# DEBRIS FLOWS: MECHANISMS FOR DRY SNOUT FORMATION

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*Key words* Debris flows and debris avalanches are complex, gravity-driven currents of rock, water and sediments that can be highly mobile. This combination of component materials leads to a rich morphology and unusual dynamics, exhibiting features of both granular materials and viscous gravity currents, even at a single instance within a single flow. For example, a dry 'snout' with collisional granular behaviour often forms ahead of a wet, viscous tail. This works explores the range of mechanisms that in theory could control the formation and extent of the dry snout, and to understand when each can play a part in a debris flow.

Fig. 1 i shows an experimental model of a debris flow, comprising a marble-water mixture flowing down a rough incline. This flow is unsteady and intermittent, which leads to difficulty in its characterisation. To separate the unsteadiness of the mean flow from the rapid fluctuations images were captured at a high frame rate, such that an ensemble average over 14 frames ($\approx$0.02 s) reliably provided mean flow characteristics. Deviation from these local ensemble averages effectively discriminates between plug-like regions with low intermittency and collisional regions with high intermittency. Fig. 1 ii shows these regions in light and dark grey respectively, together with local ensemble averaged velocity profiles through the flow depth at two positions for mono- and polydisperse flows of particles.

This method allows us to explore how a dry granular snout can form from and co-exist with a plug-like viscous flow. One of the most striking features of the Fig. 1 ii velocity maps, is that this dilute, collisional regime, where the stresses are all supported by binary particle collisions occurs even for monodisperse flows so it does not require segregation to occur. This is somewhat surprising since the formation of a dry snout is usually attributed to particle size segregation and the role of fine sediments [2]. The formation of snout architecture in monodisperse flows with relatively high particle Reynold?s numbers, suggests that there are alternative fluid-particle processes at play.

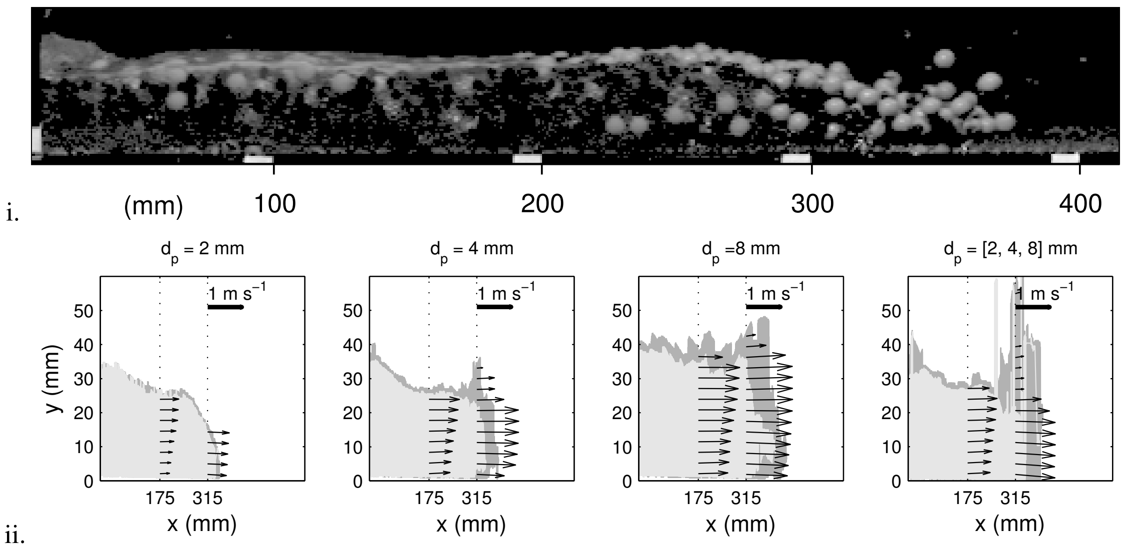


**Figure 1.** i. Side view of 1 litre glass bead-water mixture, with solid volume fraction 0.4, released from behind a lock gate to flow down a $27^\circ$ chute, $\mathrm{Re_p} \approx 10^4$. The beads have diameters 8 mm (coloured white), 4 mm (coloured black) and 2 mm (colourless), and the chute has 8 mm diameter beads fixed to the surface to generate roughness. ii, Debris flows of $d_p = [2, 4, 8]$ mm diameter glass beads and a mixture of those sizes in water over a rough surface formed of 4 mm diameter beads. The flow front is at 9 times the length of the release volume down the slope. Quivers show the magnitudes of the velocities at 10% and 50% of the flow length from the head averaged over 14 video frames. Pale grey indicates regions with low standard deviation from this mean, and dark grey regions are those with high standard deviations from the mean.[1]

## References

[1] B. Turnbull, E. T. Bowman & J. N. McElwaine, *Debris flows: Experiments and modelling*, Comptes Rendus Phisique **16**, 86–96 (2015).
[2] J. M. N. T. Gray & A. R. Thornton. *A theory for particle size segregation in shallow granular free-surface flows*, Proceedings of the Royal Society of London A **461**, 2057 (2005).