



SAFER2028 Spatial stability and integrity of montmorillonite – increasing robustness in assessing long-term climate driven scenarios (MORO)

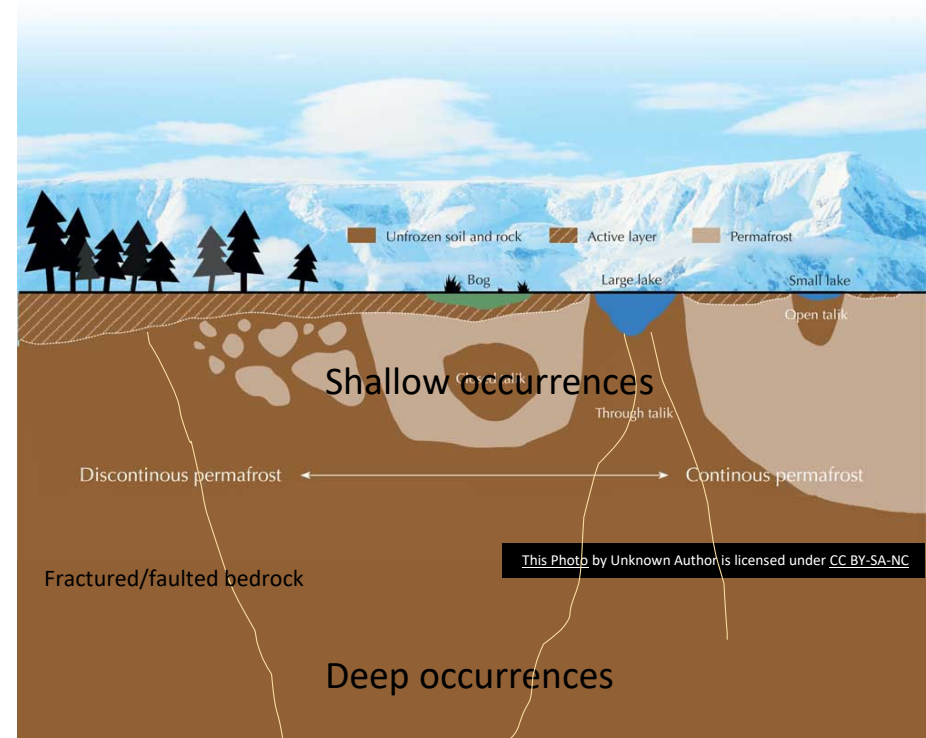
Natural Analogue Working Group – NAWG-18 9th -11th June 2026,
Manchester, UK

