Experimental study of aging-induced cementation effect on permeability property of bentonites

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Background: Bentonite Buffer Material in Geological Disposal

Bentonite buffer material is required
- ✓Low water permeation
- ✓Gap sealing by **swelling** deformation
- ✓Soundness for thousands of years

Placed in high temperature, pressure

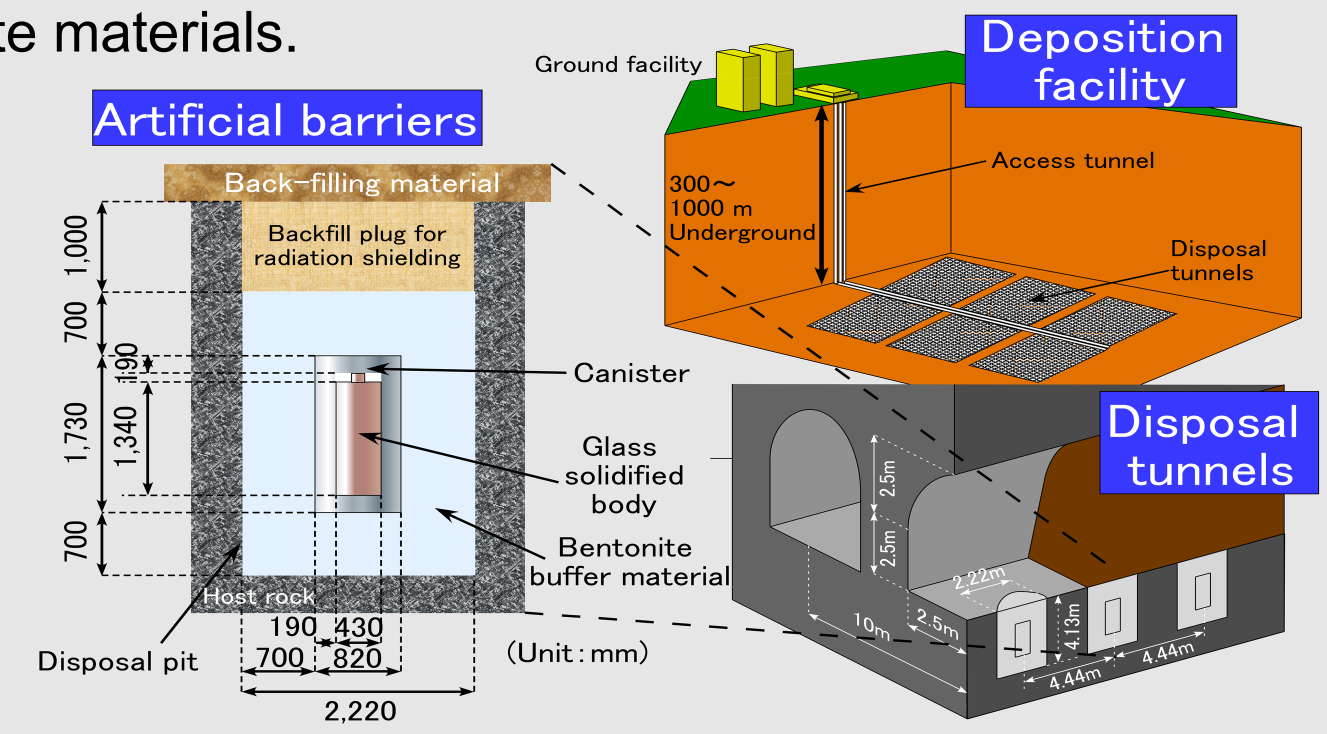
Solidified because of **cementation**, and permeability property will be changed.

Reproduction of cementation is difficult by laboratory experiments

Focusing on **bentonite ore as simulating buffer** altered by cementation.

Research Objective

✓Evaluation of **cementation effect on hydraulic conductivity** of bentonite materials.



