In-situ Measurement of Dislocation-induced Anelasticity by Using a Rock Analogue

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Abstract

We developed a new experimental system with which anelasticity of a rock analogue sample (polycrystalline borneol) can be measured in situ during dislocation creep. We attached a piezo-electric actuator to a triaxial deformation apparatus, to add a small cyclic load to a large constant load. We also attached a load cell and two laser displacement meters to measure the small cyclic load and displacement accurately. Using this new system, we deformed a polycrystalline borneol sample under diffusion creep ($\sigma = 0.27$ MPa) for about 1 day, intermediate creep (σ [?] 1.1 MPa) for about 0.5 day and dislocation creep (σ [?] 2.2 MPa) for about 1 day continuously, and performed an in-situ measurement of Young's modulus and attenuation at frequencies of 2.5 and 1.0 Hz. During the first diffusion creep, Young's modulus increased, probably due to the improved contact between the sample and the piston, and reached a constant value. Although the modulus did not change during the second intermediate creep, it gradually decreased during the third dislocation creep. The final modulus reduction was about 20%. The present result supports our previous result obtained from the anelasticity measurement of a pre-deformed sample (Sasaki et al., 2017, AGU fall meeting; Sasaki et al., 2019, submitted to JGR). In the previous study, we showed that detailed form of the dislocation creep curves can be explained well by considering a gradual increase in dislocation density during the dislocation creep. Also, reduction of Young's modulus by about 10% was observed after the dislocation creep under the similar condition to this study. The gradual decrease in Young's modulus observed in this present study provides a supporting evidence for these previous results. Frequency dependence of the dislocation-induced anelasticity obtained from our previous study is a peak at much higher frequency than the grain boundary-induced anelasticity (Sasaki et al., 2017, AGU fall meeting; Sasaki et al., 2019, submitted to JGR). In contrast, dislocation-induced anelasticity obtained from single crystal forsterite or polycrystalline olivine is a broad absorption band (Guéguen et al., 1989; Farla et al., 2012). It is important to clarify the reason for this discrepancy.

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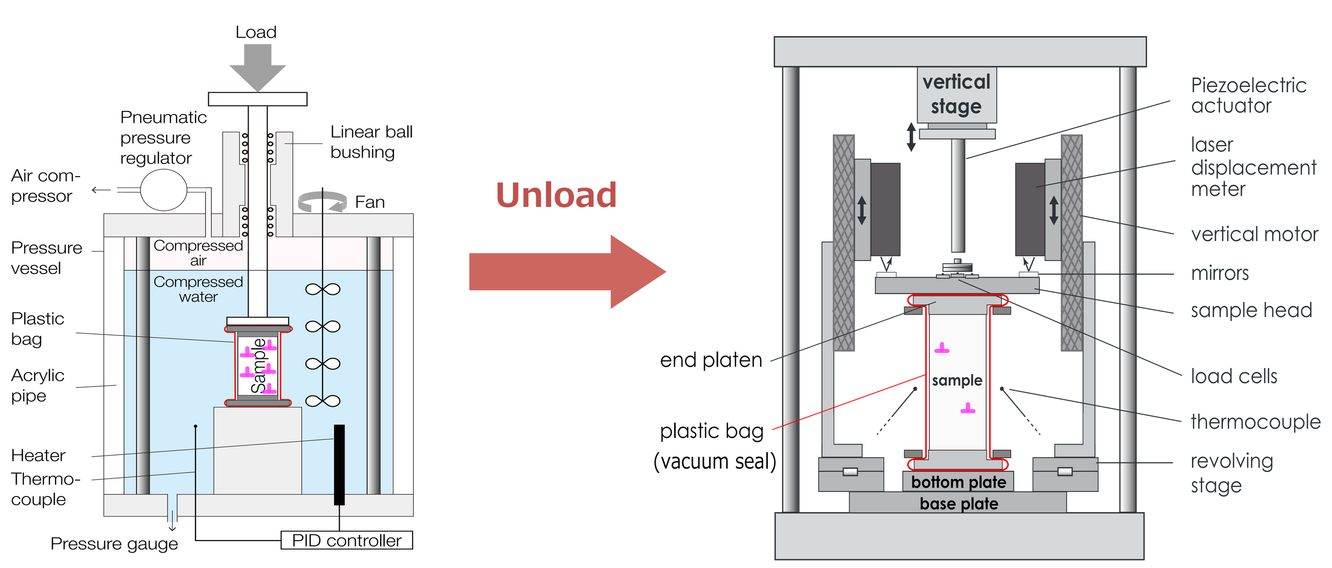
Key points

