Experimental investigation of soil creep dynamics under porous flow condition

Morgane Houssais*, Charles Maldarelli[a,*], Mark D. Shattuck[b,*], Jeffrey F. Morris[a,*]

*: Levich Institute, [a]: Chemical engineering Department, [b]: Physics Department of City College of New York

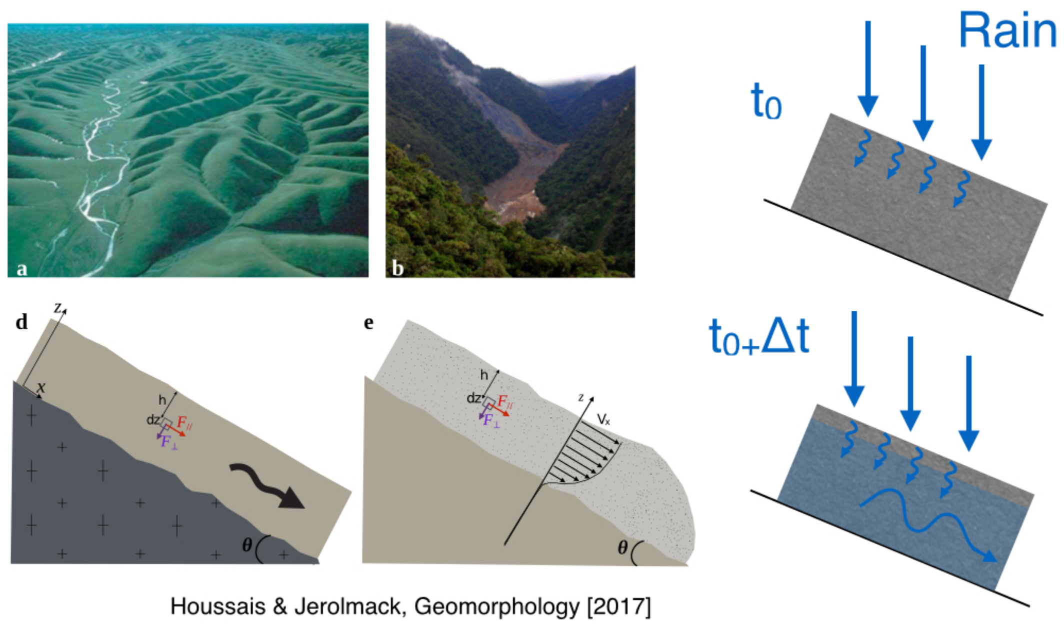
Introduction

Natural sediment is composed of a wide range of particle size, shape and compositition and is constantly deformed under shear by gravity and fluid flow. As a result, sediment transport presents a large panel of complex material behaviors. Understanding the continuity between these different regimes is a key for tackling long term term dynamics, made of slow continuous creep flow and fast granular flow events[1].

Soils present 2 major characteristics: 1) they mostly creep, and some time avalanche, and 2) they are importantly composed of fine particles, which make them cohesive.