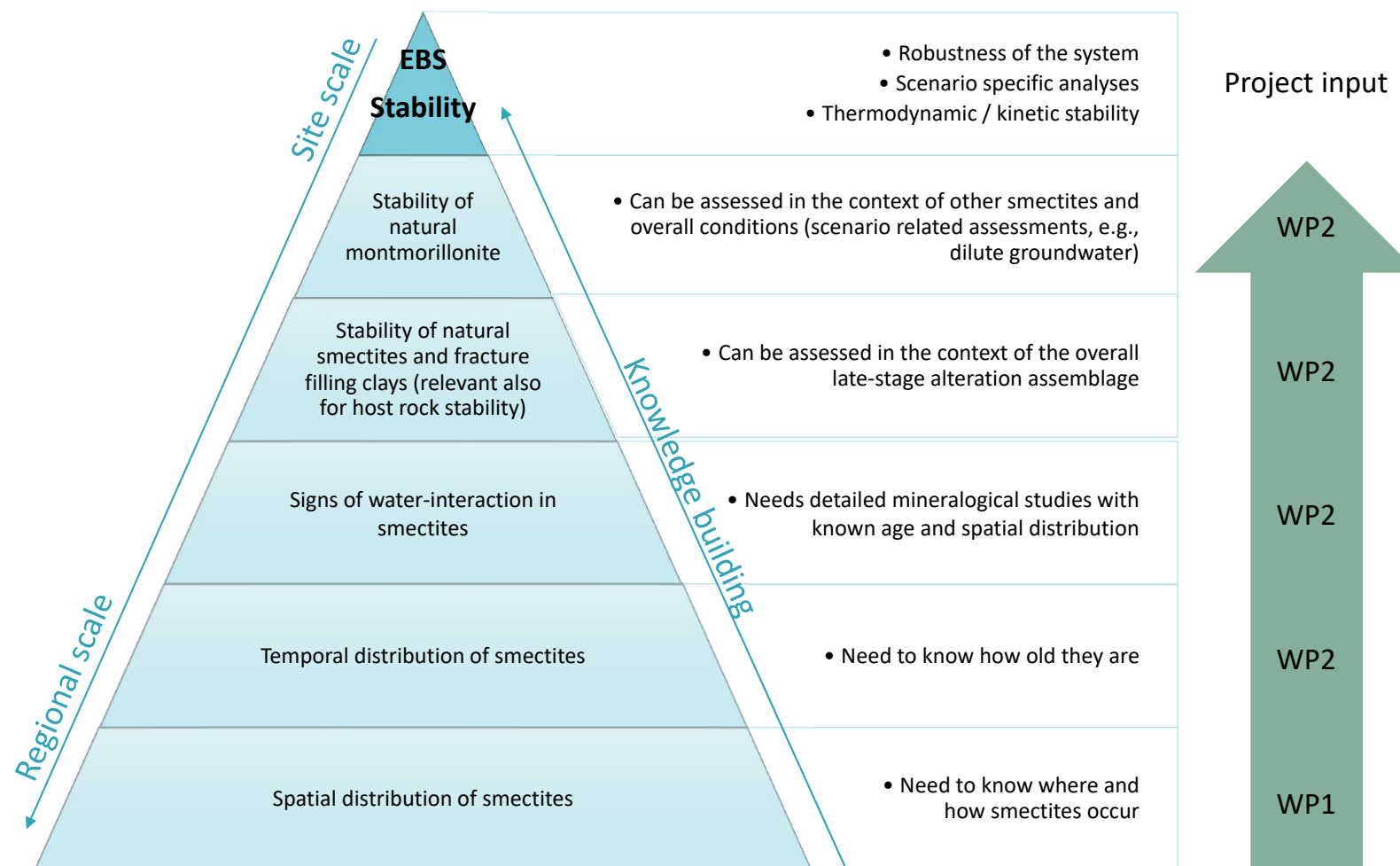
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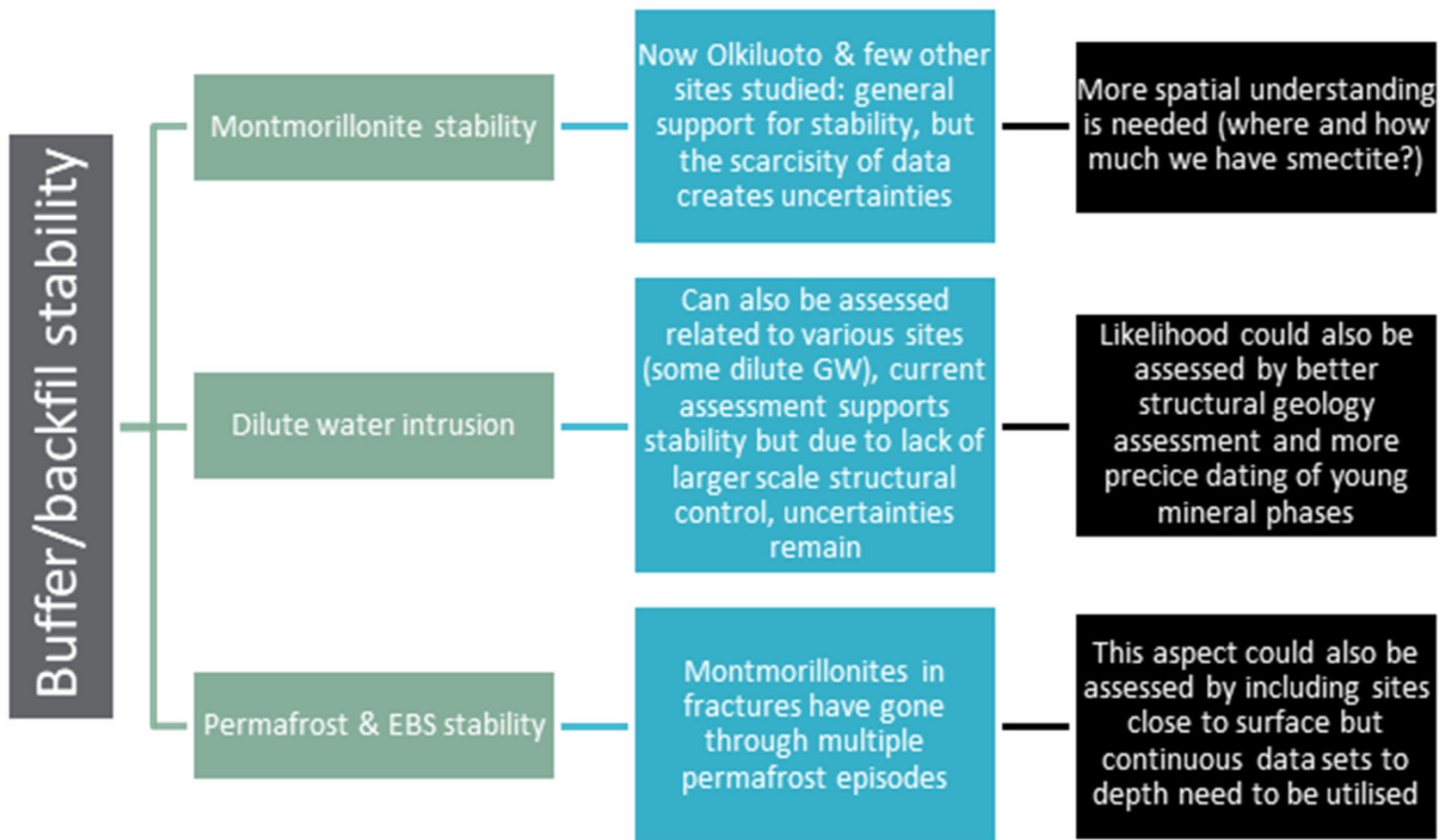
¹Geological Survey of Finland (GTK)

