NRA Japan
Nuclear Regulation Authority

Natural analogue study on the effect of loading pressure on bentonite deformation

Tatsuya KIJIMA
Regulatory Standard and Research Department
Secretariat of Nuclear Regulation Authority (S/NRA/R)

Background and Objective (1/2)

Bentonite has favorable properties for the containment of radioactive nuclides and is planned to be used in radioactive waste repositories.

Concern exists that bentonite may sink due to deformation caused by long-term loading pressure by waste package.

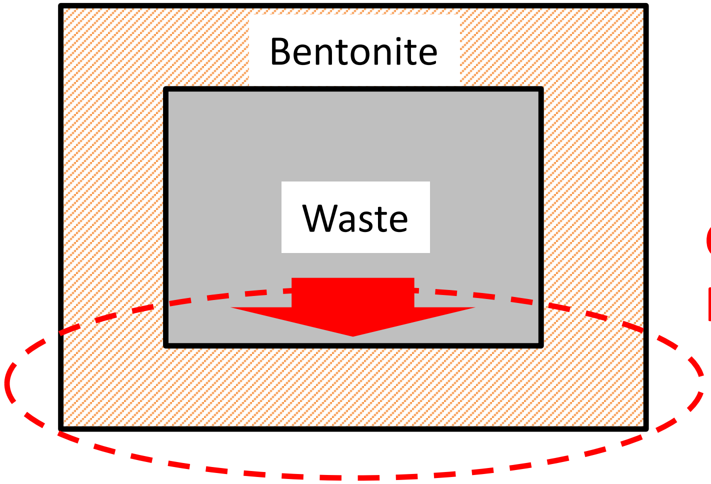
Previous studies (for example, Pusch and Adey, 1999; Nakamura and Tanaka, 2006) suggested that sinking would be negligible based on accelerated experimental and simulation results which took into account the drainage of water content in bentonite and the elastic-plasticity deformation.

Background and Objective (2/2)

The extent of bentonite deformation remains controversial because of the possibility of rheological deformation resulting from creep-induced deformation of bentonite over long time periods (i.e., millennia).

Objective

Clarifying the effect of loading pressure on bentonite deformation by investigating a site where a natural bentonite layer has been subjected to different pressure loads by overburden layer for a long period of time.



Consolidation?
Rheological deformation?

Study site

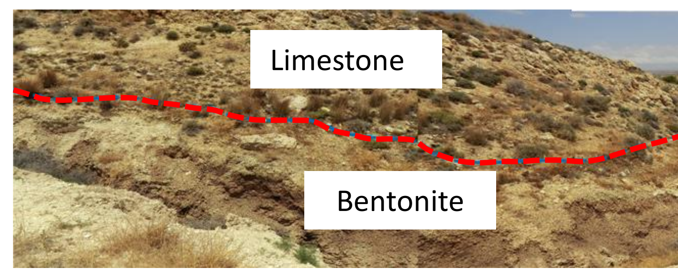
Site: Kato Moni site in Cyprus

- ✓ Various thickness of limestone directly overlying bentonite.
- ✓ No indication of a landslide was present.

Map of Cyprus

Deposited age

- ✓ Limestone was formed in the Miocene.
- ✓ Bentonite was formed in the Campanian/late Cretaceous.



Condition of limestone and bentonite at the Kato Moni site

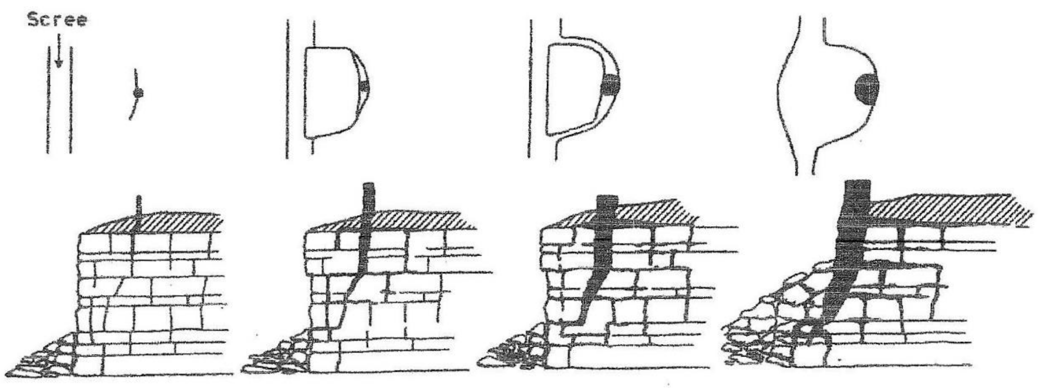
- ✓ The Kato Moni site was uplifted and exposed to the surface ca. 0.5 Ma.
- ✓ Average erosion rates of the overlying limestone are estimated to be on the order of 50 m in a million years (Pitty, 1968).