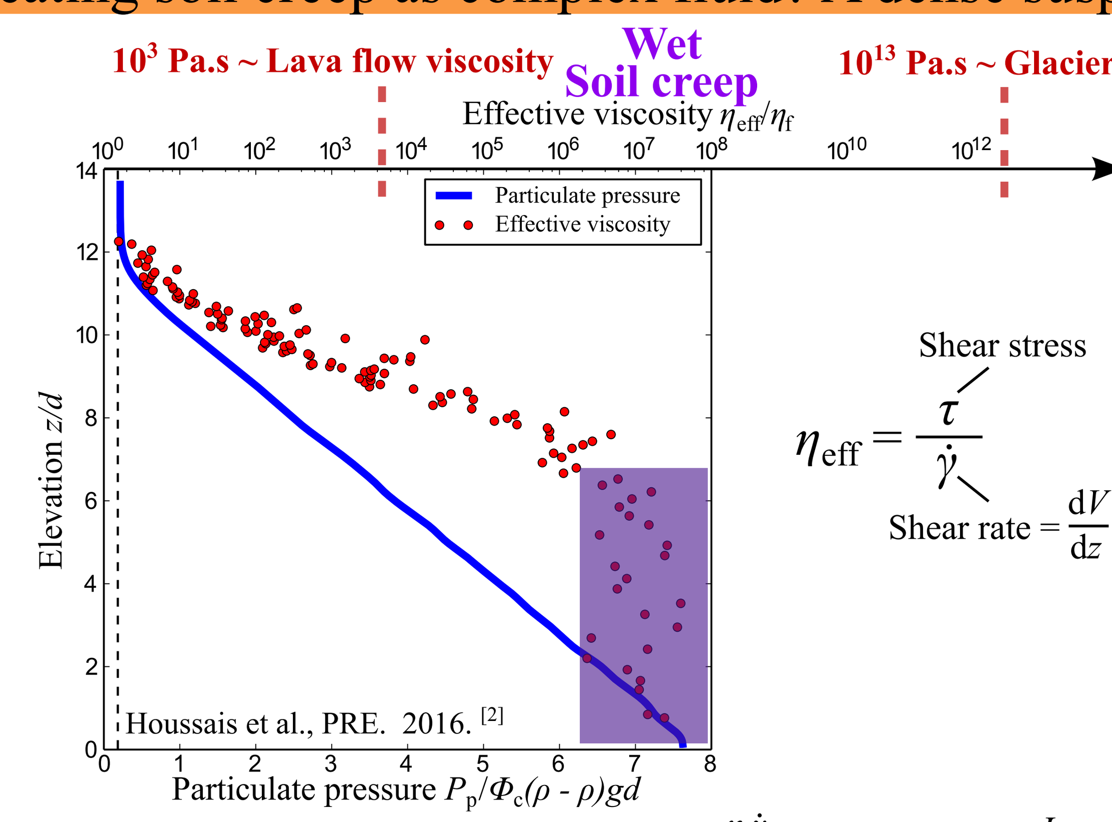
Moreover, soils are frequently traversed by porous flows, whose vertical component are known for having dramatical impact on soil destabilization. However, the effect of horizontal component of porous flow on soil creep is very much unknown.

In novel microfluidics experiments, I explore in quasi-2D channels the impact of the slope ***θ (0<θ<θ_c)***, the particle sizes **d (400→20μm)**, and the - gentle - porous flow intensity ***Q*_{in}** and fluid viscosity ***η_f*** on the creep and avalanche triggering dynamics.



Houssais & Jerolmack, Geomorphology [2017]

Treating soil creep as complex fluid? A dense suspension/submerged granular flow cooled to glassy material?



Shear stress

$$\eta_{\mathrm{eff}} = \frac{\tau}{\dot{\gamma}}$$

Shear rate $= \frac{dV}{dz}$

Effective friction coefficient $\mu = \frac{\tau}{P_p}$ Viscous number $I_v \equiv \frac{\eta_f \dot{\gamma}}{P_p}$ Effective viscosity $\eta_{\mathrm{eff}} = \frac{I_v}{\mu}$

Confinement pressure $P_p(z) = P_0 + \int_z^{+\infty} (\rho_p - \rho_f) g \Phi_c(z) \mathrm{d}z$

Packing fraction

Unified rheology: (Boyer et al, PRL, 2011[4])

$$\mu(I_v) = \mu_s + \frac{\mu_d - \mu_s}{I_0/I_v + 1} + I_v + \frac{5}{2}\Phi_c I_v^{1/2}$$

Dense dry granular flow rheology (GDR MiDi, 2004)

Dilute suspension flow rheology (Einstein, 1905)

Just like for glassy materials, soil creeping means the system exhibits a slow time evolution/aging/rejuvenation.

