Origin of asthenosphere inferred from polycrystal anelasticity

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Asthenosphere is observed as seismic low velocity and high attenuation zone. However, temperature of such region is, for the most part, below the solidus temperature of dry mantle peridotite. This suggests that seismic wave velocity is significantly reduced in the absence of melt or in the presence of a very small amount of melt stabilized by volatiles. Effects of partial melting on the seismic velocity and attenuation have long been studied within the framework of the direct effect of the melt phase, such as poroelastic effect. Because the direct effect is small for very small melt fraction, it is difficult to explain the relatively large velocity reduction in the asthenosphere.

Rock anelasticity, which can cause low velocity by grain boundary sliding without melt, has been considered as a key to solve this problem (e.g., Karato, 1993; Faul and Jackson, 2005). However, due to the difficulty of high temperature experiment, we have had a limited understanding of rock anelasticity at the seismic frequencies. Recent experimental studies by using a rock analogue (organic polycrystals) has revealed that polycrystal anelasticity is significantly enhanced from just below the solidus temperature in the absence of melt (Takei et al, 2014; Yamauchi and Takei, 2016). Importantly, the amplitude of this `pre-melting effect' is large even for the samples which can produce very small amounts (~0.4-0.5 %) of melt at the solidus temperature (Yamauchi and Takei, 2016). Therefore, the newly recognized effect can remove the difficulty to explain the seismic observations without melt or with very small amount of melt indicated by the thermal and geochemical studies.

Using the temperature and seismic structures of the Pacific mantle, Priestley and McKenzie (2006, 2013) captured a steep reduction in Vs just below the dry peridotite solidus. The new anelasticity model including the pre-melting effect can explain this steep reduction qualitatively and almost quantitatively (Yamauchi and Takei, 2016), whereas the other models cannot. Seismic discontinuity, which is attributed to the lithosphere-asthenosphere boundary (LAB), can be also explained by the pre-melting effect without invoking melt (Yamauchi and Takei, AGU fall meeting 2016). The new model is not sensitive to the existence or non-existence of a very small amount of melt, but is sensitive to the existence or non-existence of volatiles because of their strong effects on the solidus temperature. Possible mechanism causing the pre-melting effect is a disordering transition of grain boundary. Therefore, the new anelasticity model suggests that the mechanical properties of the asthenosphere are controlled by the dynamic properties of the grain boundary at near-solidus temperatures.

Keywords: anelasticity, polycrystal, grain boundary, partial melt