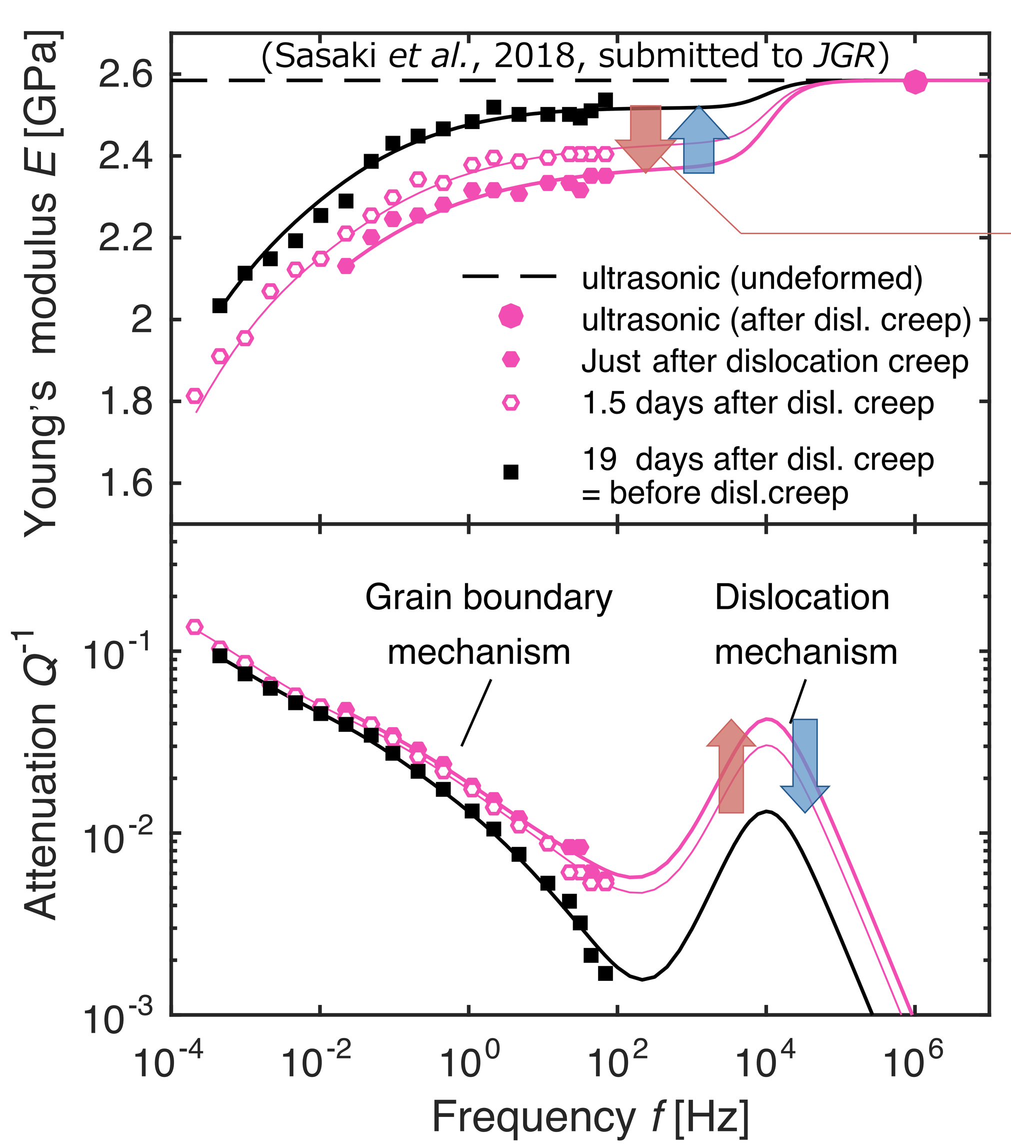
- A new forced oscillation apparatus was developed to measure anelasticity during dislocation creep.
- Young's modulus of a rock analogue sample decreased gradually during dislocation creep.
- Correlation between anelasticity and dislocation density was experimentally confirmed.

1. Motivation

Our previous study



Significant **reduction** of Young's modulus by dislocations and its **recovery** by dislocation annihilation