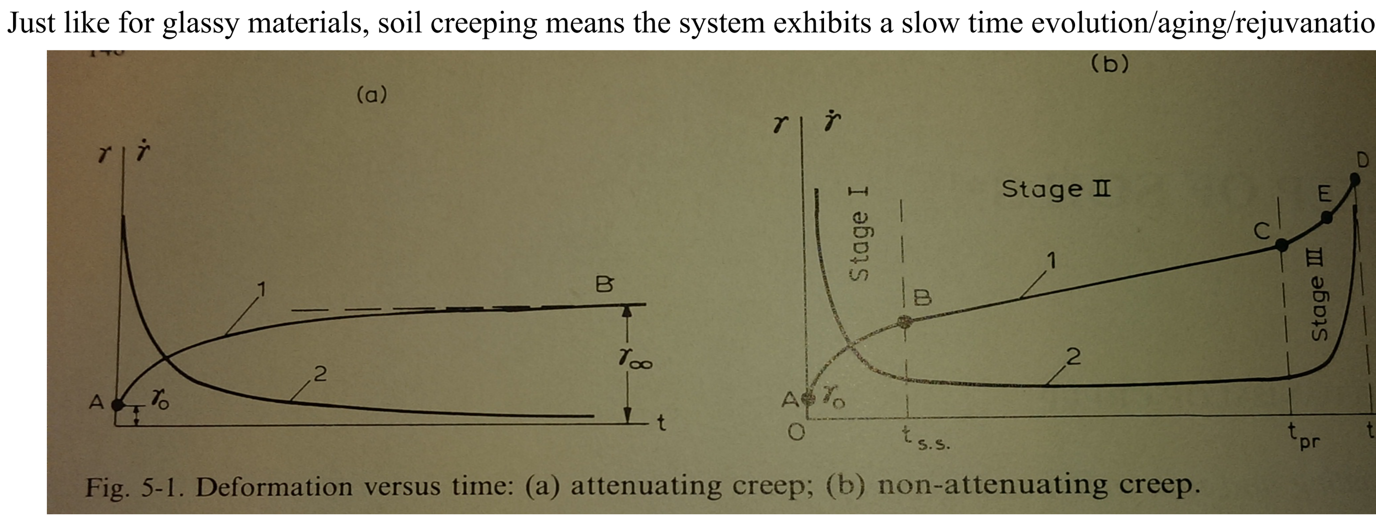
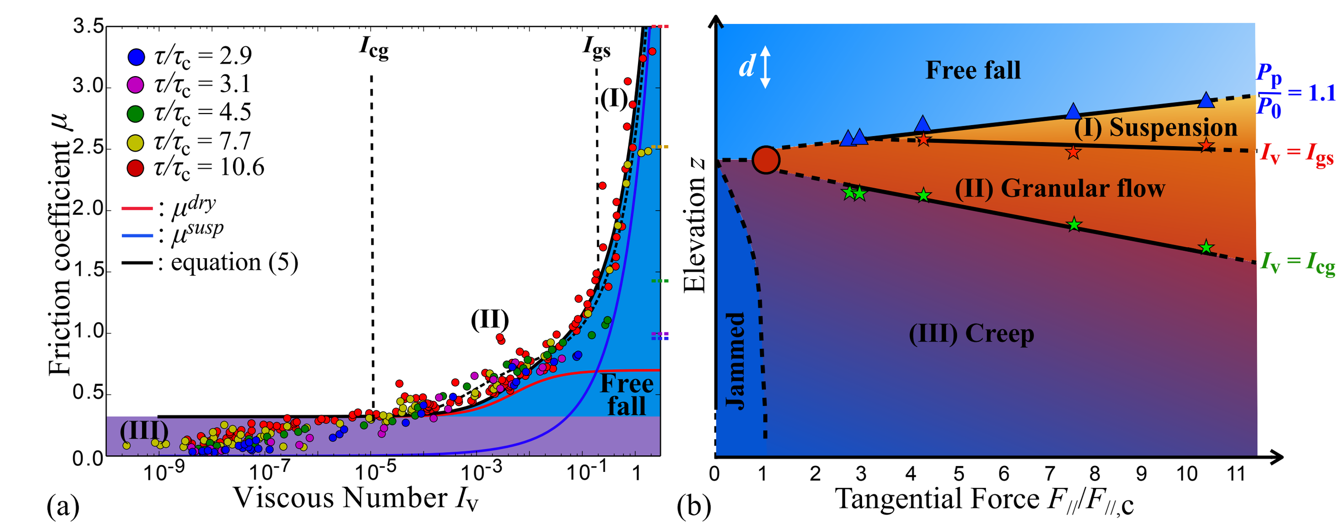


Fig. 5-1. Deformation versus time: (a) attenuating creep; (b) non-attenuating creep.

S. S. Vyalov, Rheological fundamentals of soil mechanics. (1986)



Houssais et al., Nat, Comm. 2015. [3]

