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MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HIKINA WHAKATUTUKI
NATURAL HAZARDS RESEARCH PLATFORM
VOLCANIC RISK SOLUTIONS

How pyroclastic flows outsmart granular friction during volcanic eruptions

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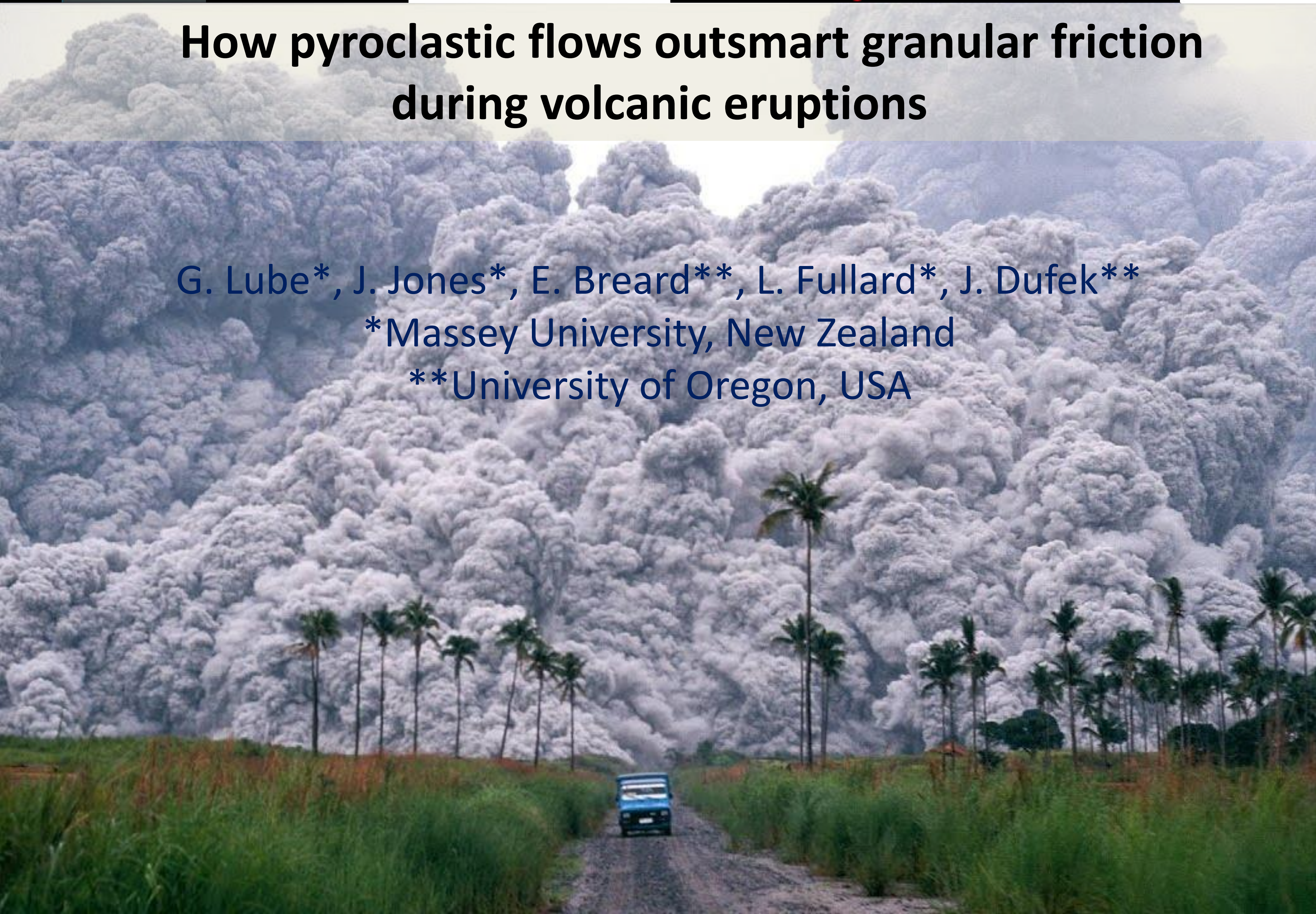
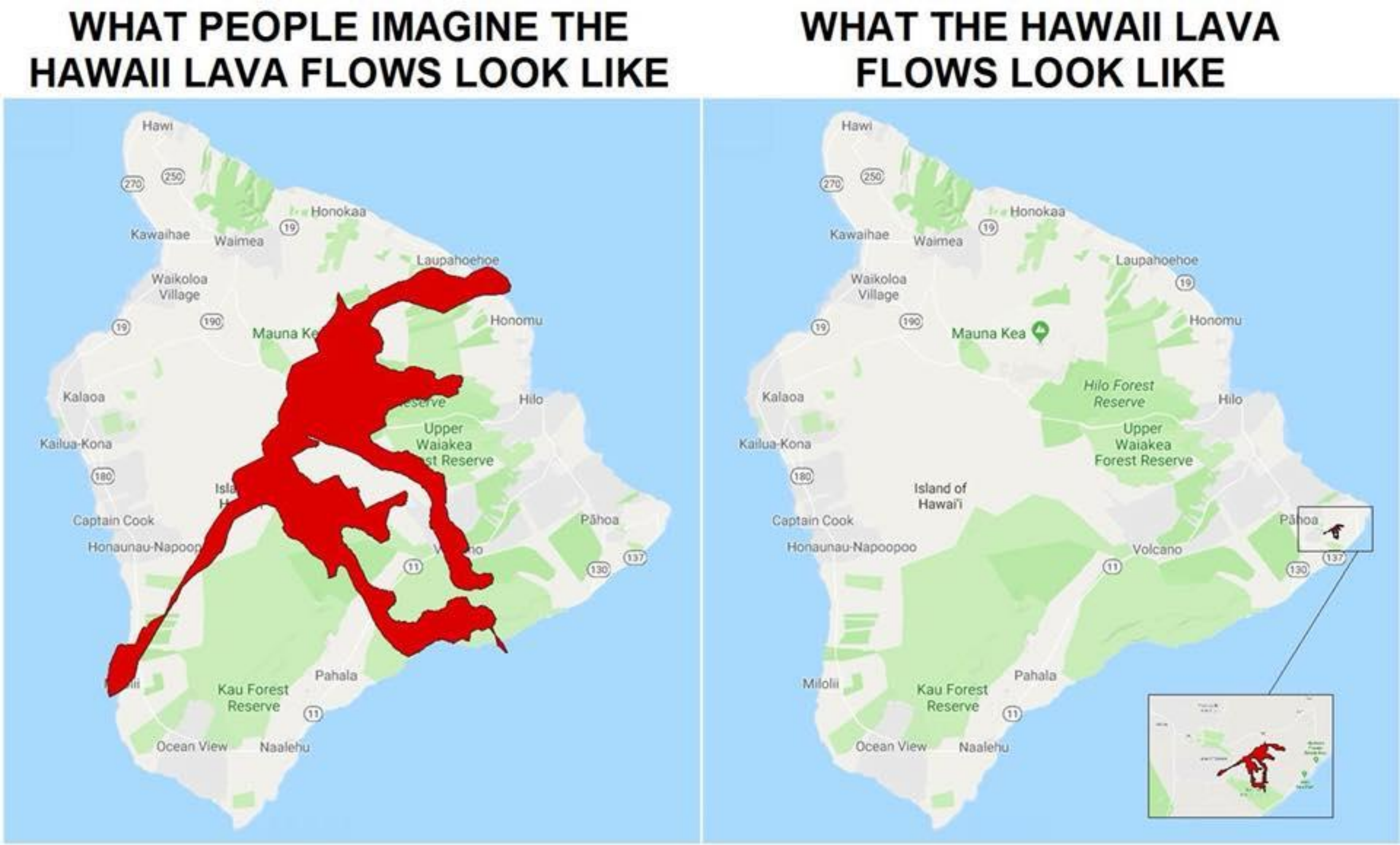