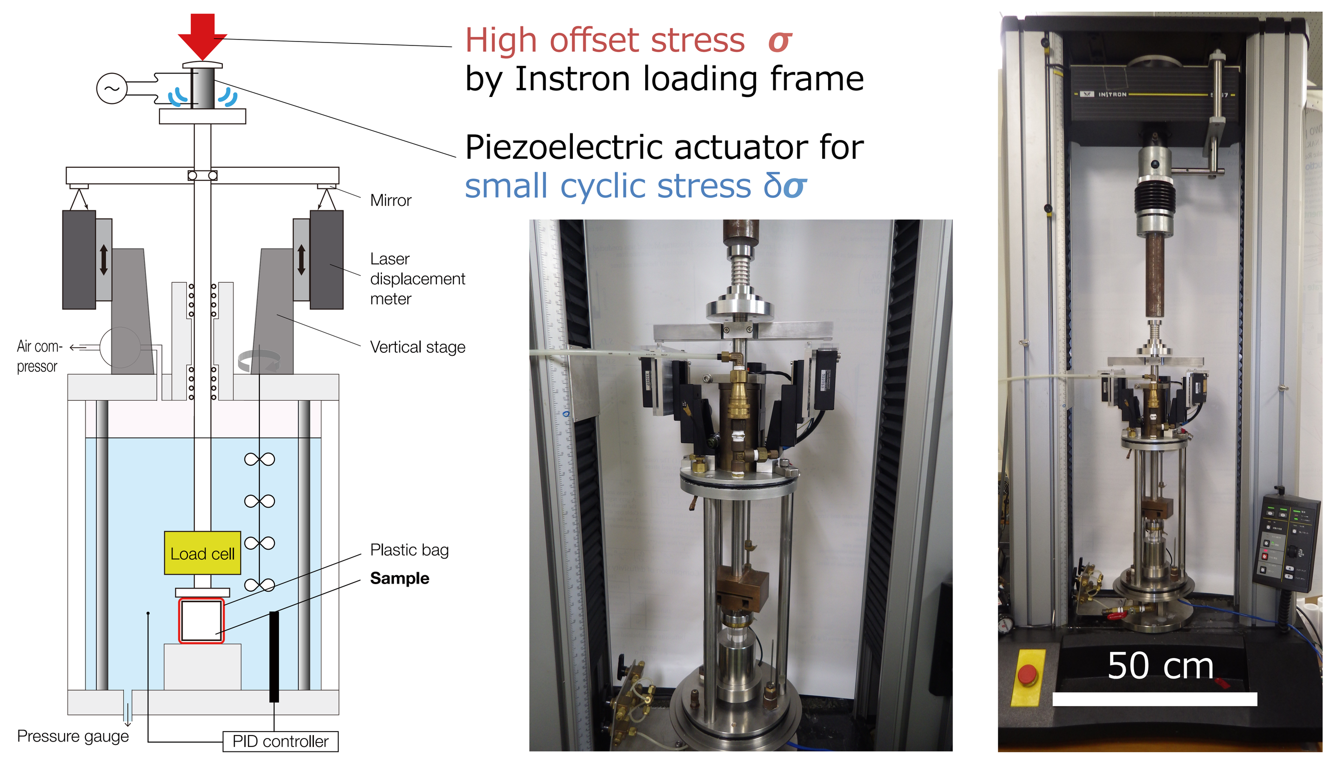
Problem:

Dislocation recovery during anelasticity measurements disturbed detailed testing (e.g., nonlinearity, *T*-dependence, etc.)

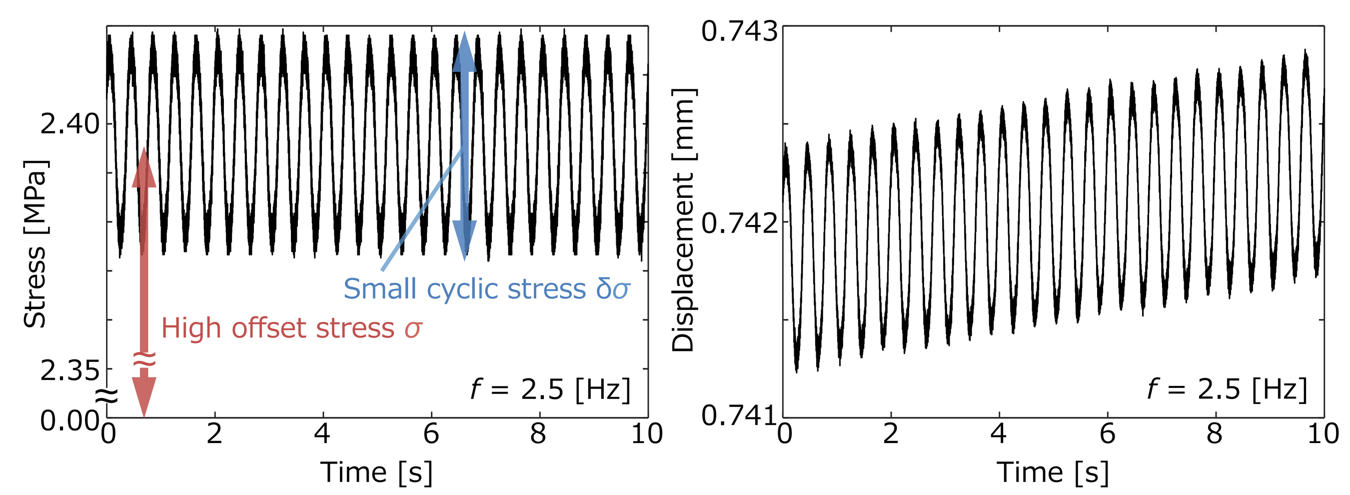
This study

In-situ measurements of anelasticity during dislocation creep.

