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The physics of melt lubrication on seismic faults: multiple coupling and feedback

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Recent estimates of dynamic strength from exhumed ancient faults, combined with laboratory experiments conducted at high shear rate and intermediate normal stress (up to 1.3 m/s and 20 MPa), suggest surprisingly effective lubrication, low coseismic friction in the presence of melt, weak dependence of friction on normal stress and rate-weakening behavior. These experimental results are not trivial to interpret, because the lubrication mechanism depends on an articulate, self-regulating system of many coupled parameters (e.g., temperature, viscosity and thickness of the melt layer, shear rate and stress, rock melting rate, etc.). However, it is possible to reproduce the observed behavior reasonably well by treating the thermal diffusion problem in both the rock and the melt layer as a Stefan boundary problem, coupled to the fluid dynamic problem of melt shearing and extrusion. Experimental observations allow to make a number of simplifying assumptions leading to a system of six coupled equations, resolvable in terms of effective friction (or more precisely, shear resistance) as a function of normal stress and shear rate. The solution closely reproduces the steady-state behavior observed in the experiments: shortening rate, melt temperature, melt thickness, normal stress dependence and rate weakening are reasonably well predicted. Friction can be computed for higher normal stress or slip-rates, and the parameters (diffusivity, density, viscosity, etc.) adapted to any type of rock, in order to model seismic source behavior in the presence of melt under a wide range of conditions.