Effects of debris-flow magnitude-frequency distribution on avulsions and fan development

T. de Haas[1,2*], A. Kruijt[2], A. L. Densmore[1]

1) Department of Geography, Durham University, Durham, UK; 2) Faculty of Geosciences, Universiteit Utrecht, Utrecht, The Netherlands; *) Presenting author: tjalling.de-haas@durham.ac.uk, t.dehaas@uu.nl

Durham University

Netherlands Organisation for Scientific Research

Utrecht University

Introduction

Shifts in the active channel on a debris-flow fan, termed avulsions, pose a large threat because new channels can bypass mitigation measures and cause damage to settlements and infrastructure. Recent, but limited, field evidence suggests that avulsion processes and tendency may depend on the flow-size distribution ans associated flow-size sequences, which are difficult to constrain in the field.

Objectives

Here, we investigate how flow magnitude-frequency distribution and associated flow sequences affect the spatio-temporal patterns of debris-flow-fan development. To do so, we study and compare the evolution and avulsion mechanisms of three experimentally-created debris-flow fans formed by different flow-magnitude distributions.

Methods

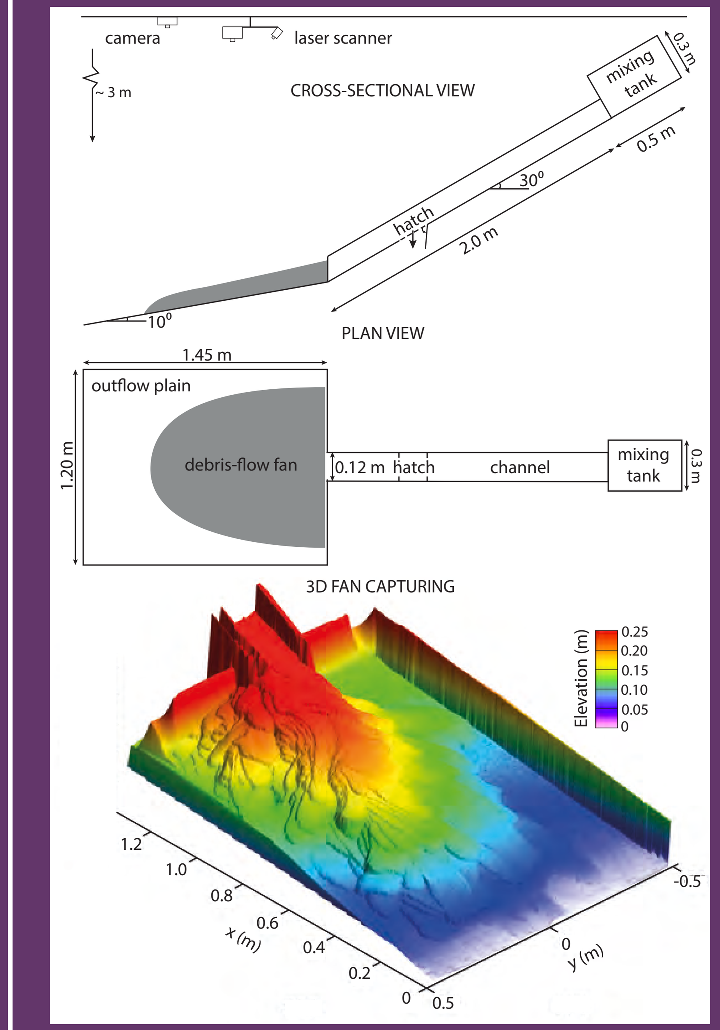

Fig. 1: Experimental flume setup. The 3D fan image shows the final morphology of fan 01. The flume setup is similar to that used in De Haas et al. (2016).