Material and Methodology

Fundamental properties of ore sample

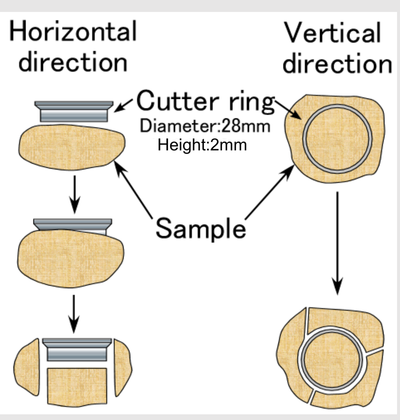
	Tsukinuno	Ten Sleep	Liufangzi
Geological age (years)	10 million	100 million	150 million
Burial depth (m)	200	10	200～250
Soil particle density (g/cm³)	2.77	2.67	2.73
Liquid limit (%)	419.1	588.2	541.6
Plastic limit (%)	29.2	57.2	35.6
Plasticity index	389.9	531.0	506.0
Content of montmorillonite (%)	44.7	50.4	51.1
Leached cation Na^+ (cmol(+)/kg)	43.7	60.7	48.8
Leached cation Ca^{2+} (cmol(+)/kg)	5.6	14.4	21.0
Leached cation Mg^{2+} (cmol(+)/kg)	0.9	0.4	3.4
Leached cation K^+ (cmol(+)/kg)	Lower than minimum determination limit		0.6

Tsukinuno ore (Japan)

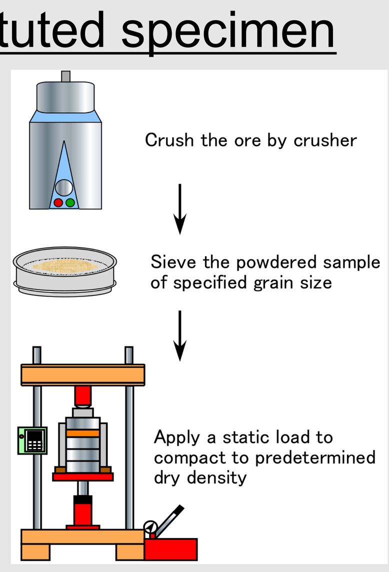
Ten Sleep ore (USA)

Liufangzi ore (China)

★Specimen: Undisturbed and reconstituted specimen



Undisturbed specimen
(Retained cementation)
→Molded into column shape for specimens' size



Reconstituted specimen
(Removed cementation)
→Crushed ore and made of powder (~0.425 mm), then compacted statically

★Test system: Falling head hydraulic conductivity test

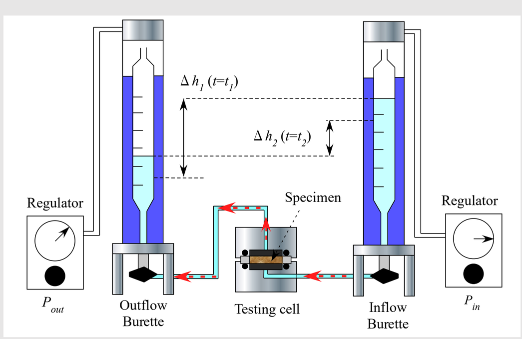
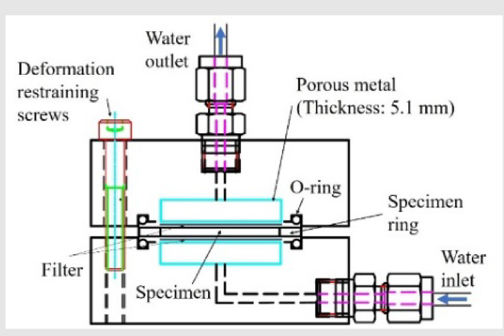
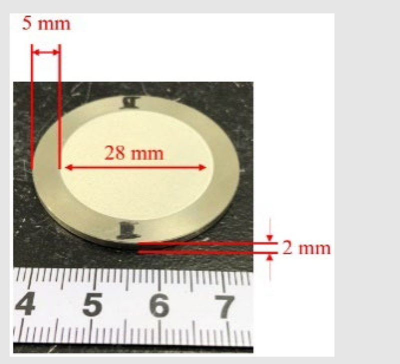


