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Origin of Pseudotachylites during slow creep experiments

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Pseudotachylites are interpreted as solidified friction induced melts which form exclusively during seismic or impact events and are thus accepted as 'unequivocal evidence' of paleo-earthquakes on exhumed faults. However, we found in experiments that pseudotachylites can form under clearly aseismic conditions at confining pressures and temperatures typical of mid crustal levels (Pc = 500 MPa, T = 300˚C).

The starting material consists of granitoid powder crushed to a size of $\leq 200\ \mu$m in diameter. This material (0.1 g), with 0.2 wt% water added, is placed between alumina forcing blocks pre-cut at 45˚, weld-sealed in platinum jackets with an inner nickel foil insert and deformed in a solid medium deformation apparatus (modified Griggs rig). We applied displacement rates of (10^{-8} ms^{-1} $< \dot{d} <$ 10^{-6} ms^{-1}) which approximate typical tectonic plate velocities of a few cm/a. In the ~0.7 mm thick layer of fault rock, this produces a bulk shear strain rate of ($\sim 10^{-5}$s^{-1} $< \dot{\gamma} <$ $\sim 10^{-3}$s^{-1}). The samples reach a peak shear strength of (~1200 MPa $< \tau <$ ~1500 MPa) at bulk sample strains of ($1.5 < \gamma < 2.3$). Only at the highest displacement rates ($\sim 10^{-6}$ms^{-1}), the samples fail abruptly shortly after reaching peak strength, possibly due to fracturing of the forcing blocks. However, at slower displacement rates (10^{-7}ms^{-1} to 10^{-8}ms^{-1}) the samples reach a peak strength of 1200 – 1400 MPa, then weaken slightly (by ~30 MPa), and continue to deform at approximately constant stress without any abrupt stress drops. The weakening is accompanied by a transient increase of the measured displacement rate of the forcing piston by ~25%. The friction coefficient, μ, on the 45˚ pre-cut is ~0.6, which is in the range of values typical of intact rock materials.

After the experiment, the fault rock consists of a S-C-C' fabric with a percolating, multiply connected layer of pseudotachylites decorating the C'- C shears. Microstructures indicative for pseudotachylites are: injection veins, flow structures, bubbles, and bubble trains following the local flow pattern, corroded clasts and amorphous glass identified by TEM. The chemical composition of the pseudotachylites varies depending on the precursor material and is in general more ferromagnesian and basic compared to the bulk rock indicating preferred melting of biotite. The calculated temperature increase due to shear heating is at the most ~5˚C. High stresses cause pervasive comminution: the smallest crystalline fragments within the bubbly melt have a grain diameter of ~10 nm. Nanomaterials exhibit a 'melting point depression' (dependence of melting point on grain size) which allows melting well below bulk melting temperatures. Thus, it seems that melting is a continuation of the comminution once the rock has reached small enough grain size. We therefore suggest that pseudotachylites may also form as 'mechanical melts' at slow displacement rates without the necessity of reaching high temperatures.