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Effect of clay type on the velocity and run-out distance of cohesive sediment gravity flows

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Novel laboratory experiments in a lock-exchange flume filled with natural seawater revealed that sediment gravity flows (SGFs) laden with kaolinite clay (weakly cohesive), bentonite clay (strongly cohesive) and silica flour (non-cohesive) have strongly contrasting flow properties.

Knowledge of cohesive clay-laden sediment gravity flows is limited, despite clay being one of the most abundant sediment types on earth and subaqueous SGFs transporting the greatest volumes of sediment on our planet. Cohesive SGFs are particularly complex owing to the dynamic interplay between turbulent and cohesive forces. Cohesive forces allow the formation of clay flocs and gels, which increase the viscosity and shear strength of the flow, and attenuate shear-induced turbulence.

The experimental SGFs ranged from dilute turbidity currents to dense debris flows. For each experiment, the run-out distance, head velocity and thickness distribution of the deposit were measured, and the flow properties were recorded using high-resolution video.

Increasing the volume concentration of kaolinite and bentonite above 22% and 17%, respectively, reduced both the maximum head velocity and the run-out distances of the SGFs. We infer that increasing the concentration of clay particles enhances the opportunity for the particles to collide and flocculate, thus increasing the viscosity and shear strength of the flows at the expense of turbulence, and reducing their forward momentum. Increasing the volume concentration in the silica-flour laden flows from 1% to 46% increased the maximum head velocity, owing to the gradual increase in excess density. Thereafter, however, intergranular friction is inferred to have attenuated the turbulence, causing a rapid reduction in the maximum head velocity and run-out distance as suspended sediment concentration was increased.

Moving from flows carrying bentonite via kaolinite to silica flour, a progressively larger volumetric suspended sediment concentration was needed to produce similar run-out distances and maximum head velocities. Strongly cohesive bentonite flows were able to create a stronger network of particle bonds than weakly cohesive kaolinite flows of a similar concentration, thus producing the lower maximum head velocities and run-out distances observed. The lack of cohesion in the silica-flour laden flows meant that extremely high suspended sediment concentrations, i.e. close to the cubic packing density, were required to produce a high enough frictional strength to reduce the forward momentum of these flows.

These experimental results can be used to improve our understanding of the deposit geometry and run-out distance of fine-grained SGFs in the natural environment. We suggest that natural SGFs that carry weakly cohesive clays (e.g. kaolinite) reach a greater distance from their origin than flows that contain strongly cohesive clays (e.g. bentonite) at similar suspended sediment concentrations, whilst equivalent fine-grained, non-cohesive SGFs travel the furthest. In addition, weakly cohesive SGFs may cover a larger surface area and have thinner deposits, with important ramifications for the architecture of stacked event beds.