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Landslides of clayey soils: a dramatic avalanche behavior

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Quick clays are unstable soils that can be responsible for severe landslides, like the infamous Rissa landslide of april 1978 in Norway. Quick clay landslides are usually attributed to rheology modifications caused by changes in the water content, extraction of the salt by subsurface water drainage, and/or triggering by external mechanical perturbations. However, the extreme instability of these soils has until recently remained poorly understood.

Quick clay is a thixotropic material, in which aging competes with shear rejuvenation. We study various samples of a natural quick clay from Tiller, near Trondheim (Norway). Rheometry measurements are done by having the material flow under an imposed constant shear stress. The bifurcation observed in the rheology as a function of the imposed stress magnitude provides a precise measurement of the yield stress, and evidences that it strongly depends on the water content. When the material is resting on a plane slope, the amount of shear stress that it must sustain is related to the plane inclination; if the inclination is large enough, the material below a yield surface parallel to the plane is susceptible to flow. For a sample with a clay content of 61%, the resulting flow is that of a classic yield stress fluid, however for a clay content of 59% a dramatic avalanche regime is observed. In the latter "landslide" regime, flow is strongly localized in a thin lubrication layer on which most of the material slides while undergoing little deformation. This is typically what was observed during the Rissa landslide: houses and trees sliding upright down the slope. The landslide regime also results in a much larger travel distance, and in a final deposit height that is independent of the plane inclination.

We propose a simple mechanical model that explains the laboratory landslide observations and allows us to relate them to the mechanical behavior measured in the rheometer. We also prepare a "synthetic quick clay" with mechanical properties identical to those of the natural quick clay at all salt concentrations. We show that the presence of a few percent of swelling clay is crucial, and that there exists a range of salt concentration for which the material's elastic modulus is highly dependent on the salt concentration. This is an evidence of the lansdslide-triggering effect of salt washing by water.

Reference:

A. Khaldoun et al., Phys. Rev. Lett **103**, 188301 (2009)