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Accelerated creep of a landslide with slip rate and state dependent basal friction

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Slope motions vary over a range of timescales: from the rapid acceleration of catastrophic slope instabilities to the slow, transient acceleration punctuating an otherwise stationary or steadily creeping slope. We examine mechanisms for the latter by considering the transient behavior that emerges from the coupling of an evolving basal frictional strength with the deformation of the overlying material. We consider that slope movement is enabled by the initiation or acceleration of slip on a basal sliding surface. Some regions of the sliding surface may be sliding while others remain locked, or unruptured. We presume the sliding surface lies parallel to and a depth h below the ground surface. We limit ourselves to situations in which variations along slope occur over dimensions larger than the h, a so-called thin-slab representation, which may be particularly appropriate for translational mass movements and permits a simplified kinematic description and equilibrium condition for the overlying material. We further presume that stress transfer is primarily facilitated by elastic deformation of the overriding material. We assume that the frictional strength at a point along the base depends on both the instantaneous local sliding rate, V, as well as a measure of its history, or state. Such dependence is inferred from carefully conducted sliding friction experiments of geological materials, which formed the basis for this description [e.g., Dieterich, 1978; Ruina, 1983]. We consider a situation in which both the instantaneous response and the steady-state rate-dependence are rate-strengthening. Such rate-strengthening permits transient acceleration while suppressing instability.

Examining the response of such a creeping slope to an external loading, such as a sudden step in loading or rise in pore fluid pressure, we find that a transient acceleration is followed by a self-similar deceleration back to a steadily creeping or locked state. Numerical solutions to the evolution of basal slip rate and state in response to external forcing are matched with a perturbation analysis of the non-linear evolution of slip rate and state in the asymptotic limit of long time. The relaxation of slip rate following perturbation occurs in a diffusive manner, in which both spreading and decay of slip rate scales with the square root of time.