Background and Rationale

- SAFER2028 National Funding Scheme in Finland – theme: Nuclear Waste Management, Final Disposal and Decommissioning
- Project started 2026
- Duration 3 years
- The project addresses **spatial variation (focusing Finland) and behaviour of smectite clays (e.g., montmorillonite)** under evolving environmental conditions
 - dilute water penetration,
 - erosion, and
 - permafrost.
- Current status of smectite stability is based on **relatively limited set of studies** (summarised e.g. by Reijonen 2025)
- Recent advances have been made to assess the reactivation ages of the fault systems, but the **ages of the late-stage clays such as smectites are still uncertain**
- There are underused datasets to further assess the occurrence







Novelty of the Methods and New Approaches

- The project integrates advanced analytical techniques, geospatial modelling, and geochronology. It aligns with SAFER2028's requirement for internationally high-level, multidisciplinary research by including:
 - Cross-disciplinary approach combining geology, hydrogeology, geochemistry, and data science
 - Application of hyperspectral imaging and machine learning for mineral mapping
 - Use of advanced dating for fracture-filling smectites
- Integration of near-surface analogues to assess depth dependent process effects (e.g. groundwater chemistry changes and permafrost)

Objectives



Assess distribution (location and depth) and geological environment (lithology and structural setting) for smectite minerals in faults and fractures



Evaluate the effects of dilute groundwater and permafrost on buffer materials



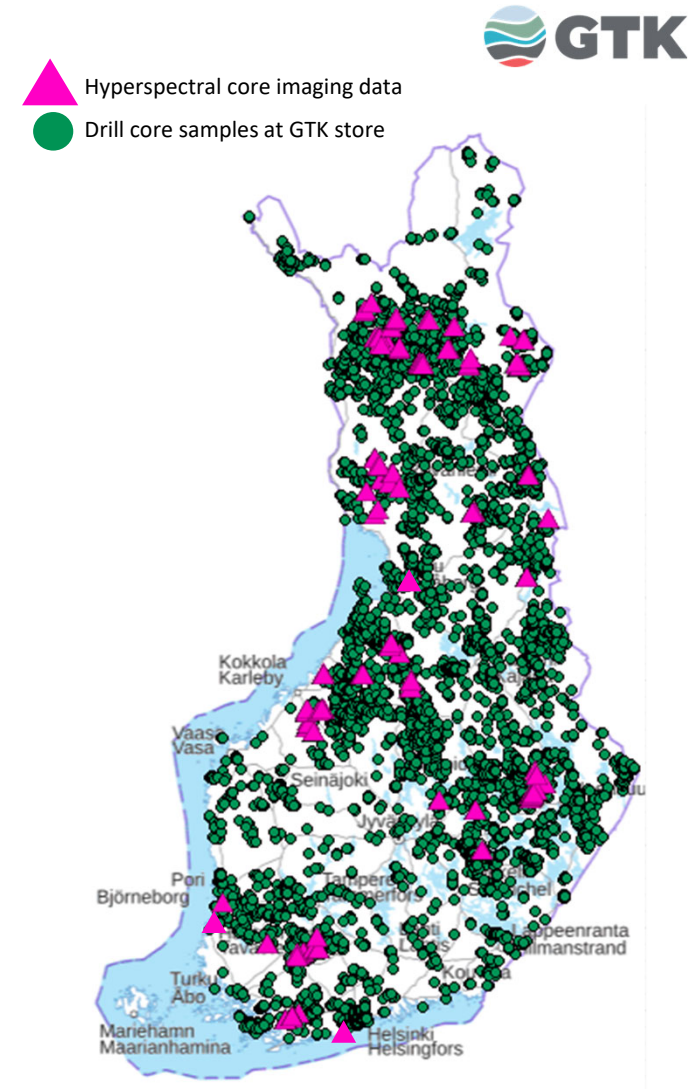
Provide data to support safety case development and buffer material optimization – increased understanding of also other smectites and clays, not just montmorillonite



