PARTICLES BREAKING OUT OF DEBRIS FLOWS

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Debris flows

- Fast moving, subaerial gravitational flows of water, sediments and coarse material (rocks, trees boulders)
- A general term encompassing lahars, landslides, jökulhlaups.

e.g. Vargas, Venezuela 1999

- With our debris flow experiments we want to
  - Understand the effect of various flow variables, e.g. surface roughness, particle size
  - Use large particle sizes to (try and) achieve Froude and particle Reynolds number similarity
  - Simultaneously measure velocity profiles, pore pressure and basal shear and normal stress

Design Criterion - Similarity

- Always difficult in particle laden flows!

Parameter	Name	Force Balance	Notts Chute	USGS Chute	1982 Oddstad
$N_{\mathrm{Bag}} = \dfrac{\phi_s \rho_s d^2 \dot{\gamma}}{(1-\phi_s)\,\mu}$	Bagnold number	Inertial grain stress to viscous shear stress	2	400	4
$N_{\mathrm{Sav}} = \dfrac{\rho_s d^2 \dot{\gamma}^2}{(\rho_s - \rho_f)\, gh \tan\theta}$	Savage number	Inertial grain stress to friction	0.2	0.2	2×10^{-4}
$N_{\mathrm{fric}} = \dfrac{N_{\mathrm{Bag}}}{N_{\mathrm{Sav}}}$		Friction to viscous shear stress	9	2×10^3	2×10^4
$N_{\mathrm{mass}} = \dfrac{\phi_s}{(1-\phi_s)} \dfrac{\rho_s}{\rho_f}$	Mass number	Solid to fluid inertia	1	4	4
	c.f. Stokes number				
$N_{\mathrm{Rey}} = \dfrac{N_{\mathrm{Bag}}}{N_{\mathrm{mass}}}$	c.f. Reynolds number	Fluid inertial stress to viscous shear stress	2.5	100	1
$\mathrm{Fr} = \dfrac{u}{\sqrt{gh}}$	Froude number	Inertial to gravitational	0.6	10	3

Data from
Iverson Richard M., 1997, Physics of debris flows, *Rev. Geophys 35, 3, 245-296*

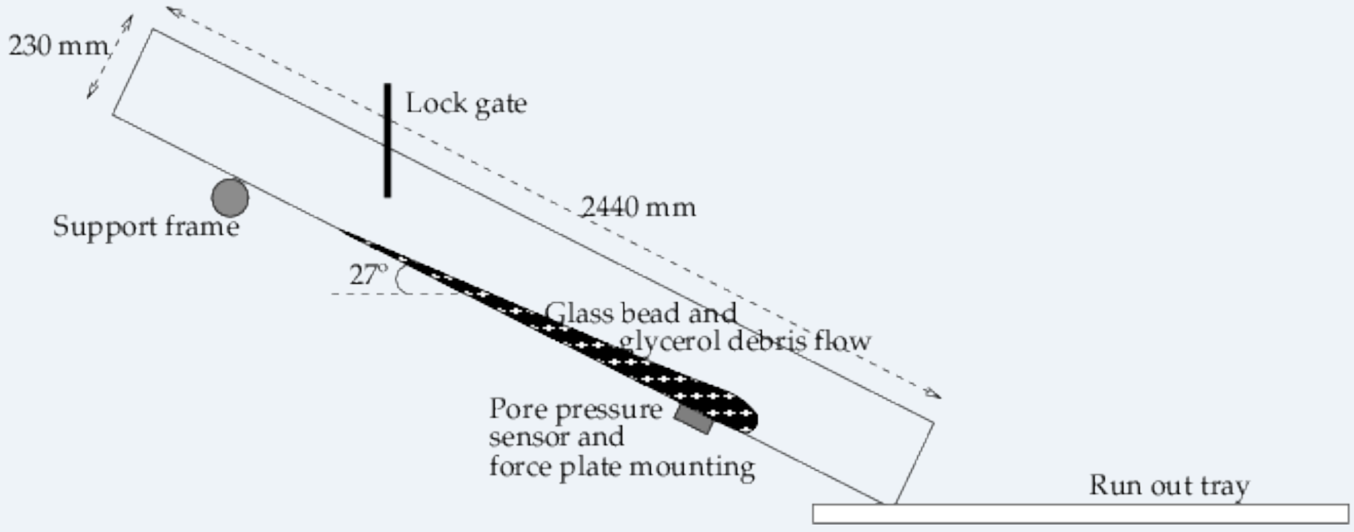
Experiment Design

2D CHUTE

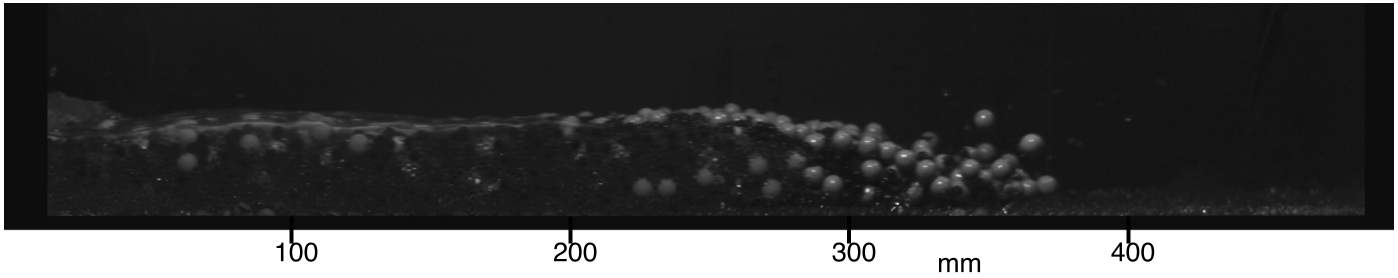
Lock release

Variable	Notation	Values	(units)
Solids volume fraction	ϕ_s	0.6	
Volume of solids	$\phi_s V$	1	litre
Roughness length	$[d_{r1},\ d_{r2},\ d_{r3}]$	[2, 4, 8]	$\times 10^{-3}\,\mathrm{m}$
Angle of inclination	θ	$27°$	
Solids: glass beads			
Density	ρ_s	2600	$\mathrm{kg\,m^{-3}}$
Diameter	$[d_1,\ d_2,\ d_3]$	[2, 4, 8]	$\times 10^{-3}\,\mathrm{m}$
Fluids: water, glycerol			
Density	$[\rho_{f1},\ \rho_{f2}]$	[1000, 1260]	$\mathrm{kg\,m^{-3}}$
Viscosity	$[\mu_1,\ \mu_2]$	[1.41, 0.8]	$\mathrm{Pa\,s}$

Experiment


230 mm
Lock gate
2440 mm
Support frame
27°
Glass bead and
glycerol debris flow
Pore pressure
sensor and
force plate mounting
Run out tray

What happens?