  →25 m of the overlying limestone was lost by erosion during the last five hundred thousand years.

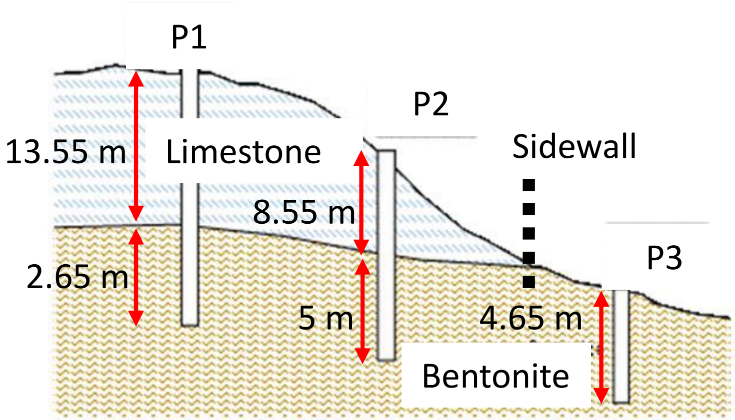
Sampling

- ✓ To capture the differences in bentonite layer pressure loading conditions, three points (P1, P2 and P3) with different limestone thicknesses were chosen as sampling points.

- ✓ It is assumed that biophysical mechanisms, such as tree-root growth, unroofed the overlying limestone at P3 (one of the sampling points).
- ✓ Limestone sidewall might be retreated by 6-12 m over ten thousand years (Larson et al., 2000).
  → The point P3 has been exposed for at earliest 50 ka by erosion processes including biophysical mechanisms because this point is separated from limestone sidewall.

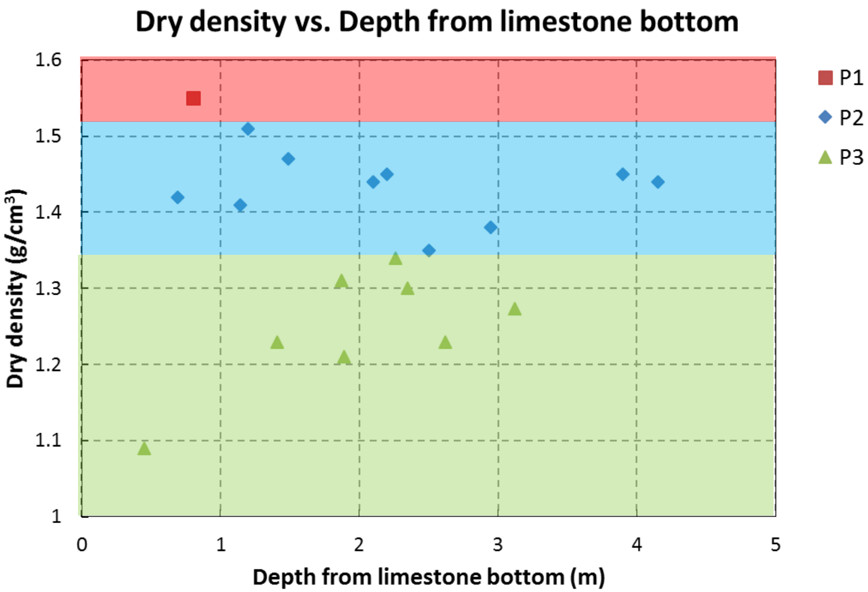


Biophysical role of tree roots in the disruption of limestone (Jackson and Sheldon, 1949).



Schematic of sampling points in Kato Moni

Mechanical test



Mechanical properties of bentonite (average value)

	Unconfined compression strength	Adhesive strength	Angle of internal friction	Shear strength
P1	481 kPa	205 kPa	19 °	370 kPa
P2	336 kPa	133 kPa	18 °	245 kPa
P3	230 kPa	65 kPa	12 °	115 kPa

<u>Density</u>

✓ Although bentonite densities fluctuated, they increased in the order of P1, P2 and P3.

<u>Evaluation of shear strength</u>

✓ Bentonite tended to have greater shear strength as its density increased.
✓ The shear strengths were greater than the loading pressure (P1: about 250 kPa and P2: about 150 kPa) on the bentonite.

