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

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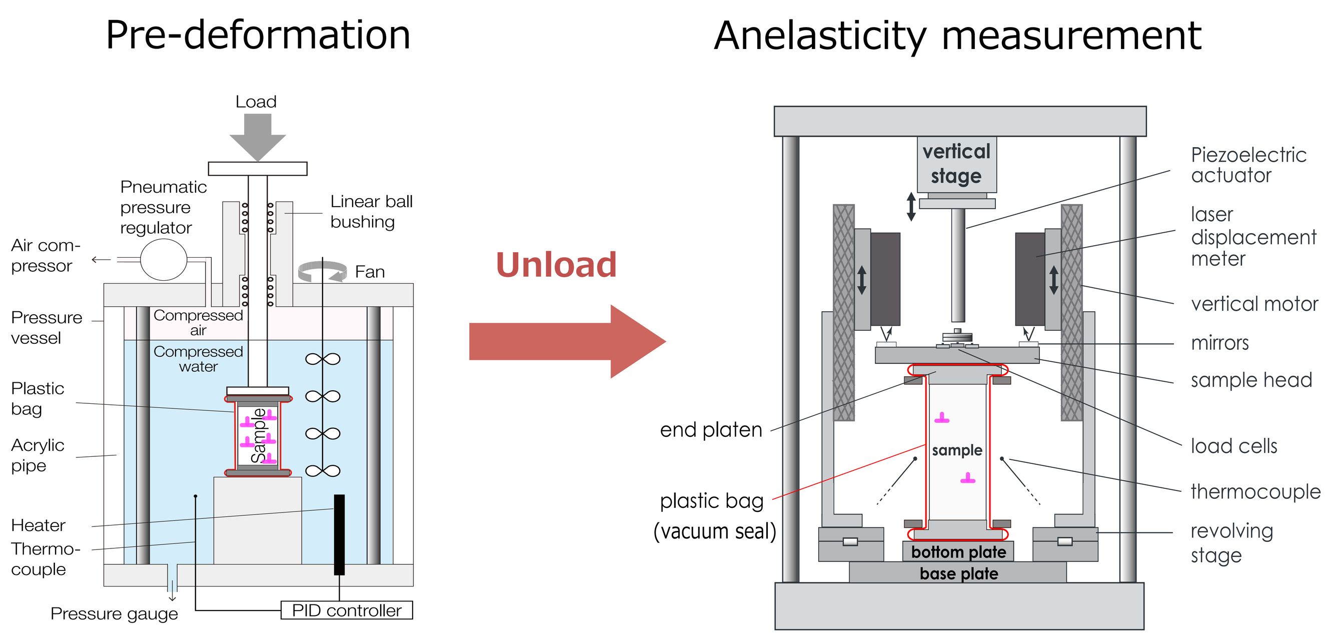
Key points

