Theoretical and experimental assessment of seismic attenuation in polycrystalline aggregates

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Anelasticity is a material property to cause seismic attenuation (Q^{-1}), or strain energy dissipation. Recent seismological studies have obtained Q structure of higher spatial resolution than ever. It is desired to reveal how rock conditions such as temperature and melt fraction control anelasticity. Grain boundary sliding (GBS) has been known as a mechanism of anelasticity [Ke, 1964], but it is impossible to estimate effects of the rock conditions based on defect microdynamics for the sliding. Therefore we undertake the following approaches to GBS: (1) forced oscillation experiment in longitudinal deformation in order to provide empirical constraints on the sample conditions and (2) calculation of dilatational dissipation based on conventional theory on elasticity. For both approaches, deformations other than shear deformation are investigated because influence of GBS has been assessed only for the case of macroscopically shear deformation [Jackson et al., 2002; Ghahremani, 1980].

(1) Forced oscillation experiments were performed by using polycrystalline rock analogue samples. The experimental apparatus has the advantages of the wide range of oscillation frequency (50 Hz - 0.1 mHz) and oscillation amplitude as small as that caused by seismic waves (less than 10^{-5} strain). The samples are made by annealing stuffed powder of borneol, an organic material [Takei, 2000]. The grain size was about 0.06 mm, and temperature was controlled to be 23 - 60^{o}C. This material is available for investigating effects of grain size because a method to produce fine powder (a grain size of 10^{-6} m) was established. Also, the material is available for investigating effects of partial melt because it and another organic material, diphenylamine, compose an eutectic system (an eutectic temperature of 43^{o}C). Therefore the results of this study become foundation of the future work on grain size and partial melt effects. Until now, the experimental run for two of the samples were successful because the sample shape were not distorted during the run. Q^{-1} from 20 Hz to 1 mHz was 0.016 - 0.026, and showed weak frequency dependence. Below 1 mHz, Q^{-1} monotonically increased with decreasing frequency, and increased with increasing temperature. This frequency and temperature dependence agrees to prediction for dissipation from viscosity of the material. Since influence of viscosity is limited to data below 1 mHz, it was revealed that the property which caused the dissipation for 20 Hz - 1 mHz was anelasticity. For this anelastic dissipation, no systematic temperature dependence was seen. The weak temperature dependence accompanying the weak frequency dependence agrees to prediction under assumption of thermally activated mechanism of anelasticity.

(2) Theoretical method to calculate the S wave to P wave dissipation ratio, Q_P/Q_S, was developed. This ratio is calculated because it can indicate dilatational dissipation by falling below 2.25. The essential point of the calculation is that Q_P/Q_S is obtained from elastic modulus for the solid framework at the limit of high and low frequency. Mechanical condition of grain boundaries can be given at those limits although the condition at other frequencies is unknown. The calculation was performed for the three-dimensional model of partially molten aggregates having pore geometry textually equilibrated under hydrostatic pressure [von Bargen & Waff, 1986]. Q_P/Q_S less than 2.25 was obtained if melt wets grain boundaries anisotropically. Larger area of wetting caused softer pore, and hence caused larger sliding displacement at dry boundaries neighboring the wet boundaries. It is revealed that partial melt can cause dissipation under application of macroscopically dilatational stress if polycrystalline aggregates have anisotropy of wetness.