# International Bentonite Longevity (IBL) Project: introduction and overview of Phases A & B

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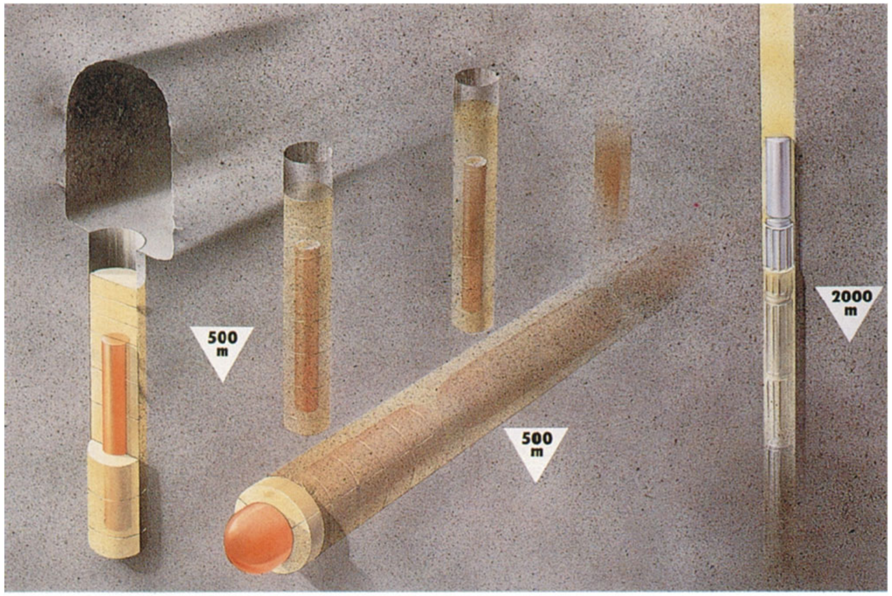
# IBL - background

- Reviews (e.g. Reijonen & Alexander, 2015; Alexander, 2018; Posiva, 2023) of existing bentonite NA studies were highly critical, pointing out that the current (e.g. surface deposits) and past (e.g. very high temperature regimes) environmental conditions were generally poor analogies to a waste repository

- As such, a new round of bentonite NA studies were launched with focus on the safety case (cf. Reijonen et al., 2023) and one, IBL, is addressed here



# IBL – status

- Initial project discussions and first site visit in 2016....
- Project initiated in 2018, stopped dead for 3 years due to COVID
- Phase A:
- initial assessment of feasibility, discussions with Oe town and Yamagata Prefectural governments, agreement(s) with KIC, preliminary sampling/storage/transport approach and mineralogical, CEC/EC, microbiological and textural analyses
- reported in Reijonen & Alexander (2024). See Beaver et al. (2021), Reijonen (2024) and Reijonen et al (2024, 2026) for further information.

# IBL – Phase B

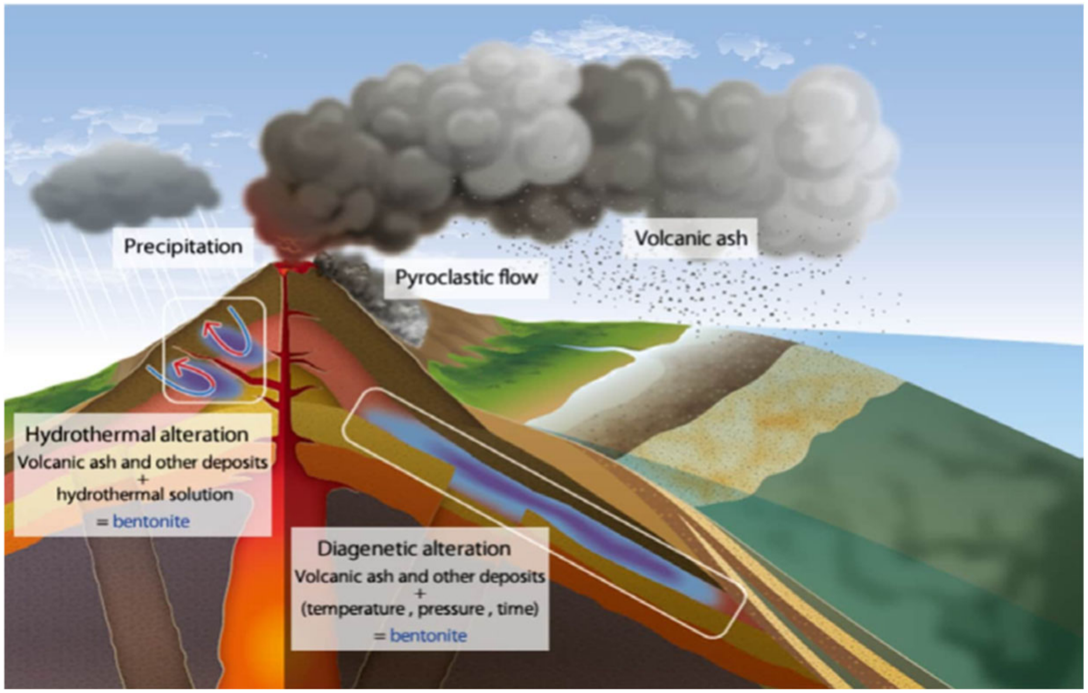
➢ **Phase B: decided to use the iFEP list (NEA, 2024) to guide and focus the project aims**

