Introduction: The EuroMinSci Initiative

The development of sub-structure is an important process in rocks deforming at elevated temperature by crystal-plastic processes. Sub-structure is a useful indicator of deformation mechanisms and palaeostress in the lithosphere. Moreover, it provides an important control on the mechanical properties of materials.

A comprehensive understanding of the nature and mechanical significance of sub-structures is key, therefore, in increasing the accuracy and reliability of palaeostress estimates and to properly describe the rheological properties of rock aggregates deforming by dislocation processes. Such an understanding will prove central in the advancement and refinement of manifold models of multi-scale dynamic processes through the material and Earth sciences, from the atomic-scale to orogenesis and mantle convection.

This study is part of a larger collaborative research project into sub-grain structure development in rocks and metals, funded by national agencies as part of the EuroMinSci initiative.

Aims of the collaboration include gaining an increased understanding in:

1. the nucleation of new (sub-) grains during deformation;
2. the behaviour of sub-grain boundaries during deformation and phase transitions;
3. the interaction of processes across all scales, from dislocations to whole grains and aggregates; and
4. the numerical prediction of sub-structure, with an emphasis on integrating in situ experimental techniques with multi-scale numerical simulations.

In situ Experiments in the SEM

In situ experiments on single crystals or selected rock-forming minerals have proved successful in the observation and quantification of recrystallisation and phase transformations up to ~1000°C (Figures 2 & 3; e.g. Seward et al., 2002; Seward et al., 2004; Bestmann et al., 2005), and the incorporation of the resulting microstructural data into numerical models (e.g. Piazolo et al., 2004).

The range of samples that can be analysed is in part limited by their material properties and the operating conditions of the SEM. That is, an interplay exist between (1) the attainment of temperatures suitable for studying crystal-plastic processes on experimental timescales, (2) preserving the integrity of lattice structure at said temperatures such that EBSD analysis is productive and pattern quality is maintained, and (3) avoiding sample deterioration (e.g. calcite, upon heating) or significantly reduced grain boundary mobility (e.g. quartz) at the reduced pressure conditions in an SEM.

Heating & Deformation Experiments

At Liverpool, we document the kinematics of intracrystalline sub-structure development and the way such sub-structures interact with intergranular boundaries during high-temperature deformation experiments of MgO and forsterite.

Deformation of single crystal, layer-cake and polycrystalline samples at a range of temperatures between 1100°C and 1400°C will provide information on sub-structure development and the interaction of sub-structure with boundaries that are relatively easy to relate to 2D models, and those representative of real rock microstructures, respectively.

A recently commissioned, custom-designed sample stage for the CamScan X500 FEG-SEM at Liverpool incorporates a high-temperature heating system with a deformation rig, permitting simultaneous heating and tensile deformation of samples with real-time EBSD analysis and conventional SEM imaging.

References