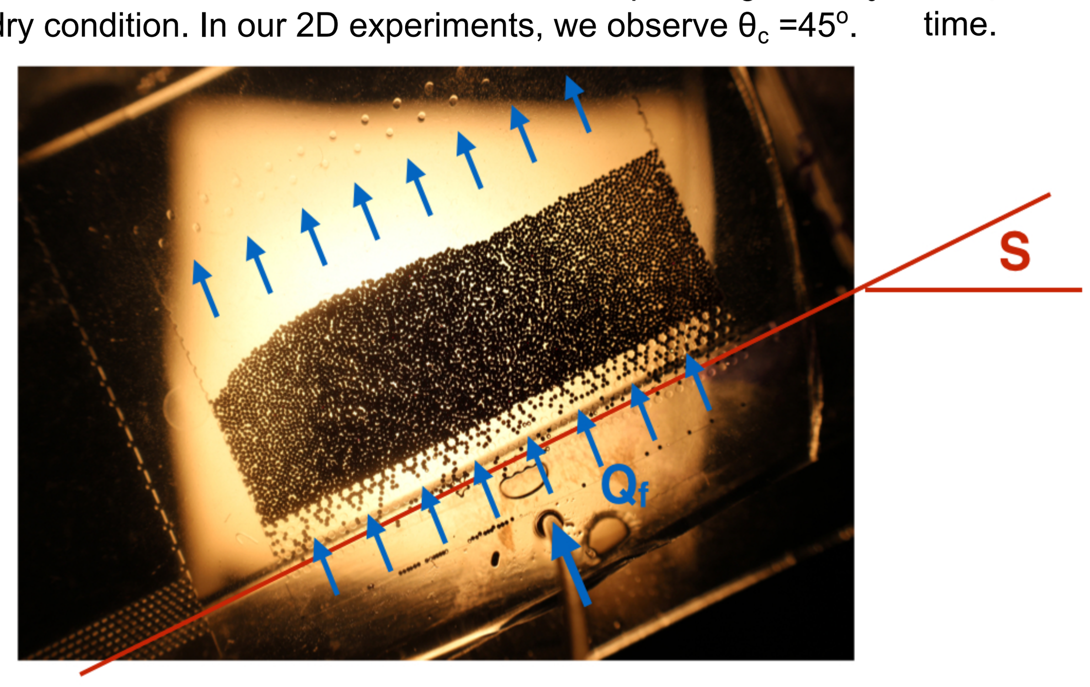
Experimental apparatus and methods

In a microfluidics channel made of silicon (PDMS) is filled up with a silicon oil (viscosity ***η_f*** = 4.5 mPa.s) and buoyant plastic particles of diameter ***d*** = 400μm.

The channel width is only 600μm (1.5*d*), to ensure the system to be very quasi-2D.

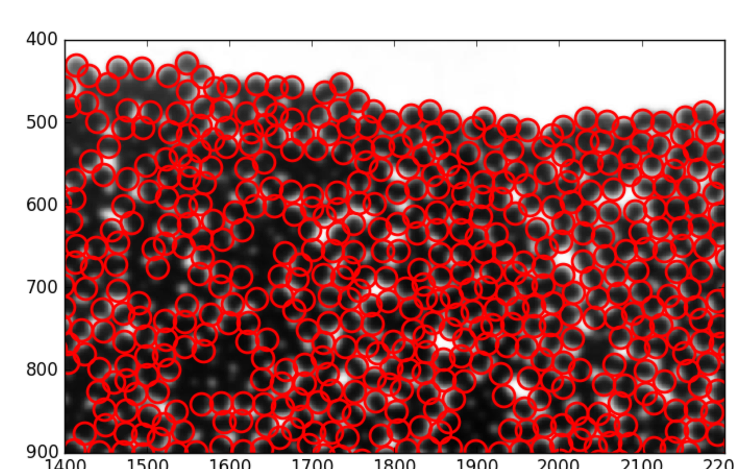
After a flat sediment layer is set in the horizontal channel, it is tilted to a slope ***θ<θ_c***, with θ_c the critical angle of avalanche in dry condition. In our 2D experiments, we observe θ_c =45°.

For each slope θ, a range of vertical porous flow is applied. The total fluid flow flux , ***Q_f*** is fixed with a micro-fluidic syringe pump, during the whole experiment, which lasts 0.5 to 4h, and range from **0<*Q*_f<*Q*_{f,c}** ; ***Q*_{f,c}** being the critical total liquid flux for fluidisation of the granular bed.