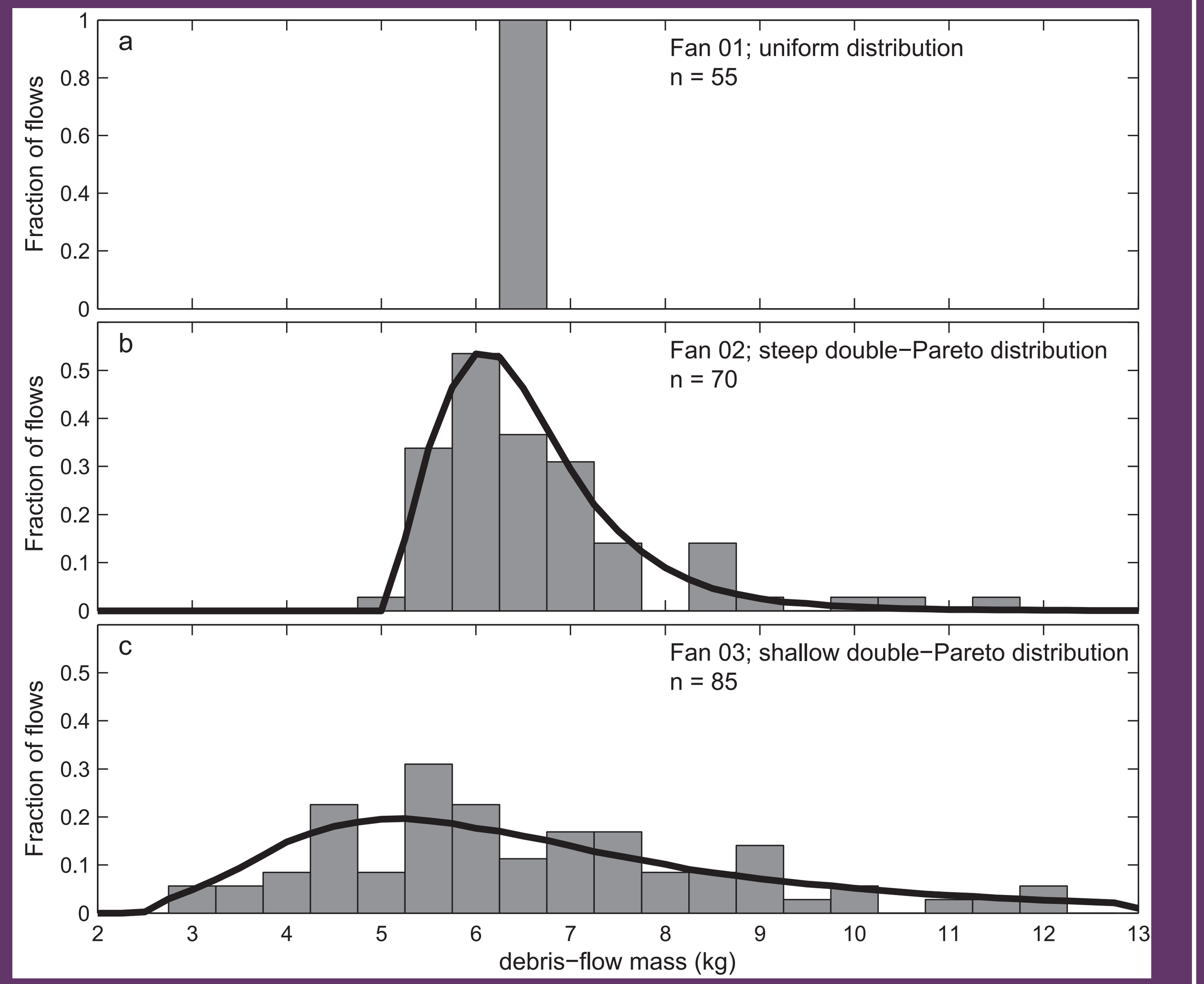

Fig. 2: Magnitude-frequency distributions of the experimental debris-flow fans. The lines denote the double-Pareto distributions from which the debris-flow magnitudes were randomly extracted. The bars denote the actual number of events in each experiment, divided into 0.5 kg bins. The mean debris-flow mass is ~6.5 kg for all experiments. (a) Fan 01 with a uniform distribution; (b) fan 02 with a steep-tailed double-Pareto distribution; (c) fan 03 with a shallow-tailed double-Pareto distribution.

