Effect of dislocation on rock anelasticity: Analogue experiment using organic polycrystals

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Seismic wave velocity and attenuation are affected by the elastic and anelastic properties of rocks. Therefore, detailed mechanism of elasticity and anelasticity has to be clarified in order to estimate the state of the Earth's interior from seismic observations. Two major mechanisms of rock anelasticity have been proposed: grain boundary sliding and dislocation motion. Grain boundary and dislocation (plane and line defects, respectively) in a rock slide and dissipate the energy, causing dispersion and attenuation of the seismic wave. Due to the lack of experimental data of anelasticity of rock with dislocations (only [1] and [2]), it is difficult to elucidate the mechanism of dislocation damping. In this study, dislocation-induced anelasticity was measured accurately over a broad frequency range by using a rock analogue.

In this study, polycrystalline borneol [3] was used as a rock analogue. Effect of grain boundary sliding on the anelasticity of this material have been clarified well [4, 5, 6], making it possible to investigate the effect of dislocation by the difference from the grain boundary effect. Following three experiments were performed.

First, a deformation mechanism map of borneol was investigated in order to clarify the temperature and stress condition for the dislocation creep. Flow law (relationship between deviatoric stress σ and strain rate $d\varepsilon/dt$) of borneol was determined at 40℃ and 50℃ by uniaxial compression tests under a confinig pressure of 0.8 MPa. As a result, a transition from diffusion creep to dislocation creep ($d\varepsilon/dt \propto \sigma^5$) was observed at about σ = 1 MPa at 50℃. Microstructure of the sample deformed under the power law regime also implied an occurrence of dislocation-induced grain boundary migration.

Second, by using a sample deformed in the dislocation creep regime, effect of dislocatioins on anelasticity was investigated at 10^{-4}–10^{2} Hz. Three creep tests with σ = 0.27 MPa (diffusion creep regime), σ = 1.3 MPa (transitional regime) and σ = 1.9 MPa (dislocation creep regime) were conducted on the same sample in the increasing order, and anelasticity of this sample after each creep test was measured by using a forced oscillation apparatus [5]. Young's modulus E and attenuation Q^{-1} (anelasticity) were measured at frequencies ranging from 10^{-4} to 10^{2} Hz. The result shows that as σ increased, E decreased and Q^{-1} increased. These changes, however, almost fully recovered within two weeks. Therefore, it is considered that anelasticity was enhanced due to the dislocations introduced during the dislocation creep and was recovered due to dislocation recovery (annihilation) during the forced oscillation tests.

Third, in oreder to constrain the frequency range of the dislocation-induced anelastic relaxations, Young's modulus E at 10^{6} Hz was measured before and after the dislocation creep (σ = 1.9 MPa), by the ultrasonic method. The obtained Young's modulus at 10^{6} Hz was not changed by dislocations, showing that dislocation-induced anelasticity is localized to 10^{2}–10^{6} Hz. This frequency range is higher than grain-boundary-induced anelasticity. Total relaxation strength of dislocation-induced anelasticity obtained in this study was ≈0.1E.

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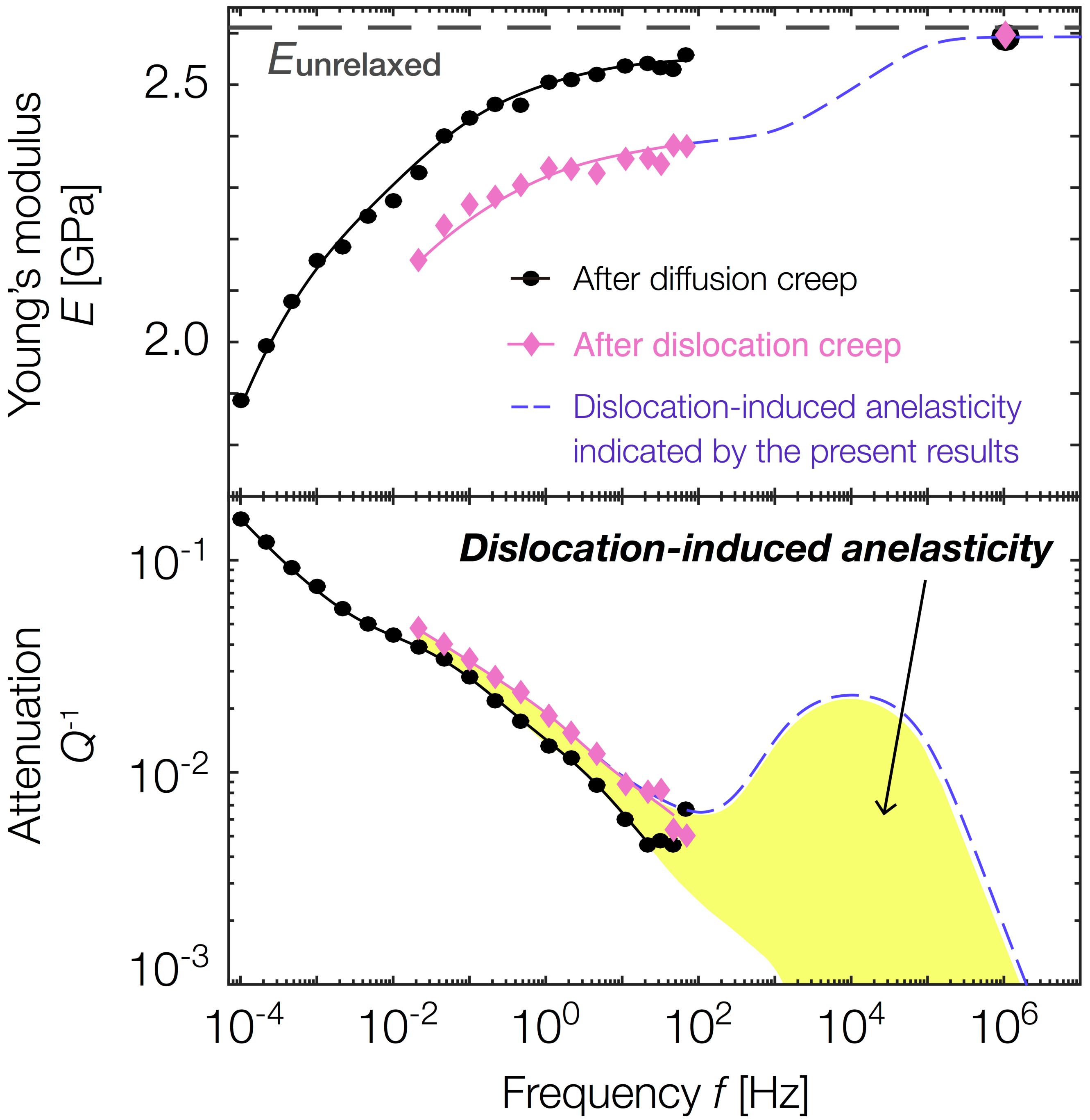
Keywords: anelasticity, dislocation, seismic attenuation, analog experiment, defect, polycrystal


Eunrelaxed
2.5
2.0
Young's modulus
E [GPa]
After diffusion creep
After dislocation creep
Dislocation-induced anelasticity
indicated by the present results
Dislocation-induced anelasticity
Attenuation
Q-1
10-1
10-2
10-3
10-4
10-2
100
102
104
106
Frequency f [Hz]