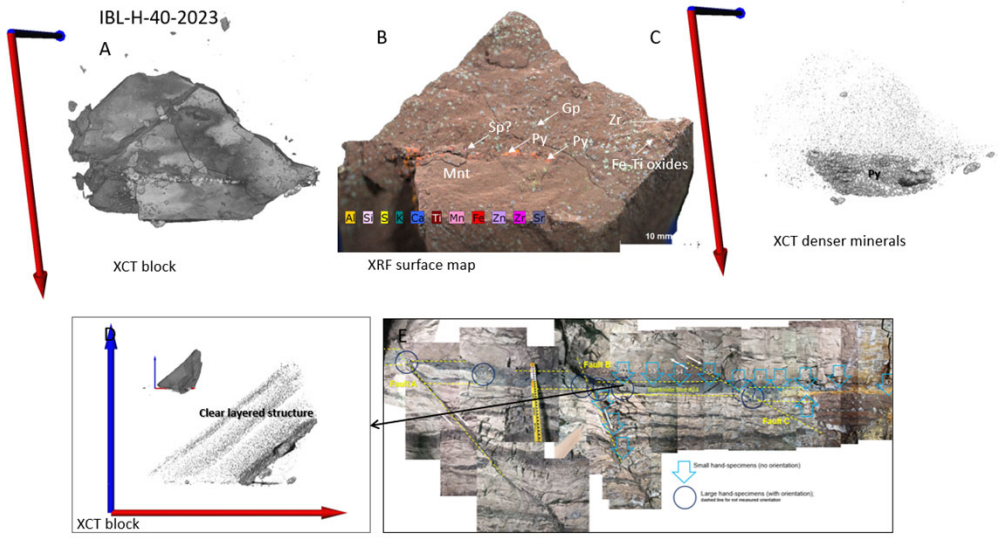

Samples



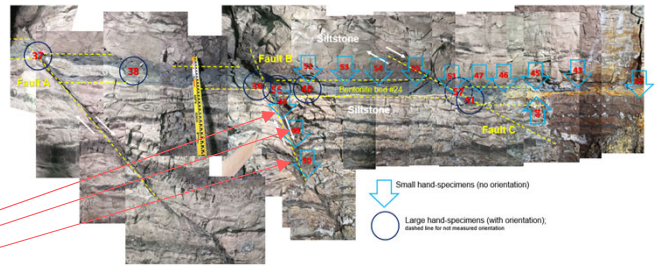

- Site consists of three normal faults
- Fault B had most bentonite extruded in the fault plane
- Hand- specimens were taken, some with recorded orientations (large samples)
- Drilling was attempted but did not sample the whole fault core due to limitations to direct the drill

# X-ray computed tomography + micro-XRF

- XCT was used to assess internal structures in the larger/oriented hand specimens (sample kept in the container)
- After opening the container: micro-XRF mapping of the chemistry on the selected surface
- Combined analysis and interpretation of probable XCT structures
- Most samples retain original structures (layering), clarity depends on the amount of dense minerals (e.g. pyrite)
- Gypsum precipitation on the sample surfaces