Fan evolution

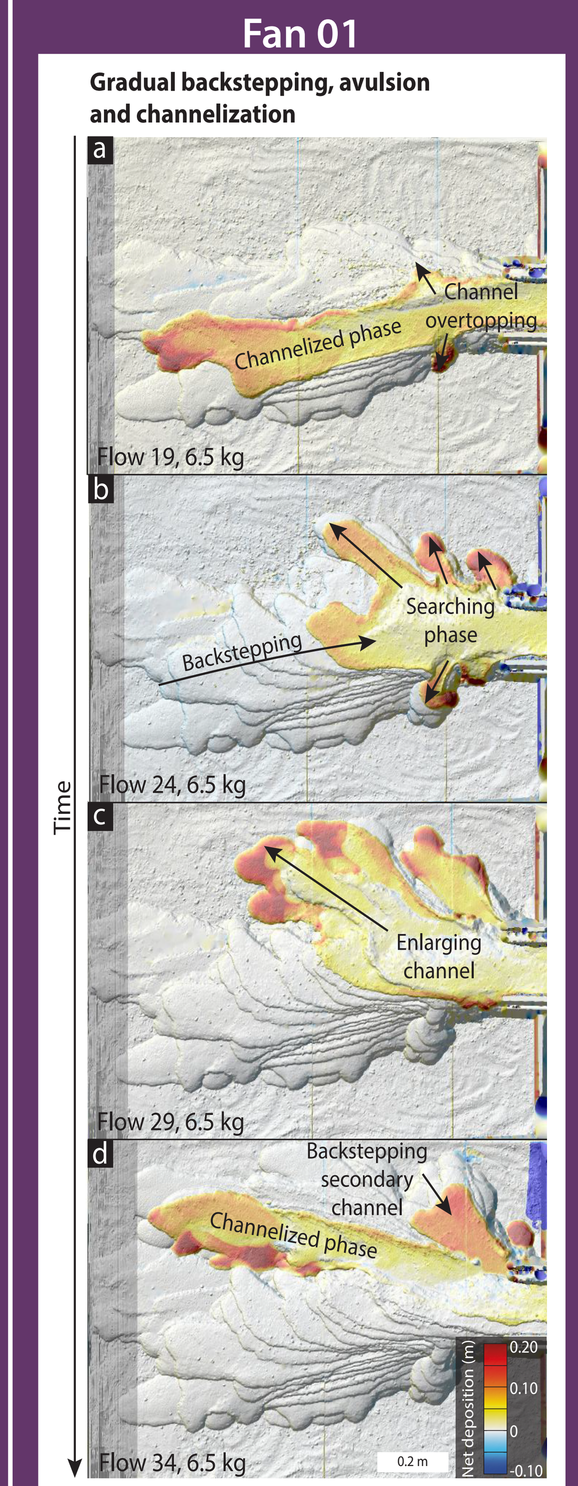

Fig. 3: Typical avulsion sequence on fan 01. Evolution from a well-defined channel (a) through gradual backstepping of deposition toward the fan apex, followed by a searching phase (b), avulsion to a new channel pathway and enlargement (c), and channelization (d).

