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# A weakening rheology of dry granular flows with extensive brittle grain damage

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The puzzle of the unexpectedly high mobility of large geophysical flows has been reported as solved many times since Albert Heim drew attention to it after a disastrous landslide at Elm, Switzerland. Many hypotheses have been proposed to explain the hyper-mobility, however, no consensus position has emerged in more than a century, and debate rages on. We conducted experiments shearing samples of granular materials of different hardness, at different normal stresses and different shear strain rates using high-speed rotary machine. These experiments were shear-strain controlled by applying a variable but known rotary shear speed. We sheared granulated quartz, dolomite, fluorspar and halite. We show a new trend of dense granular flow behaviour above 0.3 MPa with weakening at high strain rate, which may be explained by shear-thinning thixotropy (Fig. 1). Experimental results for a given shear rate at normal stresses between 0.3 and 1 MPa show a bifurcation in shear-resistance behaviour (Fig. 1). The trend of all our data deviates obviously from the traditional rheological model. We identified three regions of dense granular flow: a static region, an inertial region and a weakening region at increasing strain rate in grain flows that result in widespread grain breakage. The former two regions agree with the traditional rheological model established at lower normal stresses, however instead of entering a collisional region, a weakening region appeared. For gravitational flows, it is possible for unstable flows to occur for certain combinations of normal stress and shear strain rate. An underlying mechanism of grain crushing may greatly reduce the shear resistance due to thixotropy, which accelerates the flow and in turn causes more crushing and additional resistance reduction. The profound weakening provides a natural explanation for the observed high mobility in such geophysical behaviour as the long runout of rock avalanches, fault weakening, impact-crater evolution and pyroclastic flows.

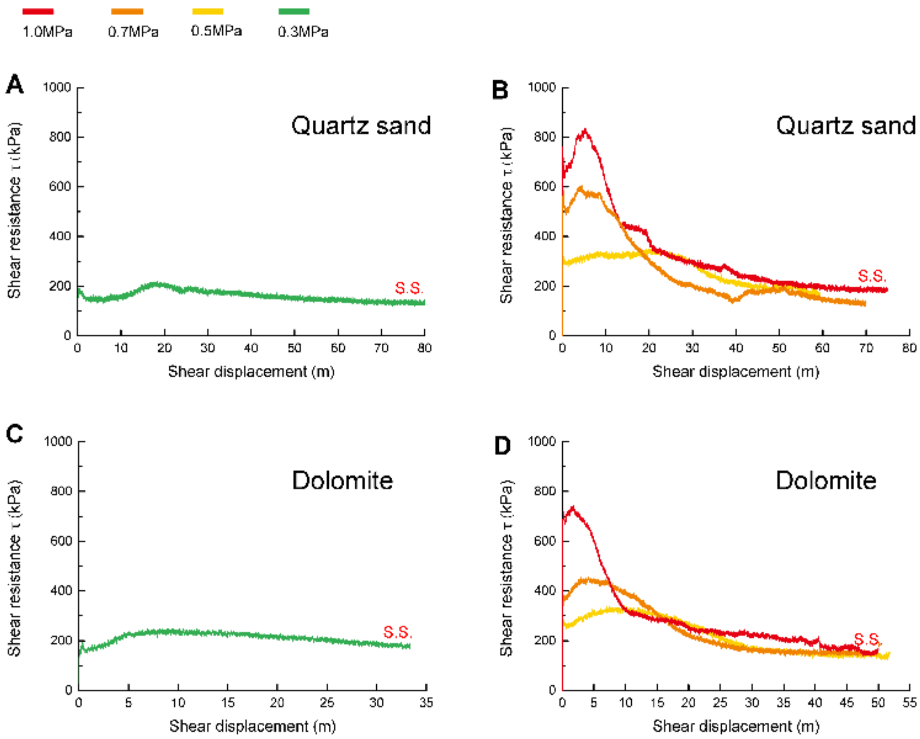


Figure 1 Variation of shear resistance with respect to shear displacement for different crushable materials under different normal stresses with 1 m/s shear speed

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