- Snout formation
- Longitudinal and vertical particle size and volume fraction variation
- Distinct collisional and continuum regions

Flow regimes

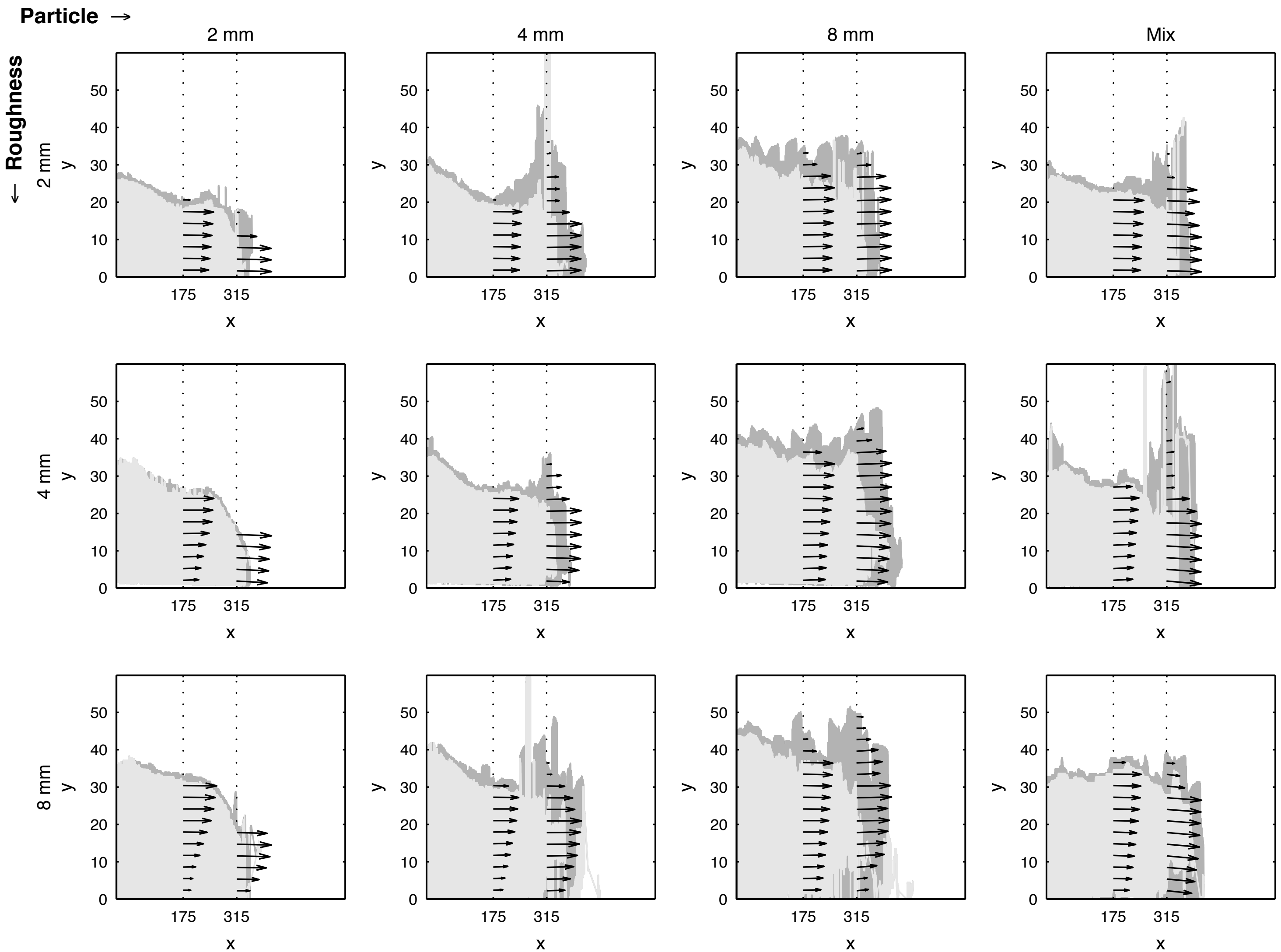
Quivers scaled by 0.1

SD>150 mm s^{-1} Granular region, dark grey

