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Rapid plastic deformation and subsequent annealing of quartz - a comparison of experimental and natural record

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Quartz microstructures produced in short-term deformation and annealing experiments are compared with those in naturally deformed vein quartz in cores from the Long Valley Exploratory Well (Long Valley Caldera, California). The experiments are designed to simulate 1) co-seismic deformation of quartz in the uppermost plastosphere and 2) annealing during post-seismic stress relaxation. The experiments are performed in a modified Griggs type solid medium apparatus. Natural polycrystalline quartz samples (grain size on the order of millimeters) are deformed at a temperature of 400°C, a confining pressure of 2 GPa, and strain rates of $\sim 10^{-4}$ s^{-1}. The differential stress reaches ∼2-4 GPa and the irreversible axial shortening is typically a few percent. In some experiments the samples have subsequently been annealed for ∼14-15 h at elevated temperatures of 800-1000°C and low stresses (quasi-hydrostatic or non-hydrostatic conditions). The confining pressure has been chosen to keep the sample in the stability field of α-quartz.

The samples, which have not been annealed after deformation, show deformation bands that are characterized by a crystallographic misorientation of up to 25° to the host quartz grain. The deformation bands vary in thickness and can grade into fractures. Transmission electron microscopy reveals a high density of straight dislocations arranged into subparallel arrays in the vicinity of a deformation band. The density of free dislocations decreases with distance from the deformation band. Microstructures in deformed samples annealed at 900-1000°C and quasi-hydrostatic conditions are characterized by strings of isometric grains with a diameter of ∼10-50 μm that show no crystallographic preferred orientation. In one experiment, in which the sample has been annealed at non-hydrostatic conditions subsequent to deformation, shear zones have developed that are characterized by elongate, small grains with a diameter of up to 30 μm. The grains are preferentially oriented with their <c> axes in a plane perpendicular to the shear zone. These shear zones are interpreted to have formed during deformation at non-hydrostatic annealing with dynamic recrystallisation. In contrast, the strings of isometric grains in the experiments with quasi-hydrostatic annealing are suspected to be due to static recrystallisation from a highly damaged zone generated during high-stress deformation, as observed in the non-annealed samples. These microstructures compare well with those observed in naturally deformed vein quartz from the Long Valley Exploration Well, with independent evidence of episodic deformation due to co-seismic loading.

Comparison of experimental and natural record provides insight into processes, conditions, length and time scales characteristic for the episodic loading and relaxation in the middle crust driven by seismic activity in the upper crust. Such insight may be crucial for the appropriate inversion of geodetic results and the interpretation of aftershocks.