Smectite amount and degree of saturation

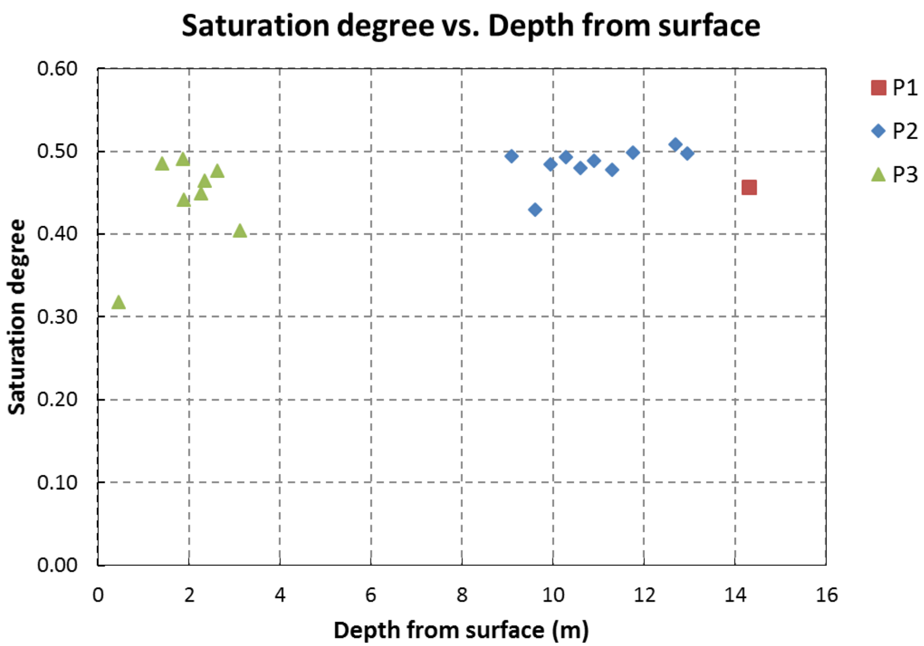
Smectite content

- ✓ Methylene blue adsorption test
- ✓ Most bentonite samples contained 20-30% smectite and some of them contained more than 30% smectite.

Degree of saturation

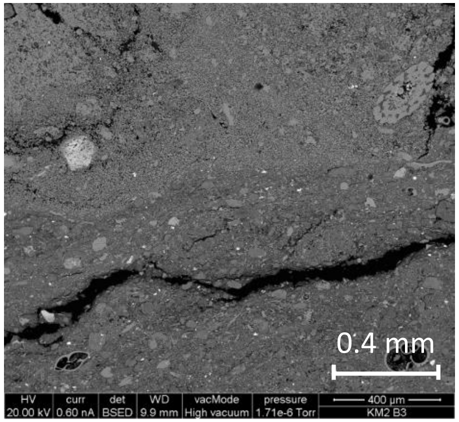
- ✓ The degree of saturation of bentonite samples was approximately 50%.

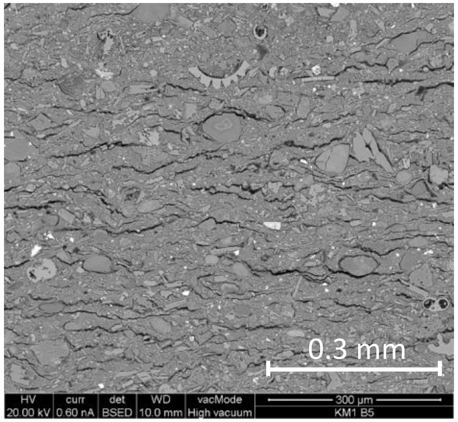
- ✓ There was not a major difference in the degree of saturation among samples except for the near-surface sample.



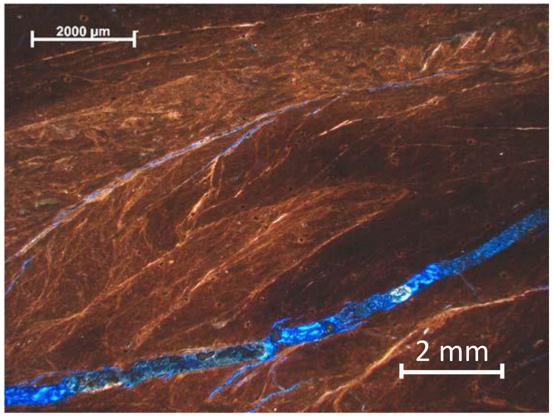
Optical and electron microscope observation