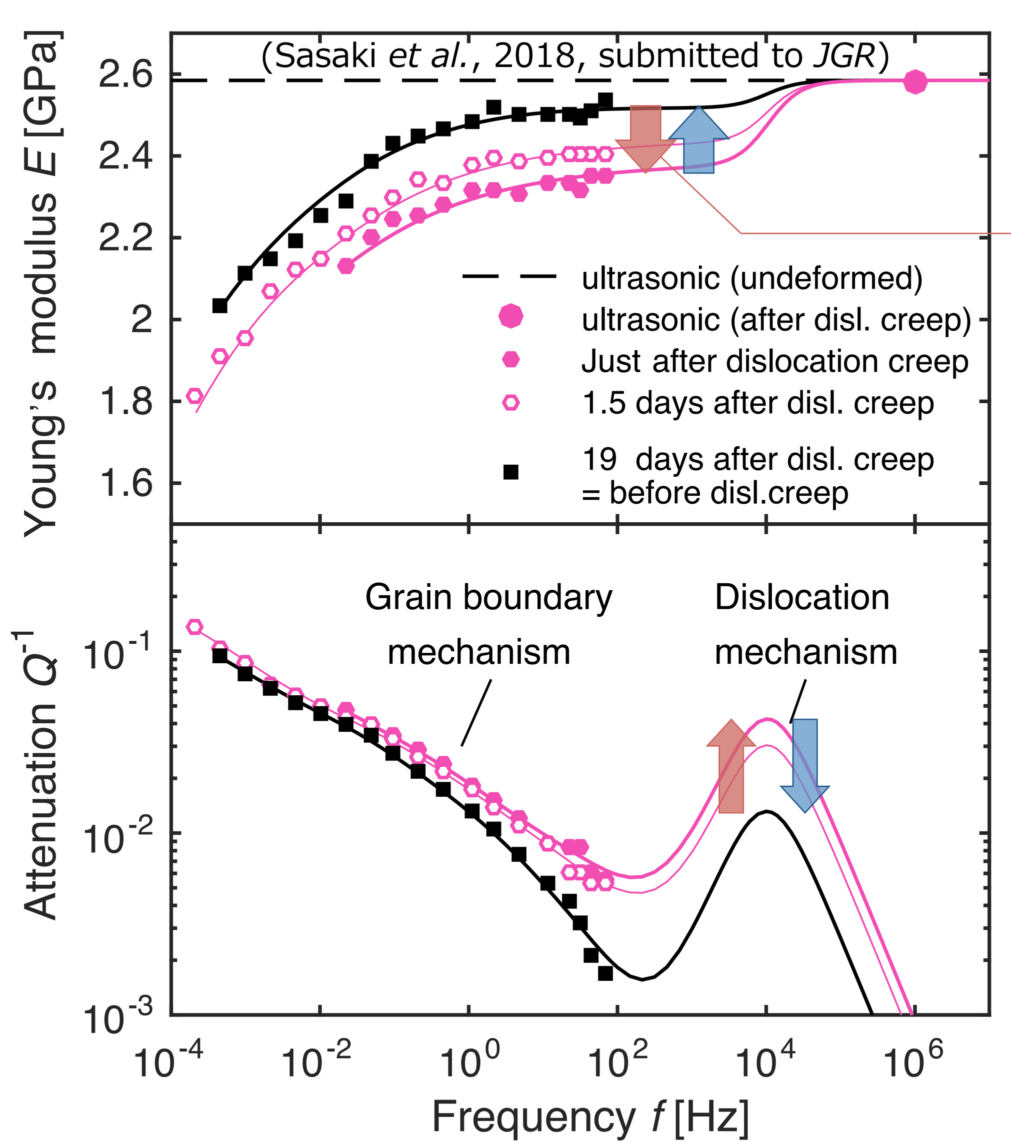
- A new forced oscillation apparatus was developed to measure anelasticity during dislocation creep.
- Young's modulus of a rock analogue sample decreased gradually during dislocation creep.
- Correlation between anelasticity and dislocation density was experimentally confirmed.

1. Motivation

Our previous study



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



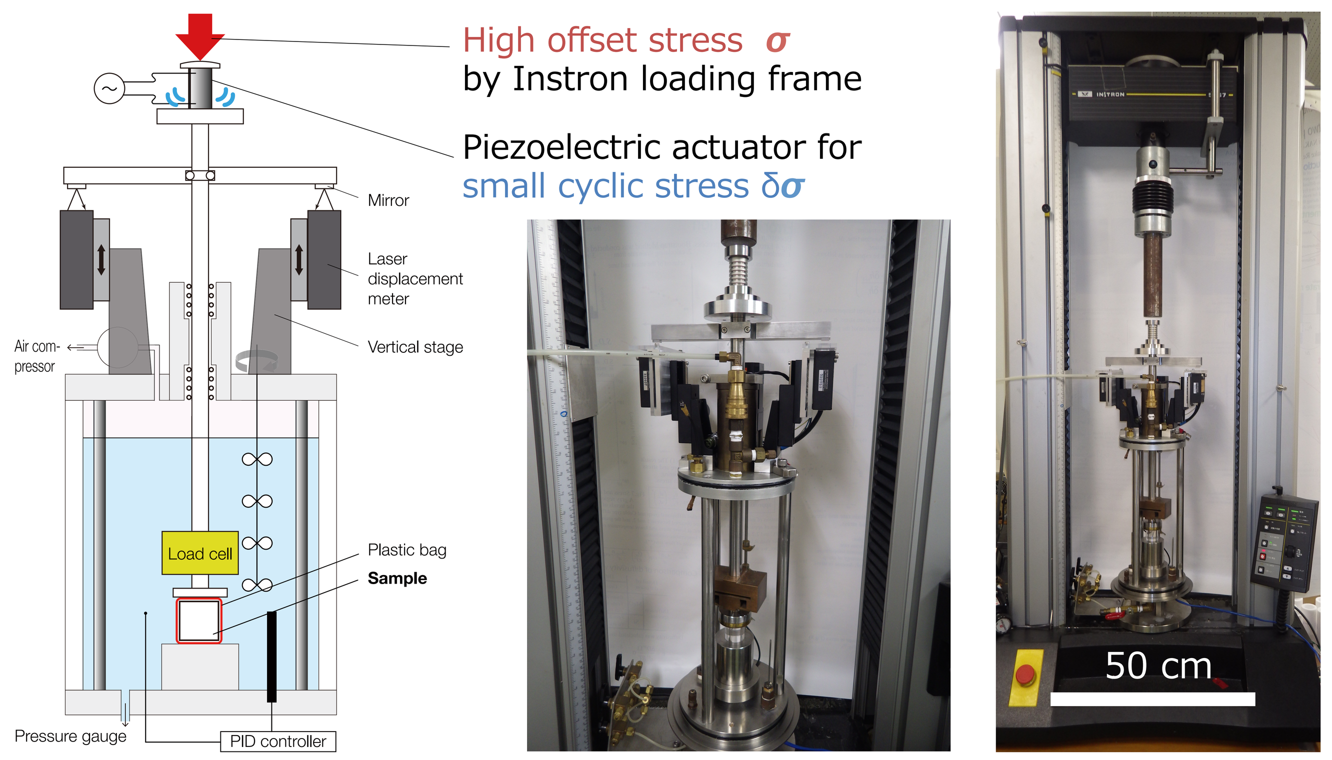
Problem:

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

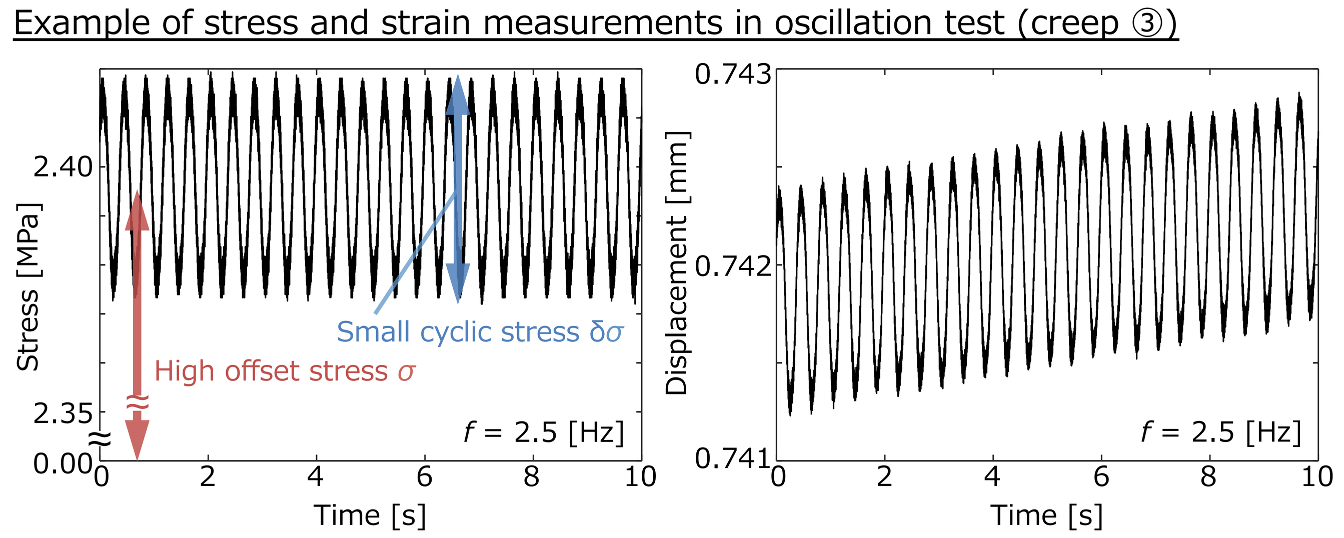
This study

In-situ measurements of anelasticity during dislocation creep.

2. *In-situ* forced oscillation apparatus



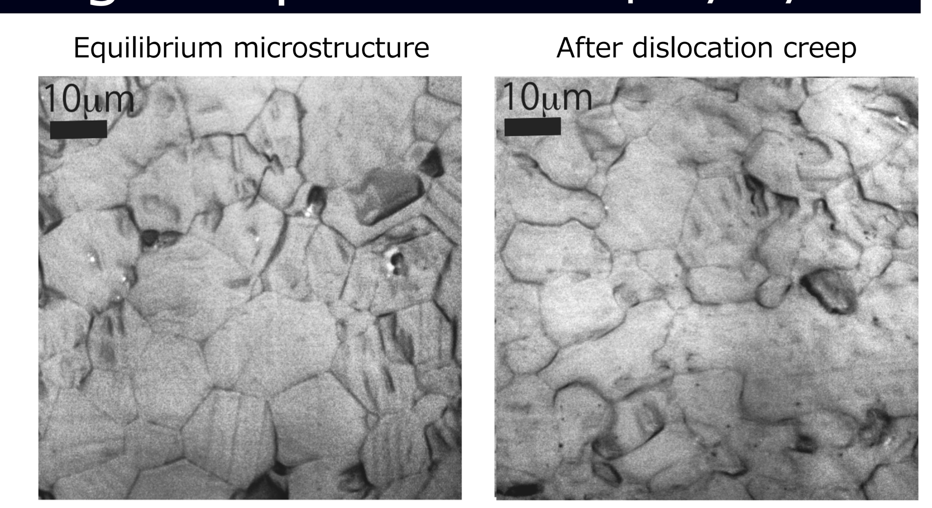
Example of stress and strain measurements in oscillation test (creep ③)



