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Strain localization during stress-loading and stress-relaxation cycles recorded in mylonitic peridotites from experiments and nature

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For the development of localized high-strain zones generally some “strain-weakening”, i.e. a lower effective viscosity of shear zones compared to the host rocks, is assumed. A related question is, whether the strength of the lithosphere should be considered the strength of “weakened” shear zones or whether it should be considered as the strength of the intact rock. Based on our observations from mylonitic peridotites and experimental peridotite deformation, we find it useful to consider two stages for the development of localized high-strain zones: (1) stress-loading, where deformation at transient high stresses results not necessarily in a high amount of strain on sample scale, but in localized highly damaged zones enabling grain-size reduction during (2) stress-relaxation, where a high amount of strain can be accumulated.

Mylonitic peridotites from the Finero complex, Southern Alps, record strain localization during stress-loading and stress-relaxation cycles within their prolonged geological history. We differentiate the heterogeneous olivine microstructure into host rock, mylonite, ultramylonite and protomylonite, by their amount and size of recrystallized grains as well as whether a foam structure is present or not. In host rocks and mylonites, a well-developed foam structure is preserved. Recrystallized grains have diameters on the order of mm in host rocks and on the order of a few hundred μm in mylonites. Mylonites represent an early stage of localized dynamic recrystallization with grain size reduction compared to the host rock. At quasi-static stress conditions, the strain energy was reduced such that a reduction in surface energy controlled grain boundary migration generating the foam structure in both rocks. During a second stage of deformation ultramylonites and protomylonites that both do not show a foam structure developed. Ultramylonites are characterized by a second generation of small recrystallized grains with diameter of a few tens of μm and sutured boundaries. They are interpreted to have formed from mylonites. Protomylonites developed by deformation of the host rock, as indicated by sutured grain and kink band boundaries of large deformed porphyroclasts. The second deformation was again localized, i.e. the foam structure is preserved locally, pre-existing shear zones were reactivated (mylonites are modified to ultramylonites) and locally the host rock (no deformation during the first stage) was affected, forming protomylonites. Thus, grain size reduction generated during the first stage did not result into an effective “weakening”. Weakening would have only been effective, if grain-size dependent deformation mechanisms with a proportional relation between grain size and strength, are effective, e.g., grain boundary sliding or diffusional creep. Here, however, microstructures indicate that dislocation glide was the main deformation mechanism, where an inverse relationship between grain size and strength can be expected. For dislocation glide of olivine at lithospheric conditions, high stresses are required. This observation is consistent with high-stress deformation experiments on previously deformed and annealed peridotites (“kick-cook-kick” experiments), where strain during a second high-stress deformation was concentrated in porphyroclasts and not within pre-existent areas of recrystallized grains. Thus, pre-existing shear zones do not necessarily imply lower effective viscosities during deformation at high stress-loading rates.