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Strain softening of siltstones in consolidation process using a constant strain-rate loading system

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1. Introduction

There are a number of ways to view the term “strain softening.” When the softening occurred during loading of the rock material, shear bands simultaneously form in the loaded specimens. Therefore, this softening is not “strain softening”, but is recognized as a phenomenon caused by plastic hardening of the material and localization of deformation such as formation of shear bands. Debate around this was mostly in the 1980s and 1990s, but has not yet been finalized.

Considering this background, we focused on the softening behavior of soft rocks and performed consolidation tests to verify whether this phenomenon is an essential property of the ground material itself (that is, an element property) or a boundary variation of deformation localization. To investigate the mechanical behavior of siltstone, a sedimentary soft rock, we performed the one-dimensional consolidation tests (hereafter called K0-consolidation test) using a constant strain-rate loading system.

Conclusions

As a first step to elucidate consolidation yielding, which is one mechanical behavior of siltstone, consolidation tests using consolidation rings were conducted for siltstone from the Boso forearc basin, central Japan. As a result, the following conclusion was suggested:

✓Strain softening was confirmed in the consolidation process of some specimens. This softening occurred immediately before yielding, but the stress values at softening differed even in specimens from the same block sample.

✓Micro-focus X-ray CT images of the specimens were taken before and after the tests. Because no cracks were observed in the specimens after the tests, it is unlikely that the softening occurred because of local brittle failure. Therefore, softening is precipitated by softening of the framework structure of the siltstone itself; this phenomenon is defined as strain softening.

2. Material

Experimental samples used in this study are siltstones taken from the Quaternary forearc basin sediments distributed in the middle and northern part of the Boso Peninsula, central Japan (Figure 1). The sedimentary age of these formations is approximately 1-2 million years and siltstones in the forearc basin are considered as soft rocks. Consolidation tests were performed using siltstones taken from the Kiwada (BosC32), Otadai (BosC10) and Ohara (BosC26) formations in the Boso forearc basin. Porosity and grain density of each sample are ca. 40-50% and 2.55-2.65 g/cm^3, respectively.

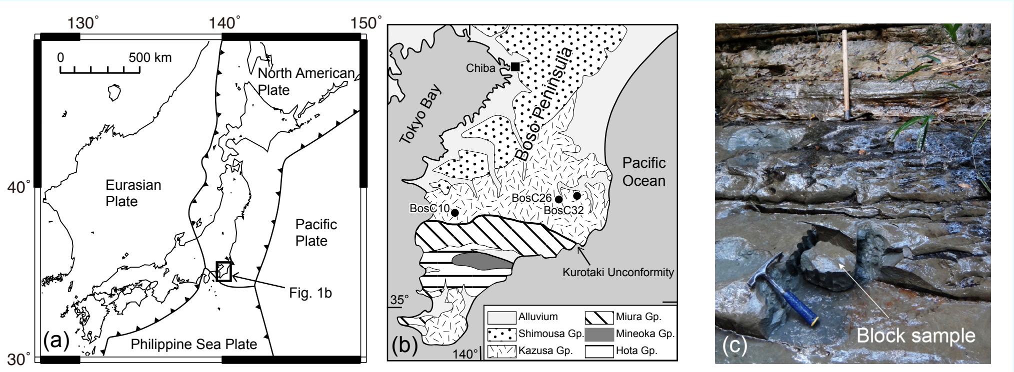
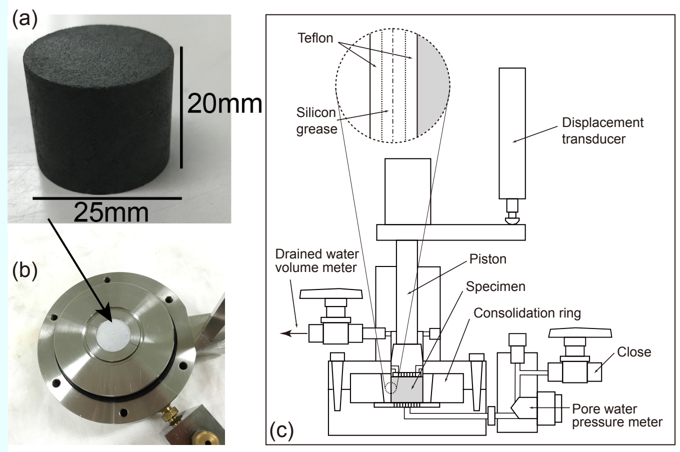


Fig. 1 (a) Plate configuration of the Japanese Islands. The rectangle indicates the area covered by Figure 1b. (b) Sampling point on the geologic map of the Boso Peninsula (modified from Kamiya et al., 2017). (c) Photograph of sampling point.