Low SD, viscoplastic, pale grey

14 frame (0.2 s) averages

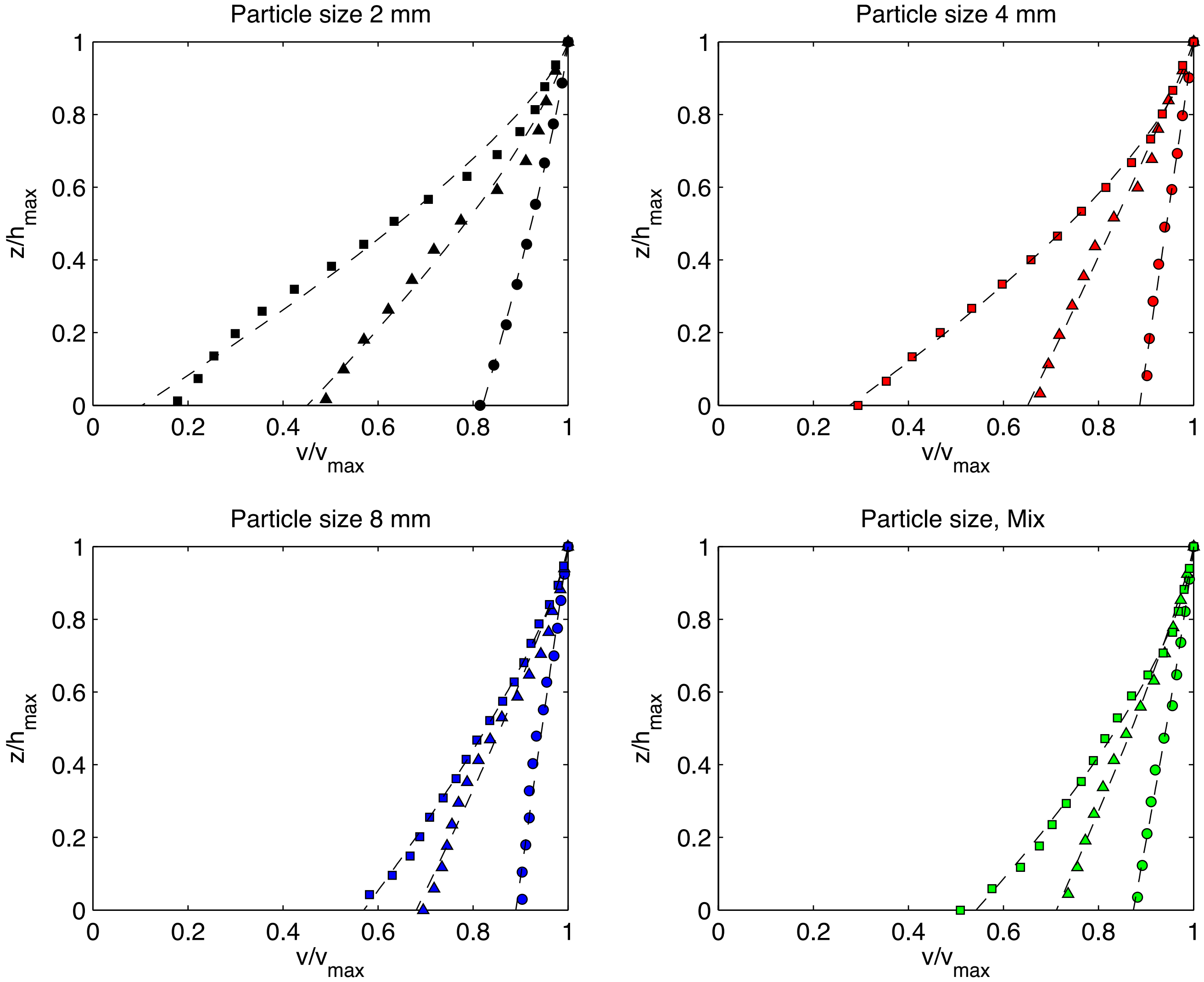
Velocities 600--1000 mm s^{-1}



Power law profiles

By particle size

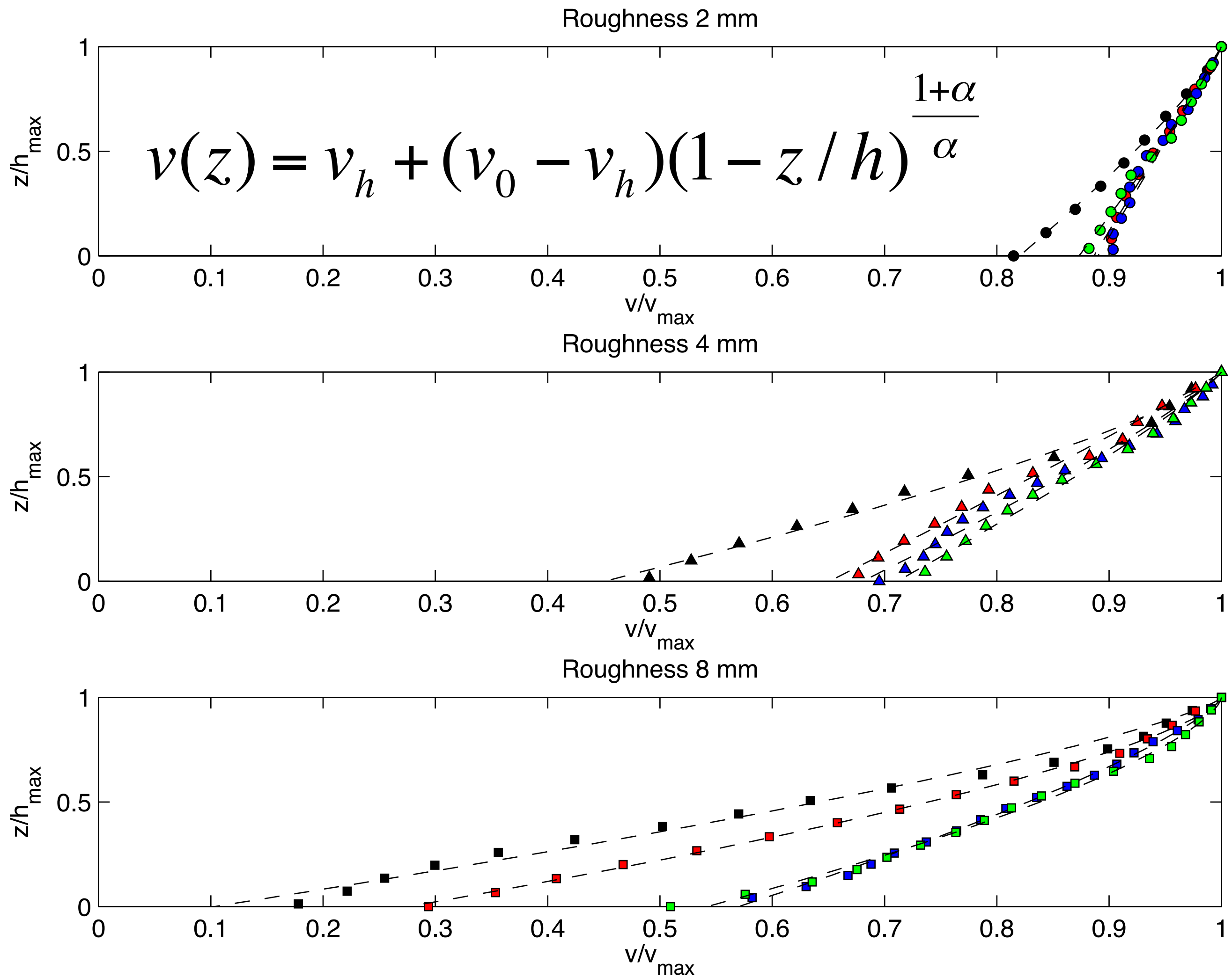
Roughness increases in the order circles, triangles, squares