Contribute to national expertise and infrastructure development in long-term safety of deep geological disposal, clay mineralogy and characterization methods needed to assure EBS performance, structural geology for assessing EBS boundary conditions

Methodology

- A multidisciplinary approach will be employed, integrating geological, structural, hydrogeological and hydrogeological aspects will be used.
- Existing experimental facilities will be utilized to support the research.
- A desktop regional assessment will be conducted to map and assess the spatial distribution of smectite minerals in Finnish bedrock.
 - This will be achieved by using hyperspectral and imaging datasets analysed by machine learning tools. The results of the desktop studies will be supported by detailed fracture mineral studies from representative sites. The analysis will include also overall structural geology characterization.
- Case studies: Samples will be obtained from GTK's Loppi core archive and from additional field samples in relevant settings. These may include comparison samples from other projects (e.g. hydrothermal montmorillonites).
- New dating of mineral samples will be undertaken.



- In MORO project, the aim is to locate smectites

- The drillhole R-307 is 233 m long and reach a depth of 211 m.
- Geophysical logging with dual laterolog resistivity , acoustic measurements (P- and S-wave) and downhole optic and acoustic imaging.

Pixel specific spectra

The graph displays reflectance (y-axis, 40 to 100) against wavelength (x-axis, 600 to 2400 nm). Two curves are shown: a solid black line and a dashed pink line. The solid black line has a prominent dip at approximately 1400 nm, while the dashed pink line has a dip at approximately 1600 nm. Vertical green lines are drawn at 1400 nm, 1600 nm, and 2100 nm. The text 'Pixel specific spectra' is overlaid on the graph.

XRD to validate

Åland – locality for simplified geology (rapakivi granites)

- Smectites are known e.g. from Olkiluoto and many other localities as fracture filling minerals (compilation e.g. in Reijonen 2025)
- Åland island has been attractive site for many structural geology and geochronology studies on fractured systems due to overall simplicity of the geology
- In MORO project, we continue to assess the smectite occurrences in known sites and better constrain the ages of alteration events in faults/fractures

