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Spontaneous dissipation of elastic energy by self-localizing thermal runaway

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Melts are often observed in the geological record as pseudotachylytes in fault zones. Yet, apart from the fact that dissipation of energy during deformation leads to heating above the melting temperature of rocks, little is understood of the deformation mechanism behind the melting process. A central question is whether the rock-melting deformation is brittle or ductile, that is, whether the dissipation of energy is due to frictional or viscous forces. Is it at all possible to melt rocks by viscous dissipation during ductile deformations?

In this study we address the problem of a ductile deformation process with account of viscous dissipation from a theoretical viewpoint. Our model consists of a viscoelastic slab which is subjected to simple shear and is in ideal thermal contact with the surroundings. The heat conduction and momentum equations, coupled through temperature dependent viscosity, are solved both analytically and numerically. It is demonstrated analytically that if a generalized Brinkman number exceeds a critical value, the thermal-mechanical interaction is inherently unstable. The critical number is a function of a characteristic dimensionless relaxation time. Hence, the stability of the solution is controlled by two dimensionless variables only. Numerical solution of the full non-linear problem verifies the analytical findings. The results show that if the Brinkman number is larger than the critical value, the stored elastic energy spontaneously dissipates as heat in a self-localizing thermal runaway. The deformation process thus terminates in highly localized shear zones characterized by extreme peak temperatures. Based on our findings we propose thermal runaway as a possible mechanism for rapid ductile deformation and generation of melts.