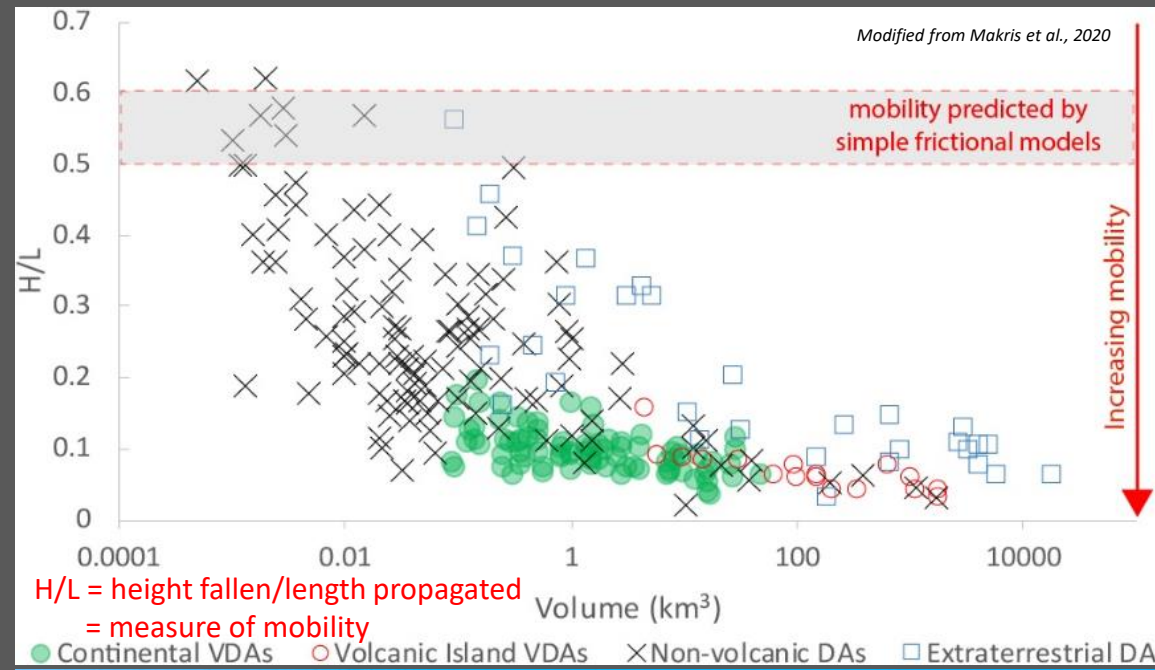


1. Long Runout Debris Avalanches - Background



Hitardalur landslide, Iceland, photo by Sumarliði Ásgeirsson, 2018
Eliasson and Sæmundsson, 2021



- Debris avalanches are large landslide events characterised by long runouts and high mobility that poses a great hazard.
- Many theories have been proposed to explain the excessive runout phenomenon but the mechanisms enabling the mobility remain unresolved and poorly constrained.
- The lack of explanation results from the difficulty of models and theoretical concepts to encompass the field observations of sedimentology and structure of debris avalanche deposits (Perinotto et al., 2015).

Understanding the mechanisms of propagation and emplacement of debris avalanches is vital from the hazard assessment perspective.

2. Debris Avalanches Vs Lahars: the role of water

Rationale



Events considered in this study:

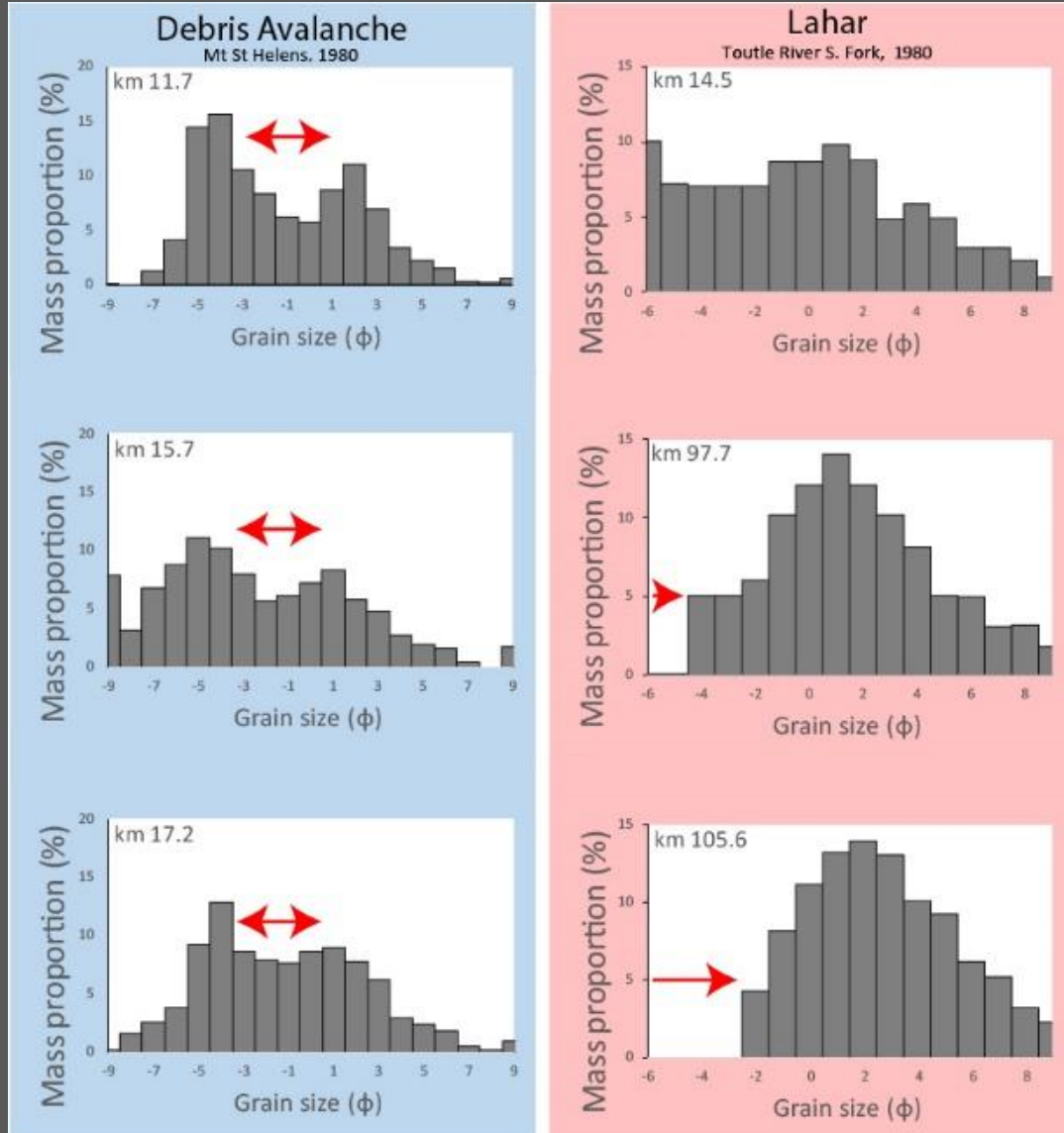
Type	Location	Age	Runout	Volume	H/L	Source
DA	Pungarehu, Taranaki Volcano, NZ	25 ka	>27km	>7 km ³	<0.09	Rovearto et al., 2015
DA	Shiveluch Volcano, Kamchatka, RS	multiple DADs	>15km	1.5 km ³	0.133	Belousov et al., 1999; Hayashi and Self, 1992
DA	Cubilche, Ecuador	>30 ka	>20km	>3–3.5 km ³	0.063	Roverato et al., 2018; Pierson and Costa, 1987
DA	San Marcos, Colima, Mexico	>28 ka	22.55k m	~1.3 km ³		Roverato et al., 2011
DA	Tonila, Colima, Mexico	15–16 ka	23.01k m	~1 km ³		
Lahar	Montegrande ravine, Colima, Mexico	15/09/2012				Vázquez et al., 2014
DA	Acajutla, Santa Ana volcano, El Salvador	<57 ka	~50 km	16 ± 5 km ³	>0.05	Siebert et al., 2004
DA	Rio Pita, Cotopaxi, Ecuador	4 ka	21km	2.1 km ³	0.12	Smyth, 1991
DA	Cotopaxi, Ecuador		20km	~2 km ³		Vezzoli et al., 2017
Lahar	Chillos Valley, Cotopaxi, Ecuador (evolved from the Cotopaxi DA)	4.5 ka	326km	3.8 km ³		Mothes et al., 1998
Lahar	Cotopaxi, Ecuador	multiple, post-1150 AD				Pistolesi et al., 2013
DA	Mt St Helens, USA		29km	2.9 km ³	0.106	Glicken, 1996
Lahar	Toutle River, North Fork, Mt St Helens (evolved from the Mt St Helens DA)	18/05/1980				Scott, 1988
Lahar	Toutle River, South Fork, Mt St Helens (evolved from the Mt St Helens DA)					
Lahar	Toutle River, Mt St Helens, USA	19/03/1982	83km		0.06	Pierson and Scott, 1985
Lahar	Popocatepetl, Mexico	2001 1997	>15km	3.3 x10 ⁵ m ³		Capra et al., 2003

To evaluate the role of water we compare the sedimentology of 9 volcanic debris avalanche deposits and 8 lahars with data that has been published in the literature. All the events considered are therefore from volcanic settings for consistency.