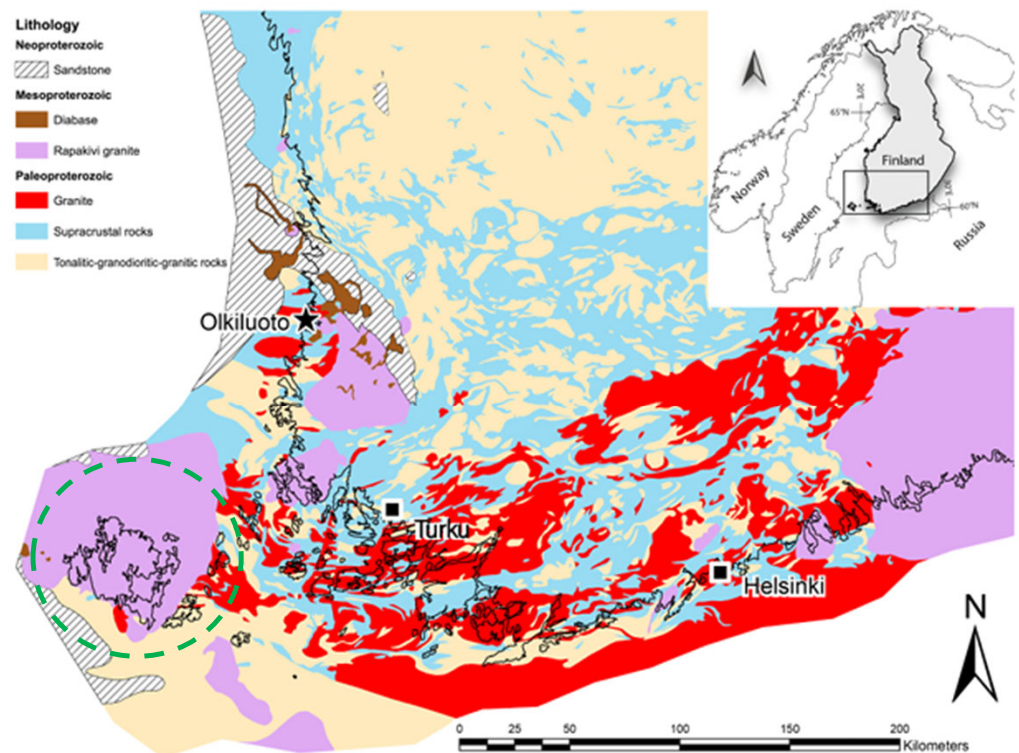
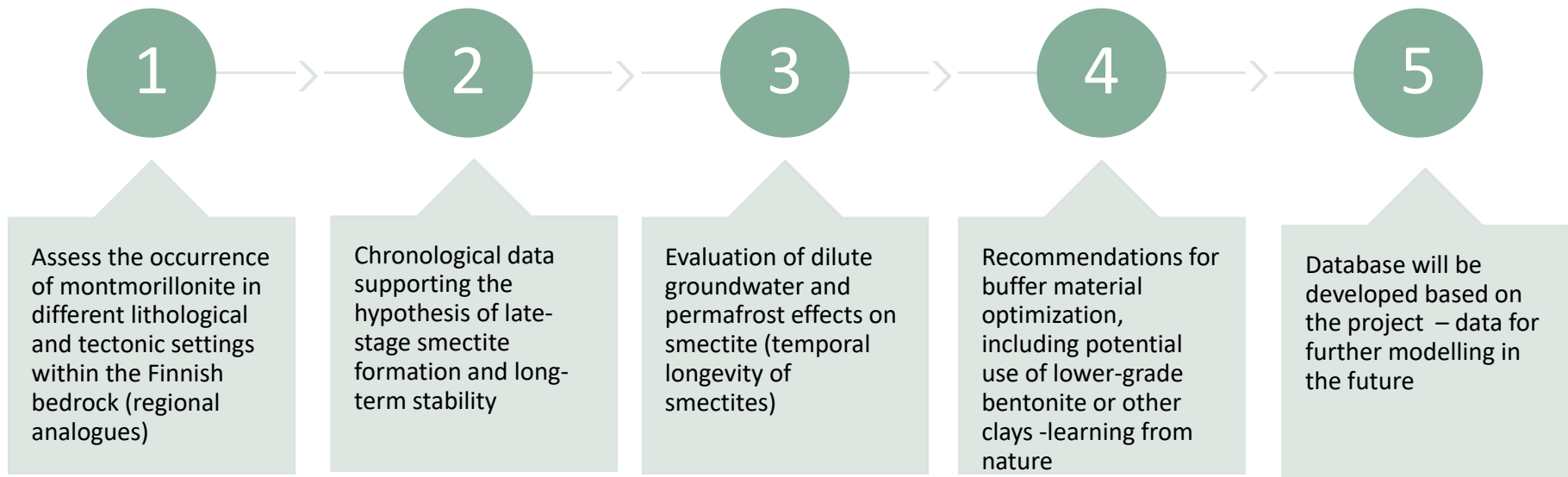


Fig. 1. Overview geological map of southwestern Finland. Olkiluoto Island is indicated by a black star.

Expected Outcomes

To provide a systemic understanding of smectite behaviour in crystalline bedrock in Finland (and Fennoscandia) to support robust safety case



Usability for End Users



Findings will be directly applicable to STUK, Posiva, and other stakeholders



Benefit to applications using deep subsurface needed for energy transition (e.g. deep bore hole disposal, deep geothermal, other deep bedrock storages)



The project will also generate new data on additional fracture minerals relevant to site characterisation



Mapping method development serves also general tunnelling projects (smectite observations related to rock stability issues)

Conclusions

- MORO project was initiated based on the topics considered of relevance in SAFER2028 research programme
- Support both from the regulator and WMO
- 3 year project foreseen
- 2026 we focus on
 - Machine learning development to be able to analyse hyperspectral datasets
 - Conduct dedicated additional analyses on known sites
 - Plan new sites for 2027 and 2028 based on the initial results
- Upcoming
 - 1st publication underway on Åland geochronology, new dating results coming
 - 1st interim results – January 2027
 - SAFER2028 webinars



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