2018 Eruption of Pu’u ‘O‘o crater Hawaii

2018 Eruption of Fuego volcano, Guatemala



Casualties Hawaii: ZERO

Fatalities Fuego: >1,000

Volcanic Risks

Volcanic Phenomena

Pyroclastic flows

>50 %

Lahars

20 %

Ash

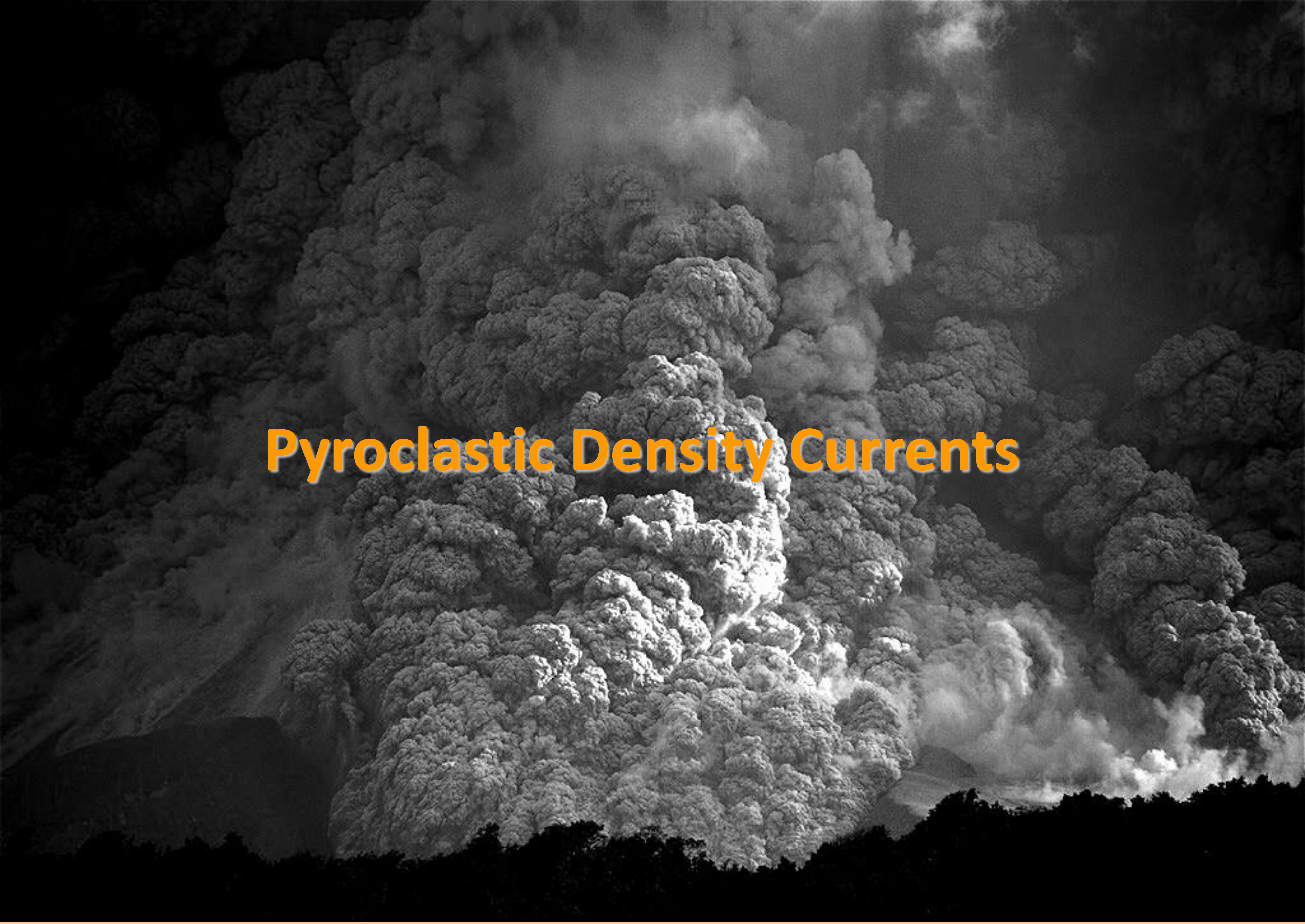
25 %

Lava

4.5 %

Fatalities

Pyroclastic Density Currents



Mixtures of hot volcanic particles and gas flowing along the ground

PDC Hazards: PDCs kill through…

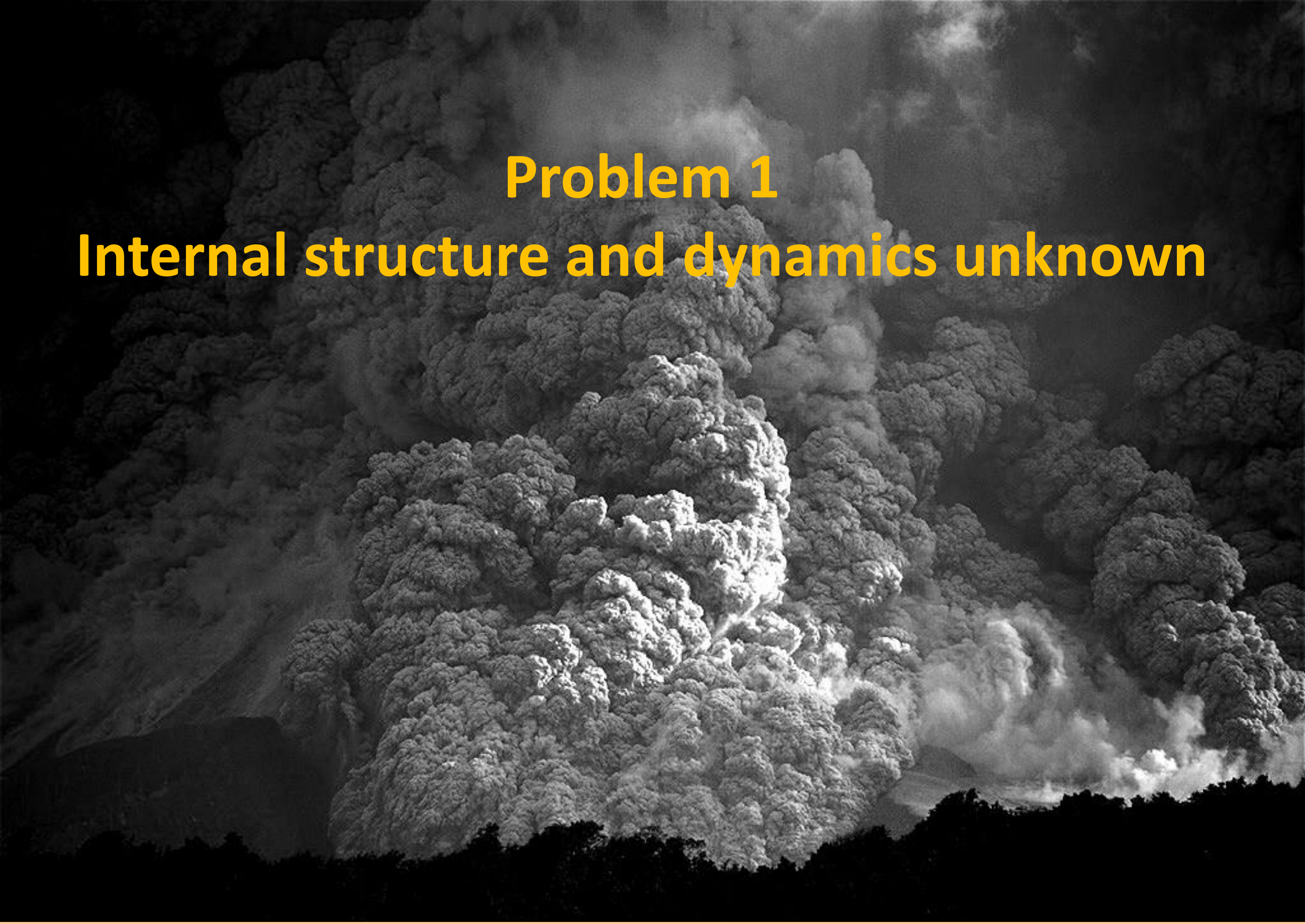
- Heat (Burn)
- Ash-load (Suffocation)
- High velocity (Escape)
- Dynamic pressure (Damage)
- Enormous travel distance
- Surmount high terrain

+ Secondary Hazards (Ash dispersal, Lahars…)

PDC Hazards become well-recognised.

BUT, we are not learning quickly enough about PDCs to save life.

Problem 1
Internal structure and dynamics unknown



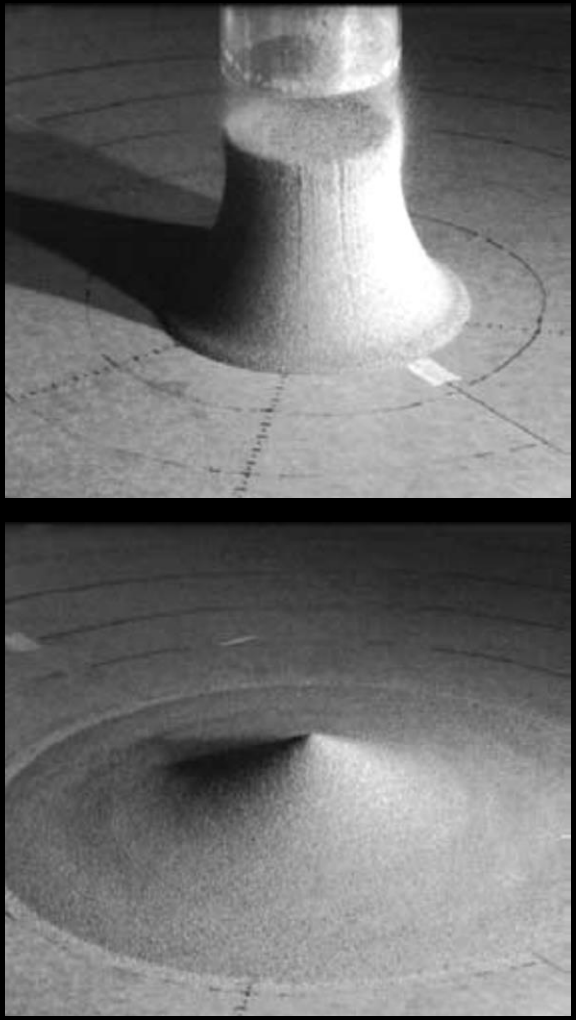
Can’t look or measure inside!

Problem 2
How on Earth can pyroclastic flows travel so far?

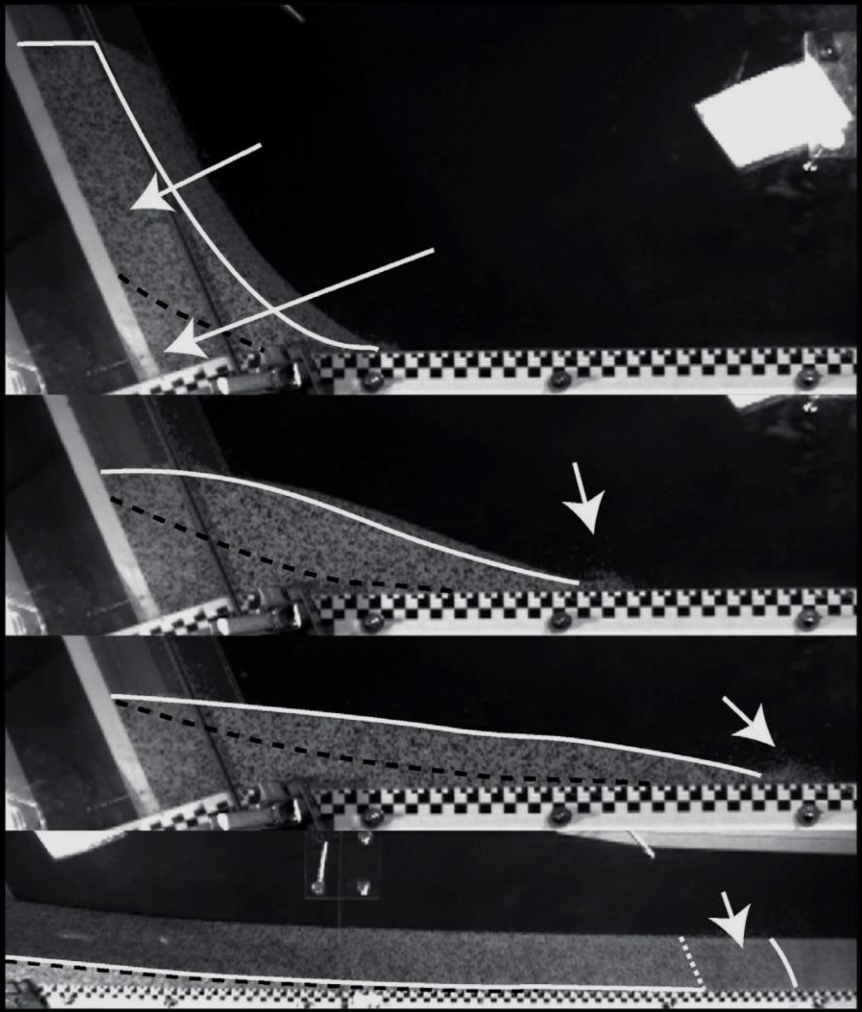
Coefficient of friction $\mu \sim \tan \phi = 0.81$