(Makris et al., 2020)

2. Debris Avalanches Vs Lahars: the role of water

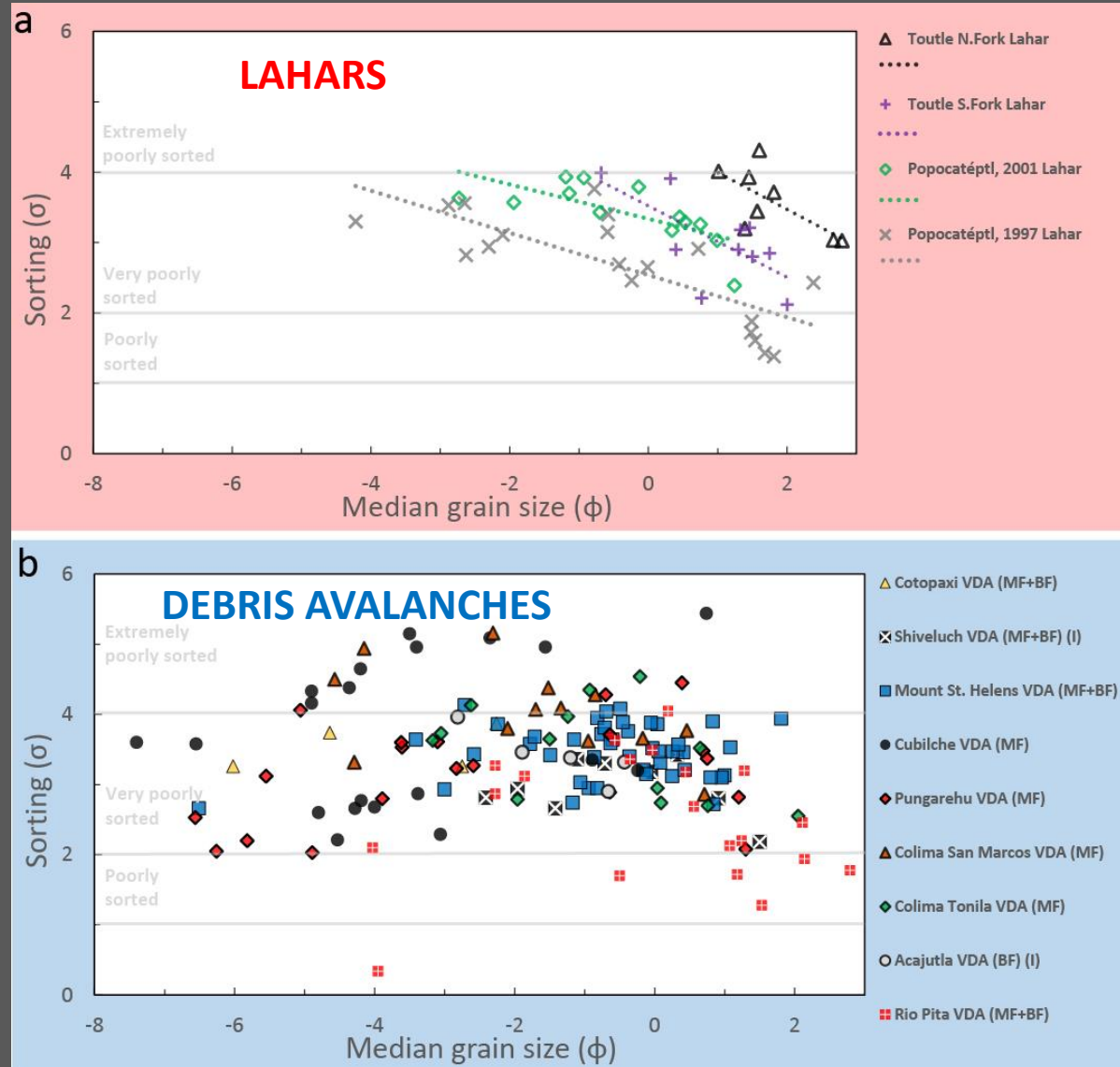
Results 1/3



- **Lahars:** progressive preferential removal of the coarsest range of the GSD.
- **Debris avalanches:** A bimodality in the grain size distribution is preserved during propagation. This is because of the preferential progressive comminution of finer particles and preservation of the coarser particles that require more energy to be broken.

