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The role of lattice defects in the localisation of strain at the grain-scale

Elisabetta Mariani (1), Joseph Aslin (1), Stephen Covey-Crump (2), Karl Dawson (1), Lars Hansen (3), David Wallis (4), and John Wheeler (1)

(1) University of Liverpool, School of Environmental Sciences, Liverpool, UK (mariani@liverpool.ac.uk), (2) University of Manchester, School of Earth, Atmospheric and Environmental Sciences, Manchester, UK, (3) University of Oxford, Department of Earth Sciences, Oxford, UK, (4) Utrecht University, Department of Geosciences, The Netherlands

Localisation of strain in rocks can be observed at a variety of scales. At the grain scale, strain nucleation is the initial process that may influence the evolution of localisation, and it is controlled by the crystal structure and the properties of lattice defects in a given mineral. Here we study the nucleation and localisation of strain in calcite and micas, as both minerals are often found in large scale faults and shear zones in the Earth's crust. Quantitative microstructural analyses of Carrara marble were carried out using electron backscatter diffraction (EBSD) in a field emission gun (FEG) scanning electron microscope (SEM). Samples of Carrara marble were previously deformed between 10^{-4} s^{-1} and 10^{-6} s^{-1} strain rates, strains between 4% and 20% and temperatures between 450˚C and 700˚C. In all samples deformation twinning contributed to the accommodation of strain. Where two or all three sets of e-twins form in a grain, an elastic strain field develops at twinning intersections and in neighbouring grains, around twin boundary terminations. A finite elastic strain of 0.5% and residual stresses of 500 MPa were measured at twin intersections using High Angular Resolution (HR) EBSD. At high strains, elastic strain is dissipated by local lattice distortion via the generation of highly organised dislocation avalanches, which may span the length of a grain. Surprisingly, slip systems r10-14<-2021> were found to be active at high temperature, in contrast with the predictions of existing models of texture development. A selection of mica-bearing mylonites were sampled on a traverse across the Pogallo shear zone, a regional scale lineament which juxtaposes mid-crustal rocks to the SE and lower crustal rocks to the NW in the Ivrea-Verbano Zone, NW Italy. At the scale of a thin section, the deformation is localised in thin, interconnected biotite shear zones. Direct-lattice transmission electron microscopy (TEM) images of deformed biotite grains show expansion of the biotite cell dimension c, perpendicular to the basal plane. This evidence suggests the presence of newly discovered defects that are unique to layered structures, known as ripplocations. Such ripple-like defects could provide an efficient mechanism for the sliding of mica basal planes without breaking bonds within the layers. If substantiated, this is an important advancement in our understanding of mica deformation and the ability of these minerals to accommodate highly localised strain.