Illustration of whole test system



Cross-sectional view of the test cell



Specimen and 2 mm thick ring

★Test procedure

1. Test cell was assembled and immersed in distilled water under reduced pressure (-98kPa) for 1 day.
2. Test cell was connected to the burettes, then hydraulic conductivity test was started.
3. During the test period, air pressure applied to the burettes was varied to change hydraulic gradient.
4. Room temperature and water levels in burettes were measured sequentially.
5. Hydraulic conductivity was calculated using following equations.

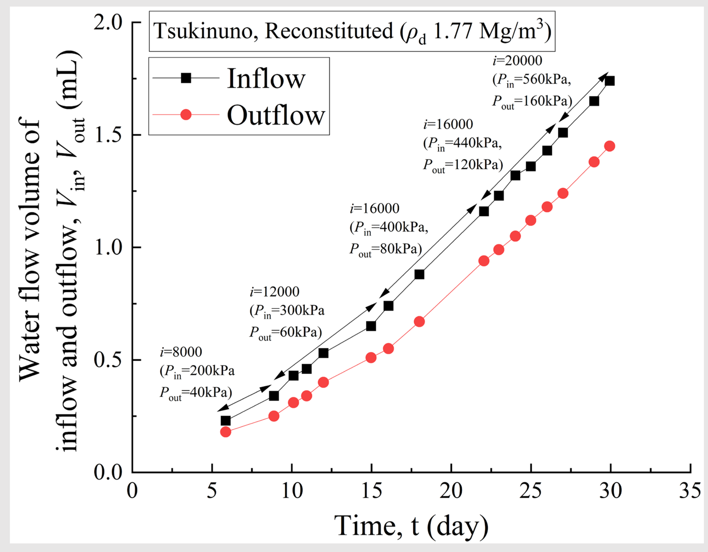
$$k_T = 2.303 \frac{(A_{in} \times A_{out})L}{(A_{in} + A_{out})A_{spe}(t_2 - t_1)} \log_{10} \frac{\Delta h_1 \gamma_w + \Delta P}{\Delta h_2 \gamma_w + \Delta P} \quad (1)$$