3. Rock analog sample: Borneol polycrystal

Sample fabrication

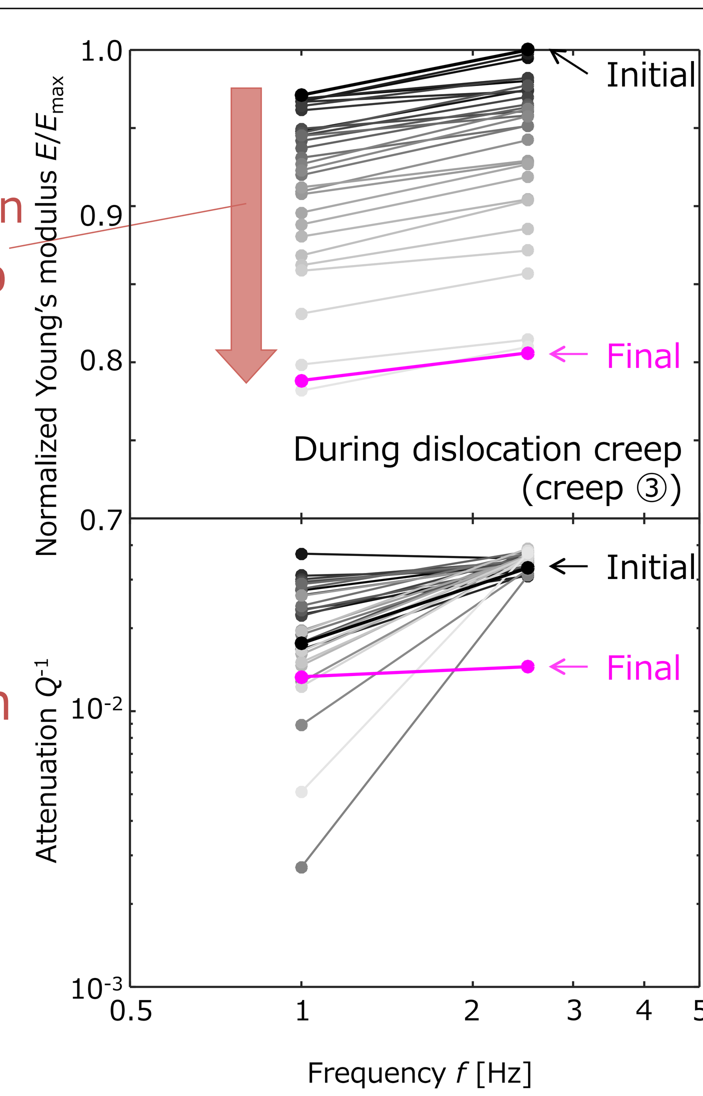
Ball-milling
(-40°C, 6 days)
↓
Press
(20°C, 3–4 days, P_c = 14 MPa)
↓
Grain growth
(60°C, 1 week, P_c = 3 MPa)



Total modulus reduction
$\Delta E/E \sim 10$–20%
(both at $\Delta\sigma \simeq 2$ MPa)