Let this go sideways

downhill

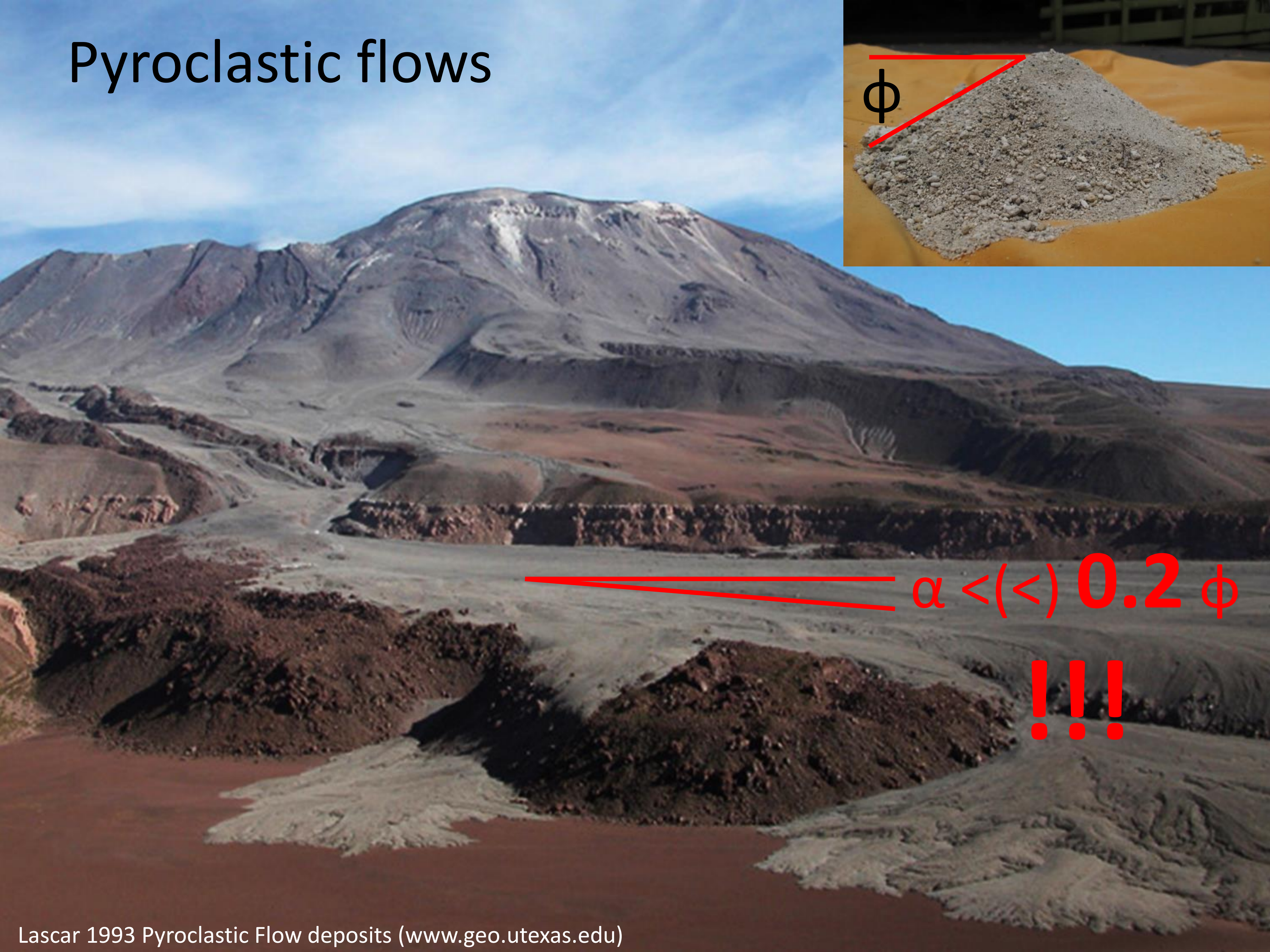


Or drop it from some height



Doesn’t matter (much) - runout L will not be far off H/μ.

Pyroclastic flows



Lascar 1993 Pyroclastic Flow deposits (www.geo.utexas.edu)

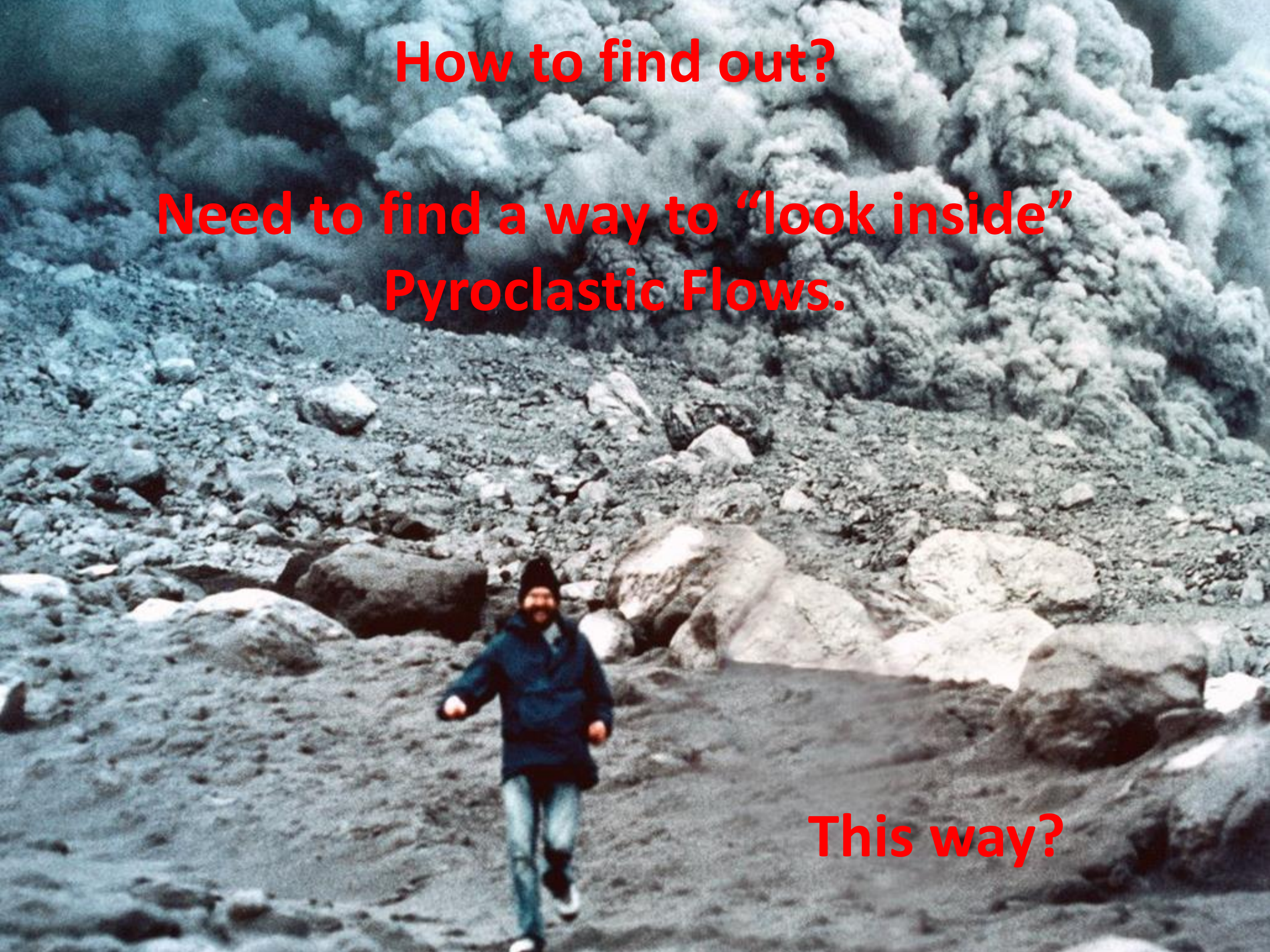
50 years of search for the mysterious friction-reducing mechanism

Still no direct observations and descriptions, but a number of theories:

- (Static) gas fluidization and hindered settling
- Acoustic fluidization
- Self-fluidization
- Fluid pore pressure

Even more in wider mass flow research

- self-lubrication, dynamic fragmentation, frictional velocity-weakening


How to find out?
Need to find a way to “look inside”
Pyroclastic Flows.
This way?

Synthesising Pyroclastic Flows in Large-scale Experiments

PELE CREW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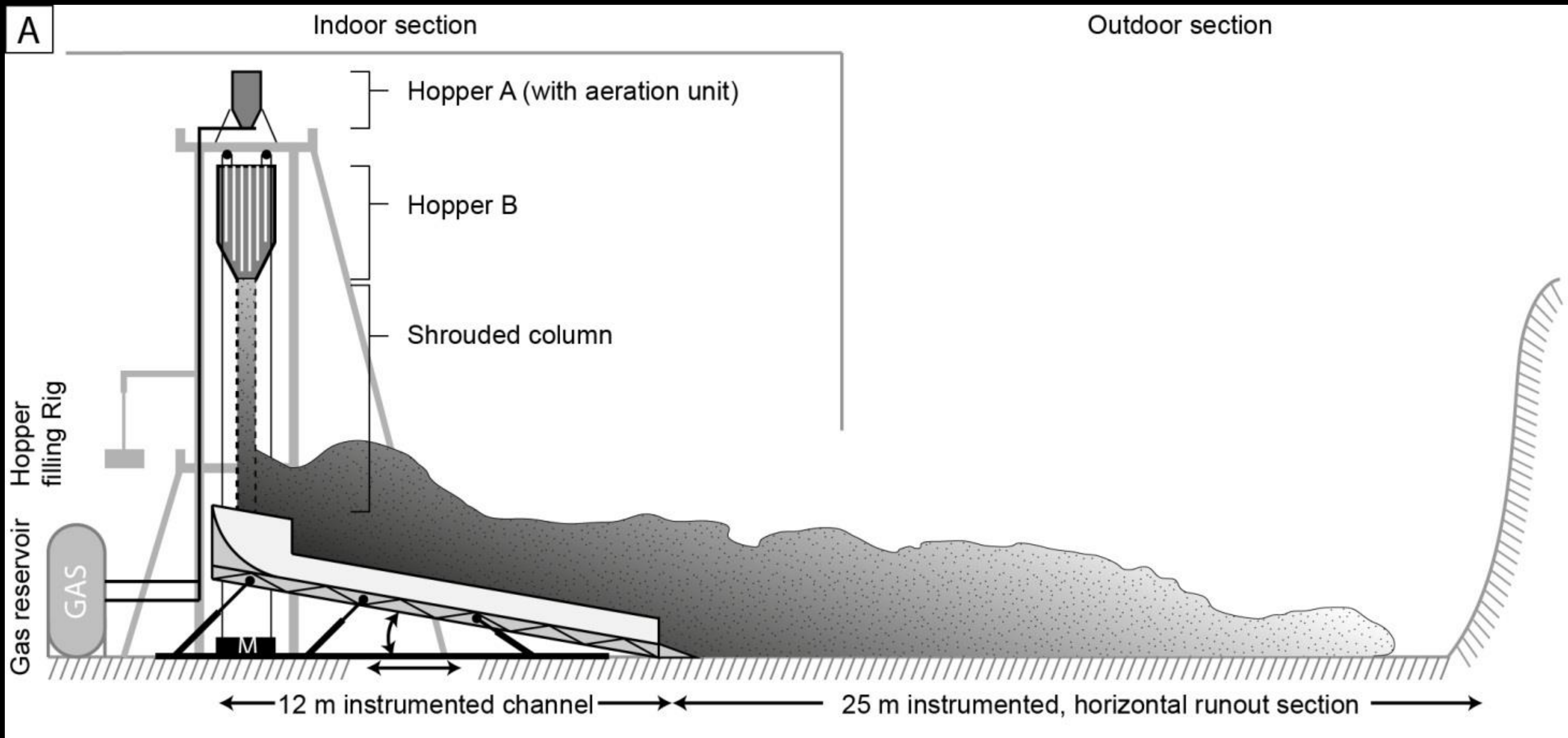
Luke Fullard (Massey)
Geoff Kilgour (GNS)
Greg Valentine (SUNY Buffalo)
Eric Breard (Georgia Tech)
Ermanno Brosch (Massey)
Tomaso Ongaro (INGV)
Joe Dufek (Georgia Tech)
Kevin Kreutz (Massey)
Shane Cronin (Auckland)
Anja Moebis (Massey)
Armin and Gert Lube (Massey)