| Feature initiating IBL Phase B and potential for research | Examples of iFEPs (NEA 2024) of interest | Where is this addressed in the report | Safety relevance and potential for further studies |
|---|---|---|---|
| Bentonite deposit outcrops at the surface, including in nearby riverbed<br>Potential to study low ionic strength water/bentonite interactions, bentonite erosion and cementation | FEP 2.3.2.1: Saturation /desaturation<br>FEP 3.2.4.5: Alteration [repository]<br>FEP 4.1.8: Geochemical characteristics and properties (water-rock (clay) interaction, cation exchange)<br>FEP 3.2.2.2: Piping/ hydraulic erosion<br>FEP 3.2.4.8: Colloid formation [repository] | Covered in task 7 | Section 9.7 |
| Bentonite occurs as bands with varying thicknesses (from few cm to ca. 7 m)<br>Repository relevant size, scale effects (from EBS buffer to tunnel seals to borehole seals). | FEP 1.2.9: Diagenesis<br>FEP 3.2.4.5: Alteration [repository]<br>FEP 3.2.4.6: Precipitation of solid phases [repository]<br>FEP 4.1.8: Geochemical characteristics and properties<br>Clay – rock interaction. Clay based buffer and backfill designs<br>FEP 3.2.5.2: (Microbially/biologically mediated processes [repository])<br>(FEP 3.3.1: Water-mediated migration [repository], FEP 3.3.1.6: Sorption and desorption [repository] – potentially for gas $H_2$) | Covered in task 3 | Section 9.3 |
| Bentonite occurs at various depths (0 – ca. 300m below ground surface)<br>Repository relevant depth (hydrostatic and lithostatic pressures) | FEP 2.3.2.1: Saturation /desaturation<br>FEP 4.2.2: Hydraulic processes [geosphere]<br>FEP 4.2.4: Chemical processes [geosphere]<br>FEP 3.3.1.1: Advection [repository]<br>FEP 3.3.1.3: Diffusion [repository] | Covered in tasks 4 and 5 | Sections 9.4 and 9.5 |
| Hosted by sandy siltstone<br>Brittle host rock: fractures, faults and water conducting features | FEP 3.3.1.1: Advection [repository]<br>FEP 3.3.1.3: Diffusion [repository]<br>FEP 3.2.4.5: Alteration [repository]<br>FEP 3.2.4.6: Precipitation of solid phases [repository]<br>-FEP 3.2.2.2: Piping/ hydraulic erosion<br>FEP 3.2.4.5: Alteration [repository] | Covered in tasks 3 and 5 | Sections 9.3 and 9.6 |
| Faulting, bentonite deformation, host rock deformation<br>Area has faults cutting bentonite bearing rocks<br>Deformed bentonite? | FEP 1.2.1: Tectonic movement<br>FEP 1.2.3: Deformation (elastic, plastic or brittle)<br>FEP 1.2.4: Seismicity<br>FEP 3.2.4.6: Precipitation of solid phases [repository]<br>FEP 3.2.4.5: Alteration [repository]<br>FEP 3.2.4.6: Precipitation of solid phases [repository]<br>FEP 3.3.1.1: Advection [repository]<br>FEP 4.1.2: Large-scale discontinuities<br>FEP 4.2.3: Mechanical processes [geosphere] (host rock and bentonite deformation)<br>FEP 3.2.5.2: (Microbially/biologically mediated processes [repository]) | Covered and confirmed in task 5 | Section 9.5 |
| In situ, the bentonite appears dry.<br>Unsaturated bentonite?<br>The bentonite could be accessed at repository-relevant depths and the overall environment was repository-relevant (including the presence of groundwaters). These are major advantages over the vast majority of previous studies of natural bentonites where the samples are from exposed surface sites in quarries. As such, Tsukinuno allows assessment of safety-relevant features such as the degree of saturation. | FEP 2.3.2.1: Saturation /desaturation, homogenisation, self-sealing, self-healing | Covered in tasks 4 and 6 | Sections 9.4 and 9.6 |
| Bentonite is pristine at depth<br>Microbial processes can be studied | FEP 3.2.5: Biological processes [repository]<br>FEP 3.2.5.1: Microbial growth and decline [repository]<br>FEP 3.2.5.2: Microbially/biologically mediated processes [repository]<br>FEP 4.1.9: Biological characteristics and properties<br>Microbial populations, organic content, copper corrosion | Covered in task 7 | Section 9.7 |

