From dislocation recovery to dislocation damping in upper mantle materials

Robert Farla[1], Harri Kokkonen[1], John Fitz Gerald[1], Auke Barnhoorn[1,2], Ulrich Faul[3] and Ian Jackson[1]

[1] Research School of Earth Sciences, Australian National University, Canberra, ACT 0200, Australia.
[2] Now at Department of Earth Sciences, Utrecht University, 3508 TA Utrecht, The Netherlands
[3] Department of Earth Sciences, Boston University, Boston, MA 02215 USA

Dislocations introduced into mantle minerals like olivine by prior/ongoing tectonic deformation may account for a significant fraction of the observed seismic wave attenuation. In preparation for laboratory measurements of such dislocation damping, we have undertaken a study of high-temperature dislocation recovery in polycrystalline olivine. Here we extend previous work on natural olivine to a new class of pure synthetic Fo_{90} material, prepared from a sol-gel precursor and pre-deformed dry at 1300°C and progressively greater levels of deviatoric stress, reaching 255 MPa, to a total stain of almost 20%.

Multiple small cores of the pre-deformed specimen were subjected to static annealing for periods of 3-50 h at temperatures of 1100-1450°C under controlled furnace atmosphere within the olivine stability field. Dislocations were revealed via an oxidation-decoration technique and imaged using backscattered electrons (BSE) in a Hitachi 4300SE FESEM operated at 5kV. For each annealed sample, dislocation densities were measured across a minimum of two regions totalling 5000 μm^2 area to reduce uncertainties. The free software package ImageJ was used to threshold and highlight the dislocations which were then automatically counted. A manual correction for their 3D orientations was applied to obtain a reliable dislocation density.

The difference between the initial and the final dislocation density follows a second-order kinetic rate law as a function of annealing time, and results suggest an activation energy of dislocation mobility of ~280 kJ/mol. It follows that dislocation microstructures developed during prior deformation can be preserved during subsequent measurements of seismic properties at temperatures as high as 1100°C.

Preliminary forced-oscillation measurements of dislocation damping between undeformed and pre-deformed olivine specimens unfortunately did not produce a distinguished result. It turns out that the friction of grain boundary sliding in our fine grained material (2-3 micron) play a greater role in damping seismic waves than the movement of dislocations. Acknowledging however that upper mantle materials are of a coarse grained nature (up to 1mm grain size), the focus of the study will now be on the differentially deformed natural olivine single crystals. In addition, investigations will be starting on creating for the first time uniform coarse grained synthetic olivine.