EGU23-3230, updated on 29 Mar 2024
https://doi.org/10.5194/egusphere-egu23-3230
EGU General Assembly 2023

Dating fossil lower-crustal earthquakes by in-situ apatite U-Pb geochronology

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The only accepted evidence in the rock record for fossil earthquakes are pseudotachylytes, quenched frictional melts produced during seismic slip. Specifically, earthquakes in the lower continental crust recently have received increased attention, because they occur at depths where the lower continental crust is expected to flow rather than fracture. Nevertheless, lower crustal seismicity is also reported from active settings, for example, below the Himalaya. In order to properly address how and why they occur, pseudotachylytes exhumed from lower-crustal terranes are used as analogues. However, in order to fully understand lower-crustal seismicity, it is important to constrain the tectonic setting in which pseudotachylytes formed, which requires determining their age. Rapid melting and quenching, re-crystallization, and extremely fine grain sizes make age dating difficult. In this context, apatite may provide useful information, as it is known to quickly reset U-Pb ages during recrystallization.

We present the first reported in-situ U-Pb ages from lower crustal pseudotachylytes. The analyses were performed on samples from the Lofoten archipelago (Northern Norway) that exposes a block of lower continental crust with only minor overprint from the Caledonian orogeny. Field observations indicate that some of the exposed amphibolite-facies pseudotachylytes in the area have been overprinted by amphibolite-facies ductile shear zones. We couple in-situ U-Pb analysis (SIMS) with cathodoluminescence (CL) and electron backscatter diffraction (EBSD) to ensure full microstructural control of the ages. Analysis was conducted on variably mylonitized pseudotachylytes. All apatites originated from the Paleoproterozoic host rock and are either preserved in the immediate damage zone within the host rock or as survivor clast within the pseudotachylytes. Our analysis reveal that apatite in pristine pseudotachylytes deformed only by fragmentation and was subsequently annealed. Apatite in mylonitized pseudotachylytes displays evidence that deformation occurred dominantly by grain-boundary sliding after fragmentation, while grains in the host rock show evidence of crystal-plasticity and recrystallization. SIMS analyses yield a bimodal age distribution at ~450 and ~350 Ma. Combination of the ages with the microstructural evidence shows that the former captures the age of the earthquake, while the latter is related to late fluid infiltration, which was localized in the pseudotachylyte-bearing faults embedded in an otherwise dry and impermeable lower-crustal block.