Inside the subduction earthquake factory: From rheology to seismic hazards

Sylvain Barbot[1]

[1] Nanyang Technological University (NTU), 50 Nanyang Avenue, Singapore,
Block N2-01C-37 Singapore 639798. (sbarbot@ntu.edu.sg)

1. Abstract

The subduction of oceanic plate underneath continents is resisted by frictional forces at the interface with the upper, continental plate. The evolution of friction on the megathrust governs the generation of earthquakes and seismic hazards. The frictional resistance of solids in sliding contact is described for a broad range of conditions and materials by the empirical framework of rate-and-state friction. The formulation successfully explains many laboratory observations and phenomena associated with fault slip. However, despite its importance in many fields of science, a theoretical foundation is still missing. I propose a physical basis for rate-and-state friction in gouge material whereby dynamic recrystallization modulates the real area of contact. The proposed constitutive relationship reads

$$V = V_0 \left(\frac{\tau}{\mu_0 \bar{\sigma}} \right)^n \left(\frac{d}{d_0} \right)^{-m} \exp\left(-\frac{Q}{RT} \right) , \tag{1}$$

with the thermally activated grain-size evolution law

$$\dot{d} = \frac{G_0}{2d} \exp\left(-\frac{H}{RT} \right) - \lambda \frac{Vd}{2T} , \tag{2}$$

where V is the sliding velocity across the shear zone, assumed uniform in the fault-perpendicular direction, τ is the shear traction in the fault-parallel direction, $\bar{\sigma}$ is the effective normal stress, μ_0 is the static coefficient of friction, d_0 is a reference grain-size, $n \gg 1$ and m are power exponents, Q is the activation energy, T is the temperature, R is the universal gas constant, d is the dynamic grain-size, G_0 a characteristic rate of surface growth, H is the activation enthalpy for grain growth, and λ controls the rate of weakening. The first term on the right-hand side of (2) assumes that the rate of grain growth is proportional to the curvature of the grain. The second term in (2) represents grain-size reduction. The constitutive framework reconciles many experimental findings, such as the scaling of the characteristic weakening distance with gouge thickness or fault roughness, the correlation between the static friction coefficient and the velocity-dependence parameter, and the influence of temperature on static friction. The proposed multiplicative form of rate-and-state friction provides a natural way of regularizing the constitutive behavior at low slip speed or stationary contact. This implies a more complex seismic cycle on weak faults than previously thought, with emerging slow-slip events, partial ruptures, and dynamic ruptures with multi-modal source-time functions, where only a simple earthquake sequence would develop on a strong fault. These findings are relevant to décollements along accretionary prisms and serpentinized shear zones near the brittle-ductile transition that may operate at low static strength.