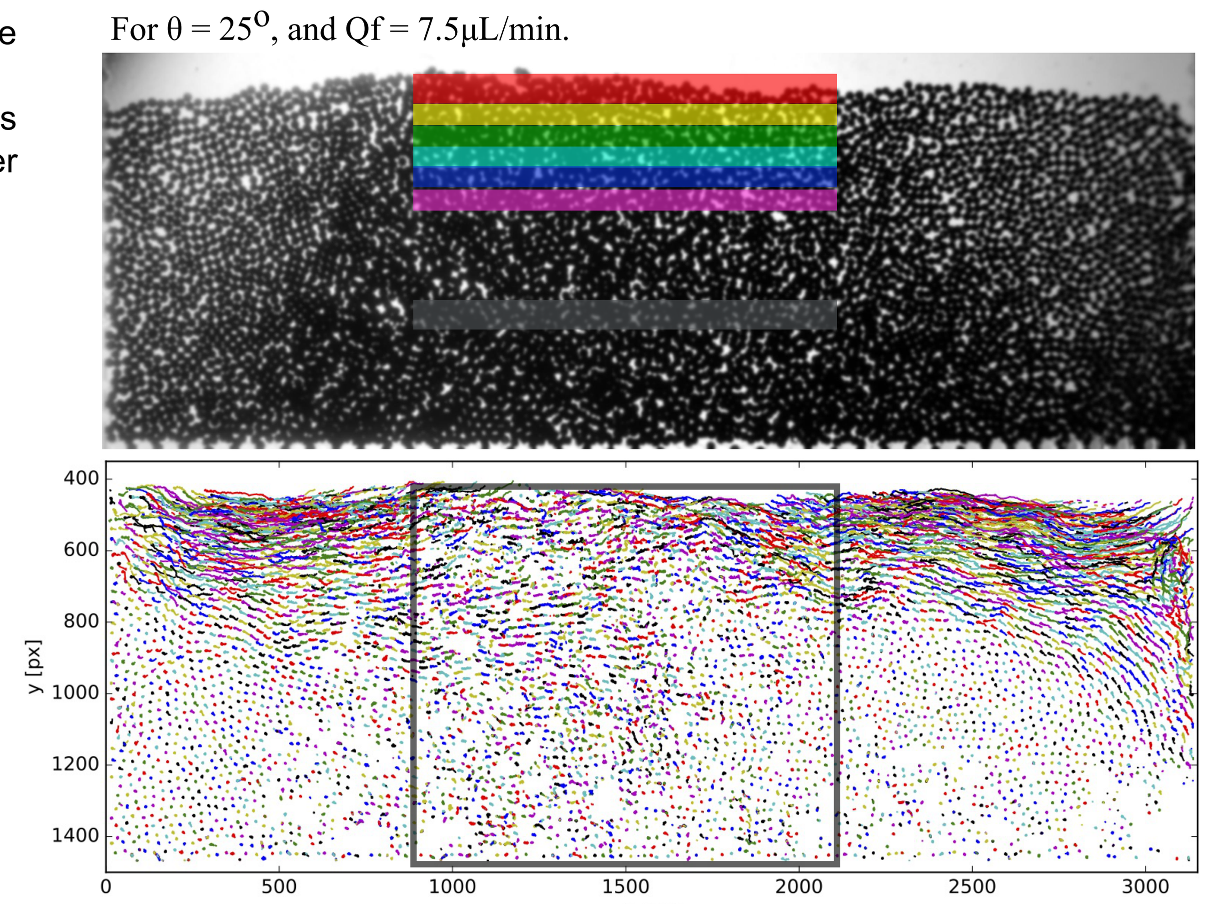


All images are rotated back to horizontal, and filtered with a particle size gaussian window.

Particles' positions are then tracked over 0.5 to several hours via images analysis[5], and deformations per elevation are computed locally[3], over time.

