A Universal (?) Nanometric Flow Mechanism for Earthquake Sliding

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Earthquake instability requires fault weakening during slip. The mechanism of this weakening is central to understanding earthquake sliding. Here we show experimentally that in both high speed sliding at low pressure and faulting at high pressure, phase transformation plays a major role, yielding a profoundly weak nanocrystalline sliding zone or, rarely, melt. Microstructures preserved in the Punchbowl Fault, a deeply-eroded ancestral branch of the San Andreas Fault of California, and rare pseudotachylytes, are consistent with these observations. We propose that the physical mechanism of low-resistance sliding of most crustal and mantle earthquakes is flow by grain-boundary sliding of nanometric gouge that is formed either as the *cause* of sliding (high pressure) or as an early *consequence* of sliding (low pressure, high-speed). This mechanism intrinsically resolves two major conflicts between laboratory results and natural faulting -- lack of a thermal aureole around major faults (San Andreas Fault heat flow paradox) and the rarity of pseudotachylytes.

Shear localization due to thermal pressurization of pore fluids in rapidly sheared granular media

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Field observations of mature, well-slipped, earthquake fault zones show that the majority of shear is often localized to principal slipping zones of order 10-100 mm width within a broader gouge layer of order 10-100 mm wide (with all that being a feature locating within a much broader, 1-10s m wide, damage zone bordering the fault). Such fault gouges are often rate-strengthening, especially at higher temperatures, and are then resistant to shear localization under slow deformation.

We show that extreme localization is, instead, a predicted consequence of rapid straining, with related shear heating, of fluid-infiltrated gouge on time scales that are too short for significant pore-fluid drainage or heat conduction. The localization is due to development of highly elevated pore pressure, hence of lowered Terzaghi effective stress, from thermal expansion of the fluid (i.e., thermal pressurization of the pore fluid, when expansion is constrained by a low-permeability host).

Results are presented for two versions of the process: In the classical one, the pore fluid pre-exists in the gouge as groundwater. In another, the study of which was pioneered by J. Sulem and co-workers, thermal decomposition reactions in hydrated silicates (clays, serpentines) or carbonates within gouge are triggered as temperature rises, releasing as volatile a fluid phase (H2O or CO2) at high pressure.

The studies reported have been carried out in collaboration with, and with major contributions from, John D. Platt (Carnegie Institution, Washington, DC), John W. Rudnicki (Northwestern University), and Nicolas Brantut (University College, London). Some of the work is published in JGR in 2014 (doi: 10.1002/2013JB010710 and 010711) and some is in review there as of late 2014.

Marine Ice Sheet Dynamics Over Short and Long Timescales

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The dynamics of marine-based ice sheets, like the West Antarctic Ice Sheet, are of interest due to the possibility of catastrophic loss of ice as the ice sheet edge retreats in a warming climate. The migration of this "grounding line", the location where the ice sheet goes from overlying ground to overlying ocean water, is crucial to understand in order for accurate predictions of ice sheet stability to be made. In this work, we therefore consider two very different components of grounding line migration, one at tidal timescales and one pertaining to longer term stability.

In the first part of this talk, we address the problem of how grounding lines migrate due to tidal forcing. We find that using a crack model for the grounding line motion predicts the grounding line is not generally at hydrostatic equilibrium and furthermore that migration is inherently asymmetric and non-linear, with migration distances that are not proportional to the tidal load. In the second part of this talk, we address the problem of how ice sheet profiles and stability are modified with more realistic basal boundary conditions. Specifically, we introduce Coulomb friction as a modification to the standard power-law rheology and find that the basal rheology necessarily transitions to the Coulomb regime near the grounding line. With this new modification, we predict a "tapering off" of the ice sheet profile in a boundary layer near the grounding line which results in very different basal stresses. This, in turn, changes the long-term stability of the ice sheet, with the ice sheet becoming more sensitive to climate perturbations. In both parts of this talk, we therefore find new areas of ice sheet mechanics that must be accounted for in order to accurately predict the future of marine-based ice sheets.