# IBL – Phase B tasks

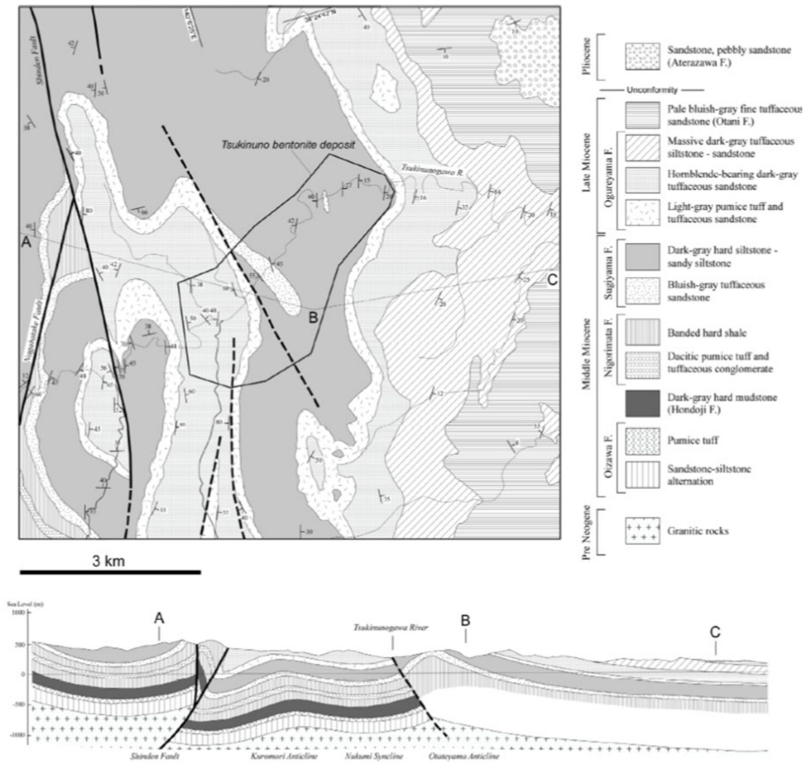
- Task 1: definition of appropriate sampling sites (*Russell*)
- Task 2: development of appropriate sampling approaches (*Russell*)
- Task 3: assessment of long-term bentonite durability (*everyone*)
- Task 4: definition of natural saturation states of bentonite (*Russell*)
- Task 5: examination of the impact of faulting on the long-term behaviour of bentonite (*Heini*)
- Task 6: the potential for bentonite erosion under repository-relevant conditions (*Ryosuke*)
- Task 7: assessment of natural microbial suppression in bentonite (*Rachel*)
- Task 8: production of stakeholder engagement and communication materials (*ongoing*)
- additional work on swelling/cementation (*Tobimaru*)