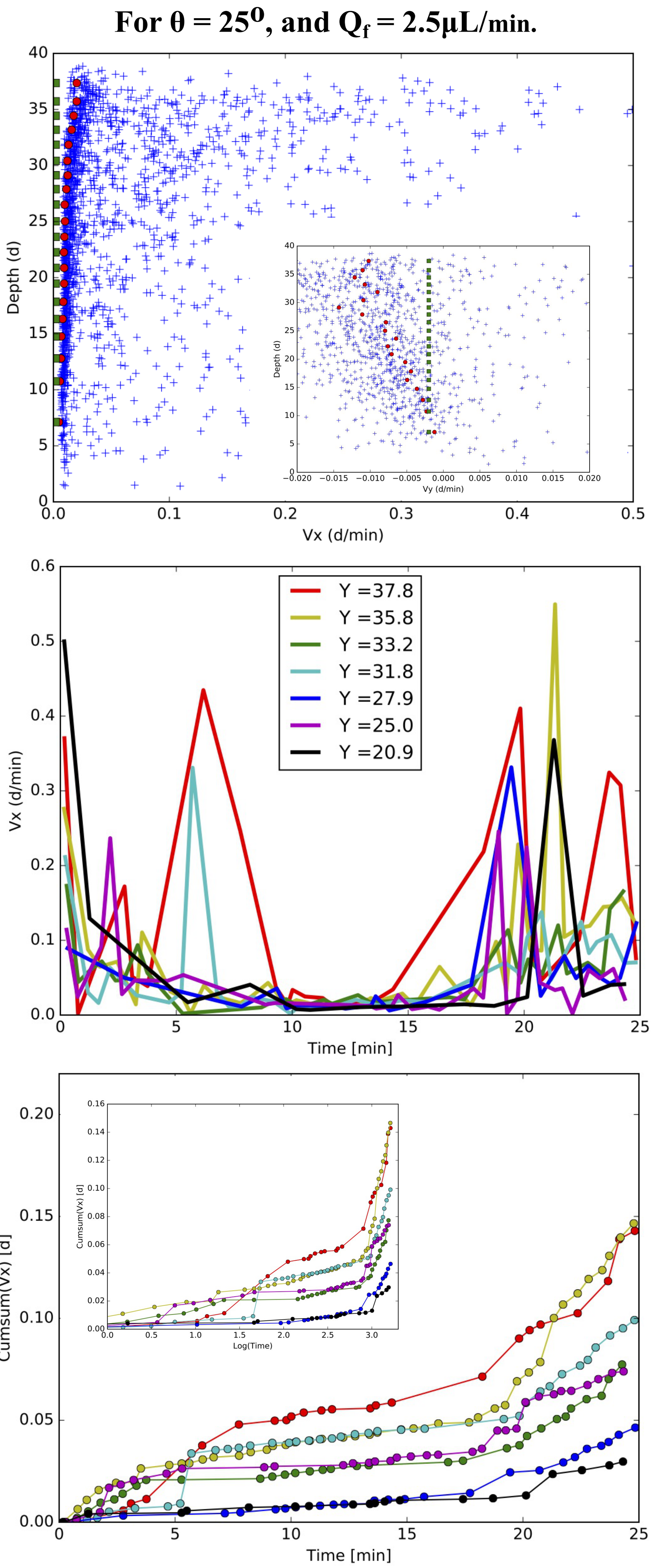


For θ = 25°, and Qf = 7.5μL/min.

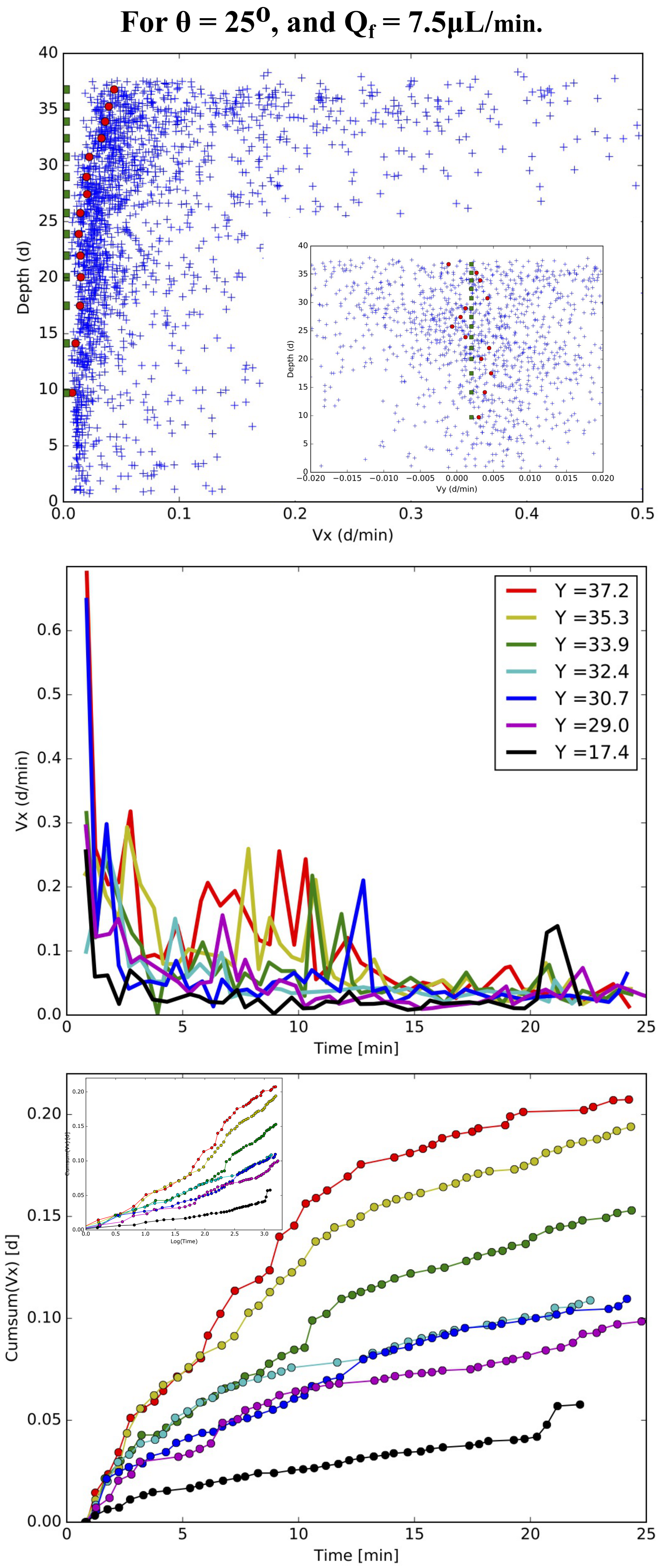


Some preliminary results - For θ = 25°

For θ = 25°, and Q_f = 2.5μL/min.