2. *In-situ* forced oscillation apparatus



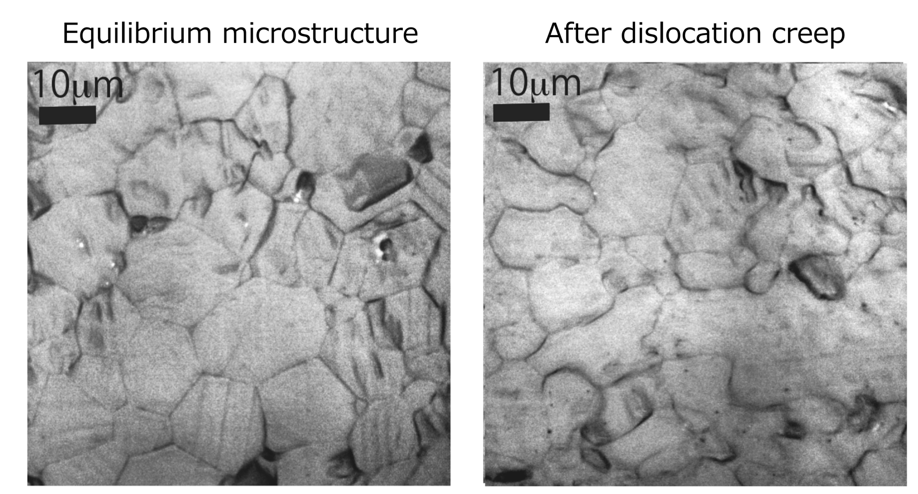
Example of stress and strain measurements in oscillation test (creep ③)



3. Rock analog sample: Borneol polycrystal

Sample fabrication

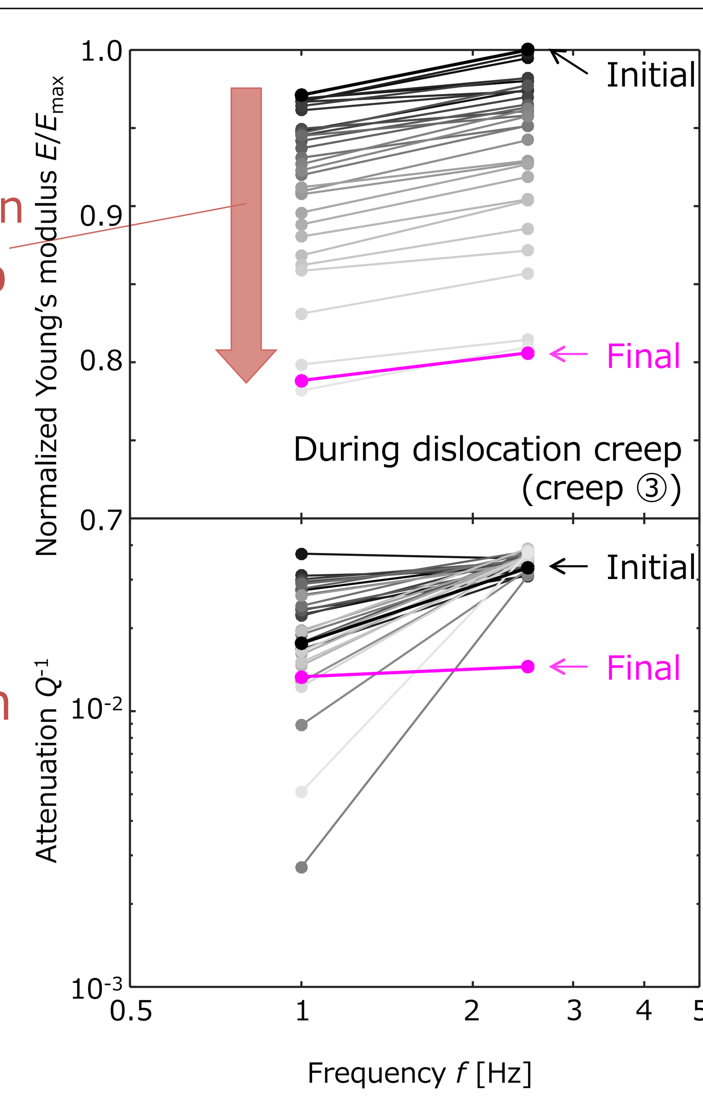
Ball-milling
(-40˚C, 6 days)
↓
Press
(20˚C, 3–4 days, P_c = 14 MPa)
↓
Grain growth
(60˚C, 1 week, P_c = 3 MPa)



Total modulus reduction
ΔE/E ~ 10–20%
(both at Δσ ≃ 2 MPa)

