Formation of stable aggregates by fluid-assembled solid bridges

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Earth’s surface is covered with soil; particulate mixtures subject to cycles of wetting and drying. The role of this transient hydrodynamic forcing in creating and destroying aggregates is virtually unexplored. We examine this process at the grain scale. When a colloidal suspension is dried, capillary pressure may overwhelm repulsive electrostatic forces, assembling aggregates that are out of thermal equilibrium. This poorly understood process confers cohesive strength to many geological and industrial materials. Here we observe evaporation-driven aggregation of natural and synthesized particulates, and then probe their stability under rewetting using a microfluidics channel as a flume to determine the entrainment threshold. We also directly measure bonding strength of aggregates using an atomic force microscope. Cohesion arises at a common length scale (~5 microns), where interparticle attractive forces exceed particle weight. In polydisperse mixtures, smaller particles condense within shrinking capillary bridges to build stabilizing “solid bridges” among larger grains. This dynamic repeats across scales forming remarkably strong, hierarchical clusters, whose cohesion derives from grain size rather than mineralogy. Transient capillary pressures are even sufficiently large to sinter the smallest particles together. These results may help to understand the strength and erodibility of natural soils, and other polydisperse partcicates that experience transient hydrodynamic forces.