2. Debris Avalanches Vs Lahars: the role of water

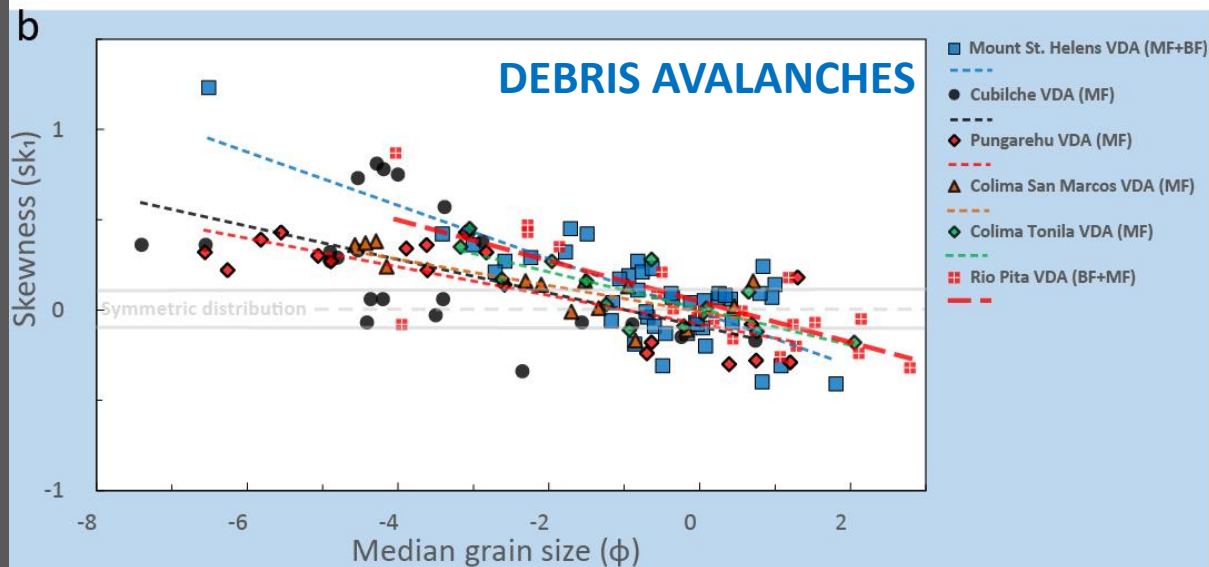
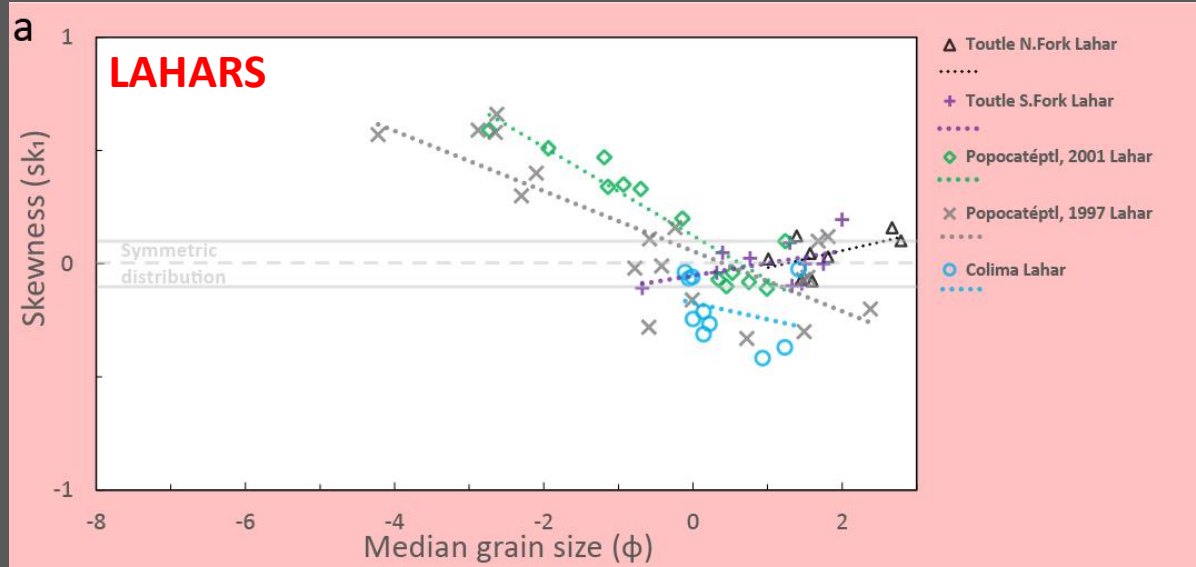
Results 2/3



- The deposition of the fine end of the histogram in **lahars** leads to an improvement of their sorting as the remaining material covers a smaller range of sizes.

