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Generation of intermediate to deep earthquakes by self-localizing thermal runaway: Constraints from petrological and numerical studies

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Convergent margins are characterized by a strong seismic activity with earthquakes occurring at depths of up to 700km. Shallow earthquakes (<60km) are explainable by the brittle failure of rocks. At greater depths, however, the increased ambient pressure should inhibit brittle failure. We present the results of a joint petrological, analytical and numerical study of thermal runaway as a mechanism for intermediate to deep earthquakes. Field evidence from the Kråkenes gabbro in Western Norway show coexisting narrow eclogite-facies shear zones and pseudotachylyte-bearing earthquake fault zones. Using an analytical and numerical model for thermal runaway (Braeck and Podladchikov, 2007), we explore under which conditions (e.g. differential stress, P-T, and rheology) these shear zones/pseudotachylytes may have formed and why they coexist within the same structural orientation. Our simulations provide an explanation for the observed coexistence of ductile deformation (shear zones) and brittle-like catastrophic failure (pseudotachylyte veins) with seismogenic strain rates and active melting at the deep-earth conditions. We demonstrate that small rheological differences in the system determine whether a shear zone will develop at a non-seismic velocity or if it will eventually rupture seismically. These rheological differences are expressed as effective viscosity contrasts between wall rocks and perturbations induced by the interaction of formerly dry rocks with an external fluid prior to the onset of strain localization. Therefore, fluids may still play an important role, but not a manner that is consistent with the traditional dehydration embrittlement hypothesis. First, SLTR requires no free fluid phase to activate failure; and second, the rock is weakened not “hardened” by fluids. Our modeling results demonstrate that the self-localizing thermal runaway mechanism is applicable for intermediate-depth and deep earthquakes in subduction zones. In fact, at depths greater than 60 km thermal-runaway occurs at lower differential stresses than brittle failure and involves realistic stress drops.