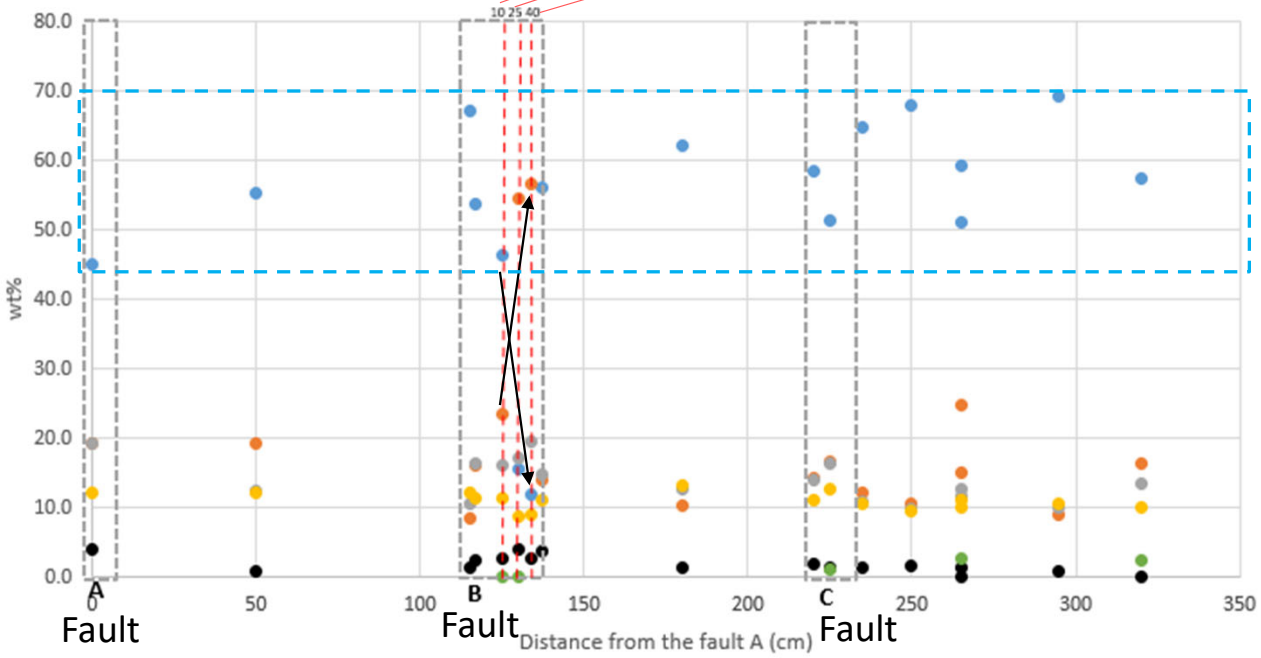
# Mineralogy (XRD)




1. Overall mineralogy homogenous along the bentonite bed

2. In extruded bentonites: Qz → higher
Sm→ lower

3. Jarosite ($KFe_3(SO_4)_2(OH)_6$) is present in the fault planes B and C, but also undeformed bentonite (observed also elsewhere close to bentonite-siltstone contacts