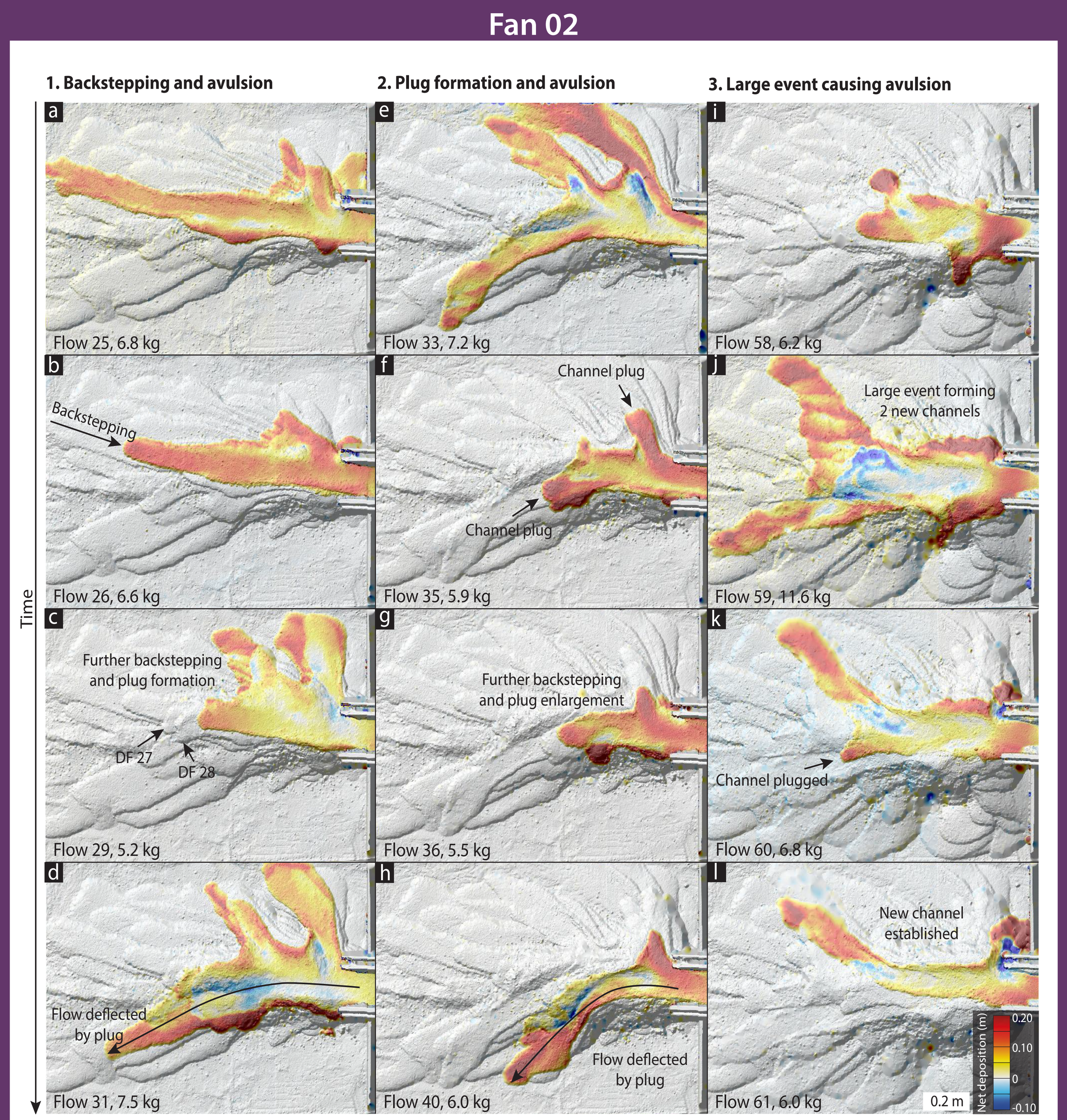

Fig. 4: Common debris-flow-magnitude sequences leading to avulsion on fan 02. (a-d) Backstepping and avulsion sequence during debris flows 25-31. A sequence of small- to moderately-sized flows induced a sequence of backstepping deposition (b and c), which was followed by avulsion during the large flow 31 (panel d). (e-h) Channel plug formation by two small debris flows that blocked the main channel (f and g), followed by avulsion during a moderately-sized flow (h). (i-l) A very large debris flow created two new channels (j), one of which became blocked by a flow snout in the next, smaller flow (k). Avulsion then proceeded into the topographically-favored right-hand channel (l).