PELE – Pyroclastic flow Eruption Large-scale Experiment

'Eruption' column collapse of variably diluted pyroclast-air suspensions

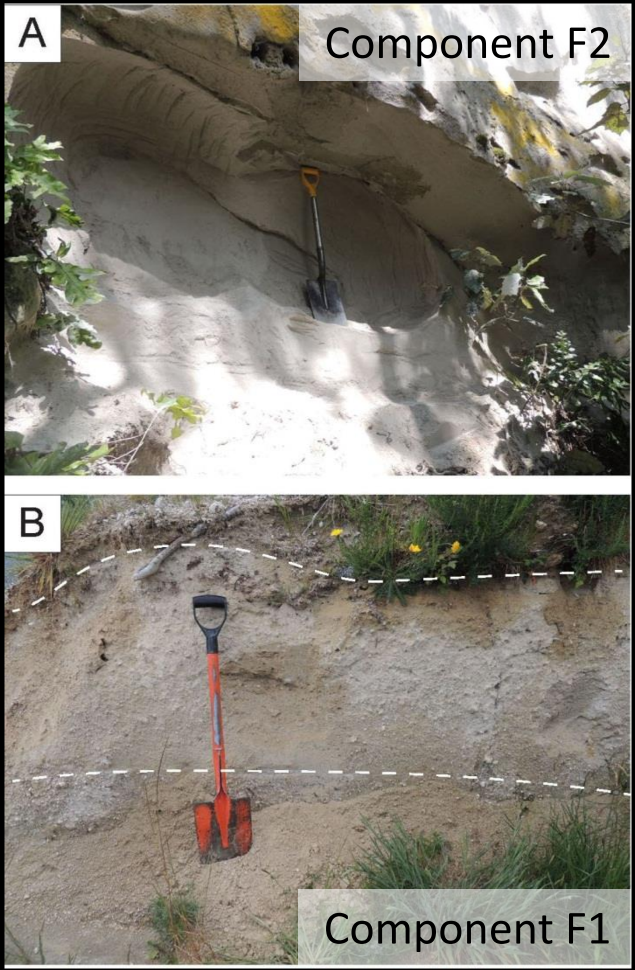


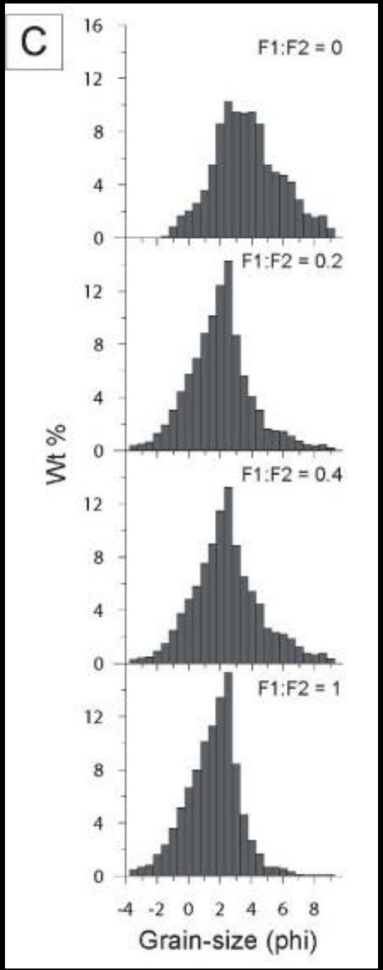
Four main parts:

1. Hopper that can be elevated in a lift to discharge height
2. Shrouded column for gas-particle mixture to accelerate and dilute during fall
3. 12 m instrumented and inclinable channel section
4. 25 m instrumented horizontal runout section

Volcanic Materials

Natural stress coupling between fluid (air) and solid phases (binary mix of 2 pyroclastic deposits)





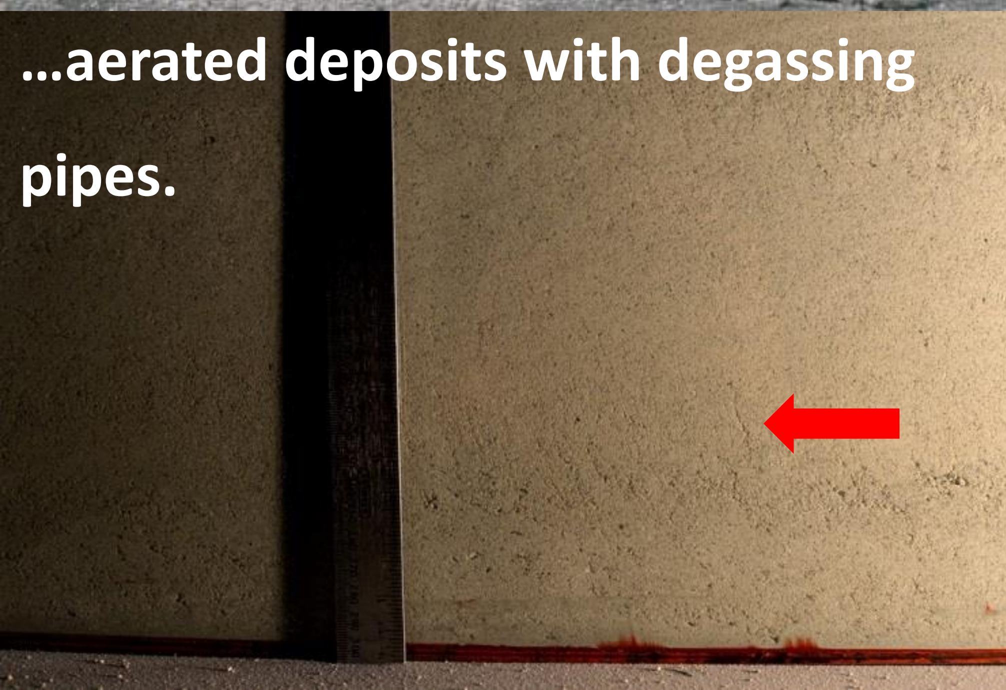
Here: 15 wt.% fine ash

Internal friction 39°

Basal friction 36°

Lobate, stratified to massive, coarse-top…

…aerated deposits with degassing pipes.



Large Scale, so what? Dynamic & Kinematic Scaling

Bulk flow scaling

Scaling	**Surges**	**Experimental PDCs**
Reynolds	10^6 - 10^9	10^4 - 10^7
Stokes	10^{-3} - 10^5	10^{-4} - 10^4
Particle Froude	0.2 - 20	0.4 - 11
Stability	10^{-6} - 10^6	10^{-6} - 10^5
Particle Re	10^0 - 10^5	10^{-1} - 10^4
Richardson	10^{-4} - 35	10^{-4} - 28

Dense underflow scaling

Scaling	**PFs**	**Experimental PDCs**
Mass number	10^2 - 10^3	10^1 - 10^3
Bagnold	10^{-2} - 10^2	10^{-1} - 10^2
Darcy	10^1 - 10^5	10^0 - 10^5
Fluidization	10^{-7} - 10^{-3}	10^{-5} - 10^{-3}
Pore-pressure	10^{-4} - 10^1	10^{-4} - 10^2
Savage	10^{-9} - 10^{-6}	10^{-7} - 10^{-3}

