Effect of Dislocations on Rock Anelasticity: Experimental Approach by Using an Analogue Material

*Yuto Sasaki[1], Yasuko Takei[1], Christine McCarthy[2], Ayako Suzuki[1]

1.Earthquake Research Institute, University of Tokyo, 2.Lamont-Doherty Earth Observatory, Columbia University

Rock anelasticity causes seismic wave dispersion and attenuation. Therefore, it is important to understand the mechanism of anelasticity to know about the Earth's interiors from seismic tomographic images. Grain boundary sliding and dislocation motion have been two major mechanisms proposed for the rock anelasticity. Although extensive studies on the grain boundary sliding have been performed [1-4], few experimental studies have been performed on the effect of dislocations on the rock anelasticity [5, 6]. In this study, by using the organic polycrystalline material (borneol $C_{10}H_{18}O$, melting temperature Tm=204°C) as a rock analogue [3], the effect of dislocations on anelasticity was measured accurately over a broad frequency range (10^2–10^{-4} Hz).

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First, in order to know the flow law of this analogue material, uniaxial creep tests were performed at T/Tm=0.66 (T=40°C) and 0.68 (T=50°C) and at various differential stresses from Δσ=0.27 to 2.3 MPa. To avoid the occurrence of cataclastic flow, confining pressure Pc=0.8 MPa was applied in a pressure vessel with a frictionless uniaxial piston designed by T. Sato in soil mechanics. As a result, we captured a transition from a linear (n~1) creep to a power law (n~5) creep: the transition occurs at Δσ≈1.4 MPa for T/Tm=0.68 (50°C) and at a higher Δσ for T/Tm=0.66 (40°C). In the deformed sample (Δε~0.5), grain boundaries became wavy and the grain size showed a larger variation than the undeformed samples, indicating the occurrence of grain boundary migration associated with dislocations. Therefore, we considered the power law creep as dislcoation creep which introduced dislocations into the samples.

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Next, three creep tests with Δσ=0.27 (diffusion creep regime), 1.4 (transitional regime), 2.1 MPa (dislocation creep regime) were conducted on the same sample in the increasing order, and after each creep test anelasticity of this sample was measured repeatedly to detect the effect of predeformation and also to detect a temporal evolution during the anelasticity measurements. Each predeformation was performed in the pressure vessel at Pc=0.8 MPa and T/Tm=0.68, and the deformed sample was cooled down to room temperature under the differential stress. The predeformation took about 16-23 hours and the cool down took about 6 hours. The sample was then removed from the vessel and anelasticity was measured in the forced oscillation apparatus [3] at ambient pressure: Young's modulus E and attenuation Q^{-1} were measured over a broad range of frequencies f=10^2–10^{-4} Hz and at several temperatures from T/Tm=0.59 (10°C) to 0.66 (40°C). The results can be summarized as follows. (1) The anelasticity obtained after the test with Δσ=0.27 MPa and Δε=0.007 agreed well with the previous result measured under the offset stress Δσ=0.27 MPa [3]. (2) In contrast, after each of the latter two tests (Δσ=0.14 MPa and Δε=0.036, Δσ=2.1 MPa and Δε=0.12, respectively), Young's modulus E was lower and attenuation Q^{-1} was higher than the results in (1), and these changes were larger for the larger stress. (3) Over time, E and Q^{-1} gradually increased and decreased, respectively, finally converging into the property measured in (1). These results are considered to be attributable to the dislocations and their recovery.

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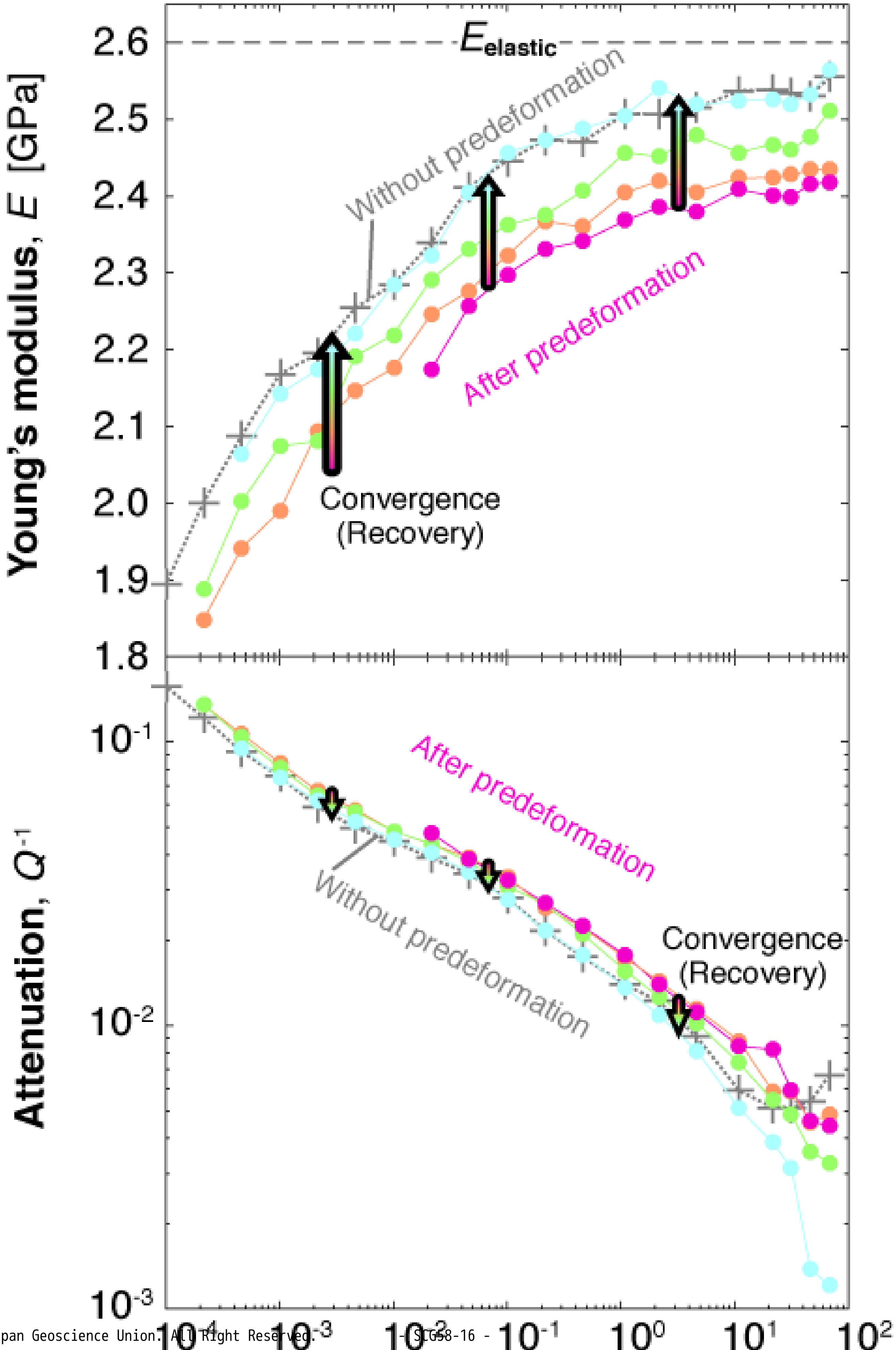
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
1.8
Young's modulus, E [GPa]
E_{elastic}
Without predeformation
After predeformation
Convergence
(Recovery)
10^{-1}
10^{-2}
10^{-3}
Attenuation, Q^{-1}
After predeformation
Without predeformation
Convergence
(Recovery)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}