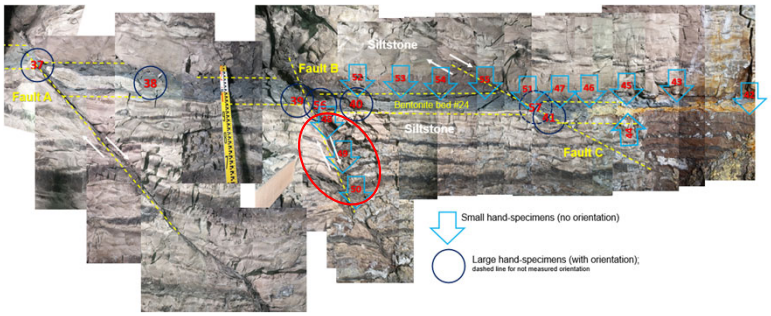



4. Bulk of the bentonite is unaffected

5. Changes are seen only in extrude/sheared bentonite

# Clay fraction

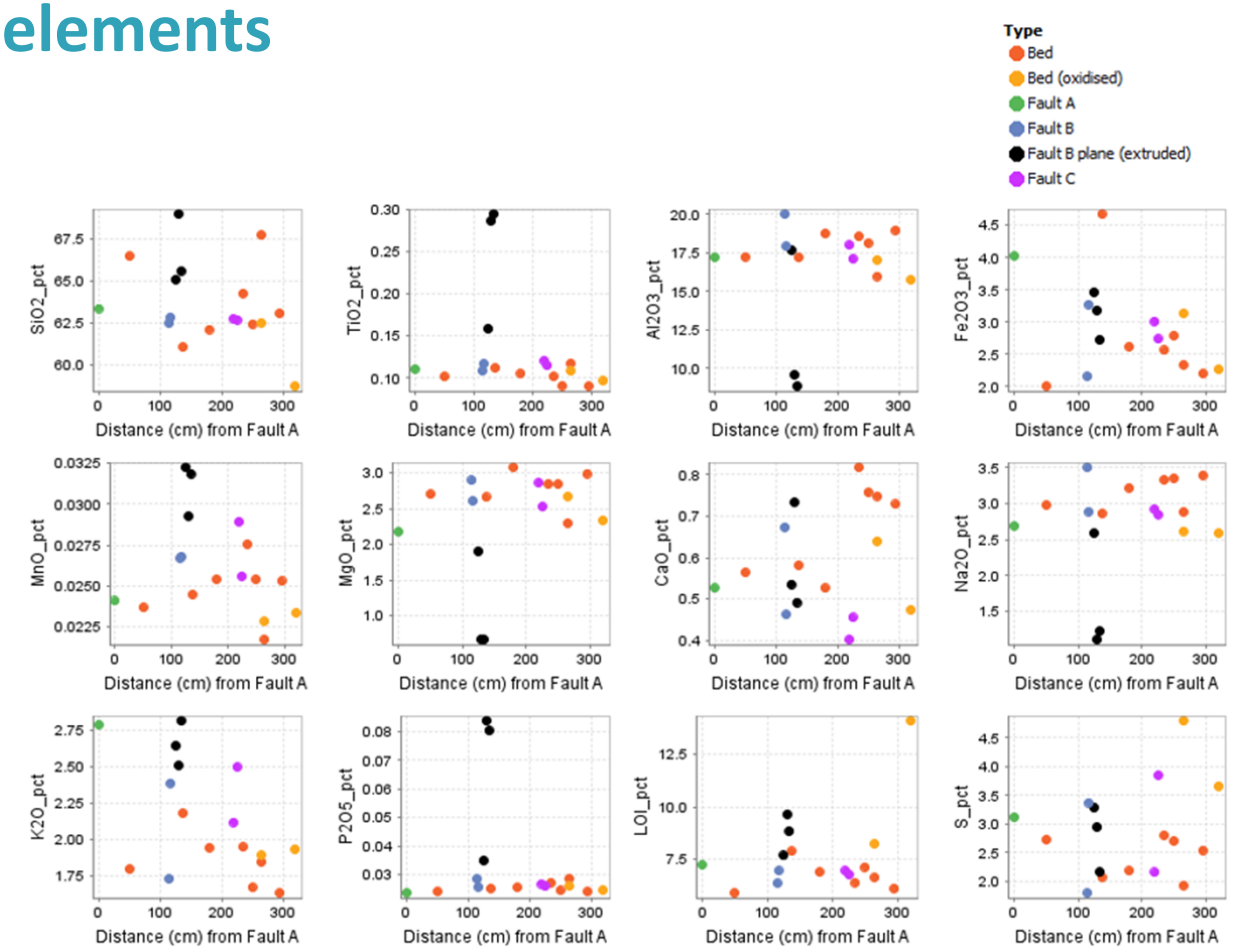
- Traces of illite and kaolinite in extruded samples
- In one extruded sample, 8.4% of clay fraction kaolinite
- Faulting related minor alteration (inorganic /microbial?)