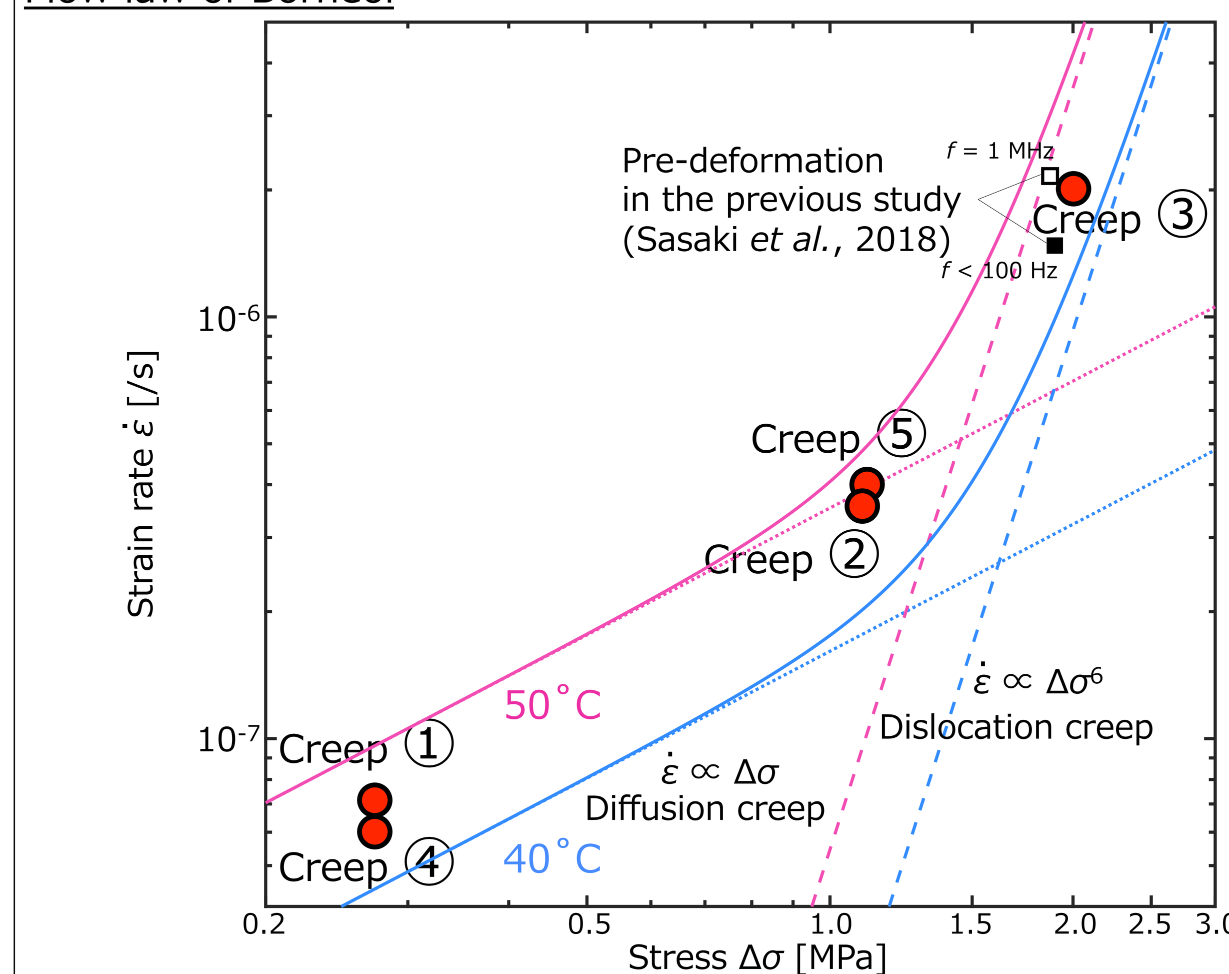
Thus,

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



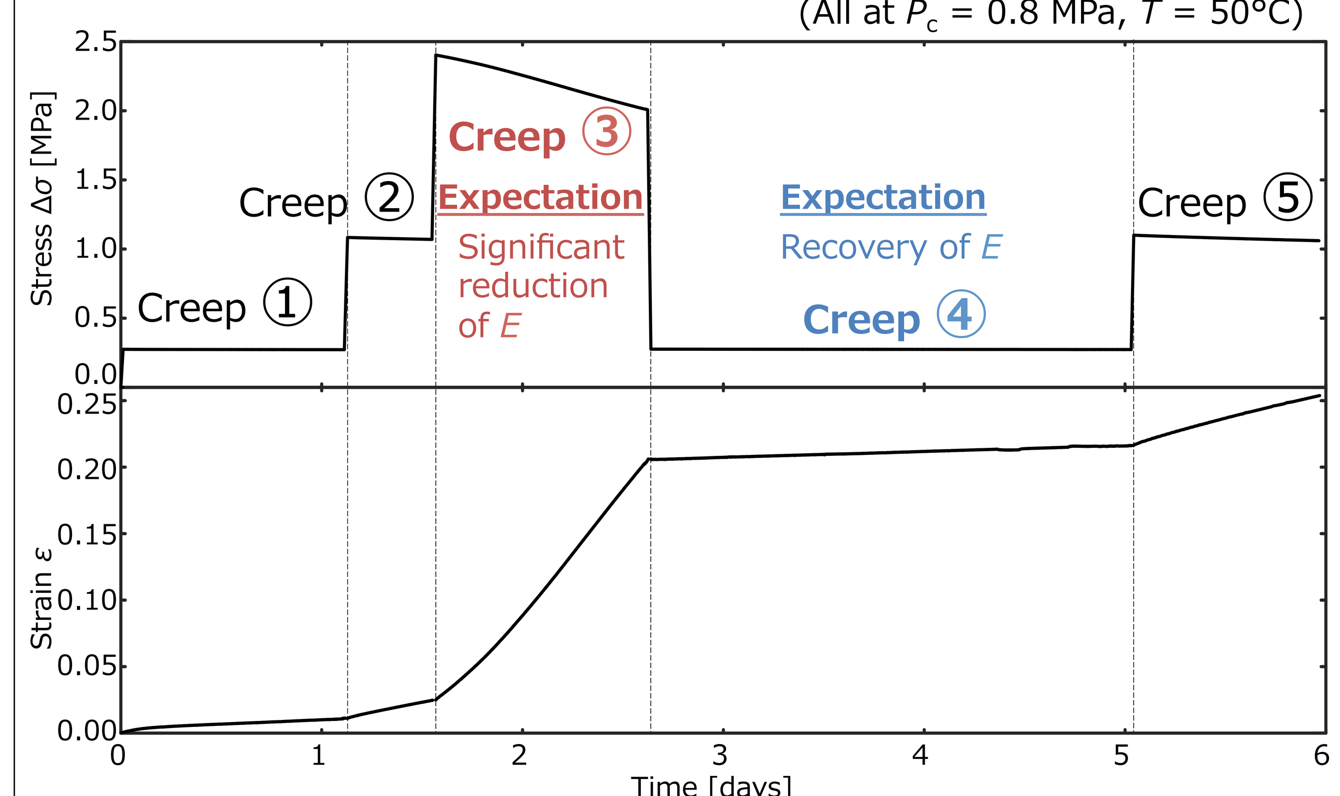
4. Anelasticity during dislocation creep

