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Strain localization and grain size reduction during high-stress low-temperature plasticity and subsequent creep below the seismogenic zone

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A sequence of high-stress crystal-plasticity with accompanying microcracking and subsequent creep at low stresses in the plastosphere can be triggered by the rupture of a fault in a major earthquake within the overlying seismogenic zone. In this study, microfabrics are analyzed by polarized light microscopy and electron microscopic techniques (SEM/EBSD, FIB, TEM) in rocks (vein quartz, peridotite) experimentally deformed at conditions that correspond to those prevailing in the upper plastosphere following a major earthquake. The experiments are carried out in a Griggs-type solid medium apparatus with a deformation stage at low temperature (300 to 600 °C) and high stress ("kick") followed by a stage at higher temperature (900 to 1000 °C) and isostatic ("cook") or low stress ("creep"). The resulting microfabrics show amazing resemblance to those observed in rocks from natural deep continuations of seismically active fault zones (i.e. shear zones). Localized zones of small new grains (a few μm in diameter) without systematic crystallographic preferred orientation within deformed host grains occur. The new grains develop by grain-boundary migration driven by the reduction in surface and strain energies at low stresses from highly damaged zones formed by initial low-temperature plasticity with associated cataclasis at high-stress deformation. A high variability in grain size is observed with the smallest grain size in the center of the highly damaged zones. The grain size reduction is controlled by strain during the initial high-stress deformation and growth is occurring only during the low-stress stage - rendering conventional grain size piezometers inappropriate. In large remnant host grains, short-wavelength undulatory extinction is reflecting low-stress modification (recovery) outside the highly damaged zones but in areas of original high dislocation densities formed at high-stress low-temperature plasticity. Extrapolation to natural conditions suggests that the observed characteristic microstructures may develop within as little as tens of years and less than ten thousands of years. The characteristic deformation and recrystallization microstructures can be expected to be stable over geological time scales, since driving forces for further modification are not sufficient to erase the characteristic heterogeneities. Thus, they are diagnostic for a past sequence of high-stress deformation (a combination of brittle failure and low-temperature plasticity) followed by creep at low stresses (recovery and recrystallization) in shear zones as deep continuations of seismically active fault zones. Such a sequence can explain initial grain size reduction localized along highly damaged zones during high-stress crystal-plasticity further leading to localized recrystallization during subsequent low-stress creep.