Power law profiles

By roughness length

Particle size increases with black, red, blue. Green is a mixture

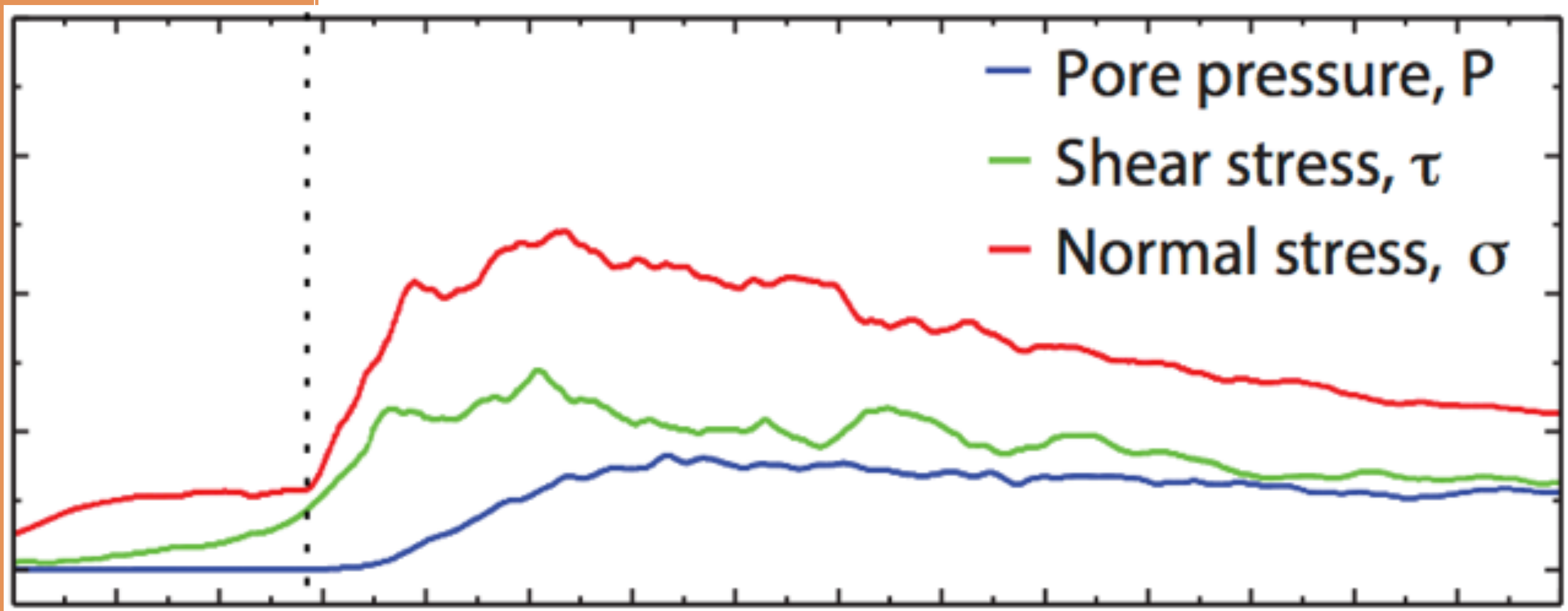


$$v(z) = v_h + (v_0 - v_h)(1 - z/h)^{\frac{1+\alpha}{\alpha}}$$

Pressures

4mm particles

8mm roughness

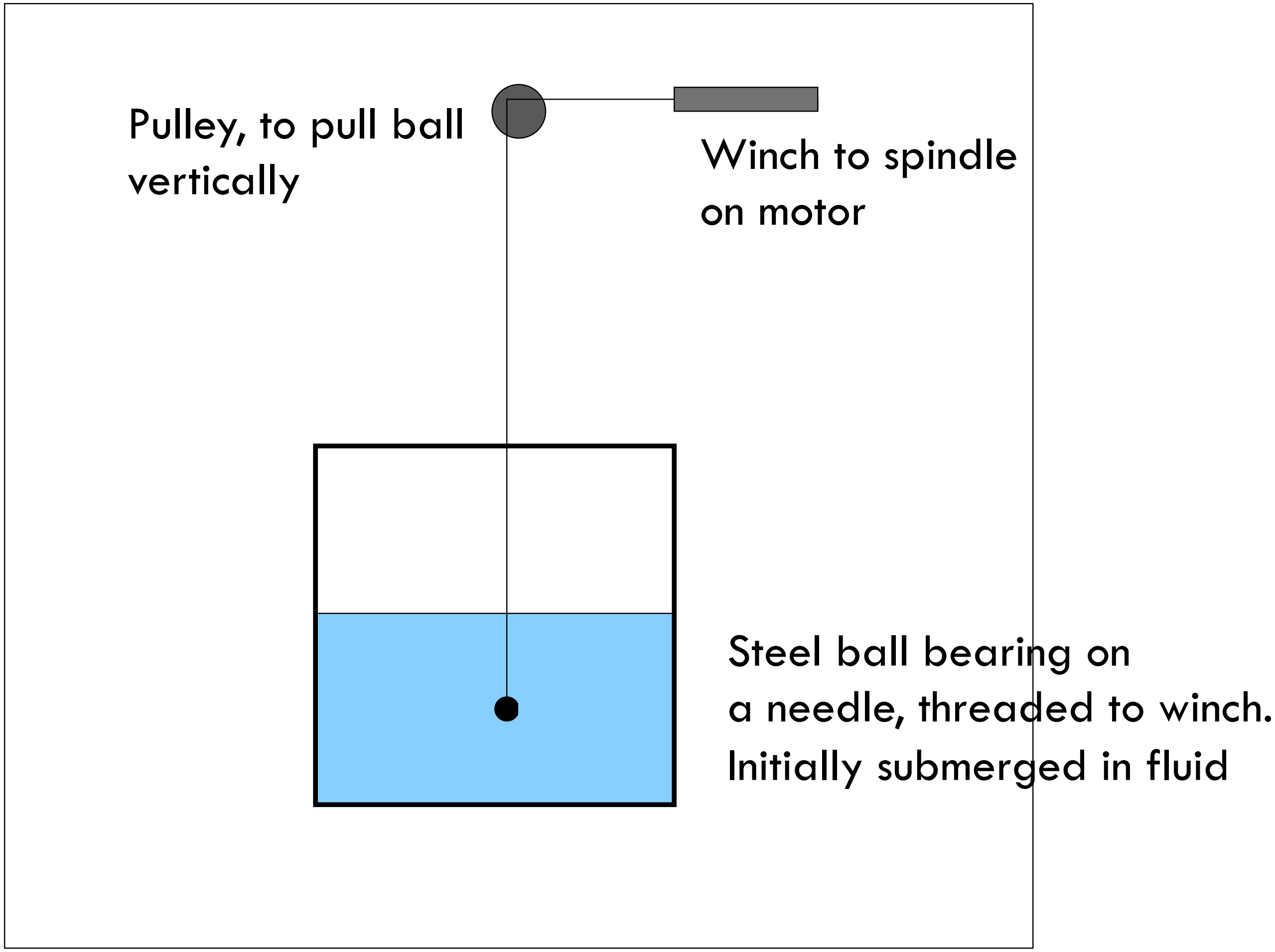


- This is a method for systematically determining the extent of continuum versus intermittent/collisional behaviour within a laboratory debris flow
- Roughness is only important in the when the roughness length is greater than or equal to the mean particle size
- But, we see that snout-body architecture formation does not require mixtures of particle sizes

What about saturation?

- So if all that snout and body architecture needs is for the may-or-may-not be larger material at the top to be moving more quickly than the rest of the flow, then the level of saturation should be important
- While rebuilding the chute to investigate this, I was wondering over what range a particle leaving a fluid surface remained ‘in touch’ with the surface

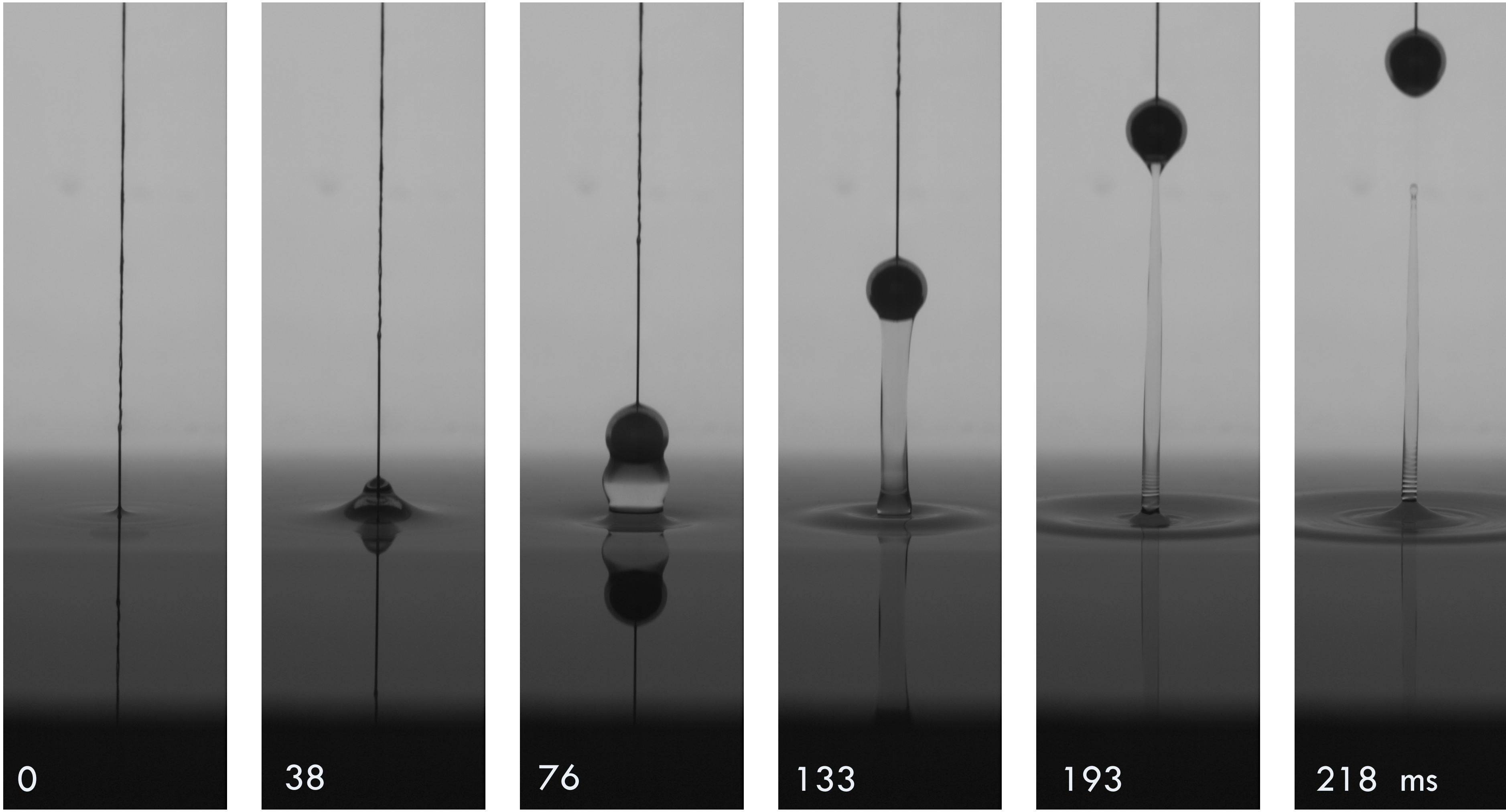
To start with, consider one….



