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Thermo-Poro-Elastic Effects in Landslide Dynamics

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Landslides are a significant natural hazard, yet many aspects of the dynamics of slide initiation and motion remain unclear. We present analysis pertaining to the role of thermo-poro-elastic mechanisms in these dynamics. Thermo-poro-elastic (TPE) affects arise when a porous, fluid-filled, shear zone is heated, either via frictional heating during sliding or from external sources such as dikes. If fluid diffusion is relatively slow, elevated temperature will cause pore pressure to rise, reducing the layer strength and its resistance to sliding. This mechanism affects both the initiation and dynamics of slide motion. We present three separate studies, all linked by the common thread of thermo-poro-elasticity:

Large slide initiation: This study focuses on the enigmatic initiation of the largest known subaerial landslide, the Heart Mountain slide, where a whole mountain range slid 50 kms down a shallow slope, seemingly violating frictional considerations. Our field observations and theoretical calculations suggest that unique conditions occurred when magmatic dikes intruded in close sequence into a confined fluid-filled layer. The dikes elevated the temperature and via a TPE affect also the pore fluid pressure at a depth of 3 kms, until the fluid pressure exceeded the lithostatic stress, allowing a whole mountain range to detach and slide.

Stability during the initial stages of motion: Motion of a large rock mass down a slope can either take the form of a catastrophic landslide, or can exhibit self-stabilization, where the sliding mass arrests on the same slope over which motion was initiated, after moving only a short distance. Thermo-poro-elasticity mechanisms may control sliding stability via the permeability of the sliding mass: Low permeabilities lead to catastrophic landslides, by allowing high pore pressure to develop and friction to be reduced. In contrast, high permeabilities lead to rapid arrest by promoting pore pressure diffusion and thus do not promote friction reduction. A pore pressure- velocity phase plane is described, divided by a separatrix distinguishing between catastrophic and arrested sliding.

Why landslide runout distances increase with increasing slide size? Natural landslides, like the Heart Mountain slide, often exhibit surprisingly large travel distances, and an unexplained decrease in apparent friction coefficient H/L (where H is the drop height and L the travel distance) with increasing slide volume, V. We suggest that the TPE mechanism operating at the base of landslides may explain this behavior: Depth-dependent permeability controls pore pressure diffusion rates from the shear-heating shear-zone, allowing larger slides to maintain high pore pressure for longer times, thus resulting in larger travel distances L and a lower H/L. The numerically obtained relation between V and H/L agrees with field data of subaerial landslides. The study is then implemented for predicting the motion of Heart Mt landslide.