3. Method

Constant strain rate consolidation tests were performed with a uniaxial compression apparatus using a rigid stainless-steel ring in a consolidation test chamber (Figure 2). The loading speed was controlled at a constant-strain rate of 0.05%/min and the maximum loading stress was 80 MPa. The tests were conducted under drain conditions.



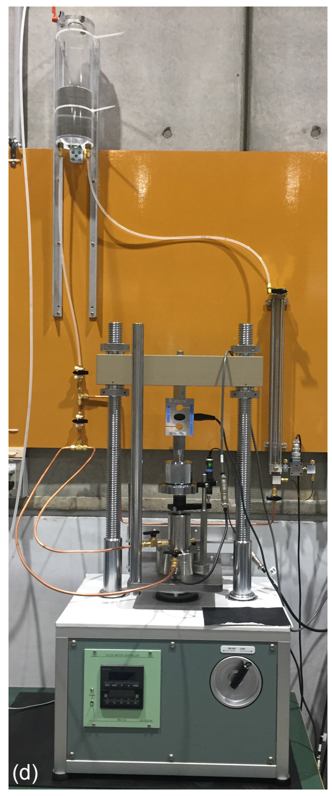


Fig. 2 Photographs and schematic illustrations of apparatus. (a) Siltstone specimen formed from block sample. (b) Consolidation ring. (c) The test chamber. (c) The compression system.