| Sample ID | Wt. % | Smectite | | Illite | | Kaolinite | | Quartz |
|---|---|---|---|---|---|---|---|---|
| | <2um | % A | | % A | | % A | | % A |
| IBL-H-42-2023 | 28.6 | 97.5 | M | 0.0 | | 0.0 | | 2.5 |
| IBL-H-43-2023 | 74.6 | 98.8 | W | 0.0 | | 0.0 | | 1.2 |
| IBL-H-44-2023 | 16.0 | 97.4 | M | 0.0 | | 0.0 | | 2.6 |
| IBL-H-45-2023 | 50.3 | 96.6 | W | 0.0 | | 0.0 | | 3.4 |
| IBL-H-46-2023 | 71.8 | 98.4 | W | 0.0 | | 0.0 | | 1.6 |
| IBL-H-47-2023 | 65.8 | 98.3 | W | 0.0 | | 0.0 | | 1.7 |
| IBL-H-48-2023 | 25.0 | 97.6 | M | TR | P | TR | P | 2.4 |
| IBL-H-49-2023 | 8.9 | 80.5 | P | TR | P | 8.4 | P | 11.1 |
| IBL-H-37-2023 | 25.8 | 98.0 | W | 0.0 | | 0.0 | | 2.0 |
| IBL-H-38-2023 | 61.6 | 97.4 | W | 0.0 | | 0.0 | | 2.6 |
| IBL-H-39-2023 | 66.0 | 98.9 | W | 0.0 | | 0.0 | | 1.1 |
| IBL-H-40-2023 | 39.7 | 98.8 | W | 0.0 | | 0.0 | | 1.2 |
| IBL-H-41-2023 | 25.1 | 98.0 | W | 0.0 | | 0.0 | | 2.0 |
| IBL-H-50-2023 | 6.9 | 84.6 | P | TR | P | 0.0 | | 15.4 |
| IBL-H-54-2023 | 62.7 | 98.8 | W | 0.0 | | 0.0 | | 1.2 |
| IBL-H-56-2023 | 26.4 | 98.5 | M | 0.0 | | 0.0 | | 1.5 |
| IBL-H-57-f-2023 | 35.3 | 98.9 | W | 0.0 | | 0.0 | | 1.1 |

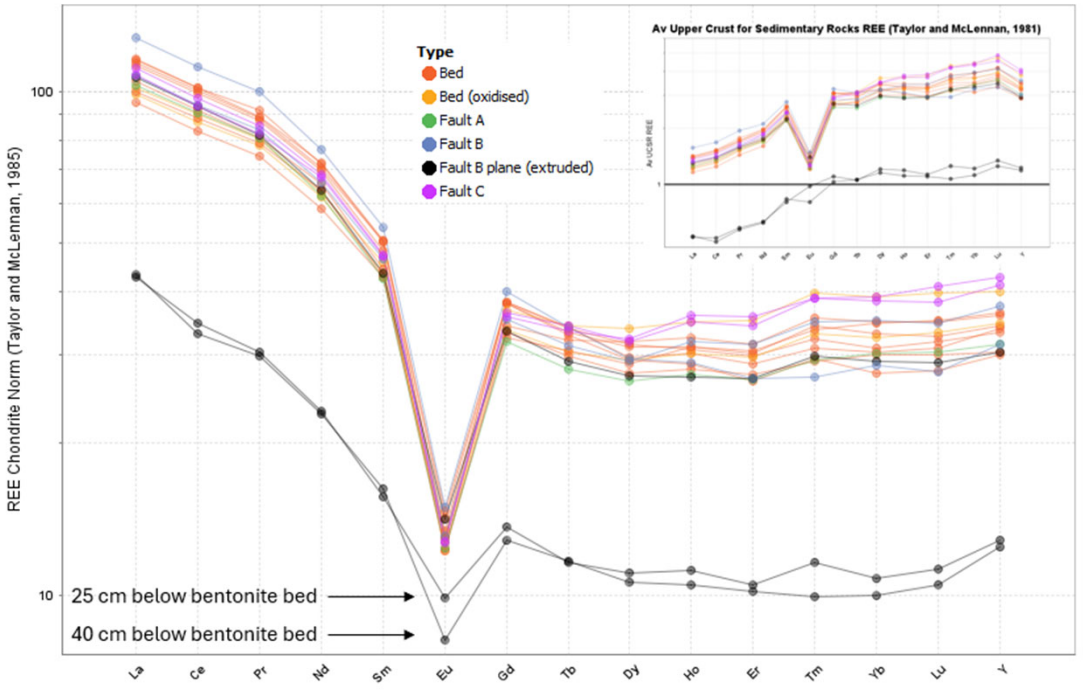
# Geochemistry – major elements

- Si and Al reflect the observed changes in bulk mineralogy
- Na,Mg depleted – Mn,K increase in fault plane samples
  - K increase → Jarosite formation (+ illite?)
  - No CEC/ECC data → would help to assess significance of the cation exchange process