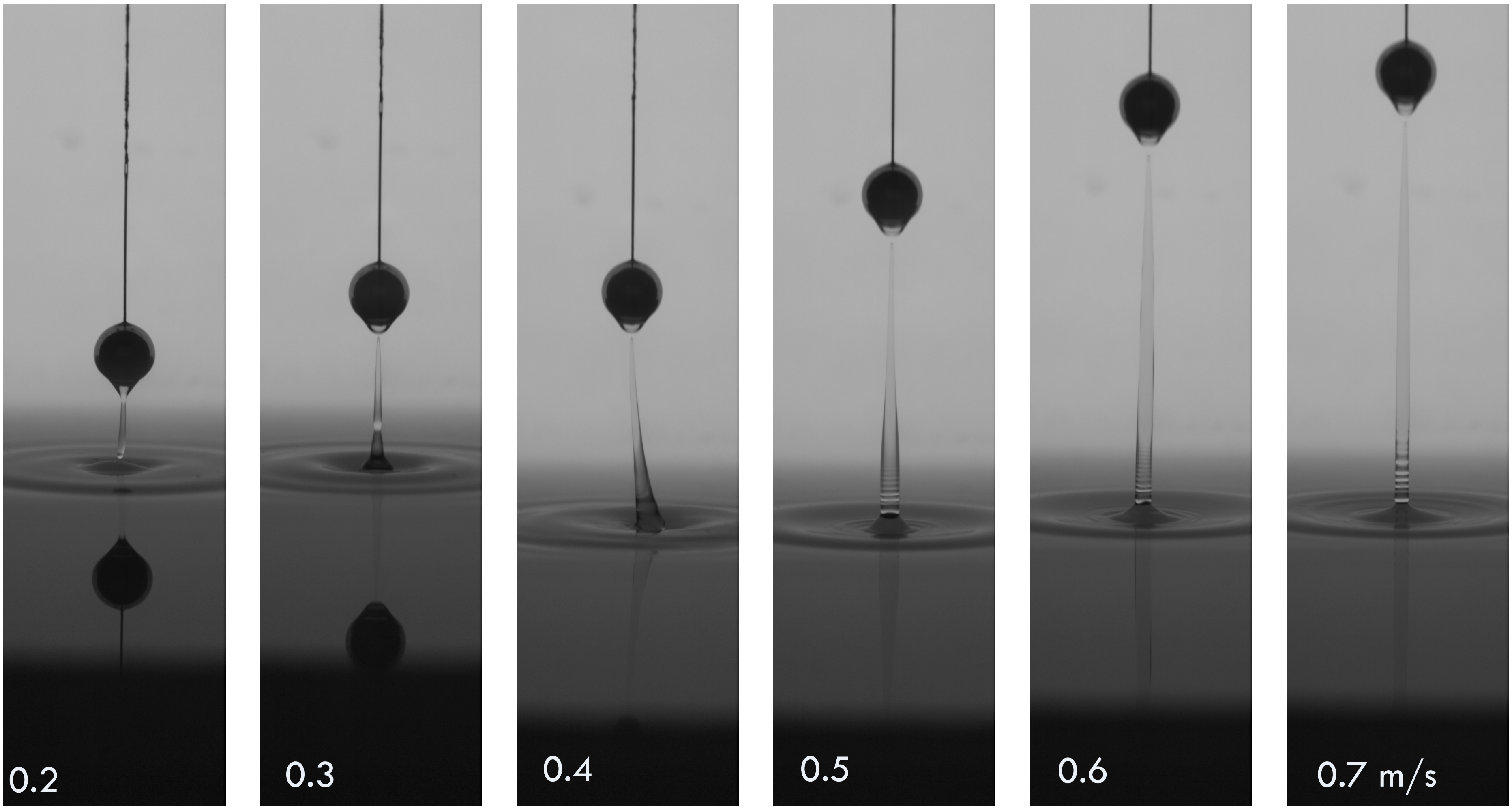
Experiments

- Particle diameters: 4, 6, 8, 10, 12 mm
- Winch speeds: 02, 0.3, 0.4, 0.5, 0.6, 0.7 m/s
- Fluids: Water, Kaolin solution (10% vol)

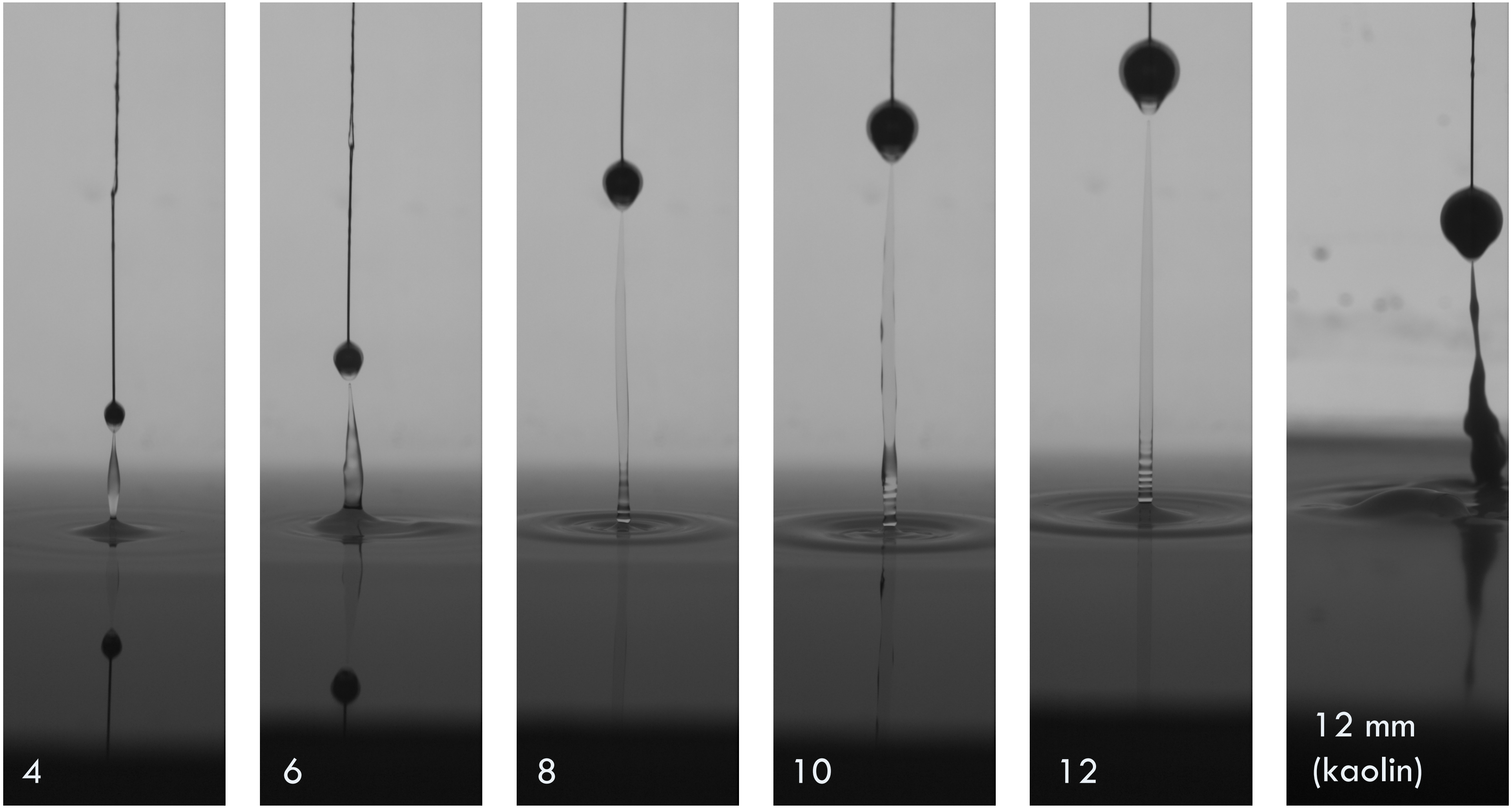
What happens?