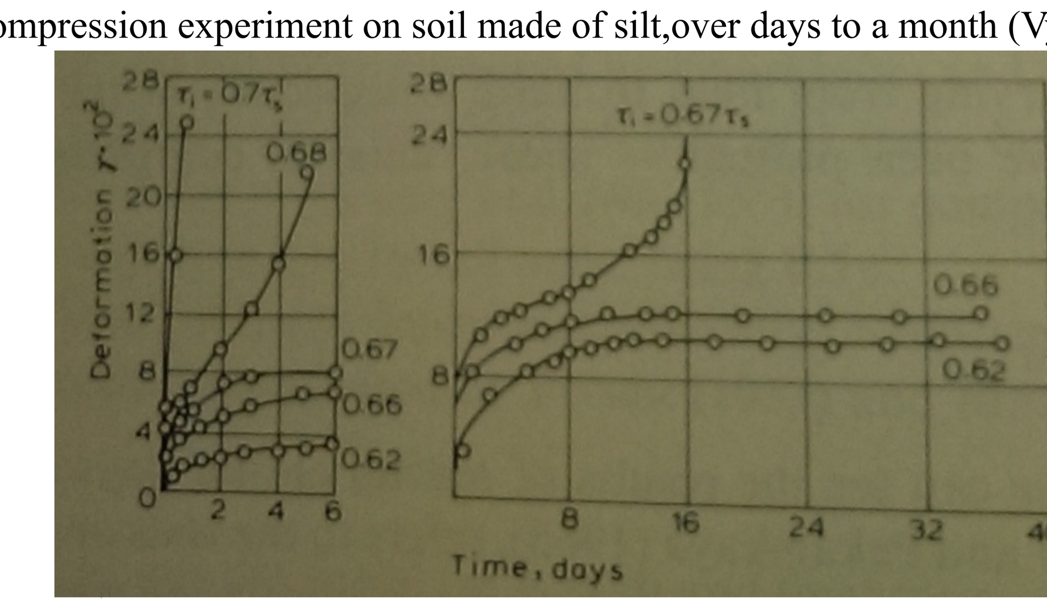


For θ = 25°, and Q_f = 7.5μL/min.

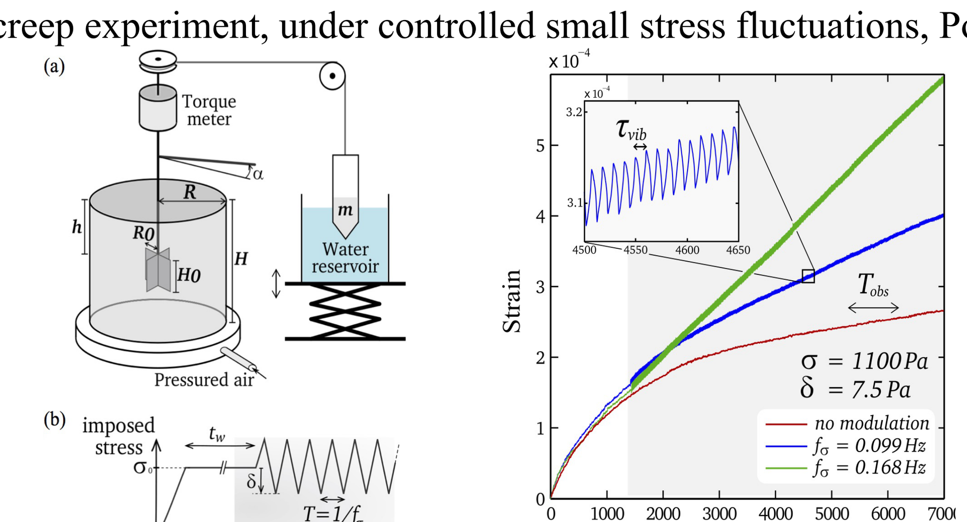


Discussion - comparison with other studies

Triaxal compression experiment on soil made of silt,over days to a month (Vyalov, 1986).