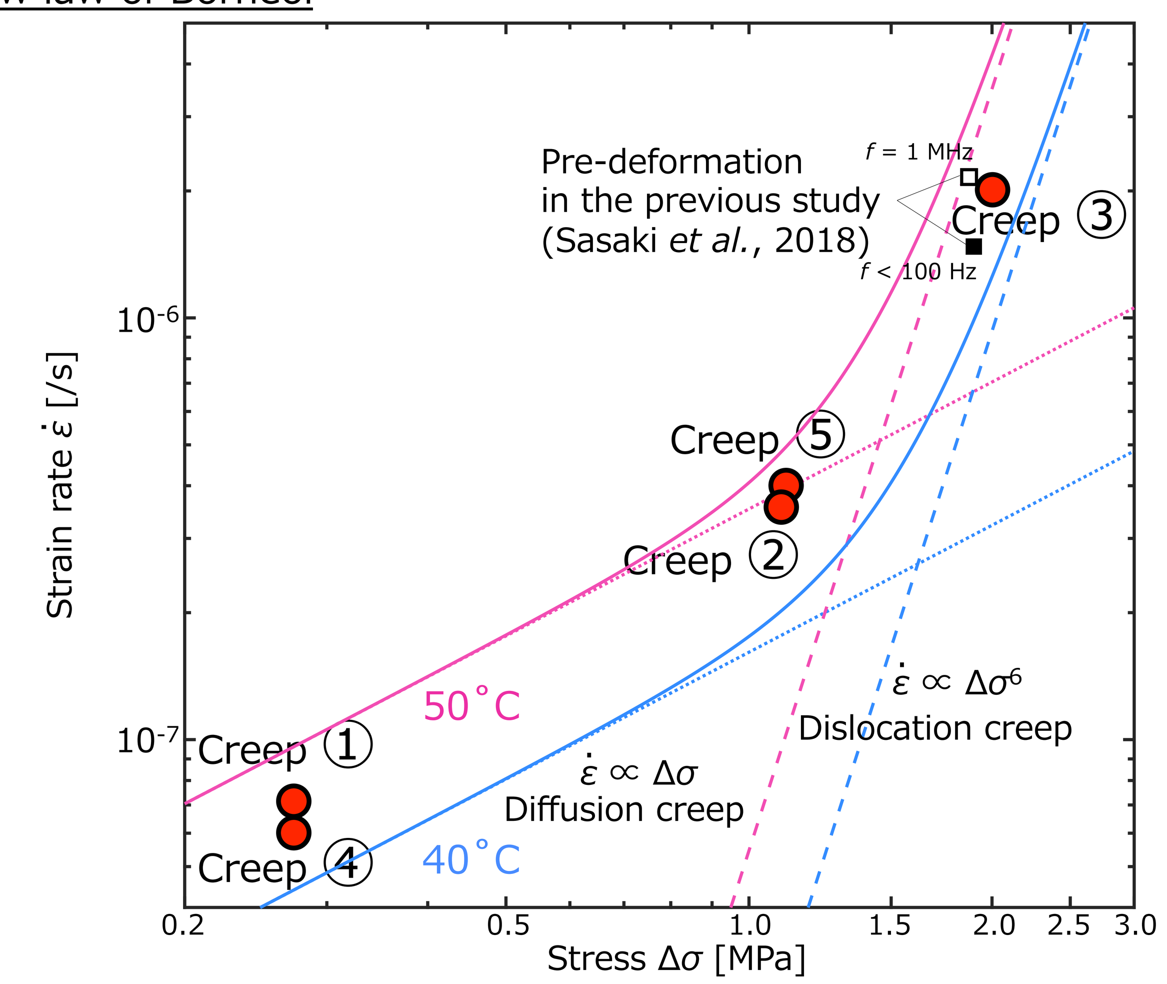
Thus,

Significant reduction of *E* by dislocations captured in our previous study truly occurred.



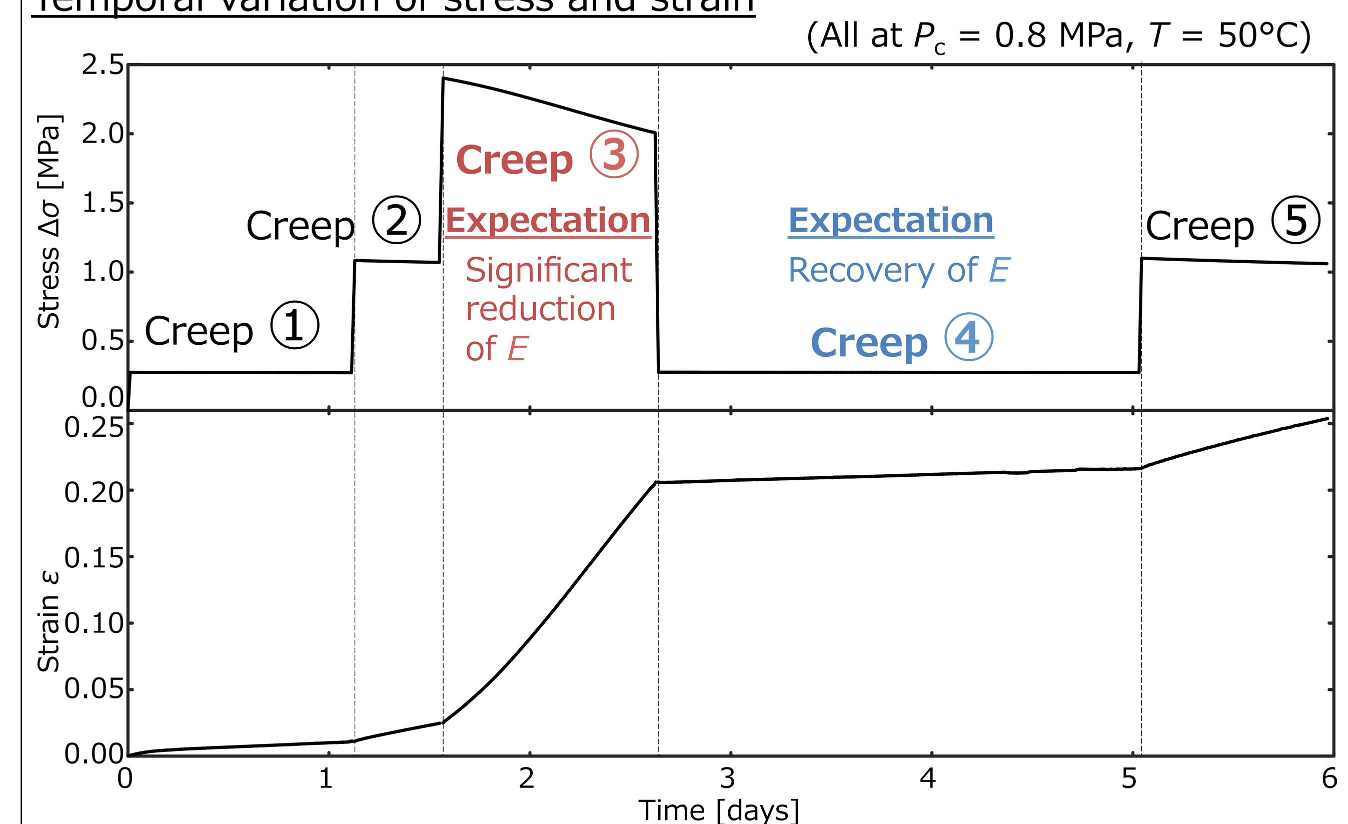
4. Anelasticity during dislocation creep

