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Microstructural evolution from stable sliding to fast stick slip: insights from rock deformation experiments on quartz

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Inferring microstructural evolution and associated fault slip behaviour along natural and/or experimental faults is a long-standing problem in fault mechanics. For example, does grain-size reduction and shear localization facilitate earthquake slip or vice versa? We have sheared granular layers of quartz gouge in a double direct shear configuration using a biaxial apparatus. We varied loading stiffness and applied normal stresses to produce a spectrum of slip modes from stable sliding at 10 μm/s, slow stick-slip (average slip velocity 100 μm/s) and fast stick slip (average slip velocity 4 mm/s). At the end of the experiments we collected the experimental fault rocks for microstructural investigations. Additional samples were collected from control experiments to investigate shear fabric development and microstructural features before the onset of stick-slip instabilities. We investigated the role of normal stress and stick-slip properties, including slip velocity, in determining fault zone microstructural features. Ranging from stable sliding to fast stick-slip we observe a progressive localization of deformation along fault parallel boundary shear planes. Only during fast stick-slip is the deformation localized along continuous, thin (1-2 microns wide), boundary parallel shear planes. The shear zones are composed of nanograins dispersed within a patchy matrix. We conducted TEM analyses to characterize these materials. In experiments at the same normal stress, fast stick-slip results in localized shear zones and fabric with nanograins whereas for stable sliding the microstructure does not show a significant grain size reduction and localization. Our results indicate that the fault rheological properties and fault slip behaviour, ranging from stable to unstable slip, plays a significant role in shear localization and fault zone fabric development.