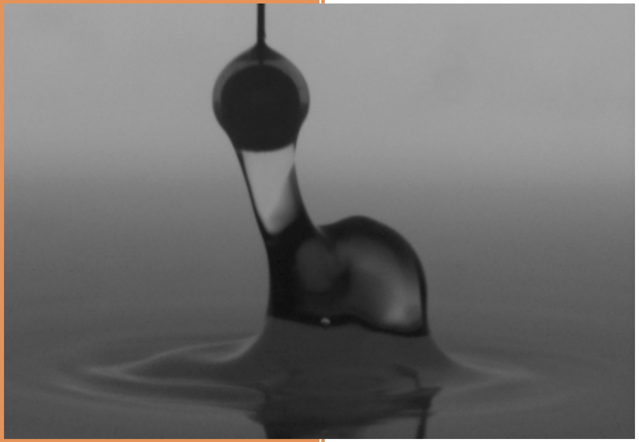
Variation with winch speed, 12 mm



Variation with particle size (0.7 m/s)

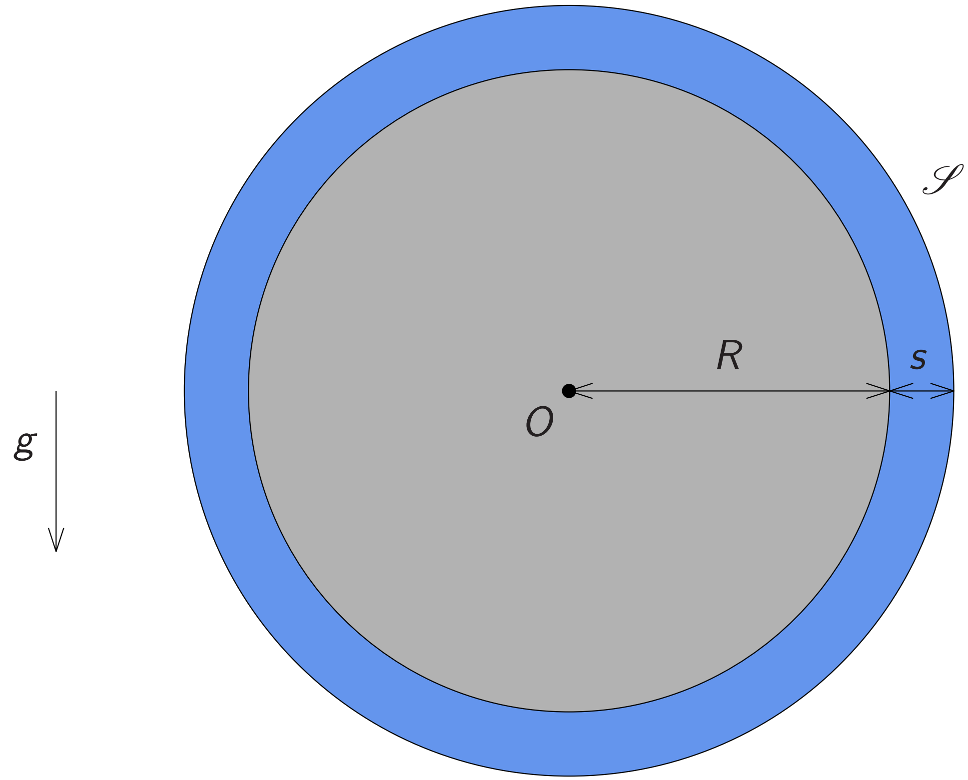


Ejection jet



- As the particle exits the surface, it leaves behind a little vortex ring
- This continues to accelerate fluid through it after the particle has left
- It may even *accelerate* the particle
- A force balance allows to estimate a timescale $T_j = \frac{u}{g}$

Draining flow



Stokes flow in a thin layer, invoke lubrication assumptions. Short time asymptotics…

Draining timescale

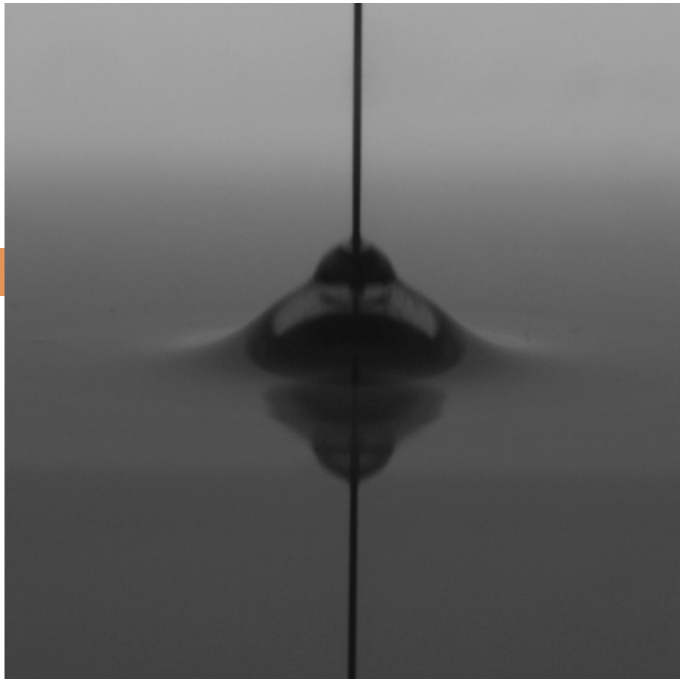
This draining flow has a layer Reynolds number that looks like