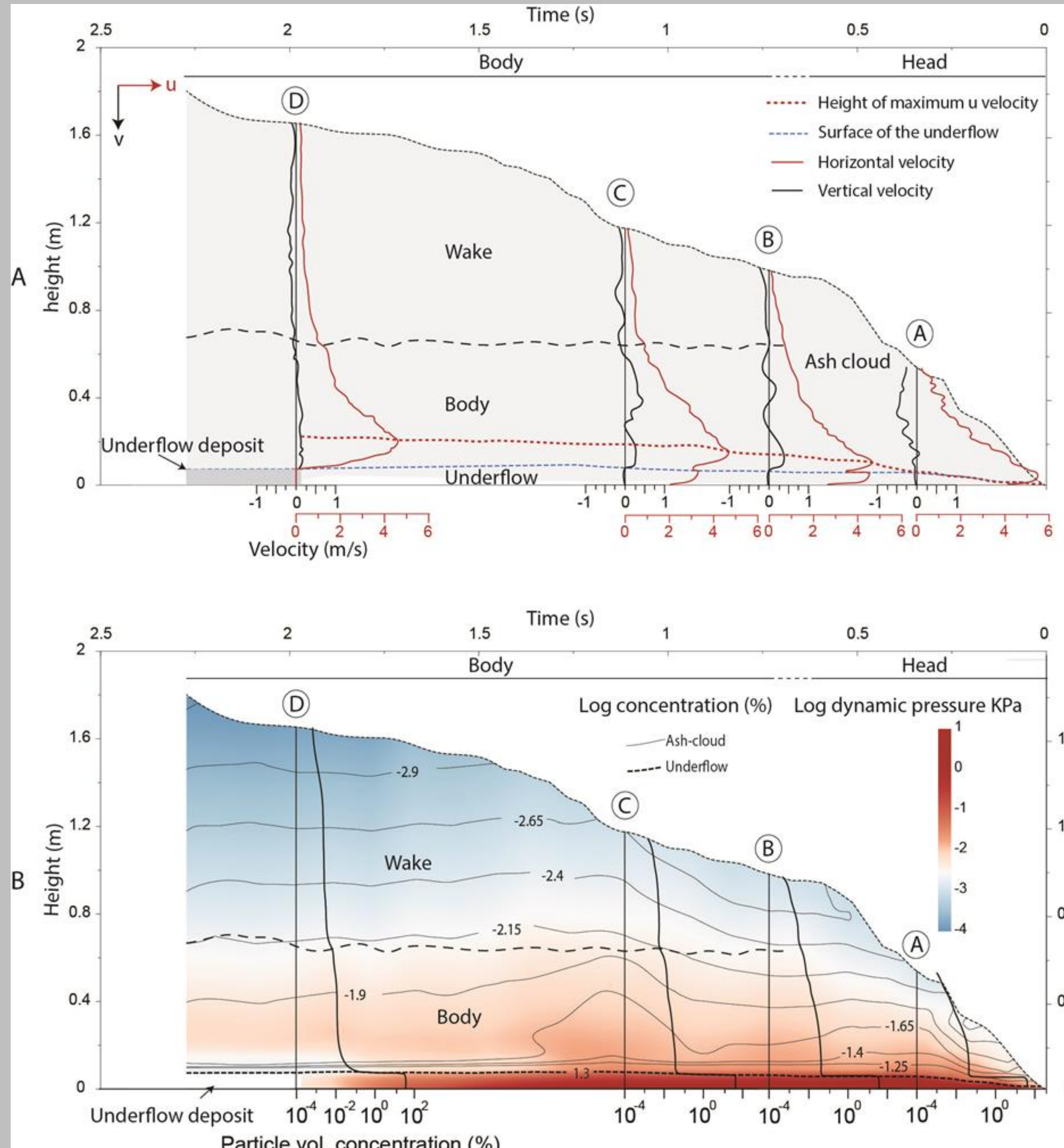
Problem 1 – Viewing inside PDCs

First quantitative views inside PDCs

Internal structure characterised through data of flow velocity, temperature, density, dynamic pressure and turbulence intensity.

Far more complex than what current models suggest.

Dynamic pressure comes in pulses.



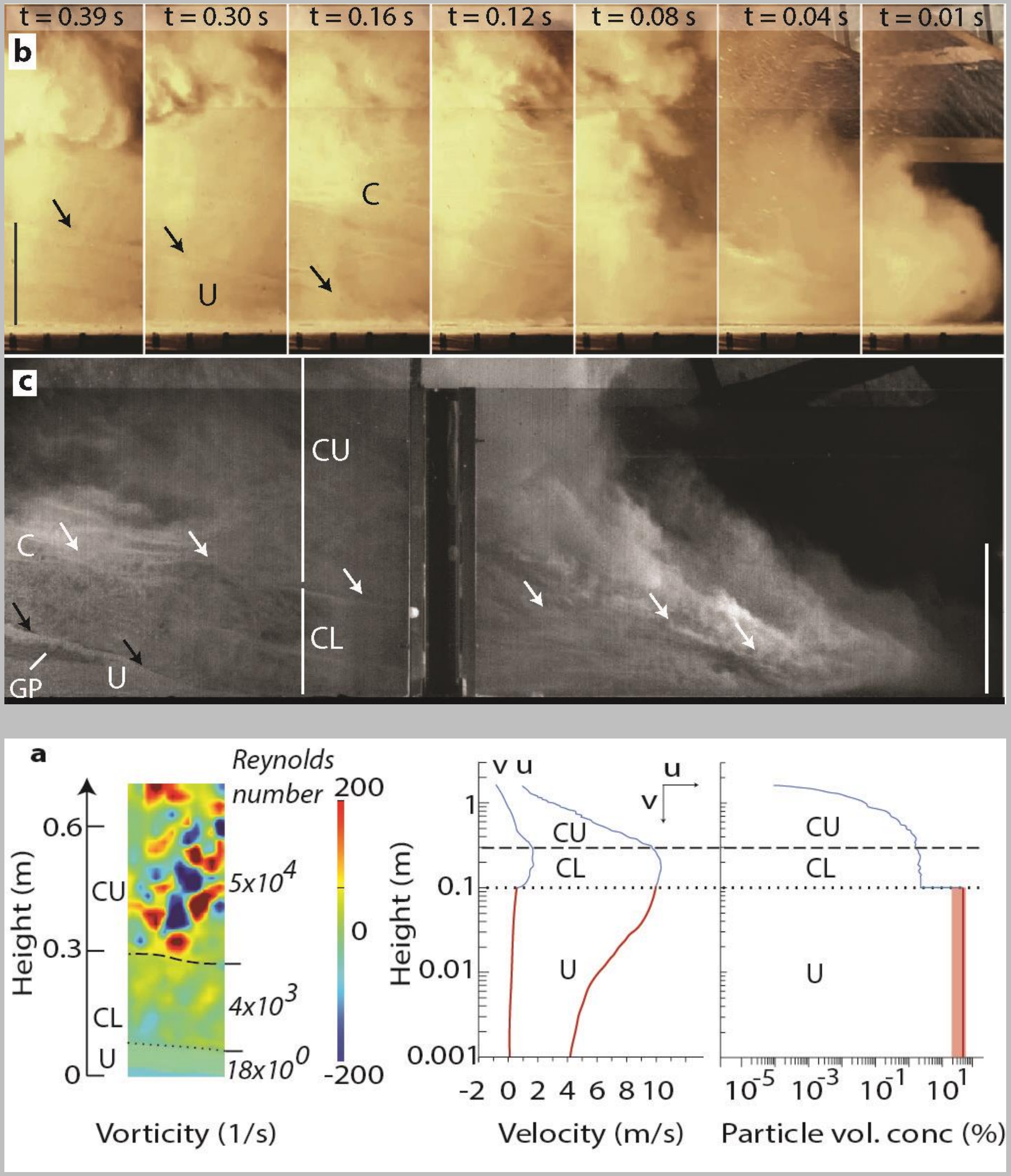
(Breard and Lube (2017) Earth and Planetary Science Letters)

Problem 1 – Internal Structure

Coupling of turbulent and non-turbulent flow regimes within PDCs.

Mesoscale turbulence clusters control flow stratification, dynamic pressure and flow runout length.

Explanation for the evolution and characteristics of real-world deposits.



(Breard et al. (2016) Nature Geoscience)

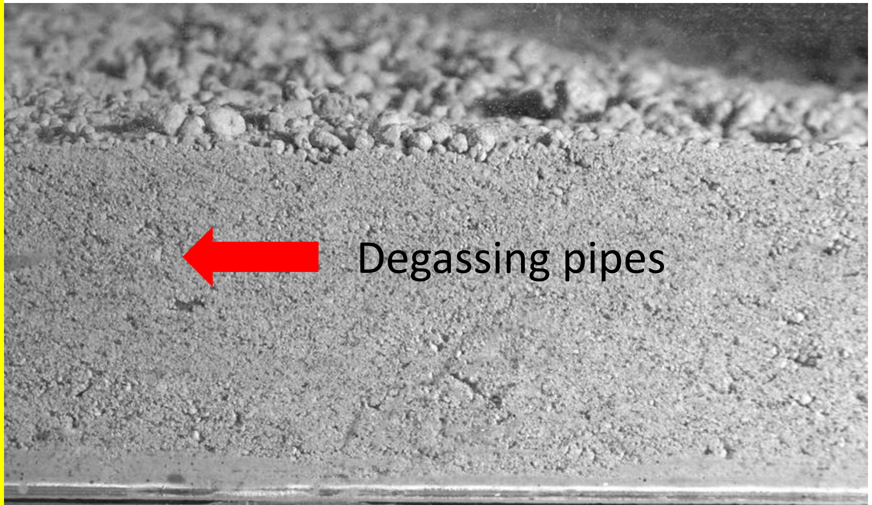
Problem 2 – Runout potential PF

Experimental Deposits

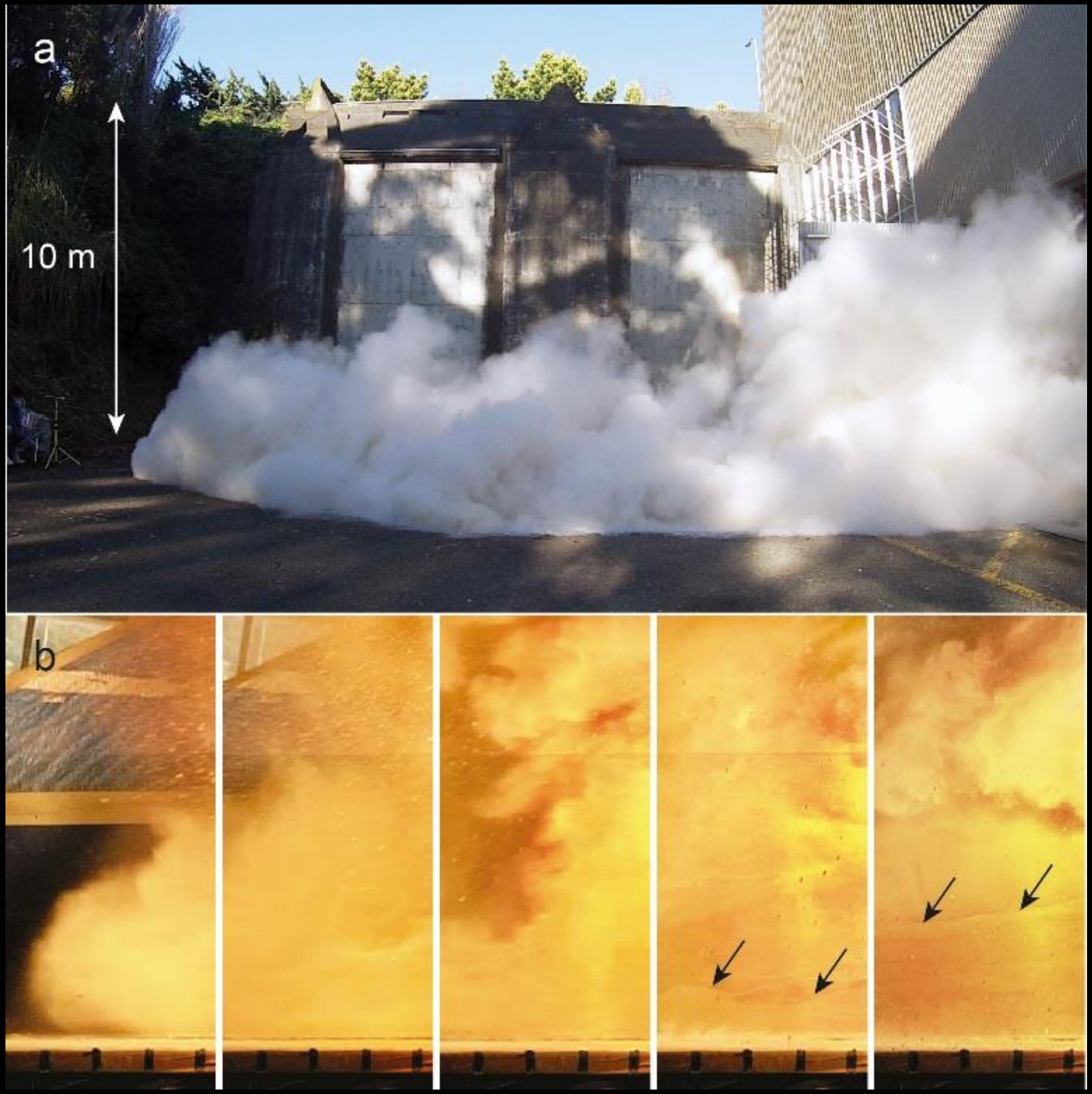
Apparent friction coefficients of experimental underflows:

μ_{app} = 0.2-0.31

ONLY
25-39 % of material coefficient of friction!
AND
Overlapping with values of natural deposits!