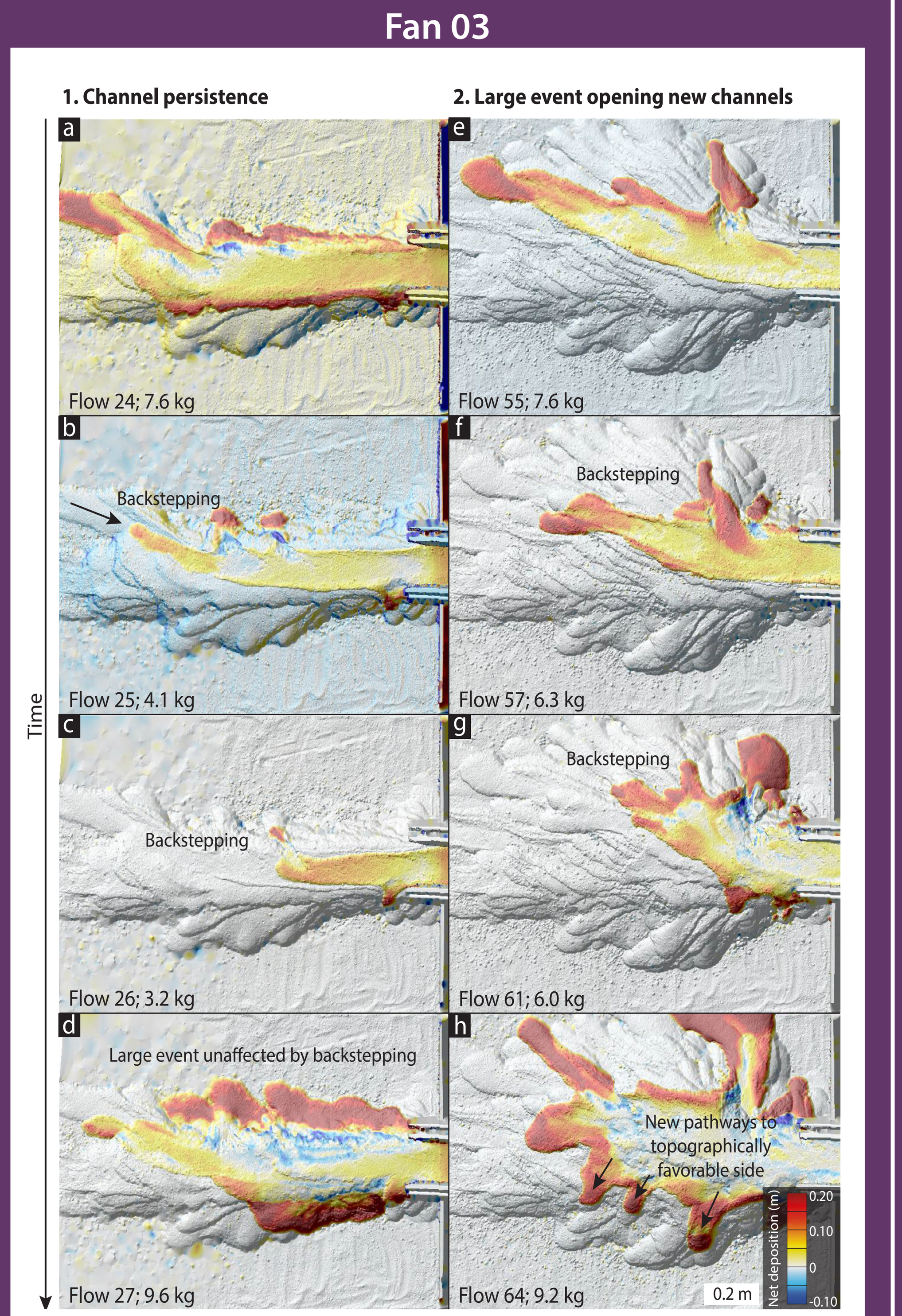

Fig. 5: Common spatio-temporal patterns of debris-flow activity on fan 03. (a-d) Persistent channel position during debris flows 24-27. The direction of the large debris flow 27 (d) was unaffected by the backstepping plug deposits from the small flows 25 and 26 (b-c). Overbank surges were abundant. (e-h) After a partial backstepping sequence from debris flow 55 to 62 (e-g), large flows 63 and 64 opened up three new channel pathways on the left side of the fan (h, shown by arrows) that allowed subsequent avulsion towards the left.