2. Debris Avalanches Vs Lahars: the role of water

Results 3/3

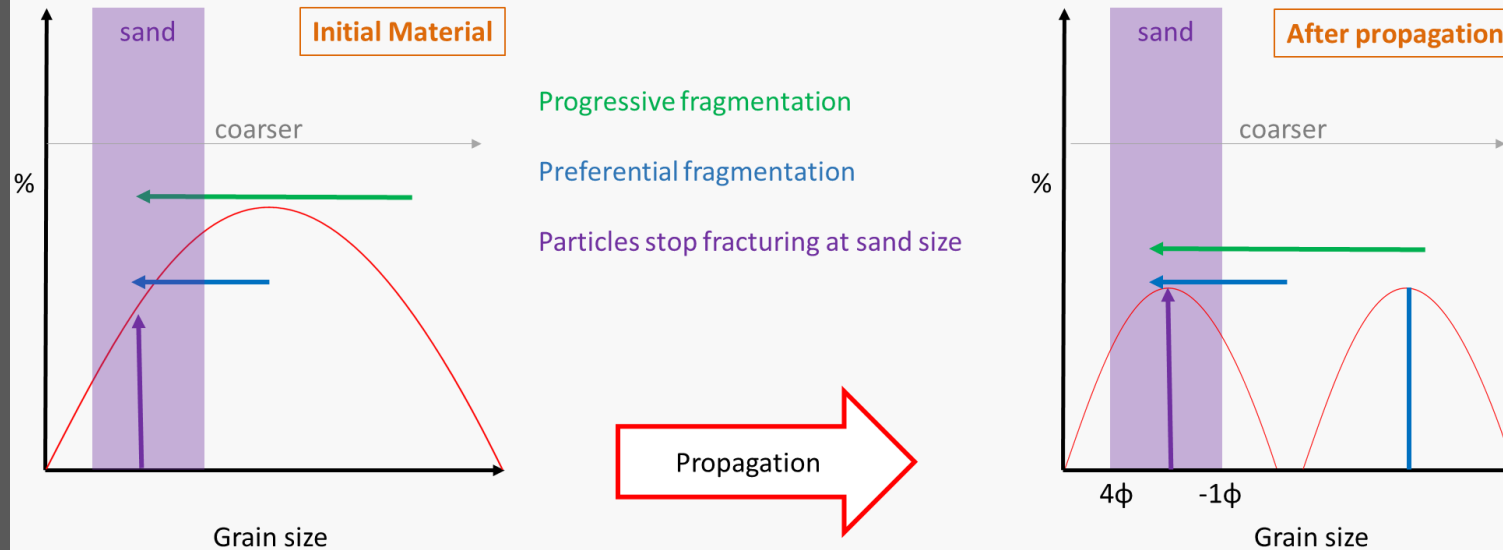


- In **volcanic debris avalanches** the preservation of the fine end of the grain size distribution progressively develops and enhances a negative skewness. This is because progressive fining adds to the fine-size 'tail' in the distribution while the coarsest particles are also preserved.

2. Debris Avalanches Vs Lahars: the role of water

Discussion

DEBRIS AVALANCHES

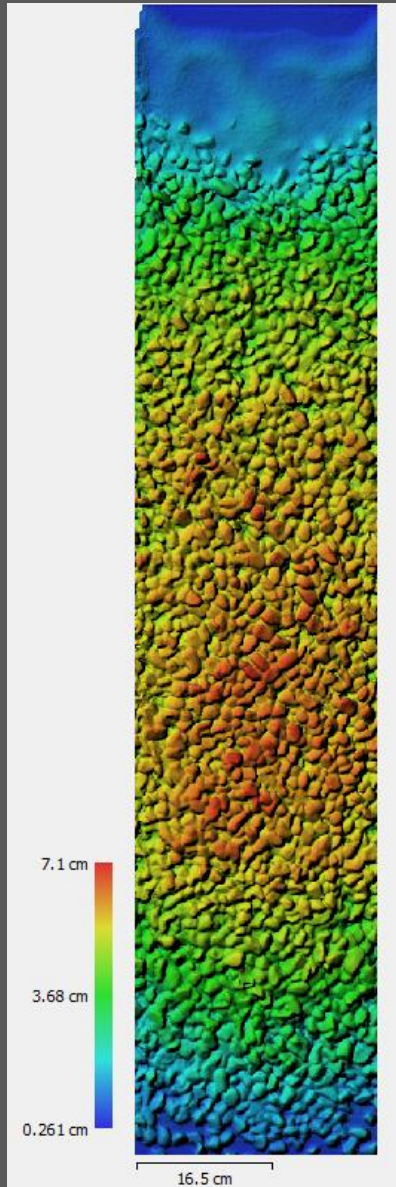


- Preferential comminution of finer particles due to particle-particle interactions in **volcanic debris avalanches**, and preservation of the coarse particles.
- Instead, preferential deposition of the coarsest particles and improved sorting suggest that the decrease in grain size of **lahars** is the result of **debulking**. Debulking is enabled because pore spaces are filled with water, which acts as the transportation medium for the sediment.