Characterising experimental pyroclastic flows



Measurements

Vertical profiles of time-variant:

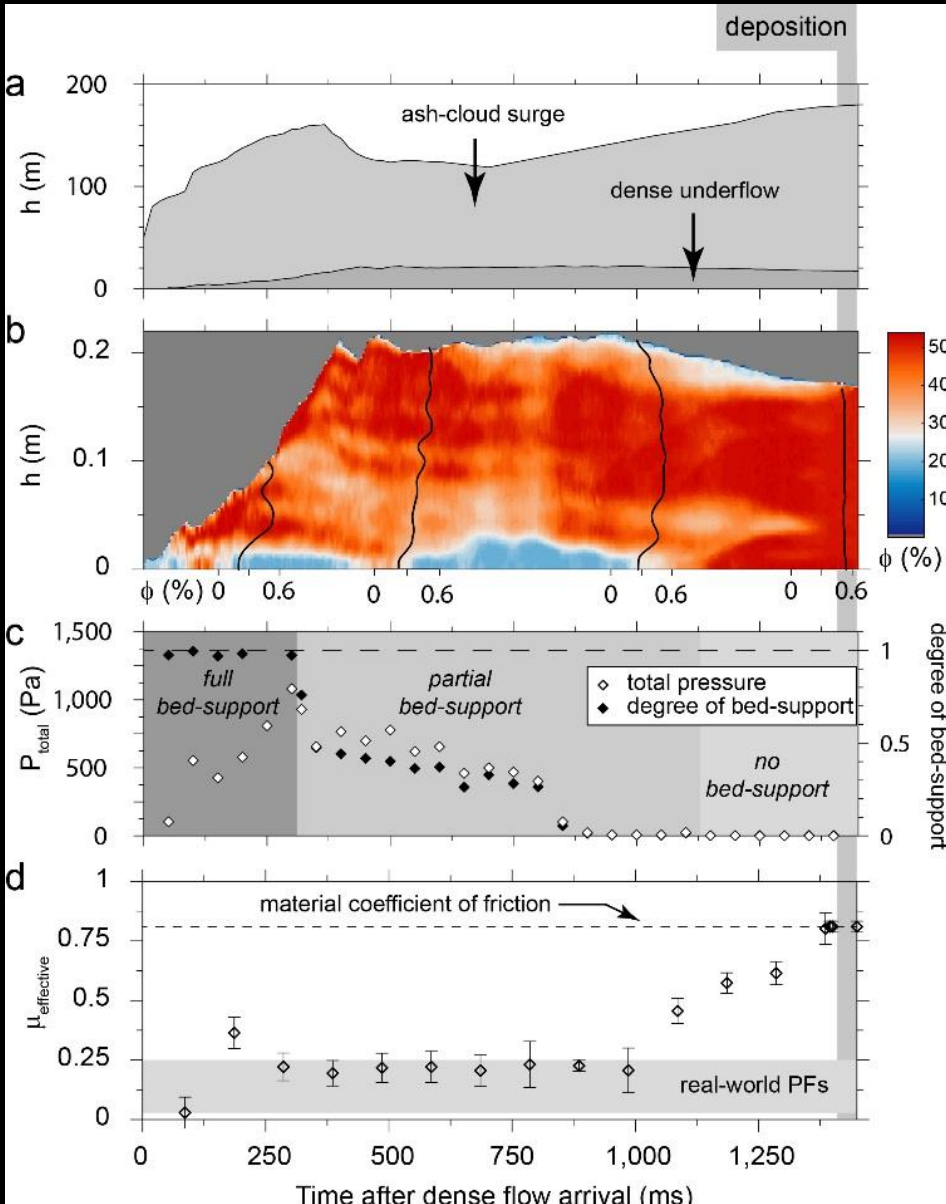
Velocity

Particle concentration

Basal weight

Basal gas pore-pressure

Characterising experimental pyroclastic flows

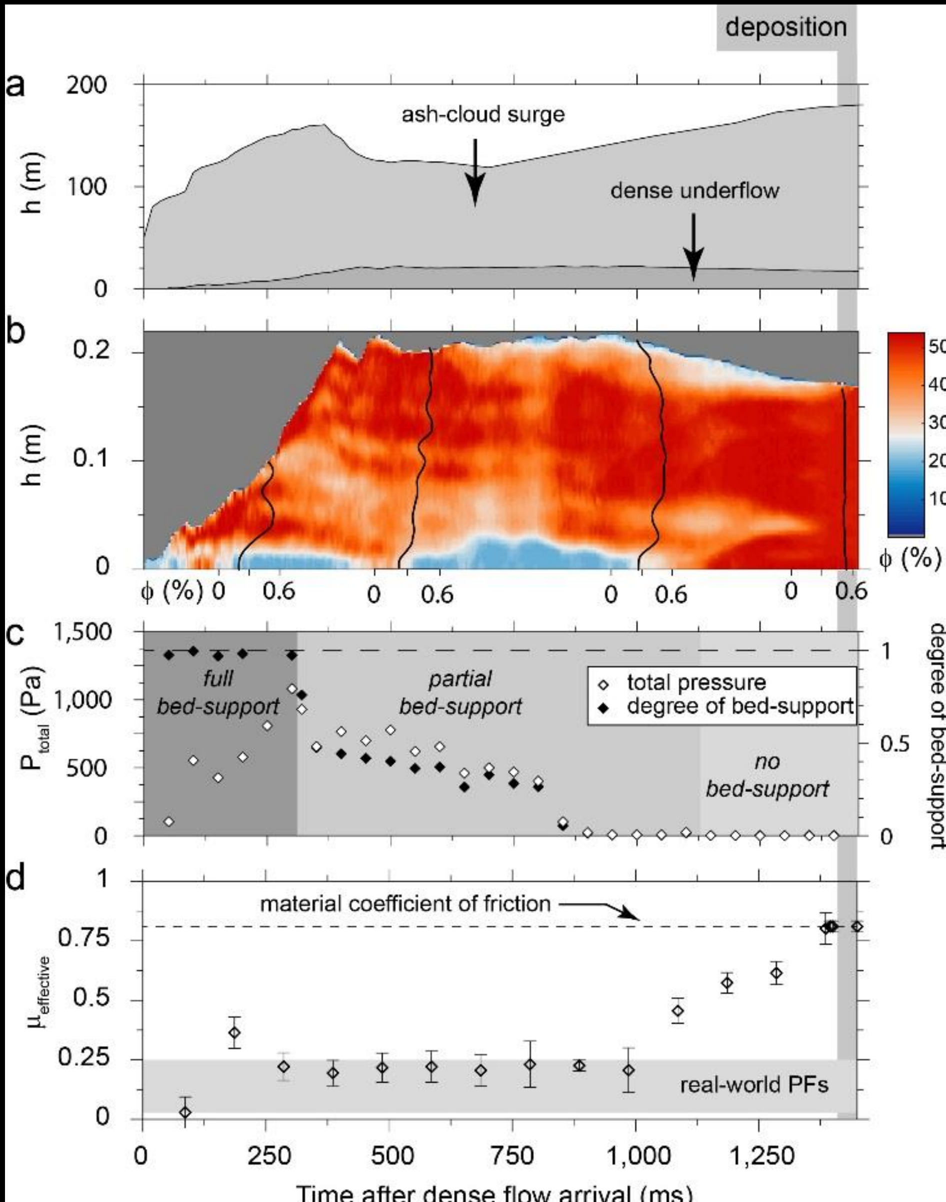


Concentration

General decrease downwards until close to flow stalling.

Lowermost part has very low concntrations of 19-24 wt.% versus 35-54 vol.% above)

Characterising experimental pyroclastic flows



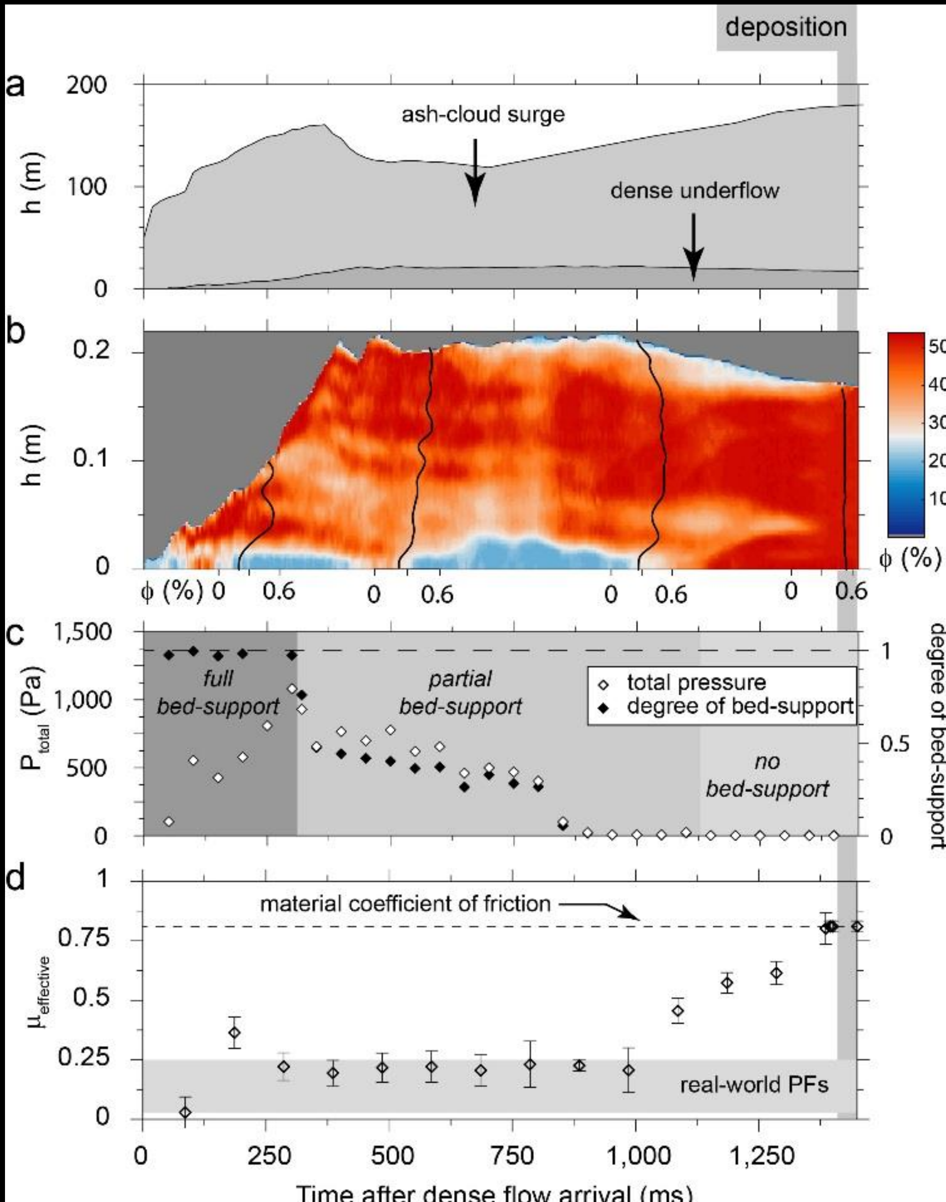
Basal static pressure

Is positive as long as low-concentration base exists.