Flow law of Borneol

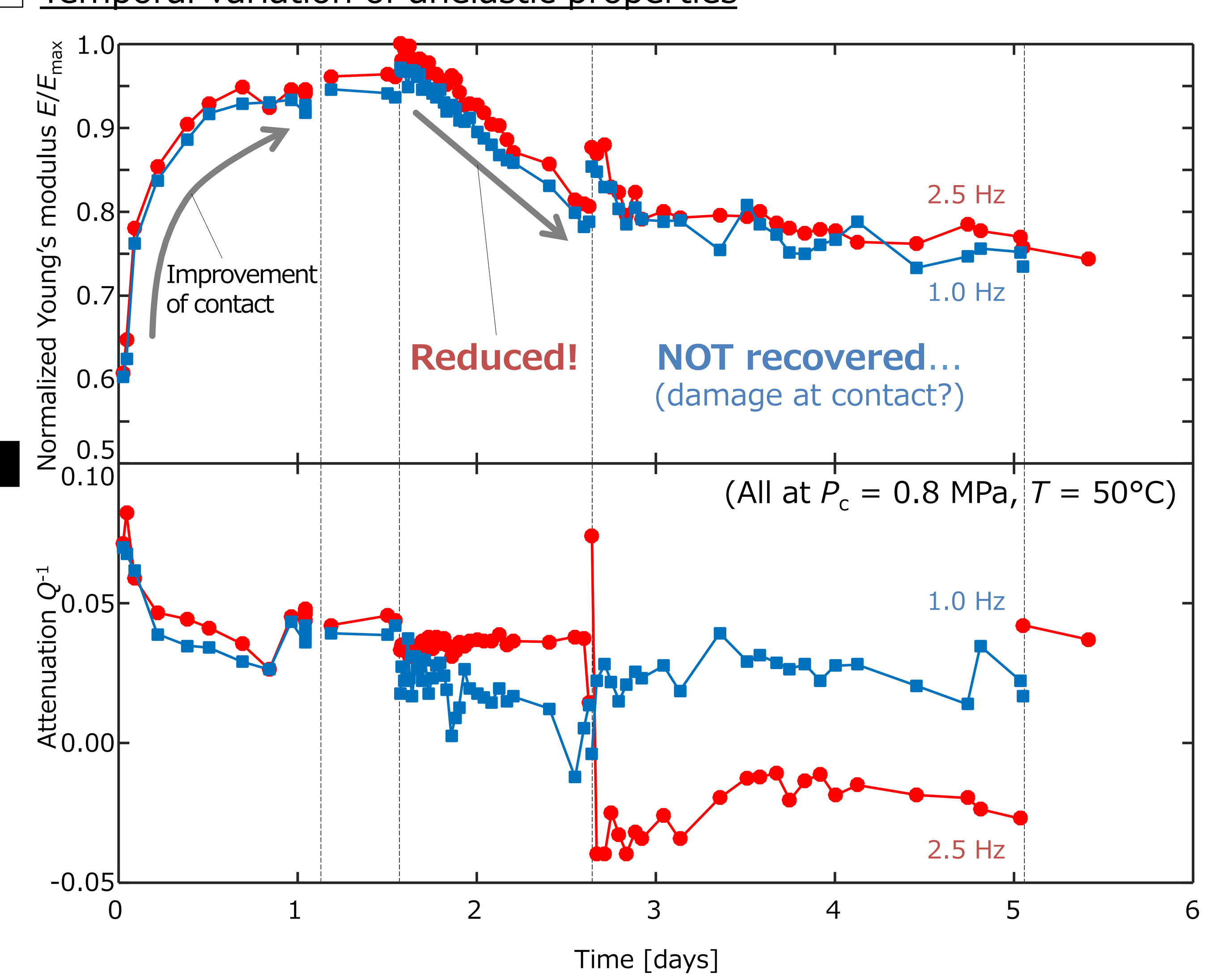


Temporal variation of stress and strain

(All at P_c = 0.8 MPa, T = 50°C)