The findings support previous studies suggesting that debris avalanches can be considered as dense granular flows where the effect of inertial collisions of solid fragments are more important than fluid effects (= ideal granular avalanches).

3. Analogue experiments

Introduction

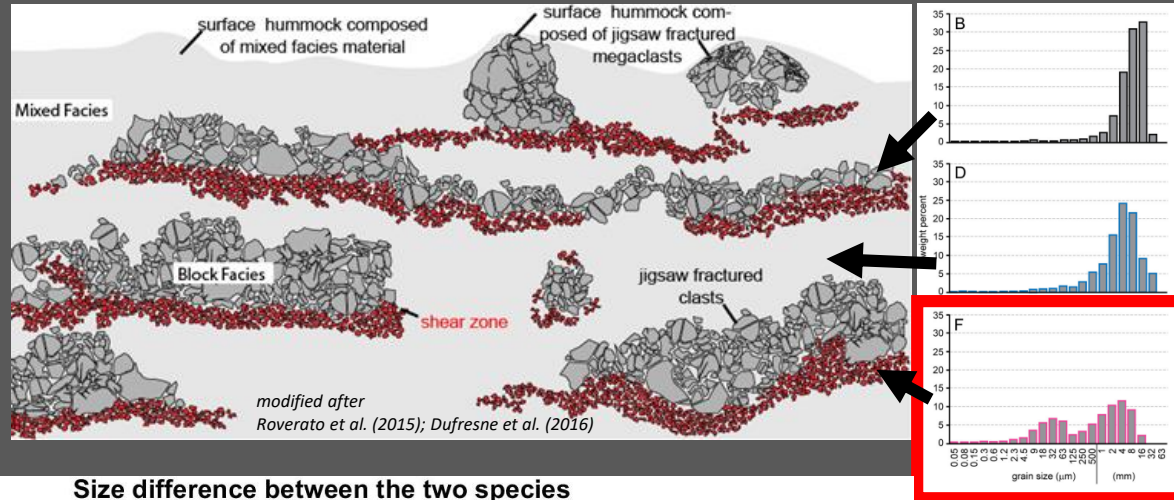


- Ideal granular avalanches can be modelled in the lab.
- Controlled granular flows were performed where variables were varied to examine their impact on energy dissipation, propagation mechanisms and mobility.
- Photogrammetry was used to create 3D models of the deposits to examine the location and the displacement of the centre of mass of the flows. This is very important when considering energy dissipation (Legros, 2002).

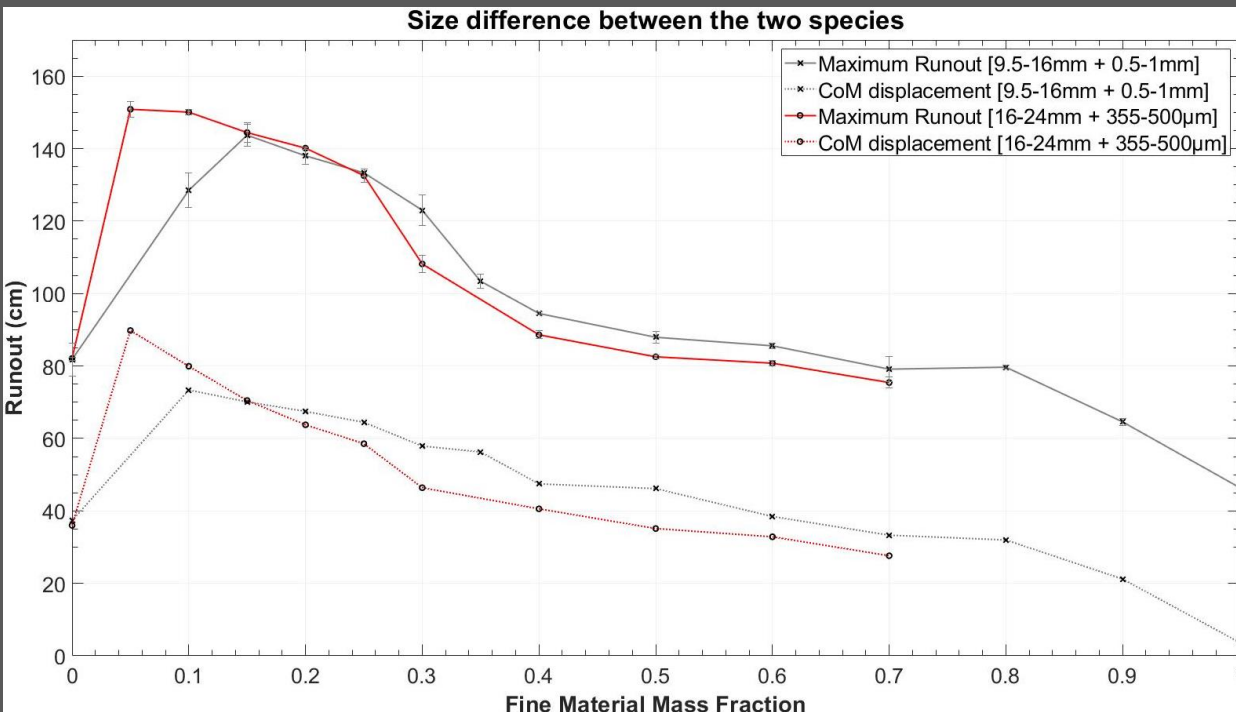
Laboratory experiments have the potential to contribute to the understanding of debris avalanches, the mechanisms that characterise propagation, their velocity and energy dissipation. Parameters can be systematically varied for their effect to be evaluated.

