

SEDI Collaborative Research: Grand Challenge for Experimental Study of Plastic Deformation Under Deep Earth Conditions

Intellectual merit

The main thrust of this new phase of grand challenge program on high-pressure rheological studies is to further develop the experimental technique of quantitative rheological studies to accomplish our initial goal: to obtain quantitative experimental data on rheological properties of materials under the conditions equivalent to the whole mantle of the Earth. During the first phase of this effort (2002-2007), we have developed two types of deformation apparatus (D-DIA and RDA) and have expanded the pressure-temperature range of quantitative rheological studies from ~3 GPa and ~1600 K to ~16 GPa and ~1800 K. The expansion of the pressure range to this level has allowed us (i) to investigate the influence of pressure on plastic deformation and deformation microstructures in olivine, and (ii) to explore the plastic deformation and deformation microstructures of transition zone minerals such as wadsleyite.

However, many issues remain before we achieve our goal that was set in 2001. First, the maximum pressure of quantitative rheological study is still limited to ~10 GPa for D-DIA and ~16 GPa for RDA. In order to investigate the rheological properties under the lower mantle conditions, the pressure range must be extended to beyond ~24 GPa. Second, the water content (or water fugacity) under high-pressure conditions has not been controlled. We need to develop a method to control water fugacity under high-pressure conditions in order to obtain experimental data that can be applied to Earth's interior. Third, based on the newly developed X-ray techniques of quantitative studies of plastic deformation, we have identified a new challenge in quantifying the stress state from X-ray diffraction data. The previous model on which stress was estimated from X-ray diffraction assumes elastic strain accommodation, whereas new data show that plastic deformation plays an important role. We need to develop a model and experimental procedure to incorporate the role of plastic deformation in the stress estimate from X-ray diffraction.

Consequently, the main goals of this phase of our project are (i) to extend the pressure range of experimental studies of plastic deformation. Anvils made (partly) of polycrystalline diamond will be used to achieve this goal. (ii) We will explore techniques to buffer water fugacity using a pair of minerals including dense hydrous minerals. (iii) We will conduct both theoretical and experimental studies to improve the X-ray method of stress measurements. This effort of apparatus and sample assembly development will be complemented by the improvement of hardware and software of X-ray diffraction to increase the resolution of stress measurements to ~ 10 MPa.

With these developments, we will be able to establish the flow laws for minerals under whole mantle conditions as a function of pressure, temperature, water content and grain-size as well as the conditions for unstable deformation that can be applied to a range of geodynamic studies. The results of fabric measurements of samples that are deformed under well-controlled deep Earth conditions will also provide us with the first data set to interpret seismic anisotropy in the transition zone and the lower mantle.

Broader impact

The development of new technique of quantitative deformation experiments (or controlled stress experiments) will contribute to a broad area of science and technology including material science as well as Earth science. The apparatus developed in this project will be available for all interested users in national synchrotron facilities coordinated by COMPRES.