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Recrystallisation of olivine after high-stress deformation - microstructures and crystallographic preferred orientations

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Experiments comprising sequences of a high-stress, low-temperature deformation stage and a low-stress, high-temperature stage were carried out in a Griggs-type apparatus on natural peridotites. In the first stage, samples were triaxially shortened by about 20% at a temperature of 600°C, a confining pressure of 1 GPa, and strain rates of about 8*10-5 s-1. Subsequent quasi-isostatic annealing lasted for 16 to 144 hours at 700°C to 1100°C and a confining pressure of 2 GPa. In some experiments a low residual differential stress was applied during the high-temperature stage. The resulting olivine microstructures are analysed by electron microscopic techniques (SEM/EBSD, FIB, TEM). They indicate that the high-stress deformation occurs by low-temperature plasticity with dislocation glide-controlled deformation associated with brittle deformation. After quasi-isostatic annealing at temperatures of 900°C and higher, zones of high strain (in TEM characterised by a high dislocation density, cell structures and defect-poor domains of <2 μm diameter within a matrix of high defect density) are replaced by new grains. Whereas nucleation of new grains appears to be controlled by the deformed microstructure, growth occurs by grain boundary migration during annealing. Recrystallised grains are almost defect-free and show smoothly curved grain boundaries. Voids are commonly present along grain boundaries. Remaining host crystals surrounded by recrystallised grains contain low-angle grain boundaries and sutured high-angle grain boundaries. Average recrystallised grain size and the area covered by recrystallised grains increase with increasing annealing temperature and time. After annealing at temperatures of 1000°C and 1100°C, recrystallised grains show a high variance in grain size. Diameters of recrystallised grains along former original high-strain zones remain generally below 10 μm. Elsewhere recrystallised grains can show diameters of up to a few tens of μm. New grains reveal a weak CPO with a varying imprint of the crystallographic orientation of the replaced host. The observed CPO does not show a systematic relationship to the shortening axis during deformation, irrespective of whether the high-temperature stage was carried out at quasi-isostatic stress conditions or whether a small residual stress was applied.

The microstructures produced in our experiments compare well to natural microstructures from shear zone peridotites, often interpreted to have developed by dynamic recrystallisation in the regime of dislocation creep. This study shows that similar microstructures can also form by a sequence of low-temperature plasticity at high stress and recrystallisation at low stress. In this case, paleopiezometers are not applicable, because grain size is not balanced between grain size reduction and growth during steady-state dislocation creep, but develops by initial nucleation controlled by high-stress deformation and subsequent growth at low stress. Also, a CPO of new grains does not reflect an activated glide system but is rather controlled by the crystallographic orientation of the host grains. A microfabric development with recrystallisation at low differential stress after high-stress deformation is relevant for peridotites of the lithospheric mantle underlying seismic active areas. Our experiments indicate that a time range required to develop such a characteristic microstructure is on the order of some hundred years at temperatures of around 600°C in nature.