3. Analogue experiments

Bimodality effect on mobility



- Bimodal grain size distributions identified at least locally in areas of high shear (Dufresne and Dunning 2017).
- Experimental findings suggest bimodal distributions generated with increased shear/confining pressures (Caballero et al., 2014; Iverson et al., 1996).
- Fine particles act to reduce frictional areas between coarse, and between particles and the base. It has been suggested by experimental studies as well as numerical simulations that they act as 'rollers' to enhance rolling over sliding contacts. This behaviour limits frictional losses (Phillips et al., 2006; Linares-Guerrero et al., 2007).

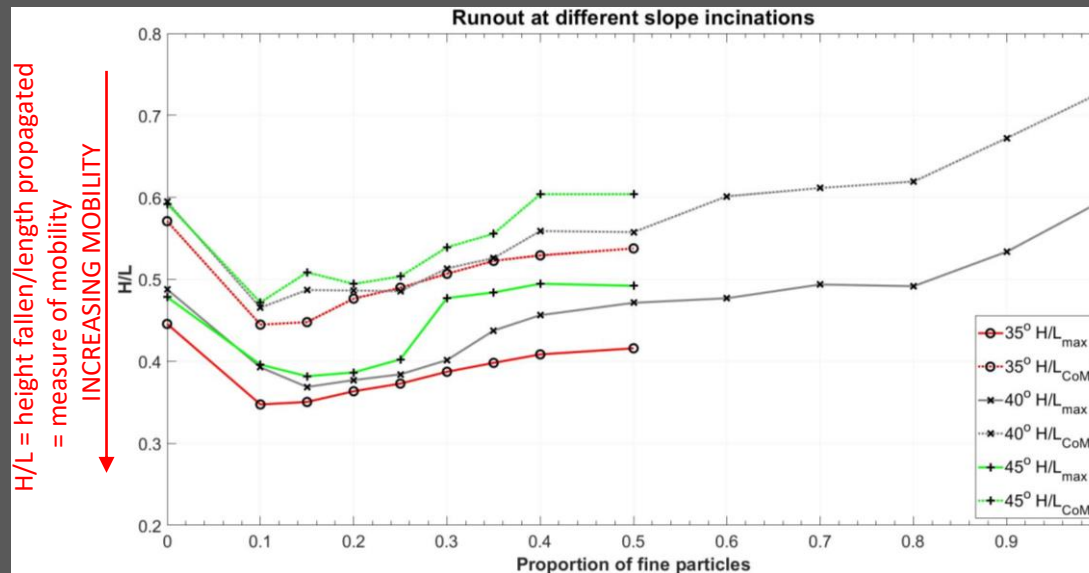


Dufresne and Dunning, 2017

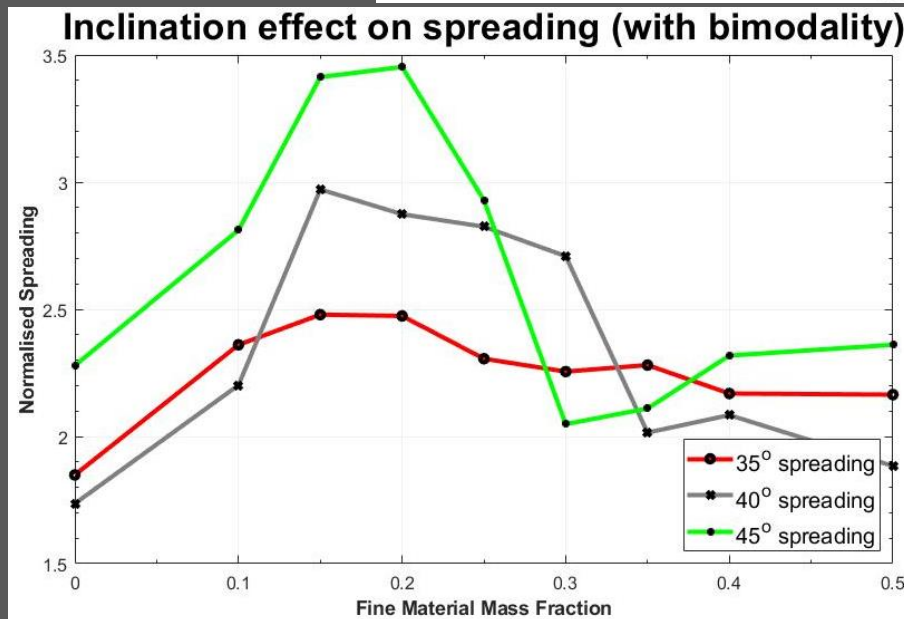
Our experimental findings support that bimodality in the grain size distribution is capable of increasing runout and the displacement of the centre of mass of granular flows.

3. Analogue experiments

Bimodality effect combined with other parameters



- The effect of bimodality on the mobility of the granular flow is further complicated when combined with other variables.
- Comparing the mobility of granular flows propagated at slope inclinations of 35°, 40° and 45°, lower inclinations yield higher mobilities.
- However, the spreading of the granular material is affected by the combination of fine particle content and inclination. At high inclinations there is high variability between the degree of spreading achieved at different fine particle contents. At lower inclinations that result in more mobile flows, the spreading is not as sensitive to the amount of fine particles in the granular material.



At higher inclinations, at the break of slope there is higher disturbance of the material. This results in higher momentum transfer between the front and the back. This energy dissipation inhibits the mobility of flows at higher inclinations even though it increases the spreading of the mass more at low fine particle content ratios.

1. Comparison of the sedimentology of saturated lahars and unsaturated volcanic debris avalanches supports previous studies suggesting that debris avalanches can be considered as ideal granular avalanches.