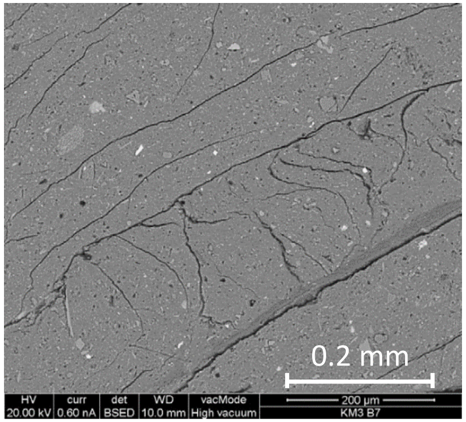
- ✓ Fractures due to bentonite swelling and irregular pattern fractures were observed at P1 (see below left figure) and P2 (see below right figure) samples.
- ✓ Indications of creep-induced rheological deformation of bentonite was not observed.





- ✓ Possible fractures indicating traces of bentonite rheology in a specific direction were observed only at P3 (see below two figures).





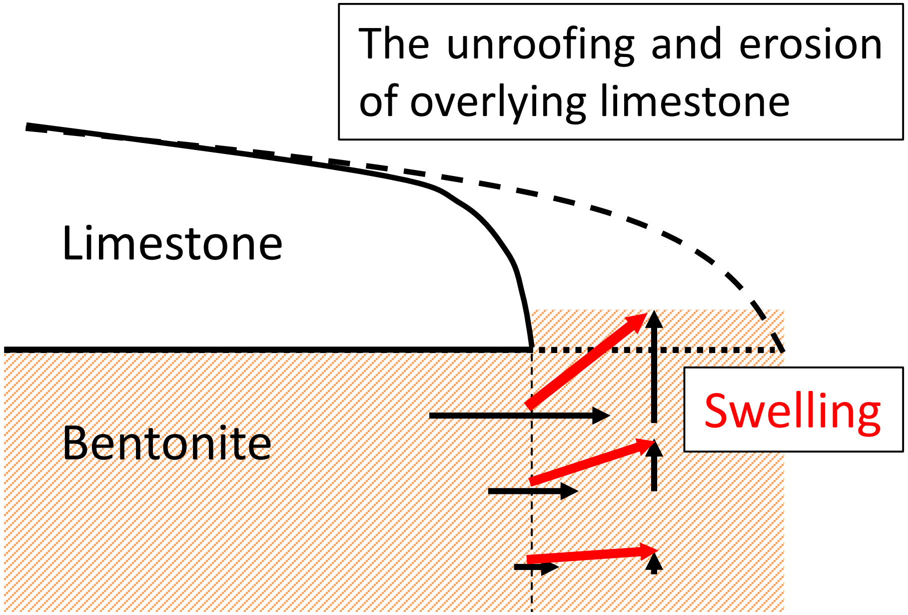
Discussion (1/2)

- ✓ It is possible for P1 and P2 samples to swell after they were collected.
  → It is assumed that bentonite had greater density (up to around 2 g/cm^3) before the samples were collected.
  (Although the samples were wrapped to prevent swelling, they swelled when they were conducted experiments a few days later after sampling.)

- ✓ It is assumed that the fractures observed at P3 were formed by vertical and lateral rheological deformation of bentonite.

- ✓ Bentonite has greater swelling pressure at higher densities.

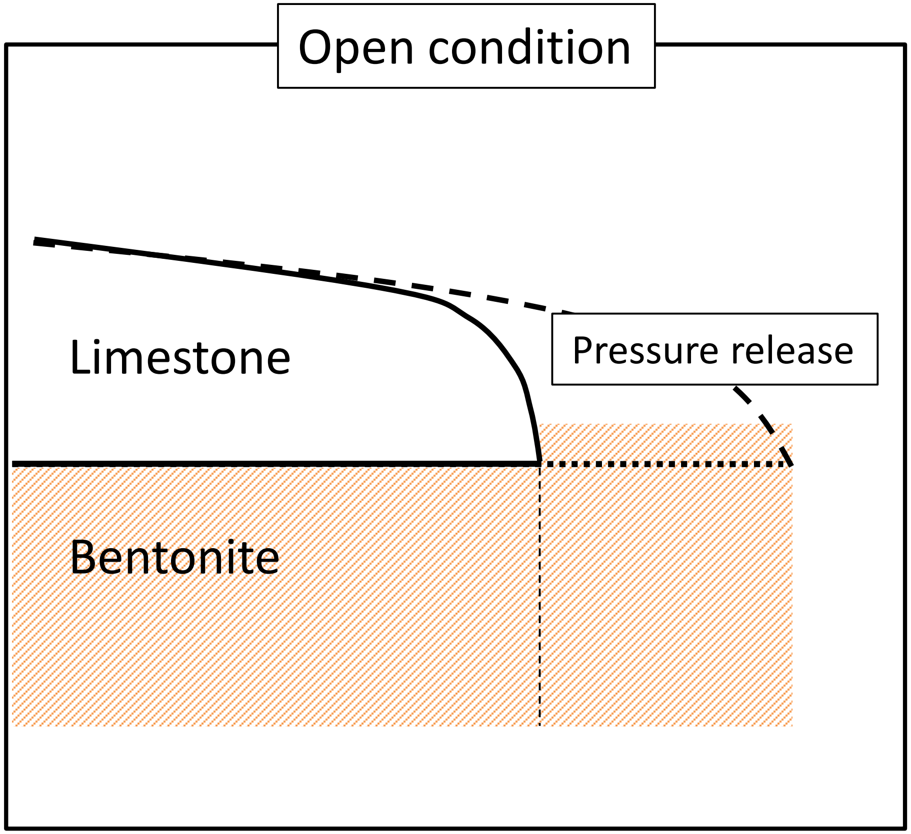
- ✓ This phenomenon was likely caused by differences in swelling due to differences in confinement pressure resulting from the unroofing and erosion of the overlying limestone.

