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Grain size assisted formation of pseudotachylites: A numerical study

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The processes resulting in the formation of lithospheric-scale shear zones are still poorly understood. Among others, shear heating and grain size reduction have been proposed to be viable weakening mechanisms to localize deformation and form lithospheric-scale shear zones. The interplay between both mechanisms is particularly interesting, as both compete for a part of the deformational work. High temperatures favor grain growth, therefore one would expect larger grain sizes in shear zones that have been formed by shear heating. However, larger temperatures increase strain rates, thus also the amount of deformational work, which in turn would favor grain size reduction. Here we investigate the interplay between both mechanisms using numerical models of a viscoelastic slab deforming in simple shear, employing a viscous rheology composed of dislocation and diffusion creep. Grain size evolution is governed by a recently developed physics-based evolution law.

We develop scaling laws for the peak stress and the dominating deformation mechanisms depending on various material parameters and boundary conditions. We find that grain size reduction alone does not localize deformation in simple shear. In conjunction with shear heating however, a localized shear zone is formed due to thermal runaway. During this process, grain size is significantly reduced. Depending on grain growth parameters, a mylonitic shear zone is formed in which deformation is permanently localized and which deforms in diffusion creep. Additionally, the stress required to initiate thermal runaway is reduced compare to cases with shear heating alone, thus facilitating the formation of a narrow localized shear zone in the ductile regime.

These results have several implications ranging and from simultaneous pseudotachylite and mylonite formation at depths below the seismogenic depth to subduction initiation.