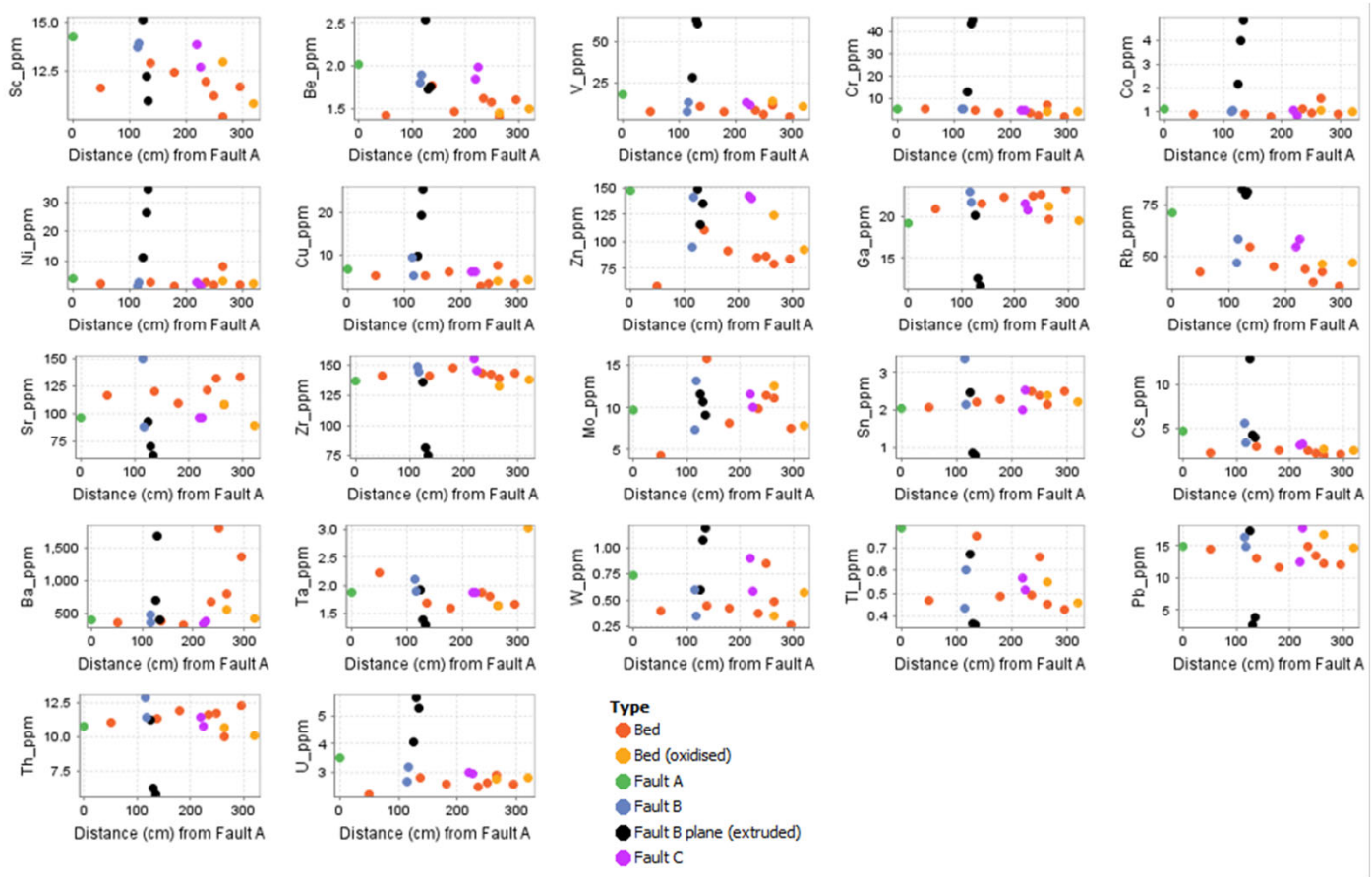
# Geochemistry – REE

- Clear depletion of all REEs observed in the extruded bentonites → leaching out (acidic and oxidizing system)
- Unaffected bentonite samples have very consistent REE compositions (also at sites A and B)
- Indication of event with higher fluid/rock ration during faulting
- Suggesting very limited disturbance for the bulk of the bentonite mass



