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Experimental study of anelasticity of a polycrystalline material near the melting temperature

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Rock anelasticity is important to interpret seismic wave velocity and attenuation structures in the upper mantle. By using organic polycrystalline borneol ($C_{10}H_{18}O$, melting temperature =204.5 ℃) as an analog to mantle rock, McCarthy et al.(2011) measured Young's modulus and attenuation Q^{-1} as functions of frequency f (=10^{-4} - 2 Hz), temperature T (20-50 ℃) and grain size d (3.3 - 22 micrometer). They also measured viscosity, and calculated the Maxwell frequency fm. When the obtained Q^{-1} spectra were plotted as functions of the frequency normalized by the Maxwell frequency fm, all Q^{-1} spectra obtained for various temperatures and grain sizes collapsed onto a nearly single curve. Moreover, data from olivine aggregates (Gribb and Cooper, 1998; Tan et al. 2001; Jackson et al. 2002) collapsed onto the same master curve as borneol, demonstrating the universality of anelastic behavior. However, experimental frequencies normalized by the Maxwell frequency of the samples were lower than $5*10^4$, which is considerablly lower than those of seismic waves in the upper mantle (f/fm= 10^6-10^9). Therefore, whether the Maxwell frequency scaling is applicable to the seismic waves or not is an open question.

Takei et al. (in preparation) measured anelasticity of organic polycrystalline borneol at lower temperatures (0-20 ℃) and higher frequencies (10^{-4}-50 Hz) than McCarthy et al. (2011). They also investigated the effect of chemical composition on anelasticity, by using the samples made of high-purity borneol and borneol + diphenylamine ($(C_6H_5)_2NH$) (eutectic temperature = 43 ℃). Before obtaining these data, our experimental methodology and data quality were much improved. When the obtained Q^{-1} spectra were plotted as functions of the frequency normalized by the Maxwell frequency, the Q^{-1} spectra collapsed onto a nearly single curve at f/fm $<10^4$, but significantly scattered at f/fm $>10^4$, where the spectra have a broad peak and the scattering is caused by the variation of the peak amplitude and width with temperature, grain size and chemical composition. Therefore, the simple Maxwell frequency scaling is not applicable to the seismic waves in the upper mantle. They found that seismic attenuation predicted from the data of high purity samples and those of the borneol + diphenylamine samples under low temperature conditions is too low to explain the seismic attenuation in the upper mantle (~ 0.01). In other words, enhancement of attenuation near the melting temperature is important to understand high Q^{-1} in the upper mantle.

In this study, we measured anelasticity of borneol + diphenylamine system at various frequencies ($2*10^{-4}$ -50 Hz) and temperatures (20 - 46 ℃), and obtained the detailed behavior of anelasticity near the melting temperature (43 ℃). The result obtained so far show that the change of viscosity and anelasticity near the melting temperature is not discrete but continuous. This result is somewhat different from our previous understanding that physical properties abruptly change when melting starts beyond the solidus. We will further obtain systematic data for various grain sizes and melt fractions.

Keywords: anelasticity, seismic attenuation