Geophysical Research Abstracts
Vol. 21, EGU2019-2104, 2019
EGU General Assembly 2019

Cockade structures as a paleo-earthquake proxy in hydrothermal systems

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Cockades are clasts completely surrounded by spheroidal-hydrothermal overgrowth rims. They are observed inside hydrothermal fault breccias and can provide insights into high-speed fault dynamics. The formation of cockades requires primary clasts to be suspended in a fluid, which injects into an instantaneously opening fracture within a fault tectonite. Tectonite fragments build the cockade core with overgrowth rims the latter being driven by fluid pressure drops and rim precipitation related to oversaturation. Knowing the primary clast size, the minimum driving pressure for such floating mechanisms can be calculated. In addition, measuring the mass added during these stages, the solubility of SiO_2 provides insights in the fluid volume necessary to grow the given rim volume. The formation of cockades requires considerable dilatational strains generating open fracture space. This fact combined with the required suspension state of the cockade to allow for 3D rim growth needs a speed processes as is the case during seismic events. While the first growth rim represent the main shock, further growth rims represent subsequent shocks pointing to the repetitive nature of associated seismic fracturing events. Hence the cockaded structure gives insights into the relative evolution of such seismic sequences. Once settled at the fracture's bottom, the cockades are cemented together by slow processes during interseismic periods.
The combination of fluid mass, geometric as well as physical considerations allows a first order estimation on the earthquake magnitude for each fracturing event. In addition, the inferred velocities give relative time constrains for both the seismic events as well as the interseismic record. Cockade microstructures therefore represent proxies for paleo-seismic activities providing an excellent base to gain new insights into spatially and temporarily highly resolved information on the interplay between fast and slow processes.