Spatio-temporal patterns

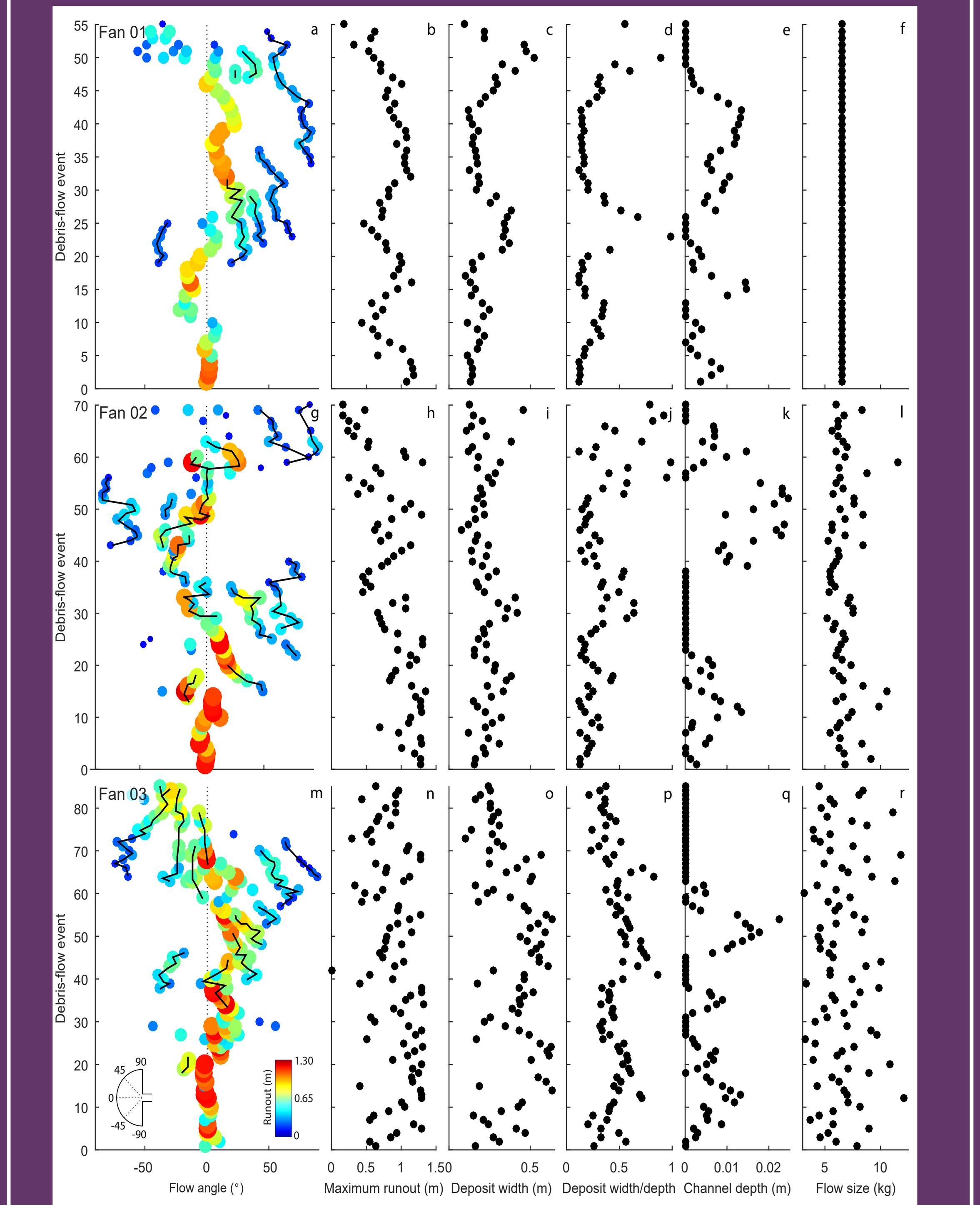

Fig. 6: Summary of the spatio-temporal patterns of debris-flow activity. Solid line segments join successive flows in the same channel. (b) Maximum runout distance during each debris flow on fan 01. (c) Deposit width during each event on fan 01. (d) Deposit width/depth ratio for each debris flow on fan 01, defined as deposit width divided by maximum runout distance. (e) Channel depth after each debris-flow event on fan 01, measured 10 cm downstream of the fan apex. (f) Debris-flow mass in kg. (g-l) As above for fan 02. (m-r) As above for fan 03.