Degree of bed support decays over time.

$$N = \frac{P_{total}}{g \int_0^{h_m} \rho(h) dh}$$

Characterising experimental pyroclastic flows



$$E_{pot\_1} + E_{kin\_1}$$
$$= E_{pot\_2} + E_{kin\_2} + E_{friction}$$

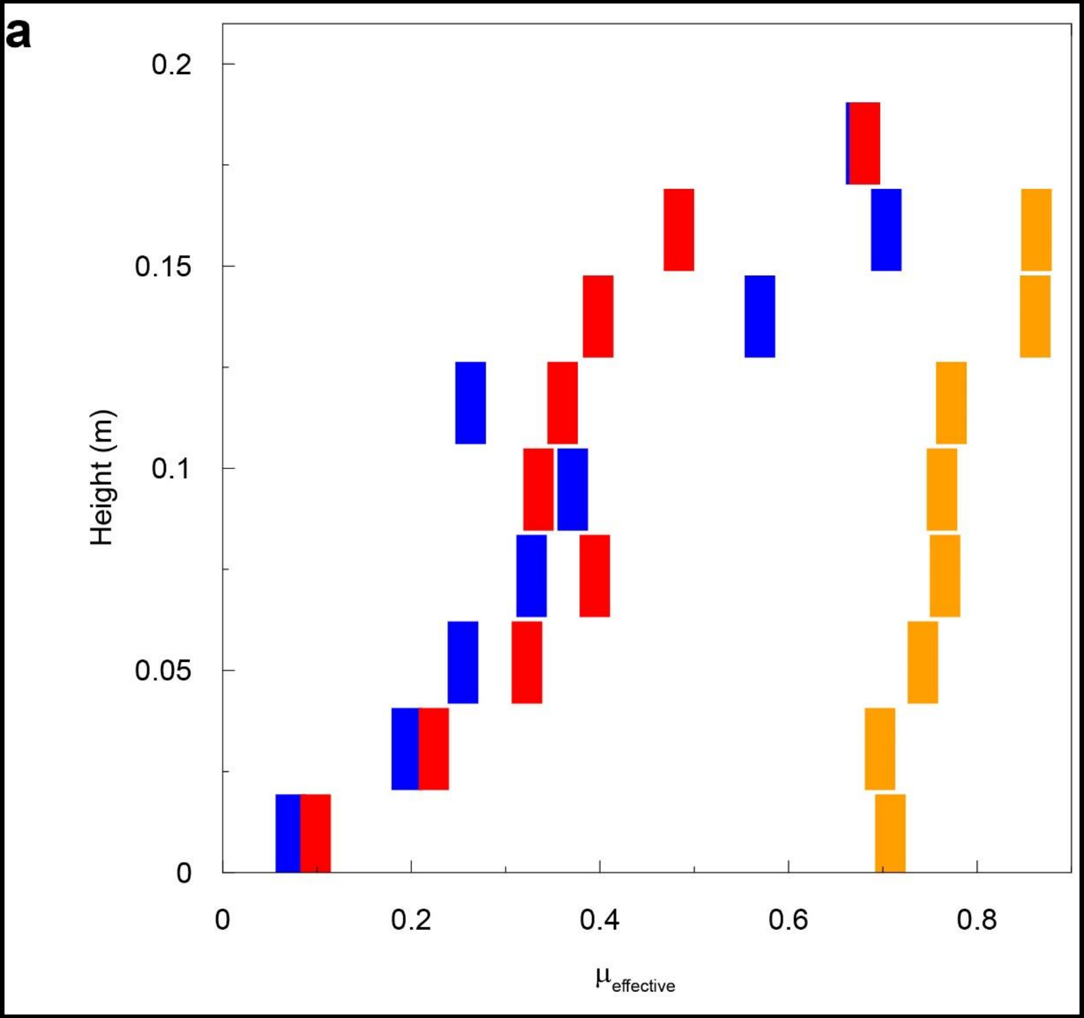
$$\mu_{effective} = \frac{E_{friction}}{F_N s}$$
$$= \frac{0.5(v_1^2 - v_2^2)}{gs\cos\alpha} + \tan\alpha$$

Depth-averaged effective friction coefficient

Obtained by energy balance.

Is very low (in natural range) for as long as low-concentration base is present.

Characterising experimental pyroclastic flows



$$E_{pot\_1} + E_{kin\_1} = E_{pot\_2} + E_{kin\_2} + E_{friction}$$

$$\mu_{effective} = \frac{E_{friction}}{F_N s} = \frac{0.5(v_1^2 - v_2^2)}{gs\cos\alpha} + \tan\alpha$$

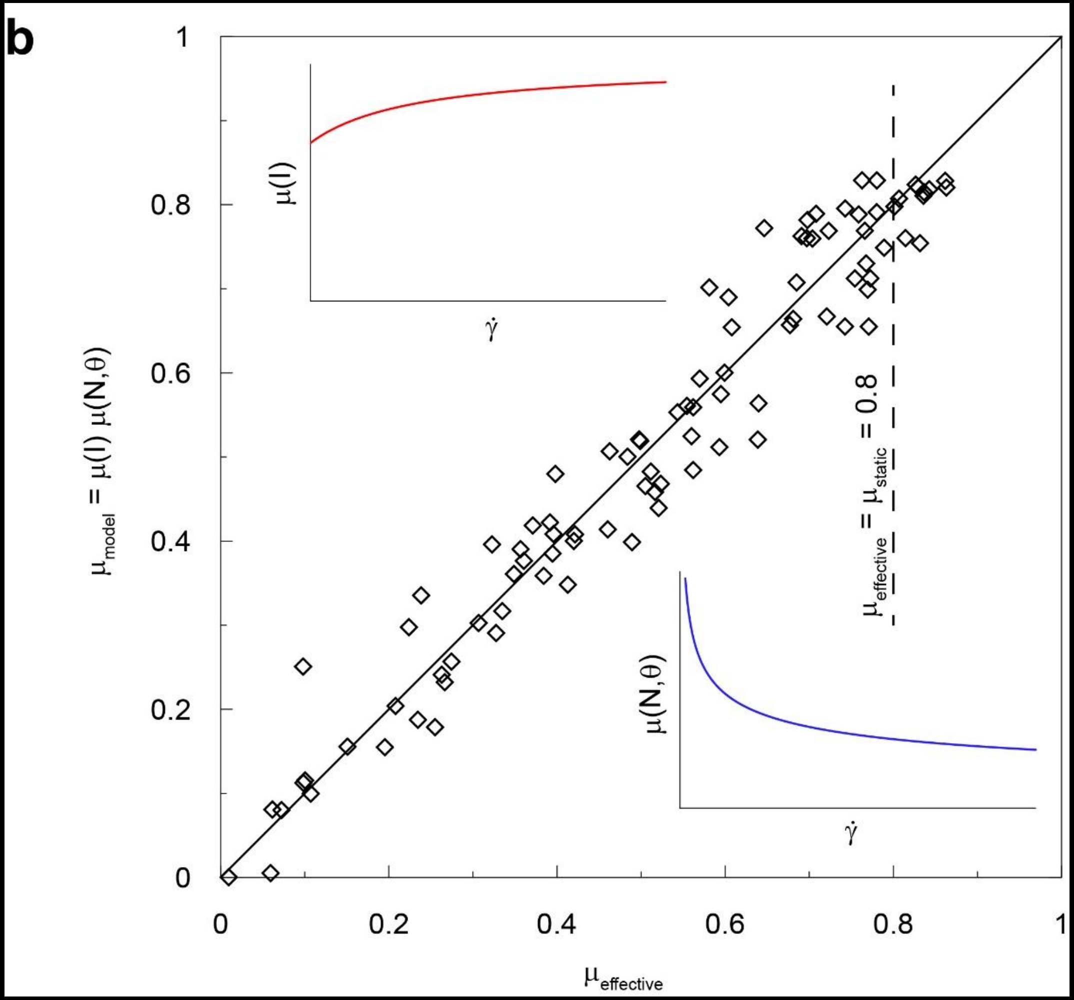
Effective friction as a function of height (and three different times)