$$\mathrm{Re}_l = \frac{g(\varepsilon R)^3}{\nu^2}$$

and, without surface tension, that leads to a timescale

$$T_d = \frac{\nu}{\varepsilon R g}$$

Clearly, this depends on the original layer thickness



Coating

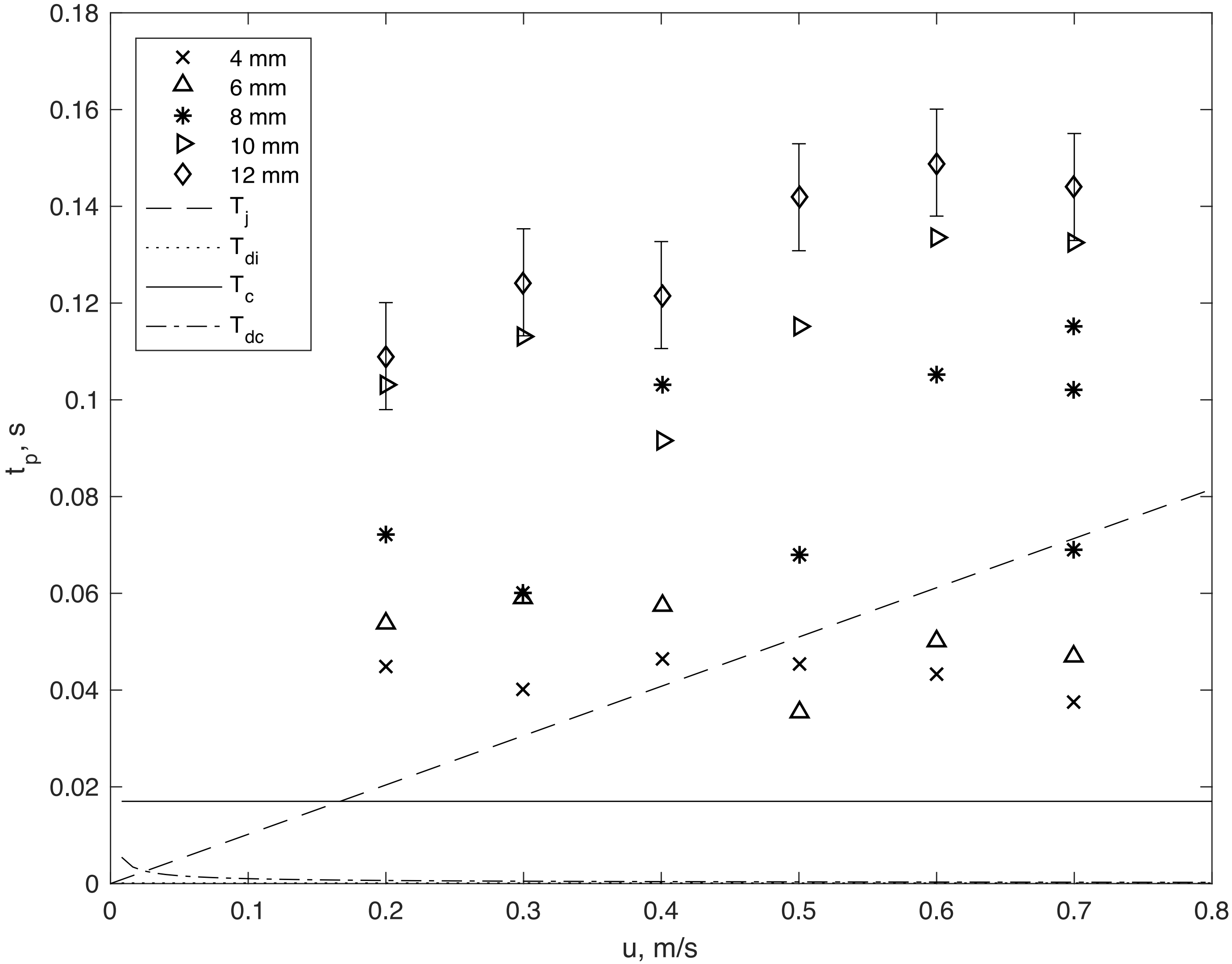
- So how thick is the initial layer in this draining problem? i.e. ε
- 1. Inertial?
- 2. Capillary?
- If inertial, then I can imagine that the fluid that gets dragged with the particle is the added mass
- If capillary, (Ca<<1, ours are ~10^{-2}), the coat thickness varies with $Ca^{2/3}$

(Landau Levitch 1942) $\mathrm{Ca} = \frac{u\nu\rho}{\gamma}$

Timescales

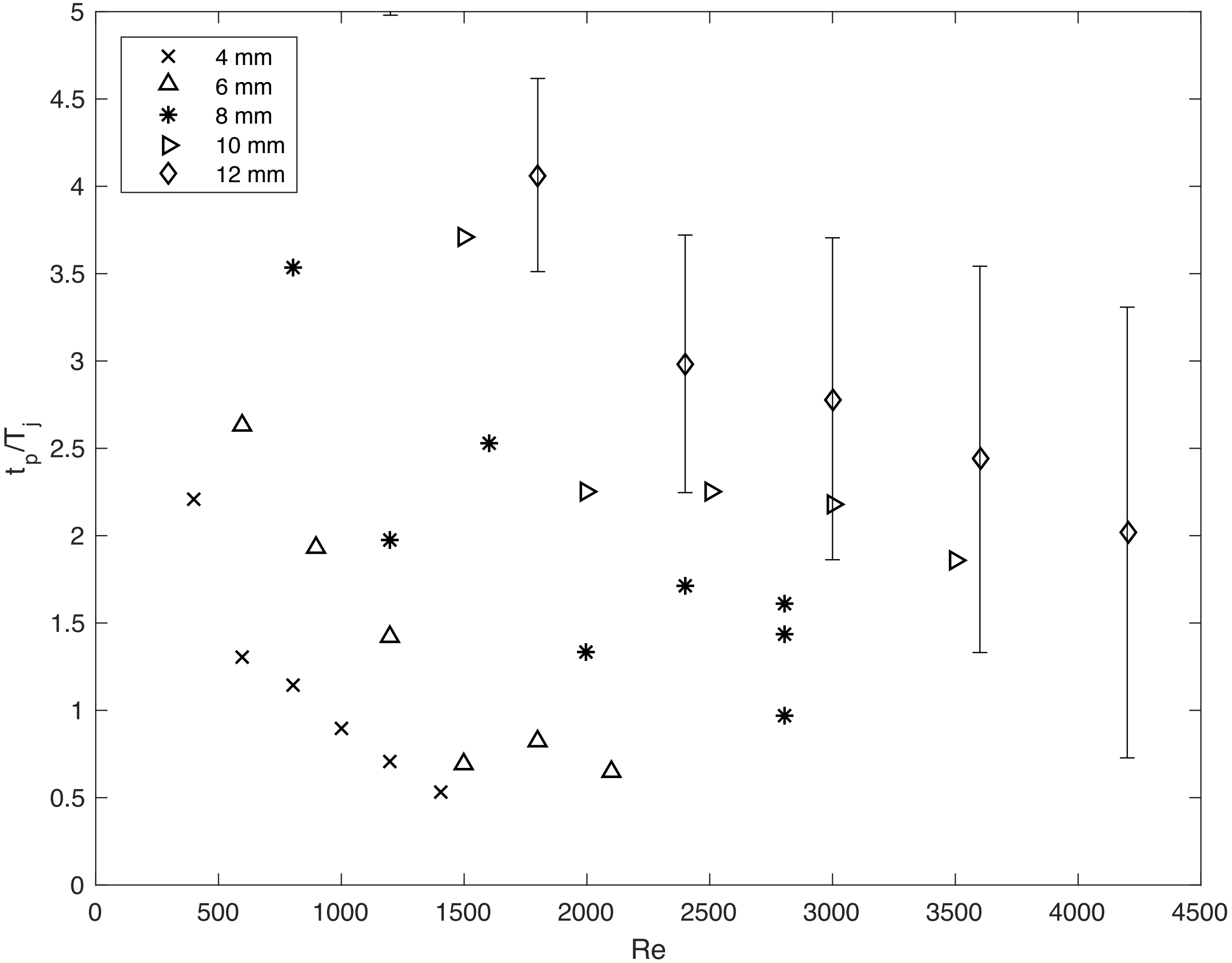
- Ejection jet $$T_j = \frac{u}{g}$$
- Draining $$T_d = \frac{\nu}{\varepsilon R g}$$
  - where $\varepsilon = \mathrm{Ca}^{2/3}$
  - or $\varepsilon = 0.14$