Cross-sections

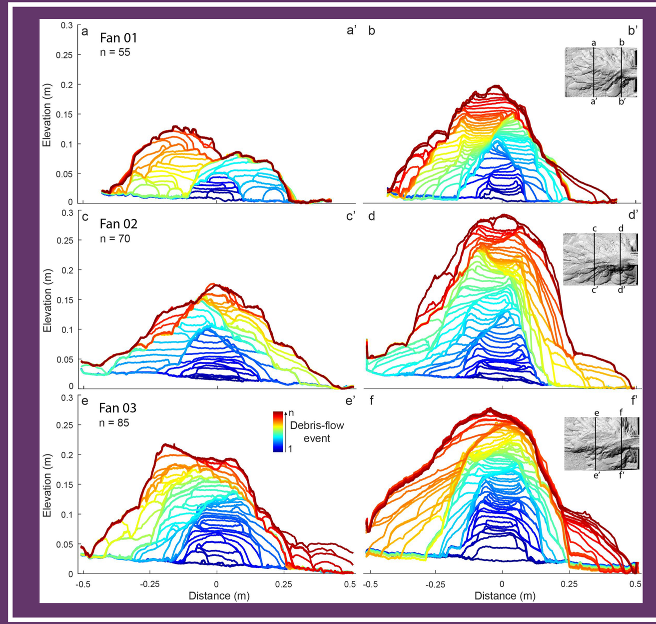

Fig. 7: Cross-profiles through the experimental debris-flow fans at distances of 0.2 m (left-hand column) and 0.8 m (right-hand column) downstream of the fan apex. Colors show progressive flow sequence from cool to warm. (a-b) Fan 01. (c-d) Fan 02. (e-f) Fan 03. Note how overbank deposition became increasingly important for fan construction and how large lateral shifts became less pronounced with increasing flow-magnitude variability from fan 01 to 03.

Exp. vs Nature

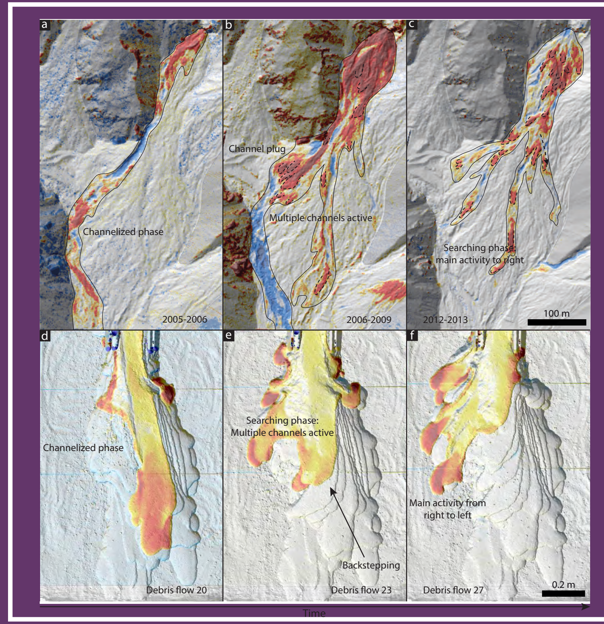

Fig. 8: Examples of the transition from channelized to searching phases on (a-c) the Ohya debris-flow fan in Japan (images modified from Imaizumi et al., 2016; De Haas et al., 2018) and (d-f) experimental debris-flow fan 01. Flow in all panels was from top to bottom. On both the natural and experimental fans, activity during the searching phase was spread over multiple channels on the proximal fan, and the locus of activity shifted laterally across the fan over multiple debris flows. Warm colors indicate deposition and cool colors indicate erosion, although absolute scales differ.

Conclusions

Overall, the three fans formed by similar patterns of development: alternating channelized and unchannelized phases governed by backstepping deposition and avulsion. Volume variations, however, lead to contrasting avulsion mechanisms: (1) Large flows can overtop the channel and carve new flow paths, initiating avulsion within a single event. (2) Series of small-medium flows can block the active channel, leading to avulsion in the next large flow. We infer that there may be an optimal magnitude-frequency distribution that maximizes the avulsion frequency, reflected by the balance of small versus large flows.