Highly stressed lower crust: Evidence from dry pseudotachylytes in granulites, Lofoten, Norway

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Due to the high confining pressures in the lower crust, the generating mechanisms of lower crustal earthquakes, occurring below the standard seismogenic zone, are puzzling. Their investigation is difficult because the records of such earthquakes, pseudotachylytes, are typically reacted and/or deformed. Here we describe exceptionally pristine pseudotachylytes in lower crustal granulites from the Lofoten Vesterålen Archipelago, Norway. The pseudotachylytes have essentially the same mineralogical composition as their host (plagioclase, alkali feldspar, orthopyroxene) and contain microstructures indicative of rapid cooling (microlites, spherulites, ‘cauliflower’ garnet). Neither the wall rock nor the pseudotachylytes themselves contain hydrous minerals, and no mylonites are associated with the pseudotachylytes. This excludes the most commonly suggested weakening mechanisms that may cause earthquakes below the brittle-ductile transition: dehydration- or reaction-induced embrittlement, plastic instability, thermal runaway, and downward propagation of seismic rupture from shallow faults into their deeper ductile extensions. Hence, we suggest that transient stress pulses caused by shallower earthquakes are the most likely explanation for the occurrence of fossil earthquakes in the analysed rocks from Lofoten.

Earthquakes are short events, but their effects on the tectonic and metamorphic development of their host can be long-lasting. The initial deformation features related to seismic events, which potentially determine these effects, are often overprinted by metamorphism driven by fluids infiltrating the rock along the seismic fault. Because of the anhydrous conditions in the present case, those structures are preserved. The wall rocks to the investigated pseudotachylytes appear undamaged in optical and backscatter electron observation; however, cathodoluminescence imaging of feldspar and quartz reveals healed fractures and alteration zones. Those areas are further investigated with electron backscatter diffraction and transmission electron microscopy to better understand the microstructural and chemical changes during and after the seismic event.