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Instantaneous healing of micro-fractures during coseismic slip: evidence from microstructure and Ti in quartz geochemistry within an exhumed pseudotachylyte-bearing fault in tonalite

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This study presents detailed microstructural and trace element (Ti) analysis of quartz deformation microstructures associated with seismic slip in order to constrain the complex deformation history during an earthquake event. Exhumed faults within the tonalitic Adamello pluton (Southern Alps) were seismic at depth as indicated by the presence of pseudotachylytes (solidified friction-induced melts).

During cooling of tonalite, early-formed joints were first exploited by localized ductile shear zones associated with deposition of quartz veins (at $\sim$500 °C), and later by pseudotachylyte-bearing cataclastic faults (at $\sim$250-300 °C ambient temperature). Adjacent to pseudotachylytes, quartz of the host tonalite shows pervasive thin (1-10 μm wide) healed micro-fractures and ultra-fine (1-2 μm grain size) recrystallized aggregates along micro-shear zones. Under cathodoluminescence (CL) the healed micro-fractures have darker gray shade than the host "magmatic" quartz that reflects a change in Ti concentrations [Ti] as indicated by NanoSIMS measurements. [Ti] vary from 35-55 ppm of the CL-lighter host quartz to 11-15 ppm along the CL-darker healed micro-fractures. These [Ti] were inherited by overprinting recrystallization aggregates developed during the high temperature transient related to frictional seismic slip. Based on Ti-in-quartz thermometry, micro-fracture healing occurred at higher temperatures than the ambient temperatures of faulting (250-300 °C at 0.2 GPa). Micro-fracture healing can be ascribed to the stage of seismic slip of faulting on the basis of the observation that: (i) they are absent in the host rock surrounding earlier high-T quartz veins un-exploited by faults; (ii) they locally occur at the tip of pseudotachylyte injection veins filling new fractures developed during the propagation of the earthquake rupture tip. The relatively high [Ti] of micro-fractures are interpreted to reflect quartz healing by a fluid overheated during the initial stages of frictional seismic slip and escaping from fault surface through the damage zone. This suggests that, in the presence of fluids, thermal pressurization of the fault did not occurred and did not prevent frictional melting.

Our investigation evidences a complex history of deformations, occurring during the short-lived event of seismic slip and the associated high-temperature transient, that includes: micro-fracturing, micro-fracture healing and dynamic recrystallization. These observations can help in better understanding the complex mechanics of an earthquake source at depth.