Temporal variation of anelastic properties



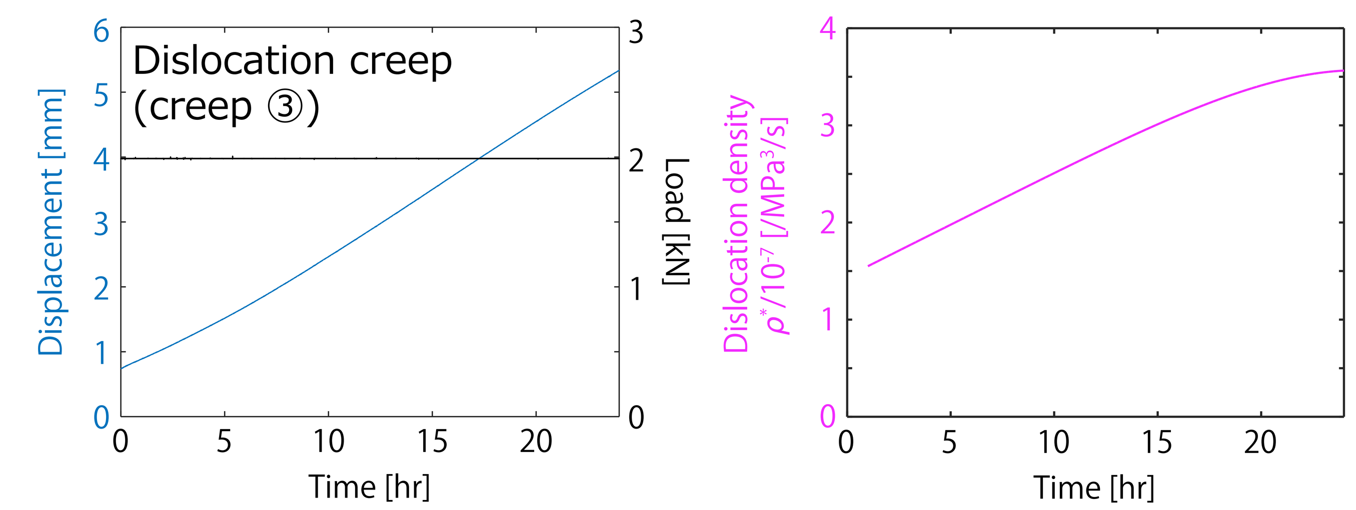
5. Dislocation density variation

Estimation of dislocation density from creep curve

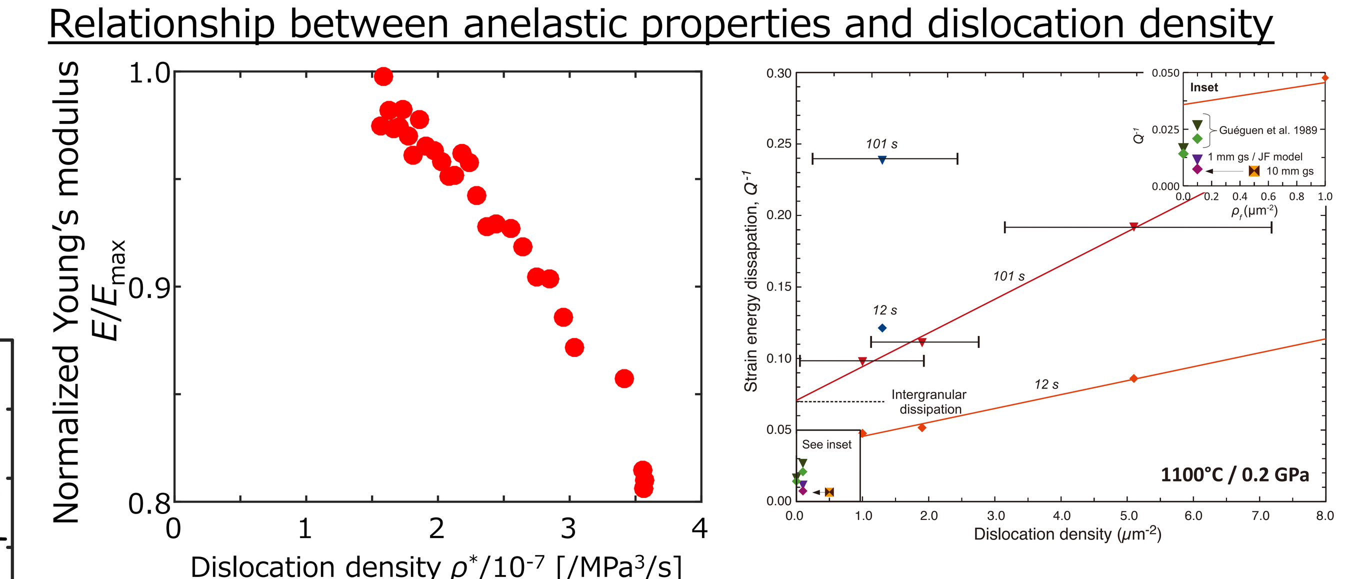
Orowan's equation:
$$\dot{\varepsilon}^{dis} = \rho v b$$
Dislocation velocity is assumed as:
$$v = C_1 \Delta\sigma^{n_1}$$
$$\Rightarrow \rho^*(t) = C_1 b \rho = \frac{\dot{\varepsilon}^{dis}(t)}{\Delta\sigma(t)^{n_1}}$$