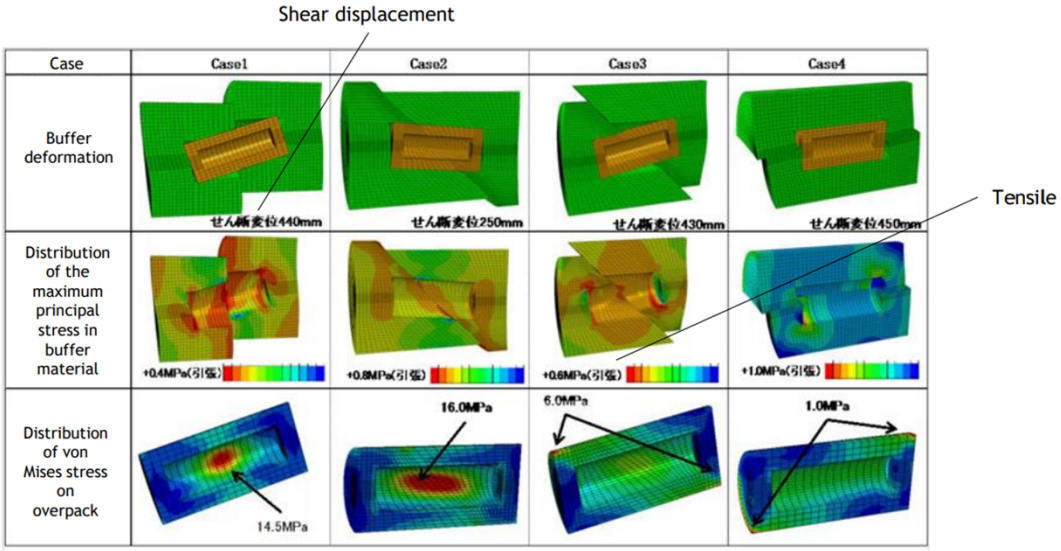
# Geochemistry – minor elements

- Anomalies seen mostly in samples of extruded bentonite – bulk of the bentonite unaffected



# Consideration of the analogue

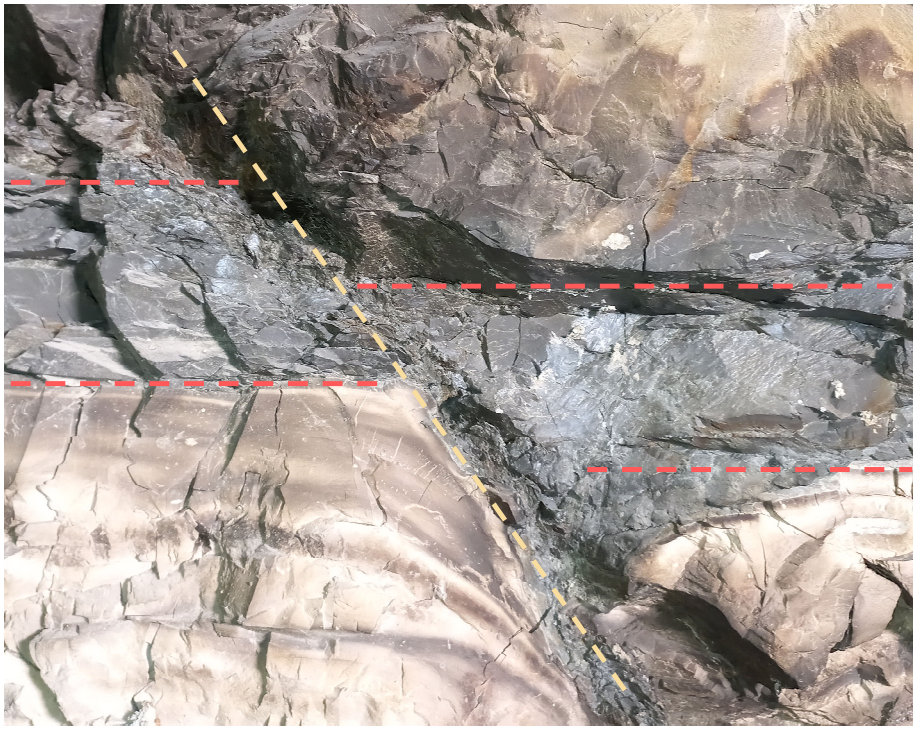
- The faulting episode at site C show similar relative movement (10-15 cm) similar to what is assumed in repository rock shear scenarios (e.g. Posiva max. 5cm, Posiva 2021d)
- Observations support the assumption of localised plasticisation of the buffer along the shear plane (Posiva 2021e)
- NUMO: *"For the buffer itself, fractures may form due to the occurrence of shear bands along the shear surface, but self-healing of such fractures (as with those generated by gas breakthrough) and recovery of hydraulic barrier properties have been confirmed by experiments (Kodaka et al. 2010)".*
- Preliminary data from NA <u>supports limited disturbance outside the fault plane</u>




