The strength of the upper mantle: grain boundary sliding in two-phase aggregates from fieldwork and experiments

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Introduction:

Mantle convection is one of the important processes that drive the slow motion of tectonic plates, which, in turn, shapes and regulates the surface of our planet. During convection in the upper mantle, rocks flow plastically below the Earth's Lithosphere. The deformation mechanisms that control mantle flow will determine the strength of the upper mantle and the rate at which it can deform, the relationships between the Lithosphere and Asthenosphere and the velocity of plate motion. It is therefore of vital importance to understand deformation mechanisms in upper mantle rocks.

The main rock types that form the Earth's upper mantle are peridotites and the most abundant mineral is olivine, with lesser amounts of pyroxenes, spinel-type minerals and garnet. Since the 1990s, scientists in the experimental rock deformation community have provided valuable insight into both the dry and wet rheologies of olivine and have produced deformation mechanisms maps that extrapolate the deformation behaviour of this mineral from laboratory conditions of stress, strain rate and temperature to natural low stresses and slow strain rates [1]. Generally, it is understood that dislocation creep of olivine controls mantle flow at shallow depths, while diffusion creep of olivine is dominant at deeper level[1] and smaller grain sizes.

However the upper mantle is polymineralic and deformation mechanisms in polyphase rocks are still poorly constrained. Recent studies have shown that two-phase aggregates of olivine and pyroxene with small grain sizes (<10um), deformed experimentally, can flow by diffusion creep accommodated grain boundary sliding (GBS)[2,3]. They have also shown that these aggregates can behave superplastically, deforming to large strains under a tensile stress[3]. A further study has hypothesised, directly from the work of Hiraga et al. 2010[3], that GBS is responsible for phase segregation, and not mixing, during deformation to high strain[4]. This contradicts previous work that proposed that GBS favours phase mixing, where the secondary phase pins grain boundaries hence maintaining the grain size small and facilitating continued deformation by diffusion creep[5]. Thus new questions arise on the importance of the rearrangement of phases during diffusion creep accommodated GBS, and on the effect that such rearrangement would have on grain growth and therefore on the continued existence or cessation of grain boundary sliding in the Earth's upper mantle.

Project Summary:

The main goal of this studentship is to understand how phase distribution and boundary properties affect the strength of the upper mantle.

Specific aims are:

1. To gain insight into grain and phase boundary sliding and phase segregation versus mixing as a function of modal abundances.
2. To understand how the distribution of phases evolves during deformation as a function of strain.
3. To monitor the effect of phase distribution on grain growth.
4. To explore how the evolution of grain and phase boundary properties with pressure may affect the process of GBS.
5. To compare experimental observations with natural examples of deformed peridotites and use these observations to inform careful extrapolation of experimental results to nature.
6. To monitor the evolution of crystallographic preferred orientations (CPO) in all samples and document the relationship with the distribution of phases in the rocks studied.

Work for this project involves the preparation of experimental charges (synthetic samples) by reaction and sintering of initial oxide powders. Samples will be prepared for compression and extension experiments that the successful candidate will run in a creep rig (Liverpool, addressing aim 1) (Fig.1), and to high strain in torsion experiments in a Paterson gas rig (Manchester, addressing aim 2). In Y1 fieldwork in the Sesia-Lanzo[6] and Ivrea Zone[7], Italian Alps, will be carried out (Fig. 2). This involves detailed mapping, at the small scale, of structures in peridotite bodies, and sampling along traverses to shear zones for texture, fabric and chemical analyses (addressing aim 4). The student will take part to in-situ deformation experiments that will be run at a synchrotron radiation facility, with the UCL group, to observe changes in grain and phase boundary properties with varying pressure (addressing aim 3). All samples with be analysed using the EBSD/EDS SEM system in Liverpool, to monitor fabric and texture evolution, together with subtle chemical changes, and compare results from experimental samples with those from natural peridotites (addressing aims 4 and 5).

Year 1: creep experiments and EBSD analysis of experimental samples in Liverpool; fieldwork in the Italian Alps (Sesia-Lanzo; Ivrea Zone).

Year 2: high shear strain experiments in Manchester, EBSD analysis and comparison between experimental and natural samples. Manuscript write-up.

Year 3: synchrotron experiments at varied pressures with UCL, further EBSD analyses and comparisons. Manuscript and Thesis write-up.

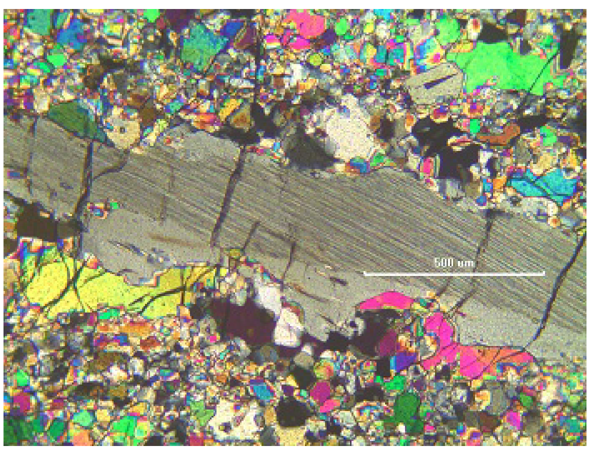

Fig. 1: *Micrograph of a Alpe Morello peridotite mylonite showing extensive grain size reduction in olivine and crystal plasticity in larger grains of orthopyroxene (from the MESci work of Josh Vaughan-Hammon, Liverpool 2016).*

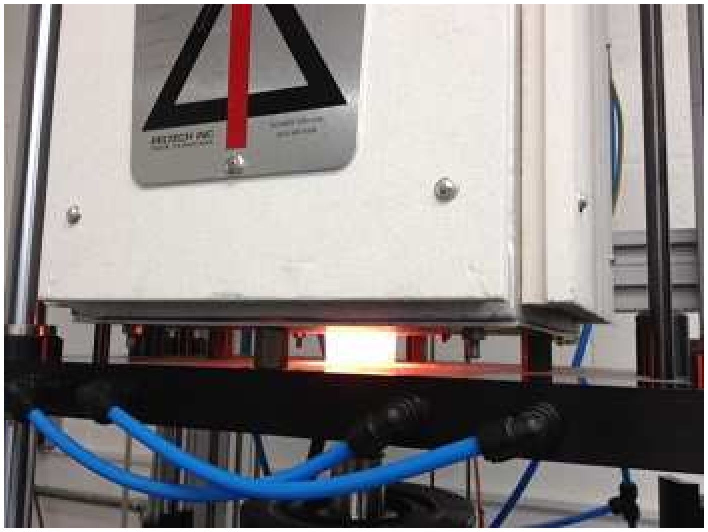 Figure 2.

Fig. 2: *Creep rig furnace with inner alumina tube glowing white during a dead loading experiment at 1400 °C. The Rock Deformation Laboratory, Liverpool University.*

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