# IBL in the Tsukinuno mine, Japan

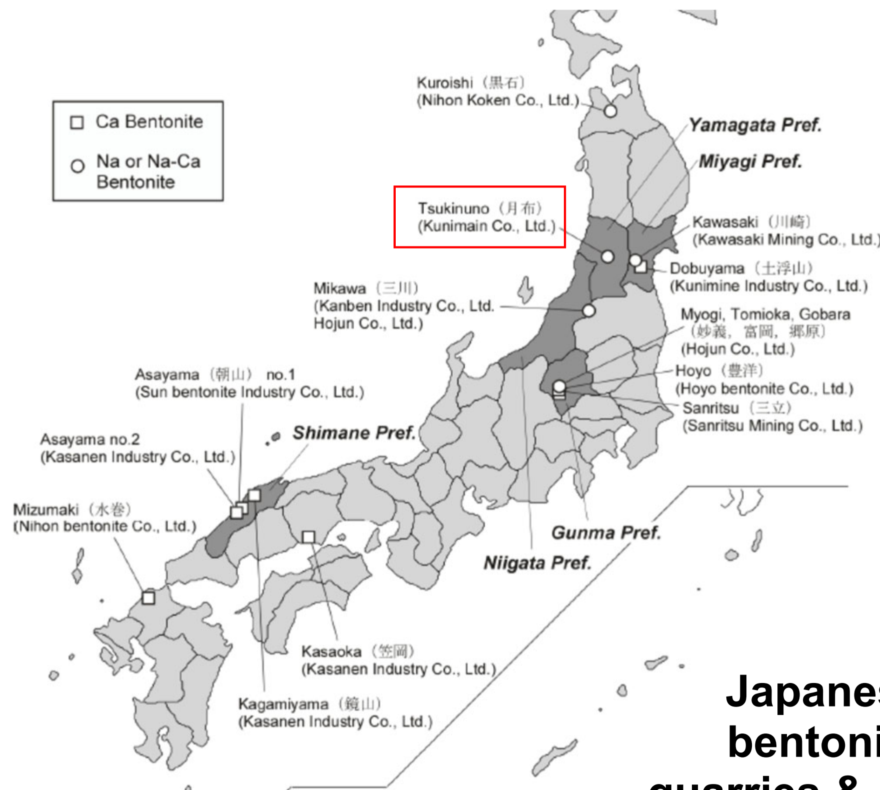



**Schematic diagram of bentonite formation mechanisms (courtesy of KIC).** ***No evidence for bentonite production via hydrothermal alteration has been found in the Tsukinuno mine to date.***

# IBL – location of the Tsukinuno mine, Yamagata Pref.




Geological map of the Ohe region, Japan (Yamaji et al., 1986).




Japanese bentonite quarries & mines (Takagi et al., 2005)

# IBL background – comparison with other bentonites

| Sample ID | Composition (Wt %) | | | | |
|---|---|---|---|---|---|
| | IBL-H-21-2019 | IBL-H-22-2019 | IBL-H-23-2019 | IBL-H-24-2019 | IBL-H-25-2019 |
| Smectite | 60.7 | 37.6 | 53.3 | 69.3 | 77.0 |
| Quartz | 27.2 | 16.3 | 21.7 | 20.5 | 6.8 |
| Calcite | 12.2 | 45.4 | 25.1 | 10.2 | 4.1 |
| Albite | | 0.7 | | | |
| Hematite | | | | | 10.9 |
| Mg-Ferrite | | | | | 1.1 |
| Chi-squared | 2.96 | 3.71 | 3.08 | 3.43 | 3.38 |
| R-Factor | 0.426 | 0.573 | 0.867 | 0.586 | 0.768 |
| Total | 100.1 | 100 | 100.1 | 100 | 99.9 |

**IBL natural bentonite: Reijonen & Alexander (2024)**

**Range of industrial bentonites: Alexander et al. (2017)**

| Parameter | Dry density kg m-3 | Water content % | Smectite content % | Liquid limit % | Plastic limit % | Plasticity Index | CEC mEq 100g-1 | Swelling pressure MPa |
|---|---|---|---|---|---|---|---|---|
| industrial Na-bentonites | | | | | | | | |
| Posiva SF rings[7,8] | 1752 | 17 | >75 | >80 | | | >60 | |
| Posiva SF disc blocks[7,8] | 1701 | 17 | >75 | >80 | | | >60 | |
| Posiva SF pellets[7,8] | 919 | 17 | >75 | >80 | | | >60 | |
| Posiva buffer Ca-bentonite[9] | | 13-15 | 65-≥75 | 60-≥80 | 50 | 10-≥30 | 50-≥60 | ≥2 |
| Posiva buffer Na-bentonite[9] | | 13-15 | 65-≥75 | 200-≥250 | 50 | 150-≥200 | 60-≥70 | ≥2 |
| Kunigel-V1[10] | 2790 | | 48 | 473.9 | 26.61 | 447.3 | 73.2 | |
| MX-80[10,11] | 2880 | | 80 | 437.3 | 38.0 | 399.3 | 110.4 | 7.312 |
| NEO-KUNIBOND[10,11] industrial Na-bentonite | 2680 | | 76 | 607.5 | 50.69 | 556.8 | 103.5 | |
| KUNIBOND[10,1] industrial Ca-bentonite | 2710 | | 84 | 128.7 | 38.4 | 90.3 | 79.5 | |