Shear stress sensitivity analysis of the HLW EBS showing examples of fault movements accounted for in safety case (Source: JAEA 2014).

# What's next?

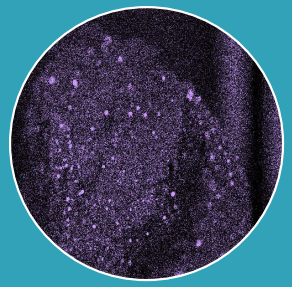
- Further analyses to assess physical properties, cation exchange, water-rock interaction and microbial populations would help in setting boundary conditions for the analogue and determine the extent of self-sealing
- SEM-EDS on epoxy-based thick / thin sections would help to confirm petrographical context
- Drilling/blasting for deeper sample is required for microbial analyses
- Other faulted sites & overall brittle structural description update around the mine
- Age of faulting (illite age with K/Ar?)



# IBL-project future outlook towards Phase C

- Continuation for the Phase B has been proposed in the report (Reijonen & Alexander, 2025)
- In addition to fault site analysis, other potential topics also remain
- Phase C proposal is being drafted by select most relevant pathways for new studies

# Overview of proposed Phase C contents

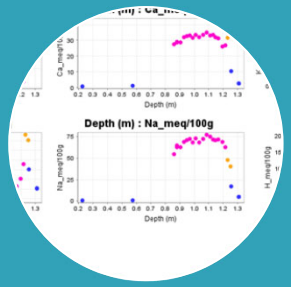


## Heterogeneity /homogeneity

- Heterogeneity of bentonites
- →Performing additional analyses on existing samples

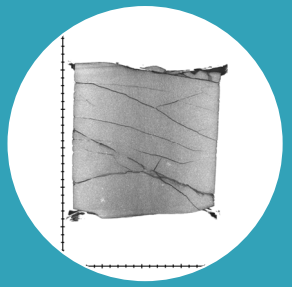
## Alteration

- Analogue for microbial induced alteration
- Gas uptake in bentonites




## Cation exchange

- Water-rock interaction models should be developed based on complete analytical results
- NDS and other isotope /natural tracer methods
- Gas uptake by cation exchange



## Physical properties of bentonites

- Further confirmation of the similarity to EBS
- Assessing self-sealing /self – healing in situ
- Requires assessment of micro-structures and swelling and other rheological properties

## Saturation

- Grain density measurement validation
- Siltstone properties should be analysed to allow further modelling of the system
- Site hydrogeology (avoiding disturbance)

## And more…

- Further bentonite erosion studies
- Host rock studies (siltstone)
- Experimental programme

IBL Phase C

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