$$k_{15} = k_T \times \frac{\eta_T}{\eta_{15}} \quad (2)$$

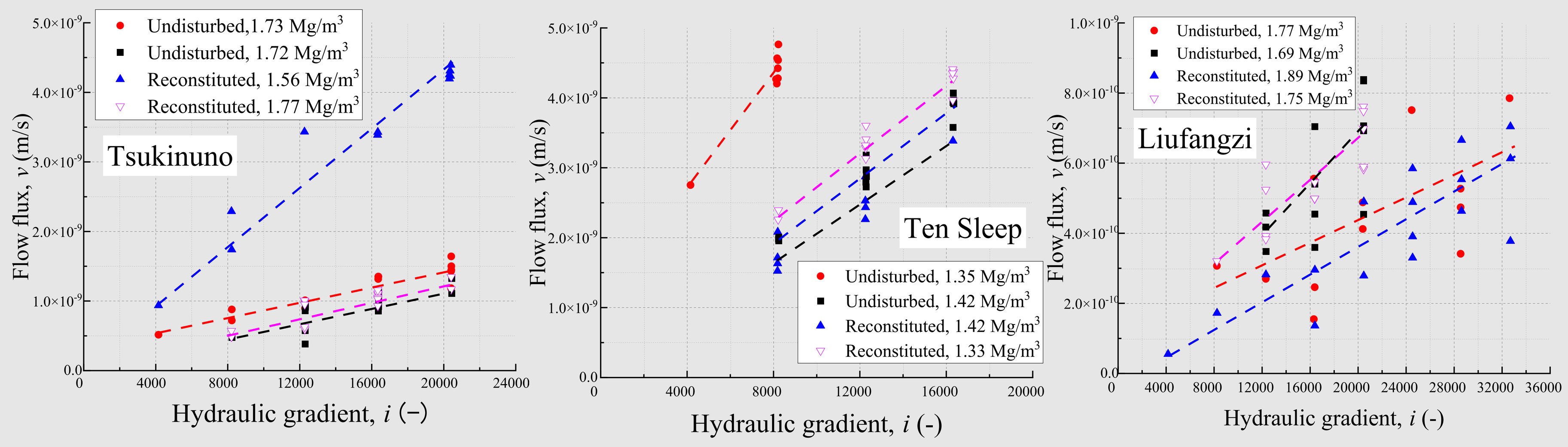
k_T : hydraulic conductivity; k_{15}: the hydraulic conductivity at a water temperature of 15℃: A_{in} and A_{out}: cross-sectional area of the burette on both inflow and outflow side (=0.51 cm²); L: specimen thickness; A_{spe}: cross-sectional area of the specimen; Δh_1 and Δh_2: water level differences at times t_1 and t_2; γ_w: unit volume weight of water; ΔP: differential pressure between the inflow (P_{in}) and outflow (P_{out}); and η_T/η_{15} is the correction factor for calculating k_{15}.

Test Results and Discussion

★Relation between flow flux and hydraulic gradient



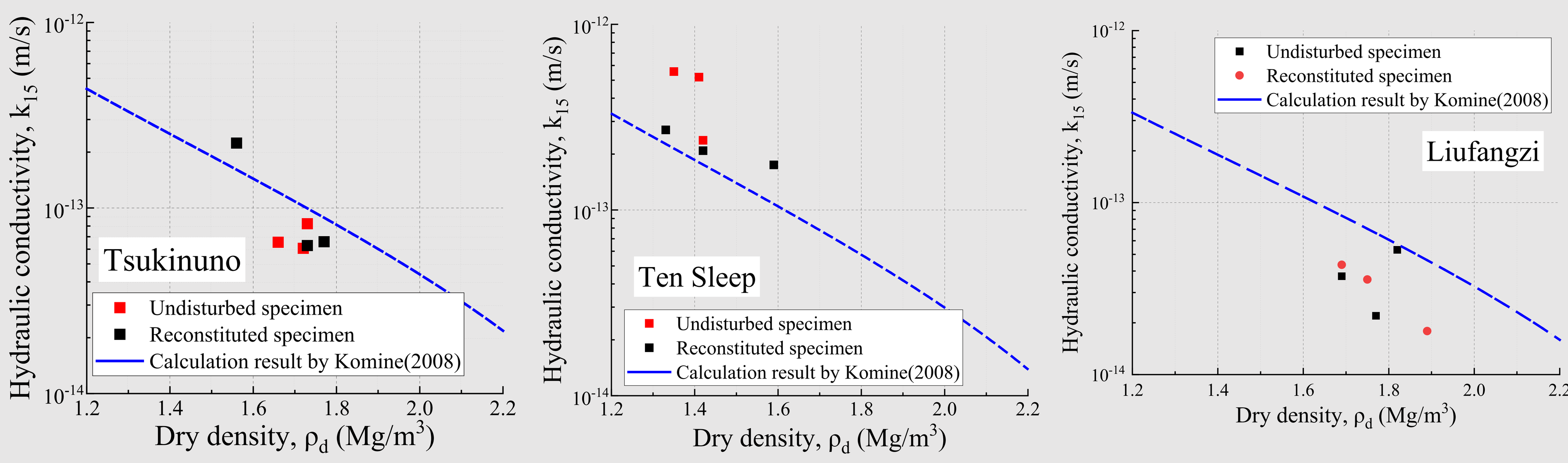
✓ Example of flow volume and time course
Hydraulic gradient increases with applying air pressure, and gradient of flow volume increase is correspondingly higher.