# IBL – Tsukinuno mine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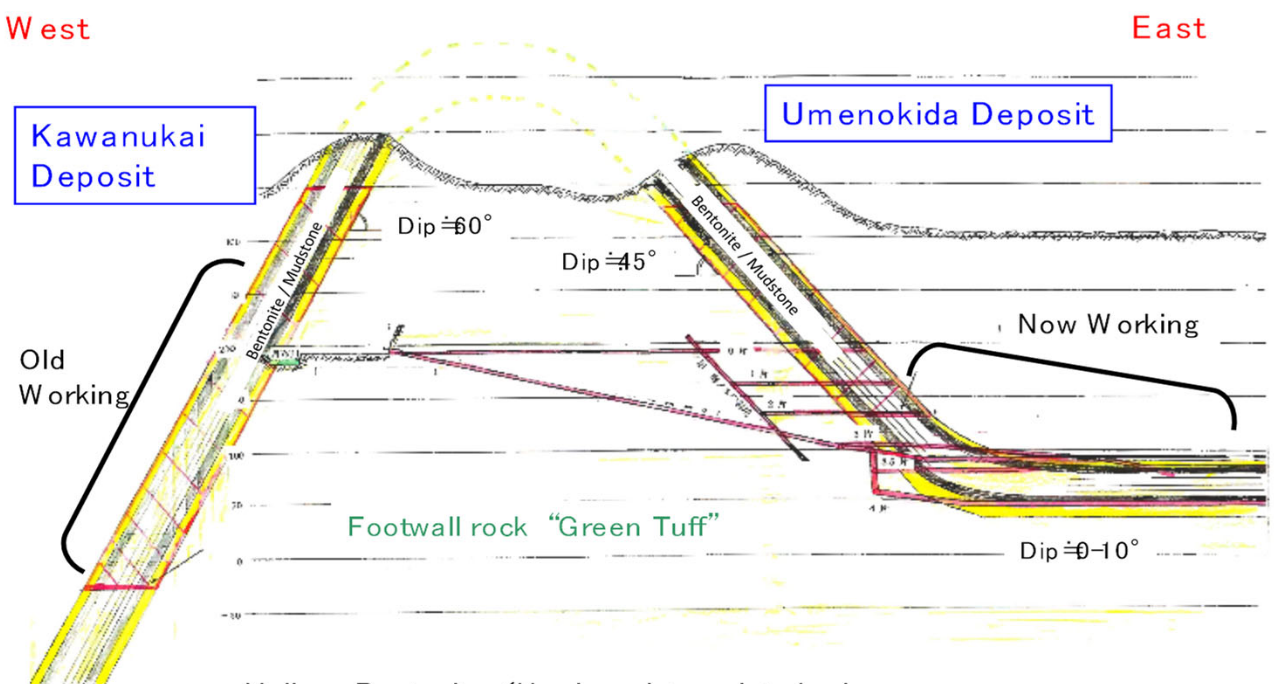


Yellow: Bentonite／Hard mudstone interbed,
Red: Inclined shaft, Cross cut

KUNIMINE INDUSTRIES CO., LTD.

