Rock anelasticity due to grain boundary premelting

*Yasuko Takei[1], Hatsuki Yamauchi[1], Akihiro Tsunoda[1]

1. Earthquake Research Institute, University of Tokyo

Recently, rock anelasticity has become a matter of concern because it provides a solid-state mechanism causing seismic low velocity and high attenuation in the upper mantle (e.g., asthenosphere). It overcomes the difficulty to interpret the seismological observations in a consistent manner with the geochemical constraint that melt fraction possible in the partially molten mantle is very small (< 0.1%, e.g., Stracke et al., 2006, EPSL). Experimental data obtained in our laboratory by using a rock analogue (binary eutectic system of organic polycrystals) demonstrate the existence of such solid-state mechanism. Our experimental results show that anelastic relaxation by grain boundary sliding is significantly enhanced from just below the eutectic temperature Te (> 0.9Te), probably due to the occurrence of grain boundary premelting (Yamauchi & Takei, 2016, JGR, Takei, 2017, Ann. Rev.). We will report our recent experimental and theoretical approaches to understanding the mechanical consequences and underlying physics of premelting.

Temperature dependence of viscosity η and attenuation Q^{-1} of a rock usually follows the Arrhenius law: $\eta = \eta_0 \exp(H/RT)$ and $Q^{-1} = Q^{-1}(f/f_M)$ with $f_M = f_0 \exp(-H/RT)$. Then, temperature dependence of shear wave velocity V_S is calculated as $d\ln V_S / d\ln T = [d\ln V_S / d\ln T]_{anh} - 2(H/RT) Q_S^{-1}/\pi$, where the first and second terms represent anharmonic and anelastic effects, respectively. This equation has long been used in seismology [e.g., Anderson, 1989]. The temperature dependence, $d\ln V_S / d\ln T$, estimated from this equation by using the observed seismic attenuation Q_S^{-1} is small, indicating that seismic discontinuity cannot be explained by a solid-state mechanism. However, we found that the Arrhenius law starts to break down at the onset of premelting, causing much steeper reductions in V_S and in η than the expectations from the Arrhenius law. Our results show that not only low velocity and high attenuation, but also seismic discontinuity and weak asthenosphere can be explained by premelting, without invoking melt.

In order to clarify the physical mechanism of premelting, we applied to our data the thermodynamic model of grain boundary developed for a binary eutectic system (Tang et al., 2006, Phys. Rev. Lett.). The model predicts a significant increase in grain boundary disorder from just below the eutectic temperature. Such structural transition in grain boundary explains well the breakdown of the simple Arrhenius law in the mechanical properties controlled by the grain boundary diffusivity. In the Earth sciences, occurrence of grain boundary premelting has been known for ice (pure system), but not for a rock (multi-component system). Because a binary eutectic system is the simplest case of a multi-component system, our result indicates the occurrence of premelting in the mantle.

Keywords: anelasticity, grain boundary premelting, asthenosphere