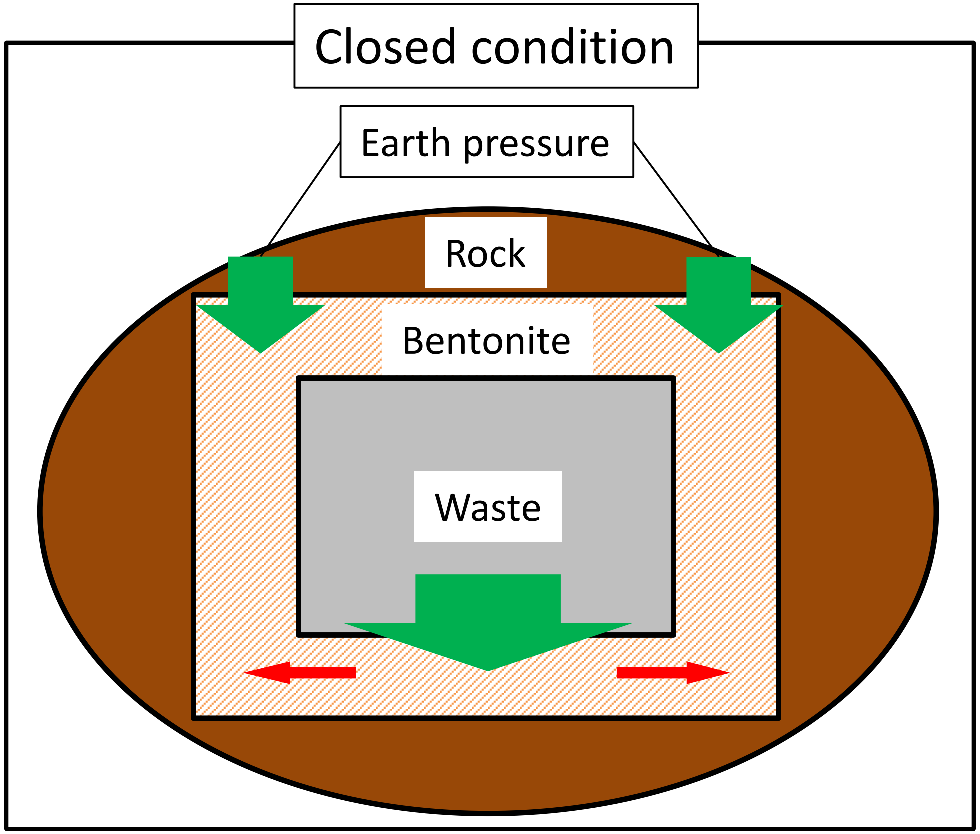


Schematic of bentonite flow

Discussion (2/2)

✓ Rheological deformation of bentonite in radioactive waste repositories is assumed to be smaller than that observed in this study since the bentonite will be placed in closed conditions.





Conclusion

- ✓ Indications of creep-induced rheological deformation of bentonite were not observed at P1 and P2.
- ✓ Rheological deformation of bentonite was likely caused by differences in swelling due to different confining pressure.
- ✓ Although it was assumed that rheological deformation of bentonite in a radioactive waste repository would be smaller than that observed in this study, it may be necessary to consider the possibility of rheological deformation of bentonite when implementing simulations.