Raw data

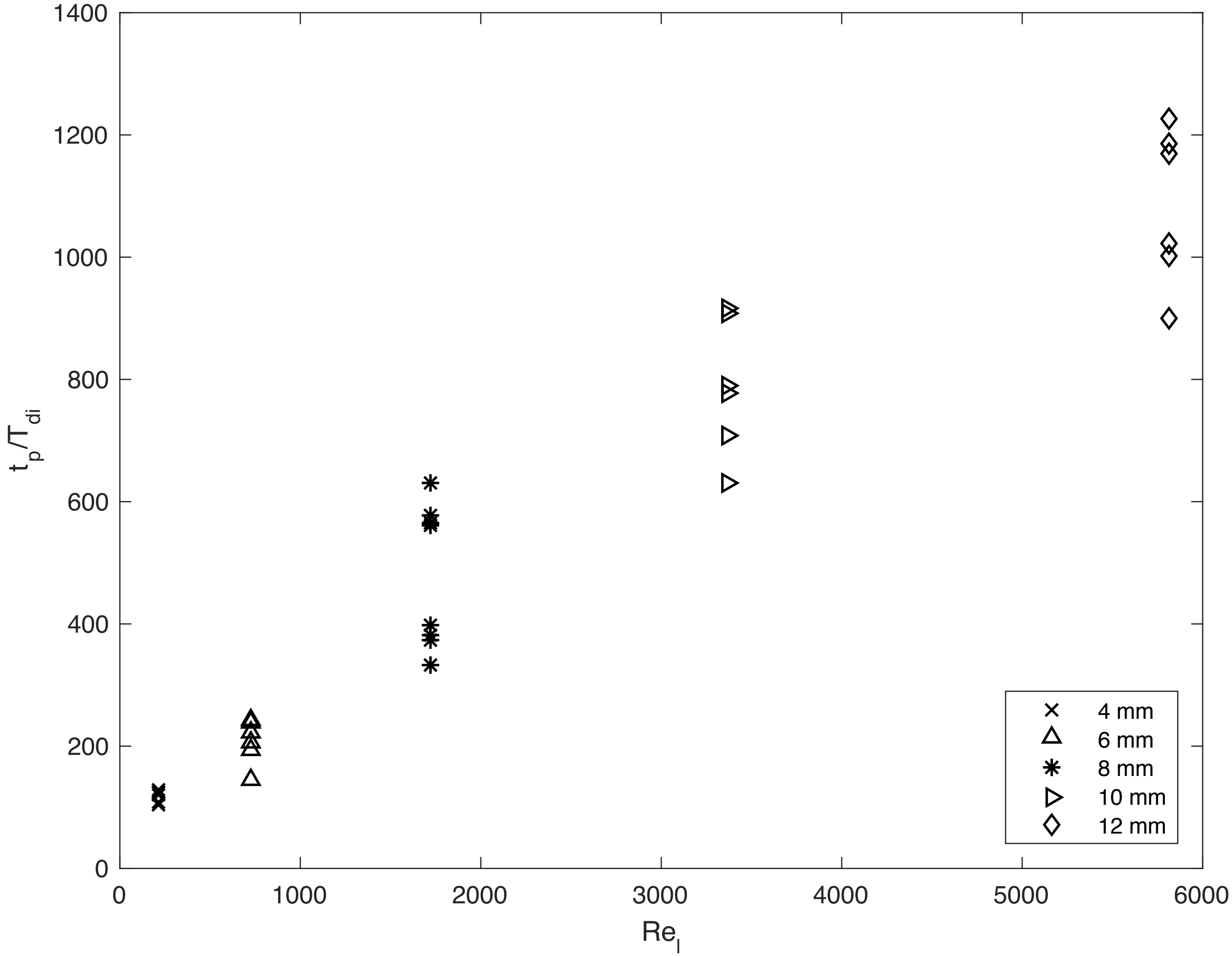


4 mm
6 mm
8 mm
10 mm
12 mm
T_j
T_{di}
T_c
T_{dc}
t_p, s
u, m/s
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

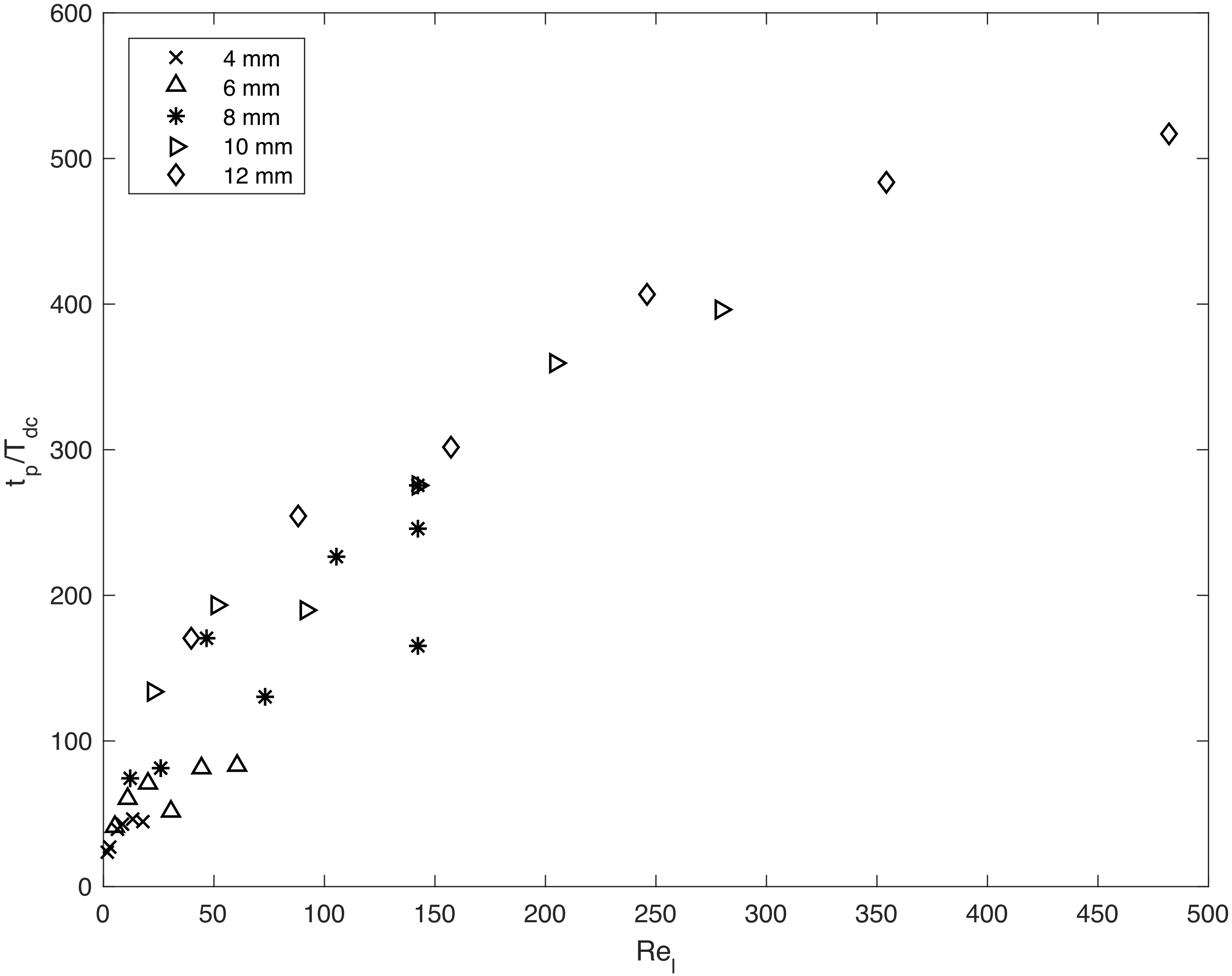
Ejection jet scaling



Draining scaling, 'inertial coating'



Draining timescale, ‘capillary coating’



So…

- The sustaining of the tendril scales more convincingly with time scales inferred from analysis of the draining flow
- But this itself depends on the way in which the particle became coated
- Include surface tension in the draining flow
- I would have done the experiments a bit differently if I had known this!

In reality?

- Rarely have real debris flows where a particle could eject in this way
- But this might give a handle on the extent of the 'intermittent' zone
- Or why particles stay *in* the flow
- More significant for lab flows