# IBL - siting


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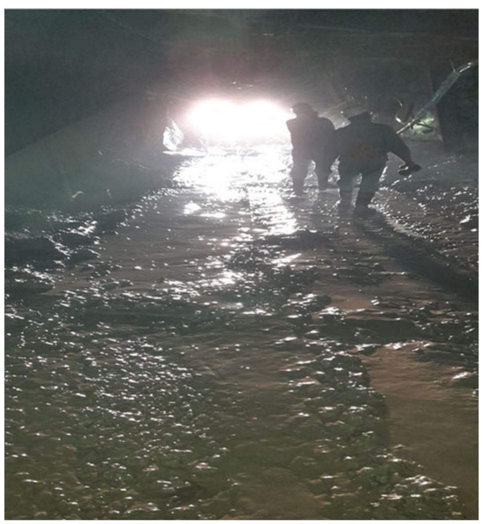
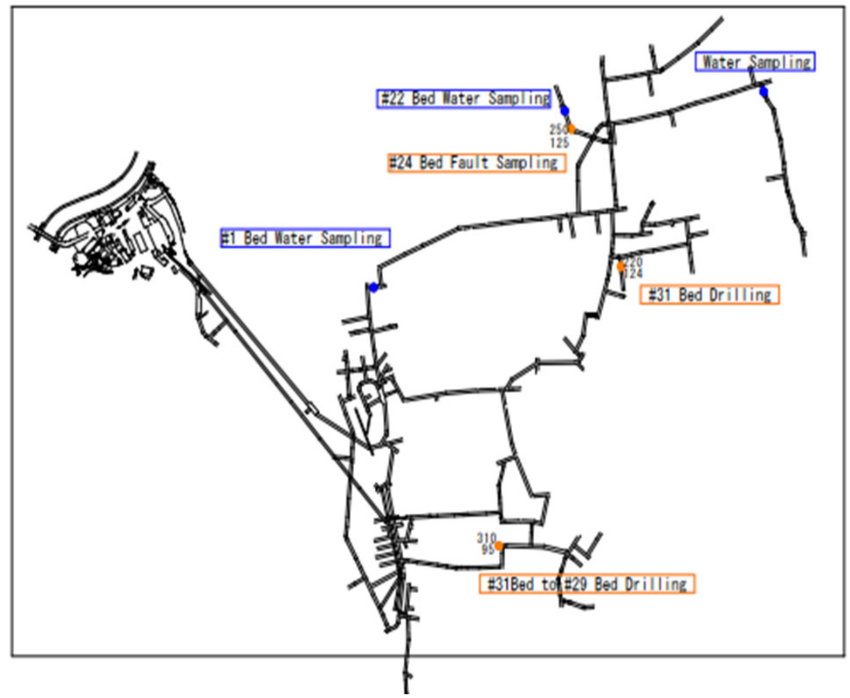
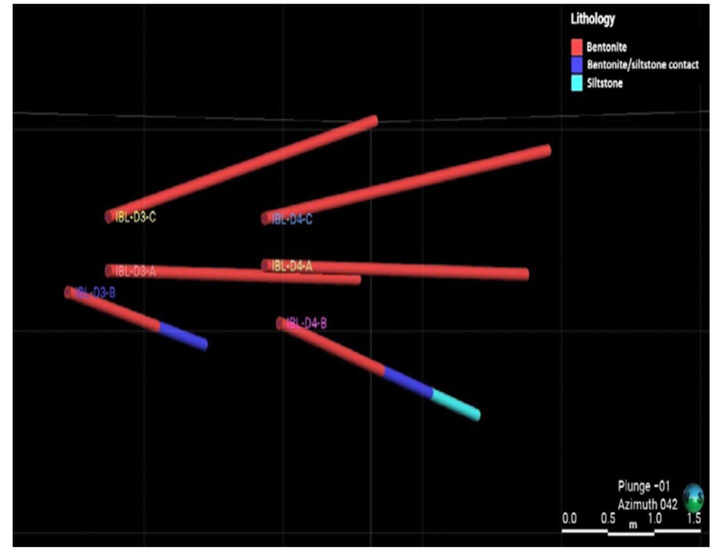
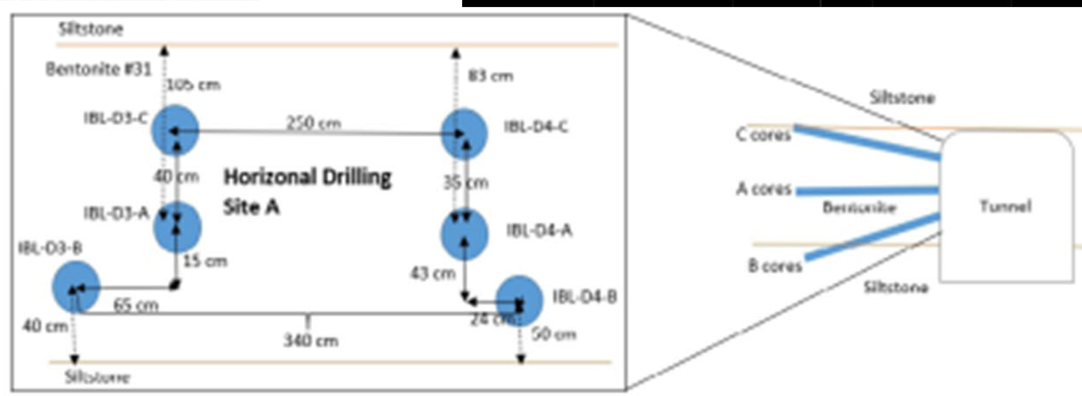