Flow law of Borneol

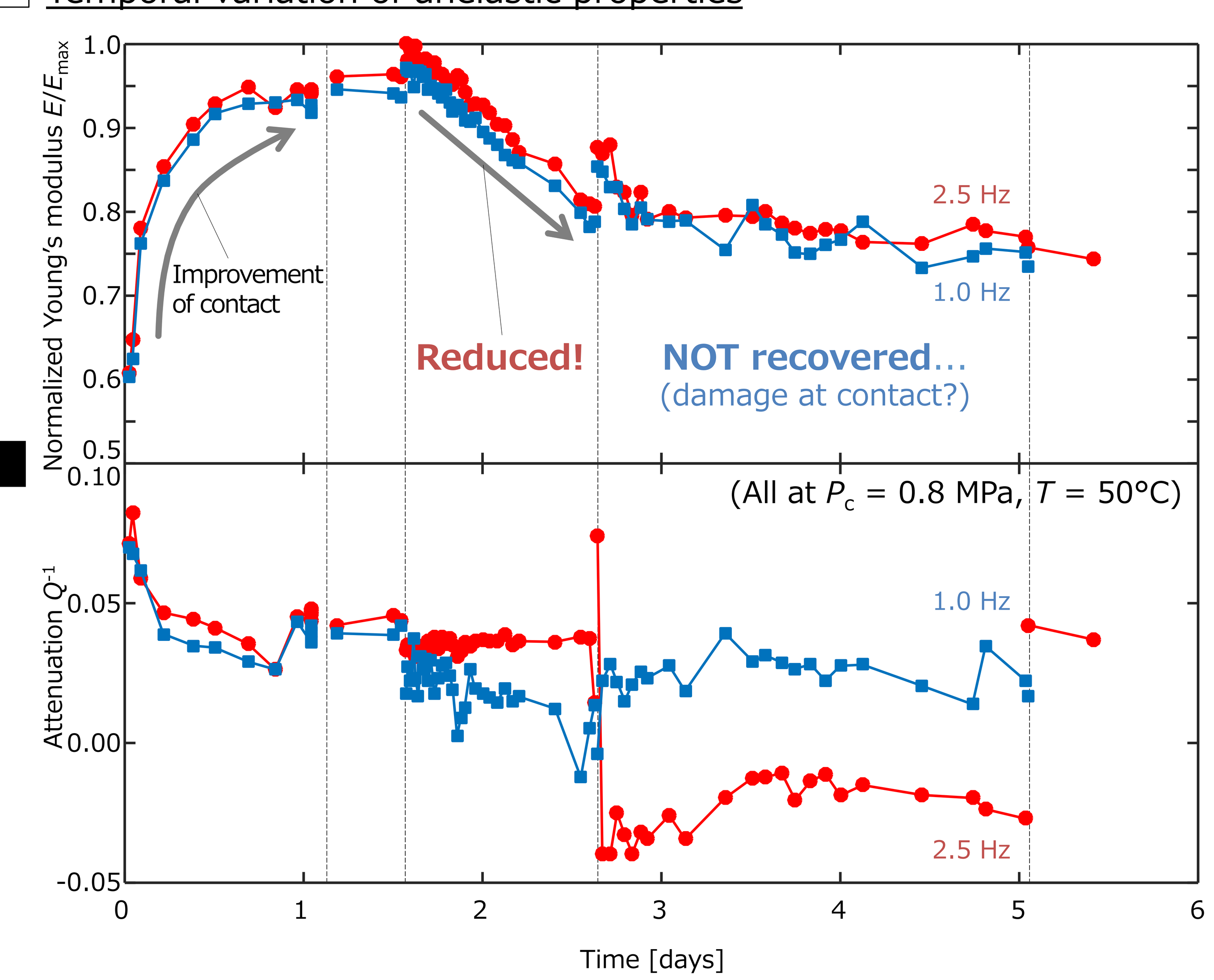


Temporal variation of stress and strain

(All at P_c = 0.8 MPa, T = 50°C)



Temporal variation of anelastic properties



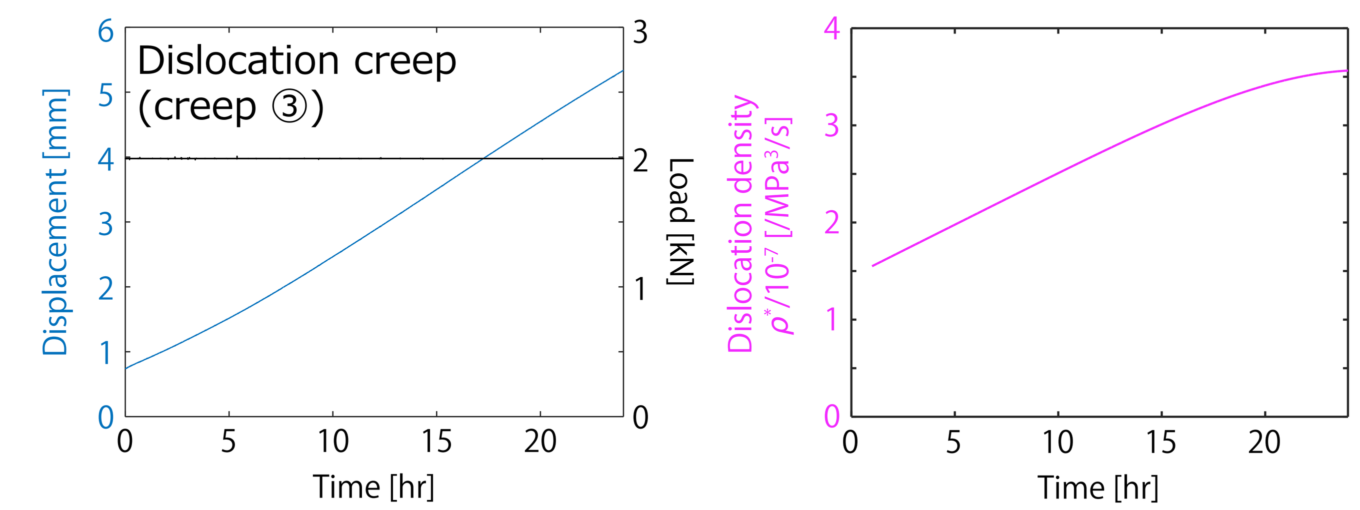
5. Dislocation density variation

Estimation of dislocation density from creep curve