$\rho^*(t)$ 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

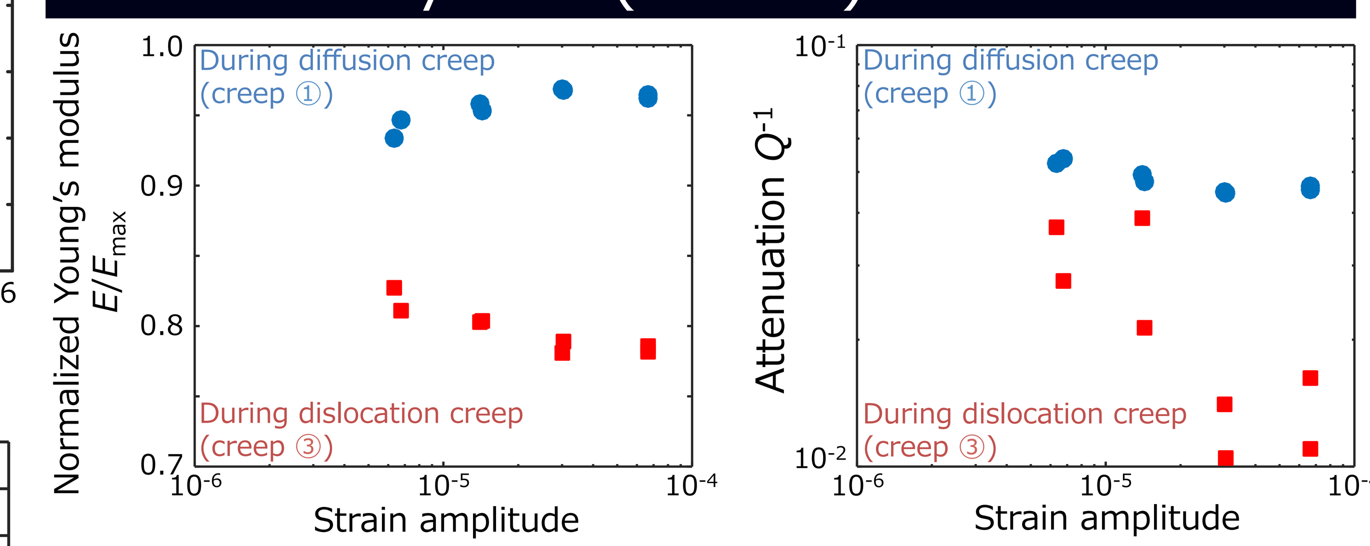


Relationship between anelastic properties and dislocation density



This study Farla *et al.* (2012)

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)

Acknowledgements

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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*