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Effects of debris-flow composition on runout distance and depositional mechanisms in laboratory experiments

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Introduction

Debris-flow composition

- Debris-flow composition (i.e., rheology) is generally neglected in runout distance predictions.
- The effects of debris-flow composition on debris-flow depositional mechanisms is poorly understood.

Need for small-scale experiments

- The effects of debris-flow composition on runout distance and depositional mechanism have been largely neglected for practical reasons.
- Experiments enable detailed control of boundary conditions, such as debris-flow composition. However, unconfined experimental debris flows with self-formed levees and a marked lobe have only been formed in the large-scale USGS laboratory flume, and have not been formed in smaller-scale flumes to date.

Objectives

- We aim to:
  - Experimentally create unconfined small-scale debris flows that show similar flow behavior, grain segregation and deposit morphology as natural debris flows.
  - Evaluate the effects of debris-flow composition on runout distance and depositional mechanisms.

Methods

Experimental setup

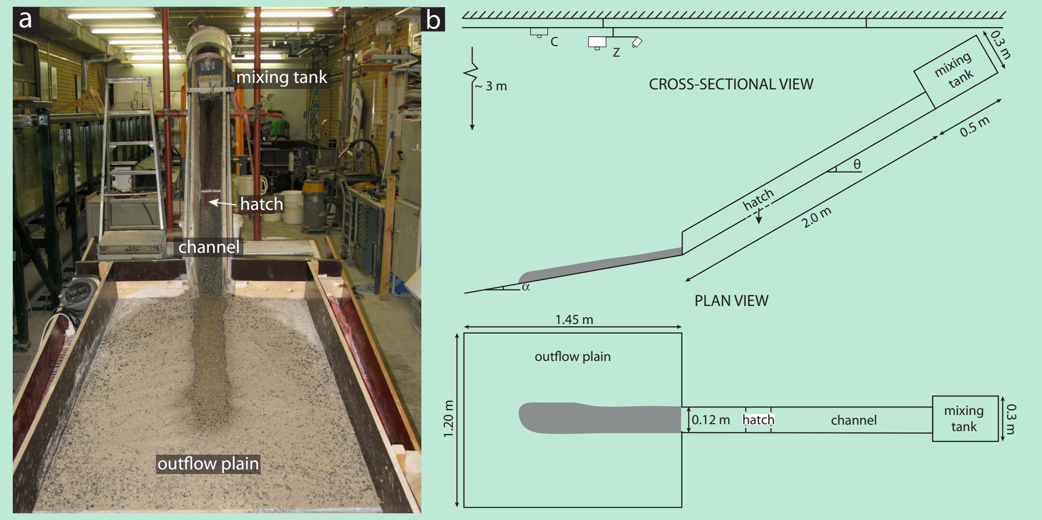

Fig. 1) Experimental setup. (a) Picture of the experimental setup. (b) Schematic overview of the experimental setup.

- We experimentally created 190 debris flows
- Flume (Fig. 1):
  - Channel: 30^0 inclination, 0.12 m wide, 2 m long
  - Outflow plain: 10^0 inclination, initial ~1 cm thick sand bed
- Hatch to divert debris-flow tail to prevent overflow of the initial deposit.