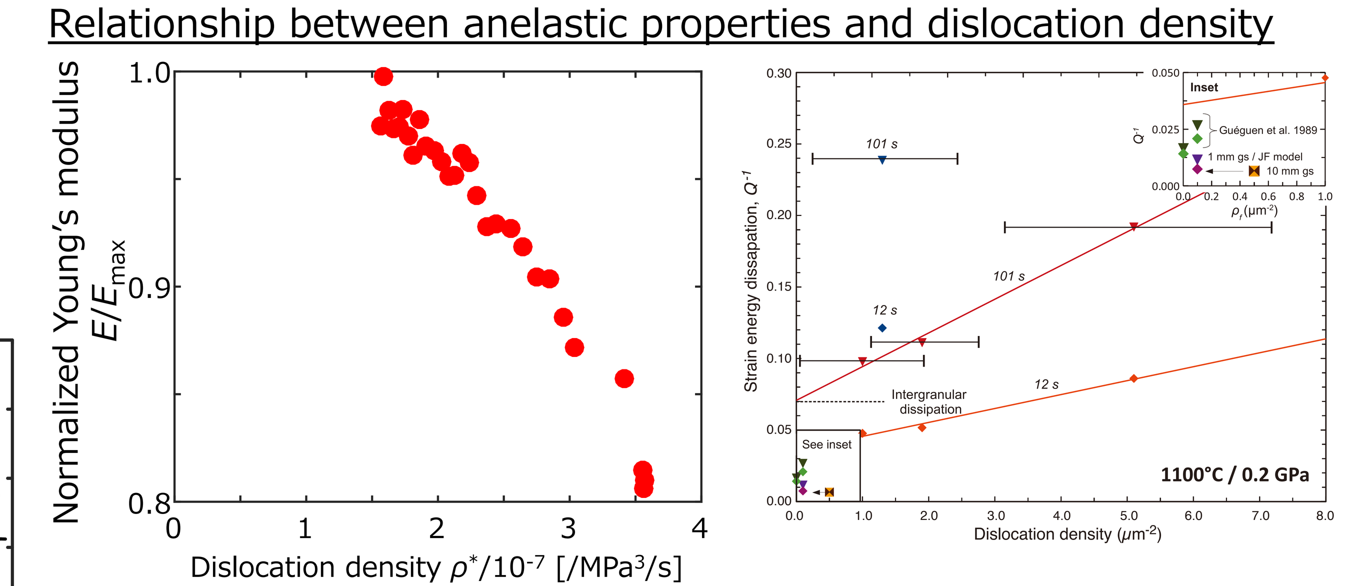
Orowan's equation:
$$\dot{\varepsilon}^{dis} = \rho v b$$
Dislocation velocity is assumed as:
$$v = C_1 \Delta\sigma^{n_1}$$
$$\Rightarrow \rho^*(t) = C_1 b \rho = \frac{\dot{\varepsilon}^{dis}(t)}{\Delta\sigma(t)^{n_1}}$$