2. Our analogue granular flow experiments have focused on the bimodality that is observed in the grain size distribution of debris avalanches at least locally:
 - Bimodality develops in shear zones where shear accommodation is focused and magnified.
 - Bimodal distributions have been suggested by experimental findings as more efficient at accommodating shear and therefore conserving frictional energy.
3. Our findings support that the bimodality combined with other variables has the potential of affecting the energy dissipation and enhancing the mobility of debris avalanches.



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- Caballero, L., Sarocchi, D., Soto, E., Borselli, L., 2014. Rheological changes induced by clast fragmentation in debrisflows. *J. Geophys. Res. Earth Surf.* 119, 1800–1817. <https://doi.org/10.1002/2013JF002871>. Received
- Dufresne, A., Dunning, S., 2017. Process dependence of grain size distributions in rock avalanche deposits. *Landslides* 14, 1555–1563. <https://doi.org/10.1007/s10346-017-0806-y>
- Iverson, N.R., Hooyer, T.S., Hooke, R.L., 1996. A laboratory study of sediment deformation: Stress heterogeneity and grain-size evolution. *Ann. Glaciol.* 22, 167–175. <https://doi.org/10.1017/s0260305500015378>
- Legros, F., 2002. The mobility of long-runout landslides. *Eng. Geol.* 63, 301–331. [https://doi.org/10.1016/S0013-7952\(01\)00090-4](https://doi.org/10.1016/S0013-7952(01)00090-4)
- Linares-Guerrero, E., Goujon, C., Zenit, R., 2007. Increased mobility of bidisperse granular avalanches. *J. Fluid Mech.* 593, 475–504. <https://doi.org/10.1017/S0022112007008932>
- Makris, S., Manzella, I., Cole, P., Roverato, M., 2020. Grain size distribution and sedimentology in volcanic mass-wasting flows: implications for propagation and mobility. *Int. J. Earth Sci.* <https://doi.org/10.1007/s00531-020-01907-8>
- Perinotto, H., Schneider, J.L., Bachèlery, P., Le Bourdonnec, F.X., Famin, V., Michon, L., 2015. The extreme mobility of debris avalanches: A new model of transport mechanism. *J. Geophys. Res. Solid Earth.* <https://doi.org/10.1002/2015JB011994>
- Phillips, J.C., Hogg, A.J., Kerswell, R.R., Thomas, N.H., 2006. Enhanced mobility of granular mixtures of fine and coarse particles. *Earth Planet. Sci. Lett.* 246, 466–480. <https://doi.org/10.1016/j.epsl.2006.04.007>