μ_{eff} remains low (0.3-0.6) for most of runout time

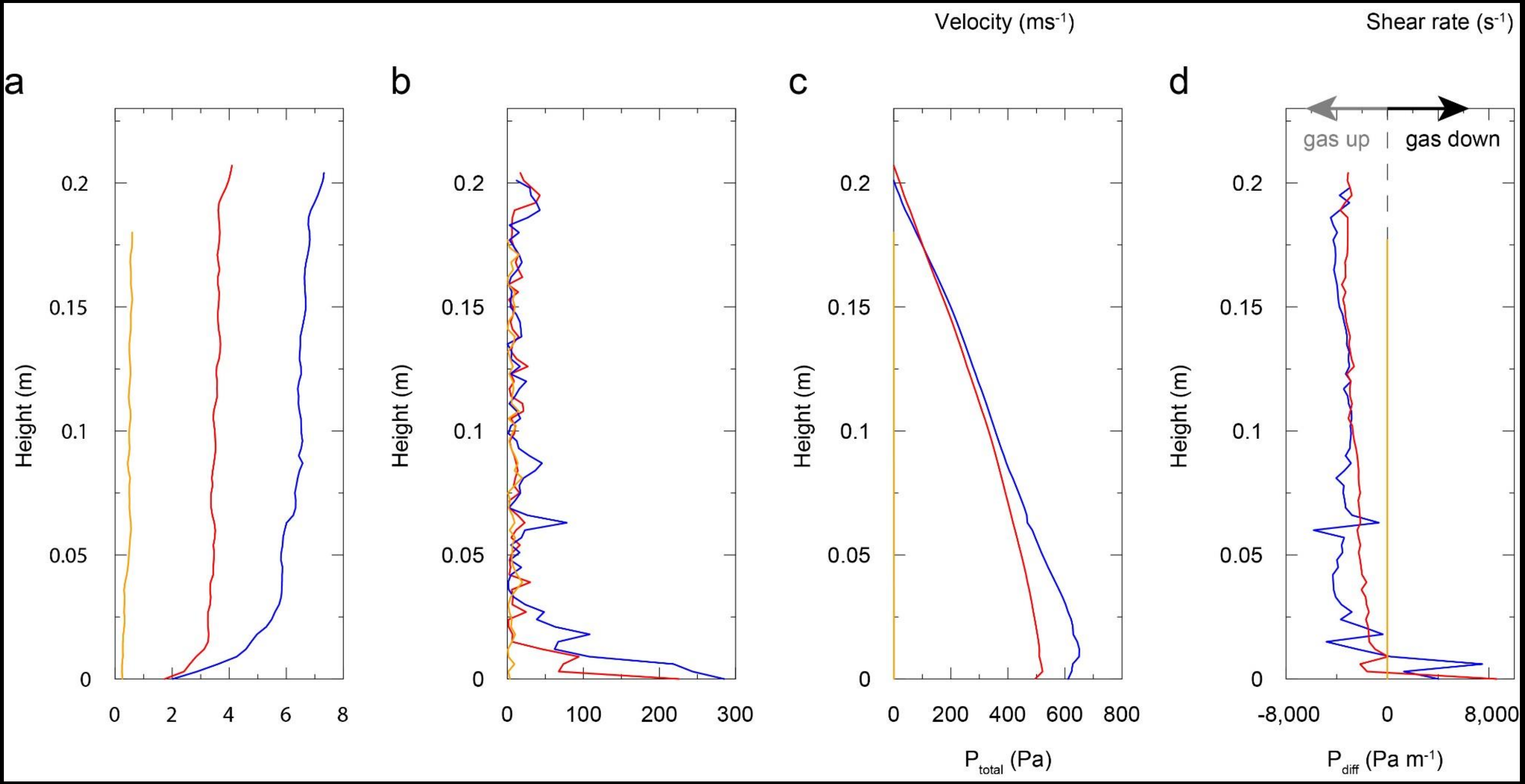
Super-low values of μ_{eff} of 0.05-0.21 in basal region.

A new rheology for the critical basal region of pyroclastic flows

$$\tau = [\mu_{effective}]\sigma_N = [(\mu(I))(\mu(\theta,N))]\sigma_N = \left[\left((\mu(I))\left(\left(\frac{\theta}{\theta_m}\right)^n (1-N)\right)\right)\right]\rho g h$$



The air-lubrication mechanism



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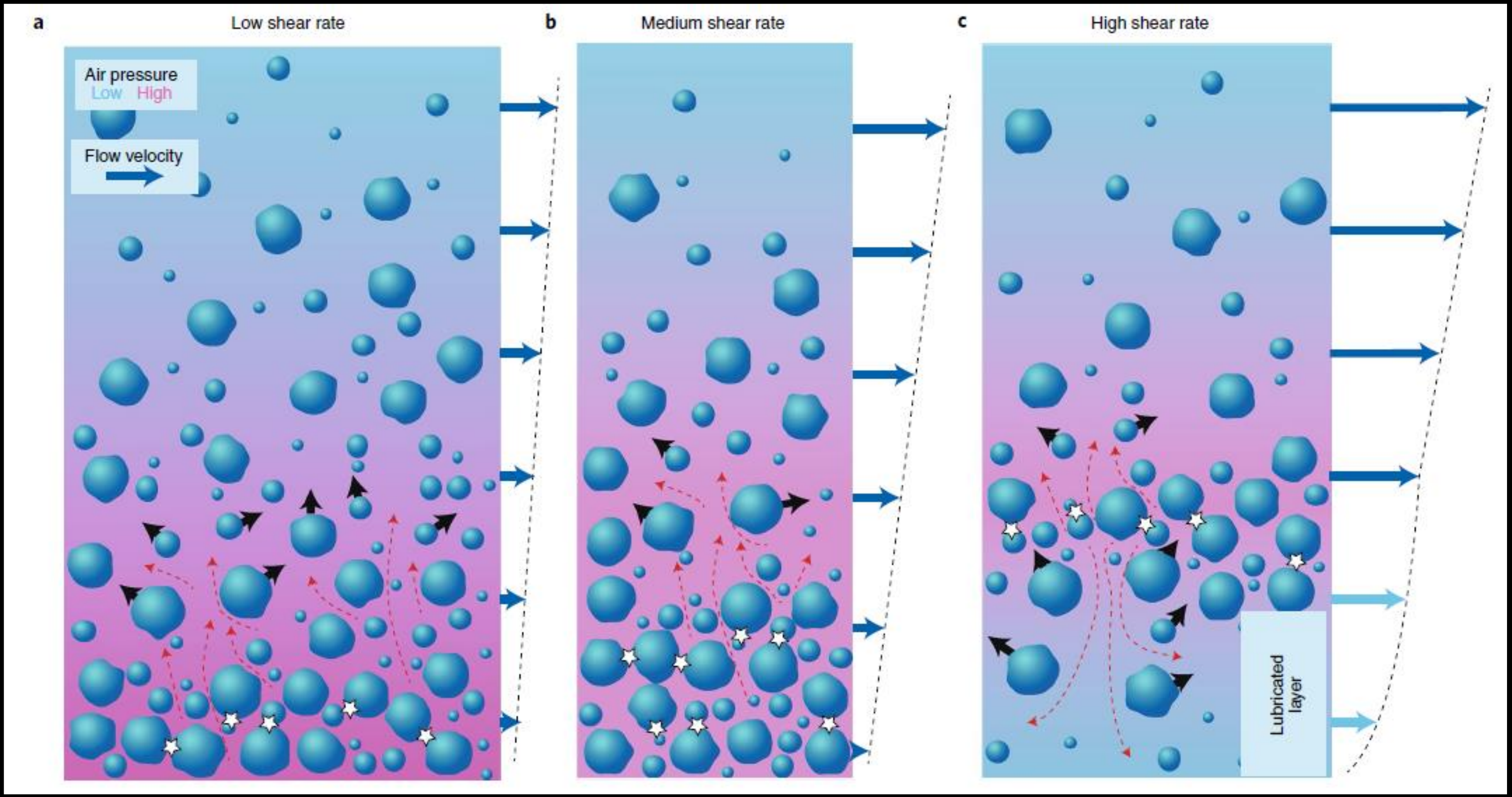
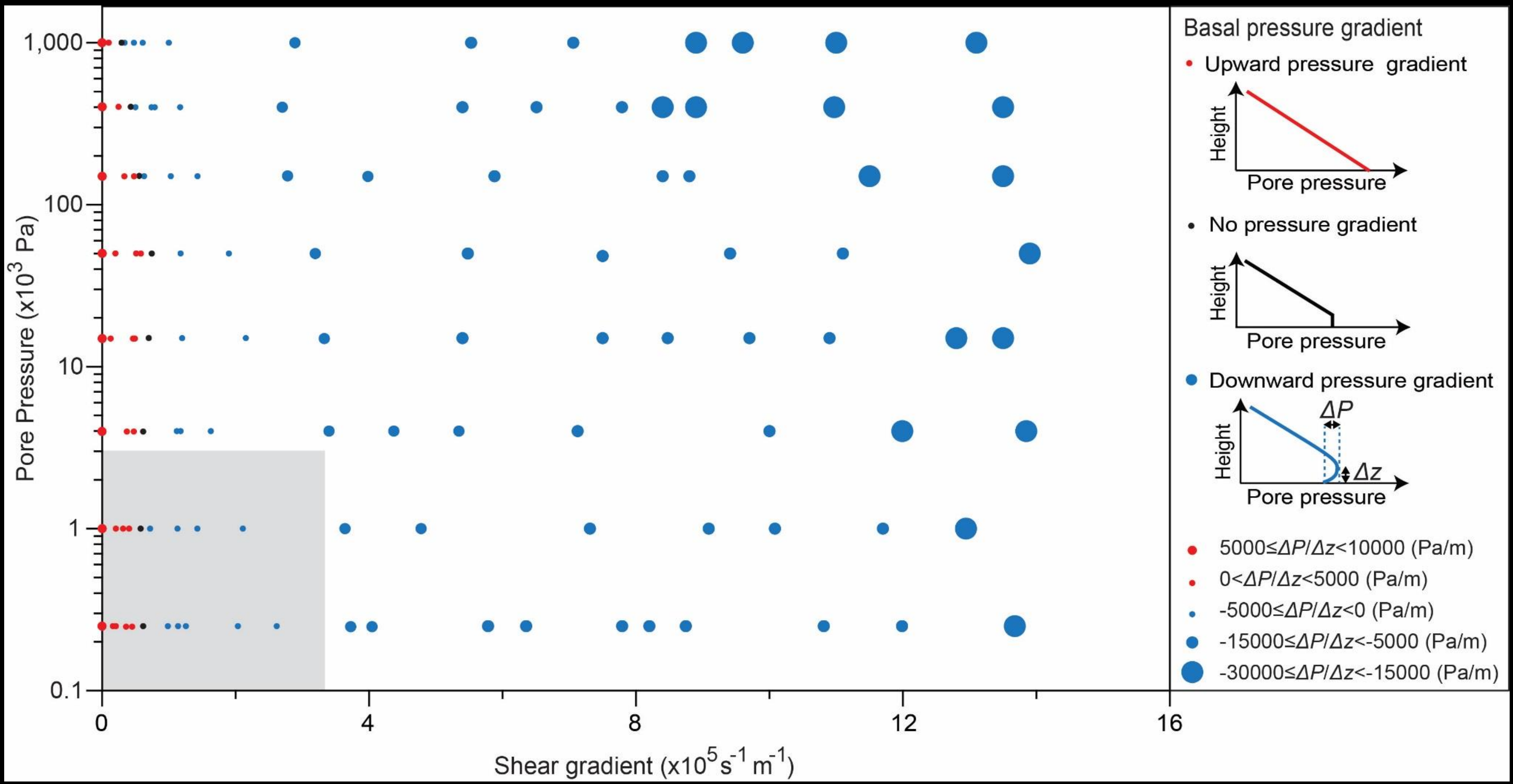


Air-lubrication in real-world flows



https://www.youtube.com/watch?time_continue=10&v=hvuP7kuX7Dk