$\rho^*(t)$ can be calculated from $\sigma(t)$ and $\dot{\varepsilon}(t)$ data.
n_1 was estimated as 3 from our previous study. (Sasaki *et al.*, 2018)

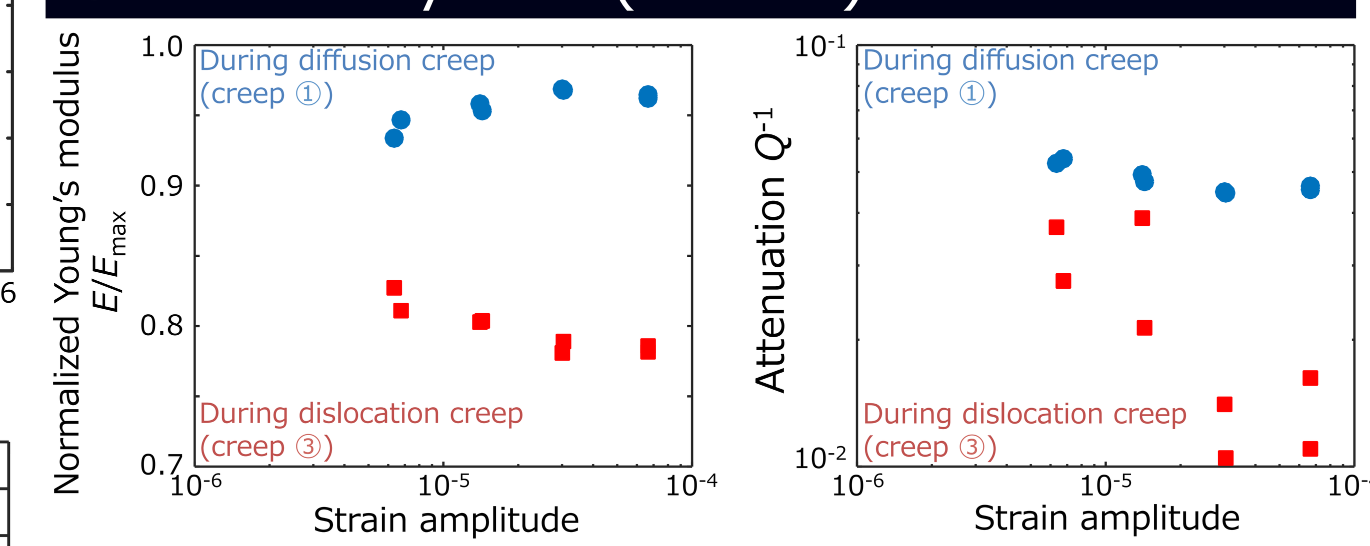
ρ Dislocation density; b Burger's vector length; C_1, n_1 Constants



Relationship between anelastic properties and dislocation density



6. Linearity test (2.5 Hz)



During diffusion creep (creep ①): Linear anelasticity (Takei et al., 2014)

During dislocation creep (creep ③): Nonlinear anelasticity suggested by Young's modulus data (Attenuation data at 2.5 Hz are not related to dislocations.)

7. Open questions

- WHY are relaxation spectra due to dislocations different between olivine and organic rock analogue?
  → More experimental data are needed.
- WHETHER is dislocation-induced anelasticity linear or nonlinear?
  → Accuracy of our *E* and Q^{-1} data should be improved. (e.g., correction for apparatus deformation)

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References

[1] Sasaki *et al.*, 2018, submitted to *JGR*; [2] Yamauchi & Takei, 2016, *JGR*; [3] Guéguen *et al.*, 1989, *PEPI*; [4] Farla *et al.*, 2012, *Science*; [5] Takei *et al.*, 2014, *JGR*