4. Results and Discussion

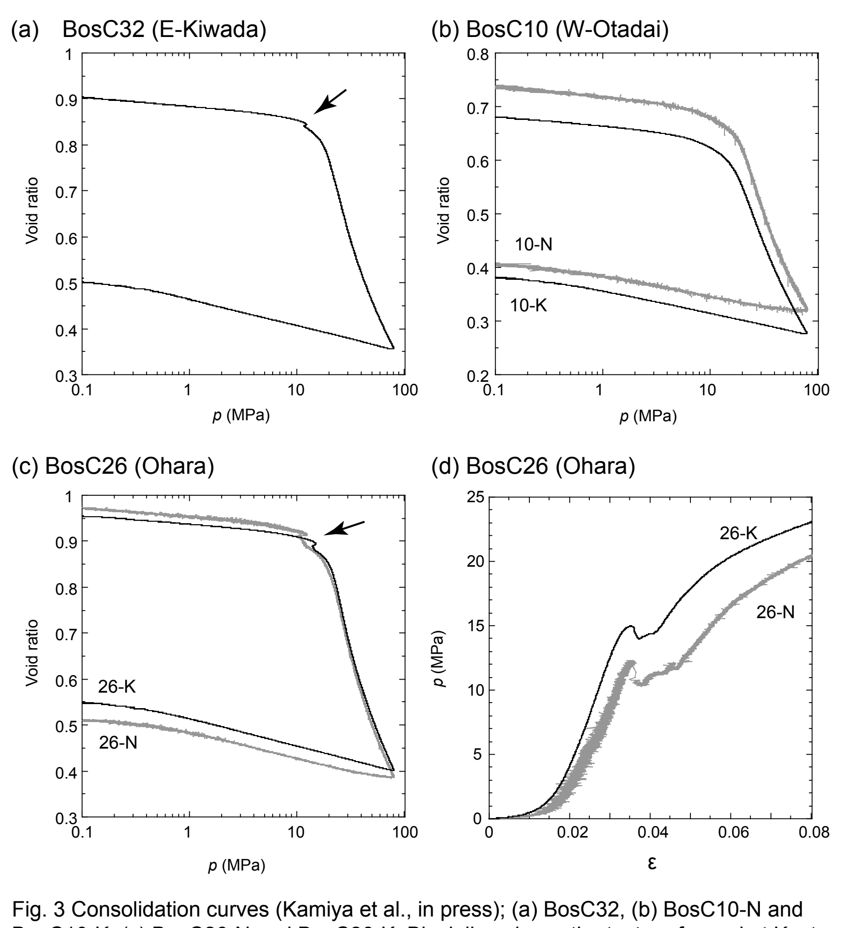


Fig. 3 Consolidation curves (Kamiya et al., in press); (a) BosC32, (b) BosC10-N and BosC10-K, (c) BosC26-N and BosC26-K. Black line shows the test performed at Kyoto University and gray line shows the test performed in Nagoya Institute of Technology. (d) Stress vs strain diagram of BosC26 focused on the strain softening.

Figure 3 shows the consolidation curves for each specimen. All specimens yielded and the consolidation curves showed over- and normal-consolidation areas. Some specimens’ stress dropped rapidly before yielding (arrows in Figure 3a and c). When the consolidation curves show a rapid stress drop, the tangents were drawn using the consolidation curves after the rapid stress drop. X-ray CT images of BosC26-N before and after the test showed that particularly large particles such as pumice and fossils were not contained in the specimen (Figure 4). Additionally, micro cracks like brittle fractures were not found in the specimen after the test. Therefore, this suggests that strain softening is not due to brittle failure in local areas but due to the softening of the framework structure of the siltstone itself.

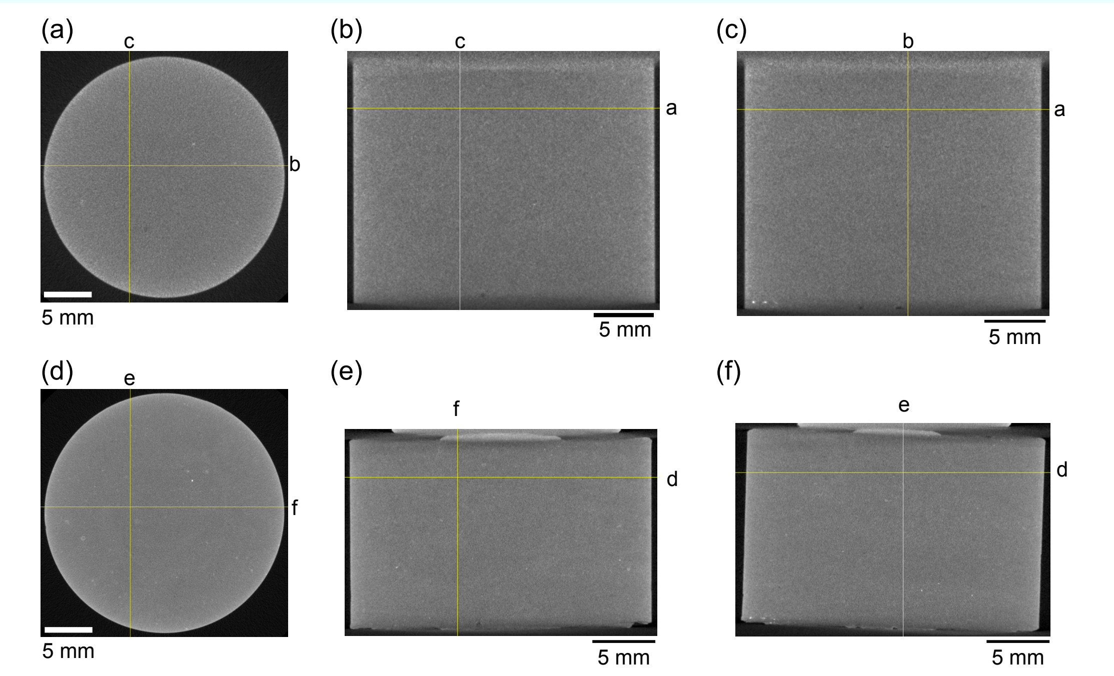


Fig. 4 X-ray CT images of BosC26-N taken before (a, b, c) and after (d, e, f) the consolidation test (Kamiya et al., in press). The compressive axis is vertical in (b) (c) (e) and (f). The lines in each image show the cutting positions.