Cohesion dictates (in)stability of soils
Soil aggregates, and what makes them

Paradigm: clay is ‘sticky’

Kaolinite particle

In suspension: electrostatic charge determines stability

Drying: can drive particles together → overcome electrostatic repulsion

Wetting: hydration effects become important

Can form aggregates when theory says we shouldn’t. Are they stable?
Let’s make some aggregates by drying

**Step 1: Evaporation and aggregation**

A simple ‘synthetic soil’:

Water droplet containing 20 micron and 3 micron silica spheres.

Retreating water interface condenses particles.

Droplet breaks into ‘islands’ around big particles.

Small particles condense in capillary bridges, are squeezed.

**Evaporation of a bidisperse suspension**
Evaporation of droplet with 20- and 3-micron particles
Let’s (try to) erode some aggregates: a tiny flume

Step 2: Rewetting and transport

B

PDMS cell

Channel depth 100 μm

Deposit

Flow

Outlet

Peristaltic pump

Stage

Microscope objective

CCD camera

Liquid

Capillary force of water–air interface pushes particles.

After that, drag force keeps pushing.

Some aggregates are unstable, some are stable.

What determines stability?
Deposit of 20-micron (large) particles: UNSTABLE to rewetting
Add some small (3-microns and less) particles: Bingo-bango, STABLE aggregates!
“Solid bridges” make stable aggregates. **How?**

Fluid stress overwhelms electrostatic repulsion: → pushes particles into “van der Waals well”. They stick together.

Experiment with **4** different particle sizes → bridges within bridges within bridges. **Fractal aggregates.**
Measuring strength of solid bridges with AFM

Measure pull-off force (curve), and total pull-off energy (bar chart), for:

- a single 20-micron particle

- a 20-micron particle bonded to 3-micron particles

- a 20-micron particle bonded to 3, 0.4 and 0.02 micron particles.

Force jumps: distinct bond breaking events!

Solid bridging: small particles are bonded by van der Waals.
→ Small particles make cohesion.
SIZE, NOT MINERALOGY, dictates cohesion!

**Illite clay particles WITH small particles:** STABLE (sticky)

- Illite clay particles WITH small particles: STABLE (sticky)
- Clay is NOT sticky if you remove particles < 5 microns!!

**Illite clay particles WITHOUT small particles:** UNSTABLE

- Illite clay particles WITHOUT small particles: UNSTABLE
- Particles stuck, NOT moved
- Particles removed by flow
Rewetting of Illite mixture (w/ small grains): STABLE aggregates
Rewetting of Illite w/ < 5-micron grains REMOVED: UNSTABLE aggregates

A COHESIONLESS CLAY AGGREGATE!!
WHAT WE LEARNED

- Significance of interfacial capillary forces
- Role of particle size
- Granular origins of cohesion
- Origins of cohesion in natural soils
- New Experimental Avenues
  - Contaminant transport
  - Collapsible soils
The unstable monodisperse illite clay aggregates can be stabilized using a small concentration (0.04 wt %) of silica nanoparticles (0.4 μm), through the solid bridging mechanism.