Dry granular creep experiment, under controlled small stress fluctuations, Pons et al., PRE, 2015 [6].



Effect of vibration intensity on dry avalanche dynamics and cessation, Gaudel et al., PRE, 2016 [7].

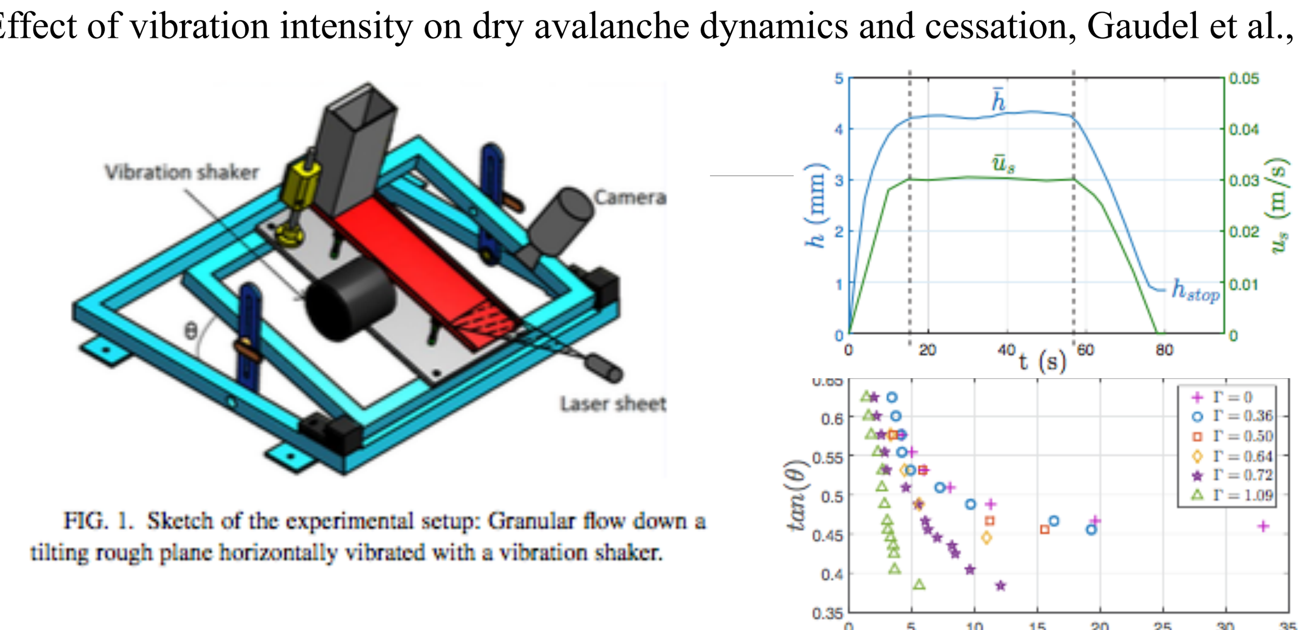


FIG. 1. Sketch of the experimental setup: Granular flow down a tilting rough plane horizontally vibrated with a vibration shaker.

References

[1] Houssais, Morgane, and Douglas J. Jerolmack. "Toward a unifying constitutive relation for sediment transport across environments." *Geomorphology* (2017).

[2] Houssais, Morgane, Carlos P. Ortiz, Douglas J. Durian, Douglas J Jerolmack. "Rheology of sediment transported by a laminar flow." *Phys. Rev. E* (2016)

[3] Houssais, Morgane, Carlos P. Ortiz, Douglas J. Durian, Douglas J. Jerolmack. "Onset of sediment transport is a continuous transition driven by fluid shear and granular creep." *Nature communications* 6 (2015).

[4] Boyer, Francois, Élisabeth Guazzelli, and Olivier Pouliquen. "Unifying suspension and granular rheology." *Physical Review Letters* 107.18 (2011).

[5] Allan, D., Caswell, T., Keim, N., & van der Wel, C. (2016). trackpy: Trackpy v0.3.2. Zenodo. http://doi.org/10.5281/zenodo.60550

[6] A. Pons, A. Amon, T. Darnige, J. Crassous, and E. Cl ement, "Mechanical fluctuations suppress the threshold of soft-glassy solids: The secular drift scenario," *Phys. Rev. E* 92, 020201 (2015)

[7] Gaudel, N., de Richter, S. K., Louvet, N., Jenny, M., & Skali-Lami, S. (2016). Granular avalanches down inclined and vibrated planes. Physical Review E, 94(3), 032904.