- ✓ **Tsukinuno & Ten Sleep**: Variation in flow flux was within a factor of two.
- ✓ **Liufangzi**: Flow flux is in same order, while variation was larger than above two ores.

→**Proportional relation between flow velocity and hydraulic gradient**.
→Water flow in the specimens is in **accordance with Darcy's flow**.

★Effect of cementation on hydraulic conductivity of bentonites

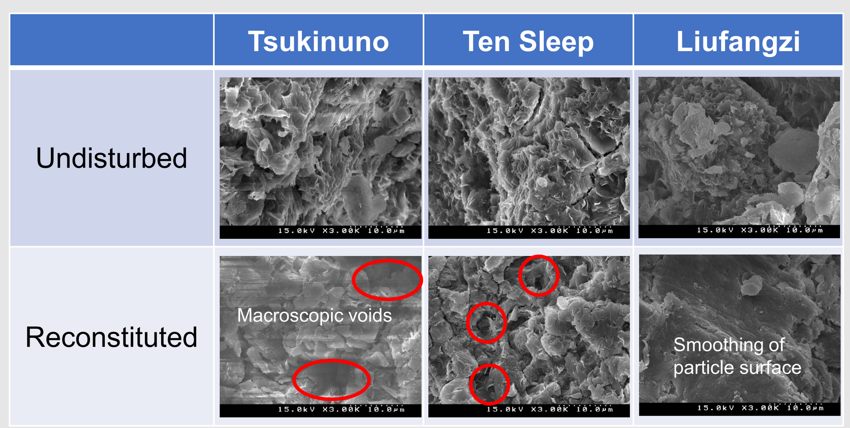


- ✓ Hydraulic conductivity of undisturbed and reconstituted specimens was **not significantly different**.
- ✓ The difference of hydraulic conductivity has **no relation with geological age** of bentonite ores. (Chronological order: Tsukinuno→Ten Sleep→Liufangzi)

→**Effect of cementation** on the hydraulic properties of bentonite might be **small**.

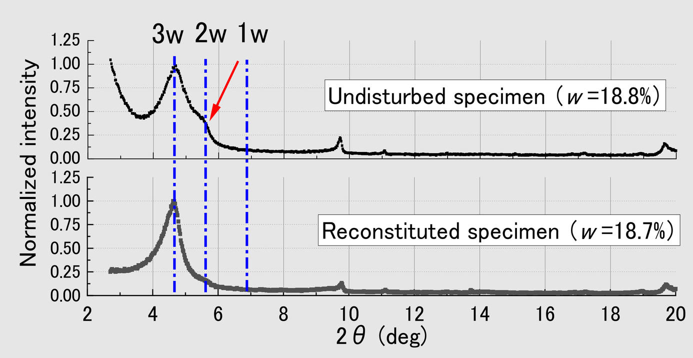
★Positive and negative factors for low permeability due to cementation

✓ Positive factor: **Complication of soil particle shape and structure**



SEM images of cross sections of undisturbed and reconstituted specimens of each ore
→In reconstituted specimens, there are **macro voids** and **smoothing of particle surface**.

✓ Negative factor: **Inhibition of swelling pf montmorillonite**



XRD results of same water content of undisturbed and reconstituted specimen
→**Montmorillonite basal spacing** of undisturbed specimen was smaller than that in reconstituted specimen.
→The **hydration and swelling** of montmorillonite was **inhibited by cementation**.

Conclusion

1. In the range of hydraulic gradient set in this study (4000-32000), hydraulic behavior of bentonite satisfies Darcy's law.
2. Hydraulic conductivity of undisturbed and reconstituted specimens is in the same order in all ores.
3. Cementation may cause both complication of soil particle structure and inhibition of swelling of montmorillonite, therefore, almost no change in hydraulic conductivity is inferred.