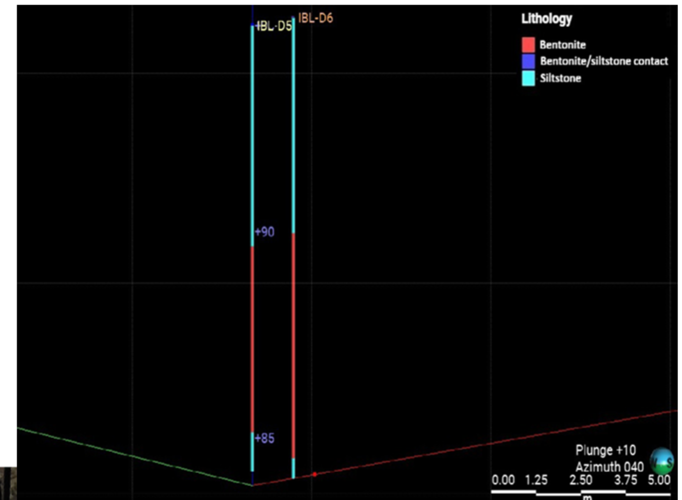

Water Sampling
#22 Bed Water Sampling
#24 Bed Fault Sampling
#1 Bed Water Sampling
#31 Bed Drilling
#31Bed to #29 Bed Drilling

# IBL – sampling site A



# IBL – sampling site B

# IBL – sampling system

TYPE TRIPLE COREPACK TUBE

トリプル VERRY SOFT - ROCK

トリプルチューブは構造上ダブルチューブとほとんど同様ですが、インナーチューブ内にアクリルパイプ（透明管）を内蔵し三重管構造になっています。アクリルパイプはコアを取り出しやすくするためスリット加工をしたものもあります。

| | 76TRIPLE | 86TRIPLE | 100TRIPLE | 116TRIPLE |
|---|---|---|---|---|
| サイズ | 1.0m | 1.0m | 1.0m | 1.0m |
| 外径 | 76mm | 86mm | 100mm | 116mm |
| コア径 | 55mm | 65mm | 75mm | 88mm |
| コア採取長 | 1.0m | 1.0m | 1.0m | 1.0m |
| 全長 | 1,558.5mm | 1,525mm | 1,475mm | 1,719.5mm |
| 重量 | 21kg | 25kg | 33kg | 50kg |
| 外内管クリアランス | 1.5mm | | 2mm | 2.5mm |
| ロッドネジ | 40.5 JIS | | | 40.5 or 50 JIS |
| 掘削水 | 清水・泥水 | | | |
| 適合地層 | 軟泥 軟質土 硬質土 軟岩 中硬岩 硬岩 | | | |

アクリルパイプは材質上、気温の変化により伸長することがございます。
ご使用前に全長をご確認の上ご使用下さいますようお願い致します。尚、保管の際にも十分お気を付け下さい。

特徴　超軟弱・軟質～軟岩

- 三重管構造(アクリルパイプ使用)になっており、軟弱な地層の場合はコアを管内に入れたまま保留可能。
- 海底、軟弱地盤、沿岸、水害の地域等で活躍。
- コアに対する外圧を防ぎ、高品質なコアをスピーディーに採取します。
- SM・RSへ切替え可能で軟弱層～硬岩～破砕帯まで幅広く使用できます。
- スリーブが不要な場合は部品の切替えで簡単にスリーブ無し仕様に変更できます。



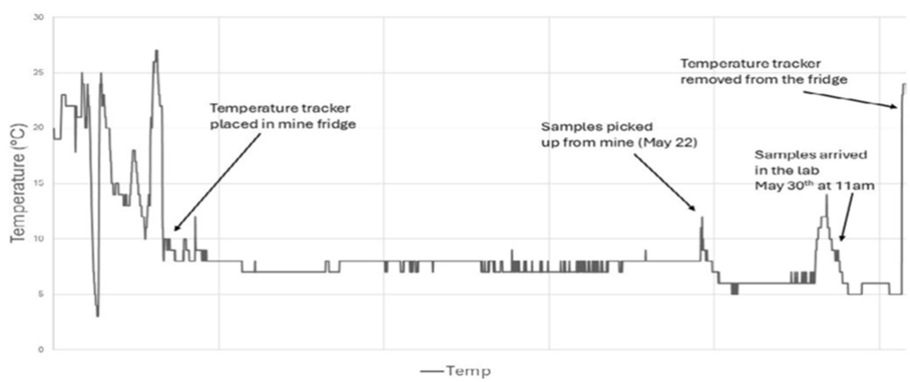
# IBL – sampling/sub-sampling

**Fluorescein dye was added to the drilling fluid during the drilling of core D6 to assess potential drilling fluid contamination of the cores**

**Fluorescein dye was observed in the core sections only sparingly and then only between core barrels 2 and 3 (i.e. not in contact with the bentonite). In only one sample (D6, 9.60-9.85 m) was dye observed in contact with the bentonite as, in this case, barrel 3 had been damaged, allowing ingress of drilling fluid**

**Microbiological sampling/sub-sampling was massively time-consuming, both in the mine and in the surface prep-rooms, but seems to have gone well (our genes have not been found so far)**

# IBL – sample storage and transport

# IBL – sample storage and transport

# IBL – saturation

<u>Full saturation is assumed in most repository designs as a long-term condition for the bentonite</u>

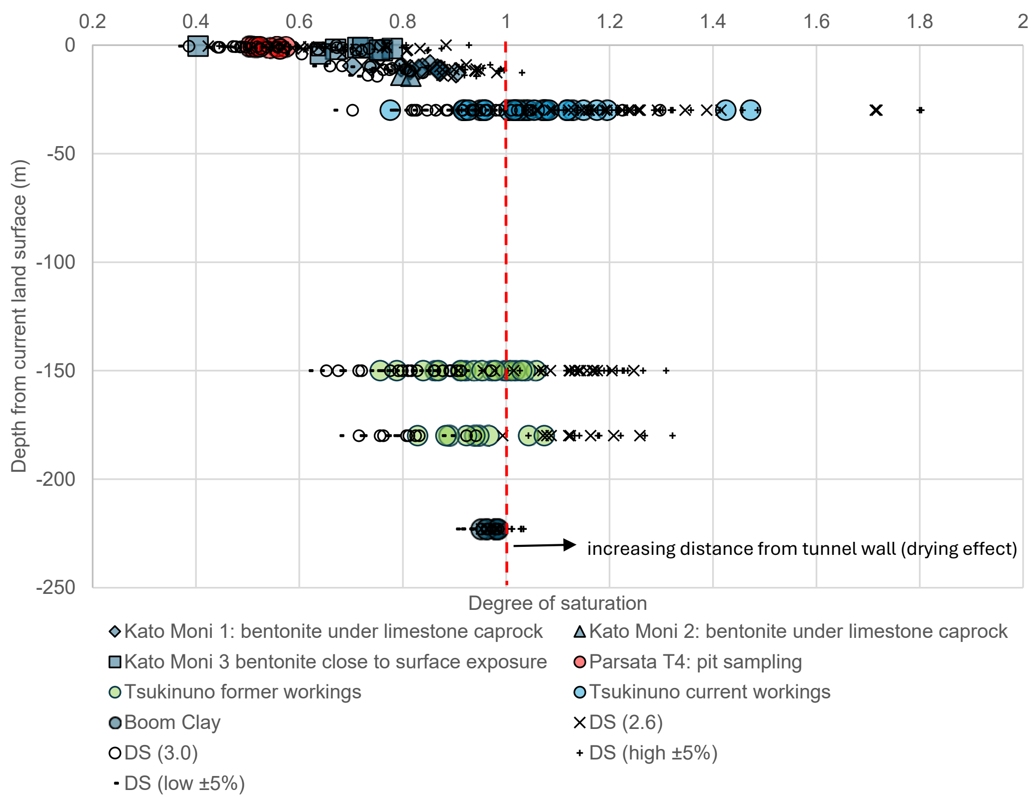
**However, the period before full saturation can be very long when the decay heat of the waste affects near-field conditions, especially in cases where the host rock is relatively dry**

**By looking at natural bentonite occurrences at repository relevant depths, some open questions can be answered:**

- **What is the long-term saturation state of bentonite and how does it vary as a function of the surrounding local host rock lithology, groundwater chemistry etc?**
- **Are the safety case (SC) assumptions too simplistic?**
- **Can further studies help in conceptualisation of the bentonite-water processes so that the SC applications would be more realistic?**

# IBL – saturation

## Preliminary results for 3 bentonites, 2 from quarries in Cyprus, 3rd is Tsukinuno mine



# IBL – saturation

In the Tsukinuno mine, dryer and wetter bentonites are clearly observed, need to understand why. What are the implications for the safety case?

To assess this, we plan to look further at:

- beds adjacent to water-conducting features
- beds adjacent to 'dry' host rocks
- saturation state (and full suite of physico-chemical parameters), CEC, EC, stable and radioactive isotopic profiles, hydrogeochemistry, etc.

For the current (preliminary) results from Phase B, please see Reijonen et al. (2026) for details

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# IBL – acknowledgements

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# IBL – last word