Data collection

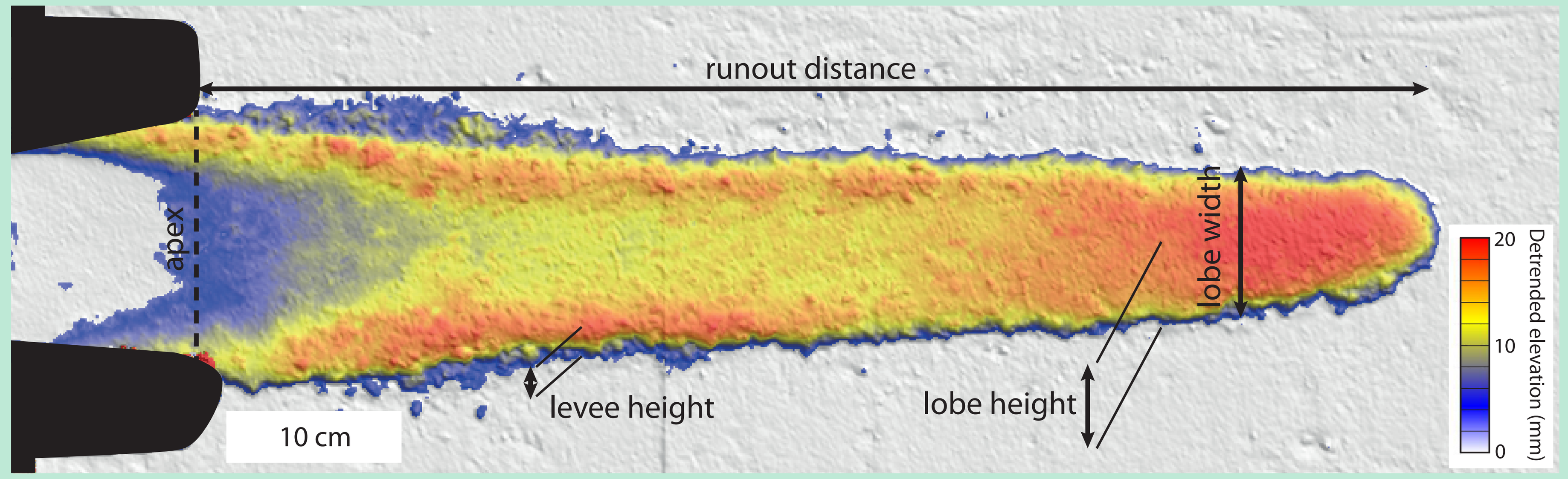

Fig. 2) Mapped quantities of debris-flow deposits; runout distance, lobe height, lobe width and levee height. DEM resolution is 1 mm.

Key experimental results

- The small-scale experimental debris flows comprised multiple surges, coarse particles accumulated at the flow front, and were subsequently shouldered aside to deposit in lateral levees by a more liquefied flow body. This resulted in strong sorting, with the coarsest particles concentrated in lateral levees and at the frontal margins (Fig. 3).

Fig. 3) Morphology and sediment sorting of selected debris flows. F_g denotes gravel fraction, F_c denotes clay fraction.

- Clear optimum between runout distance and gravel fraction (Fig. 5). Low gravel fraction: levees insignificant , causing lateral spreading and small runout length. More gravel: increased collisional forces, enhanced levee formation, longer runout. Very high gravel fractions: reduced runout by large resistive coarse-grained flow front. Deposition induced by frontal resistance.
- Clear optimum between runout distance and clay fraction (Fig. 6). Clay fraction up to 0.2: clay suspension in pore-fluid, liquefying the flow and increasing runout. Larger clay fractions: viscous flows, very high yield strength, strongly decreased runout distance. Deposition induced by viscosity and yield strength in clay-rich flows.

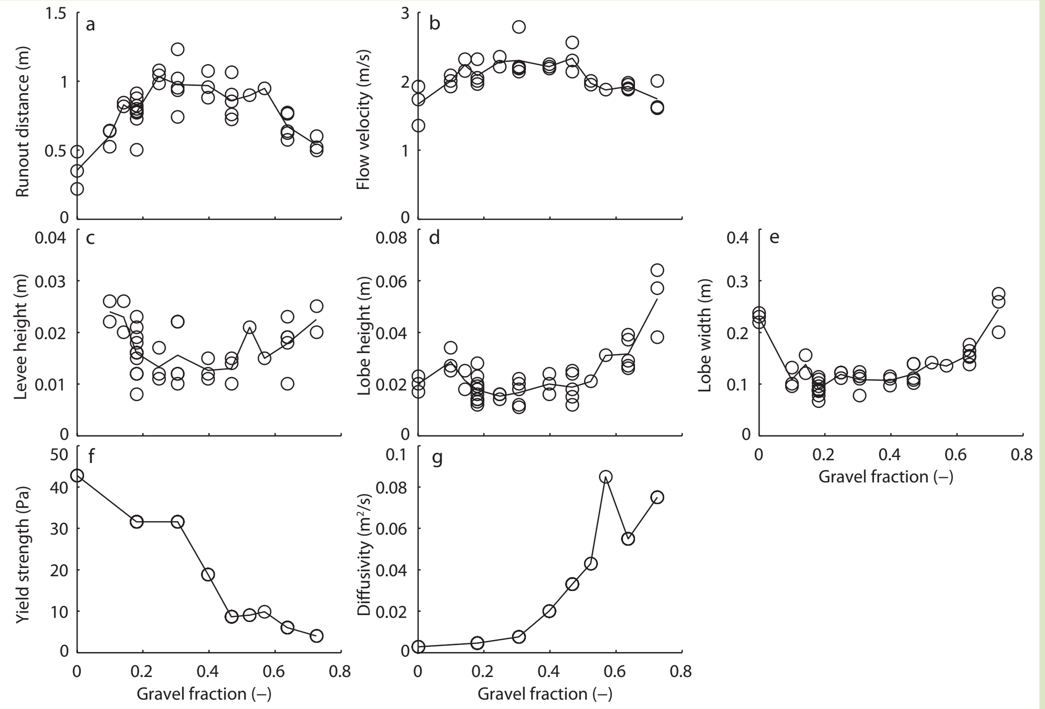

Fig. 5) Flow, morphological and geotechnical properties as a function of gravel fraction in otherwise the same conditions. The solid line connects the values averaged by gravel fraction class.

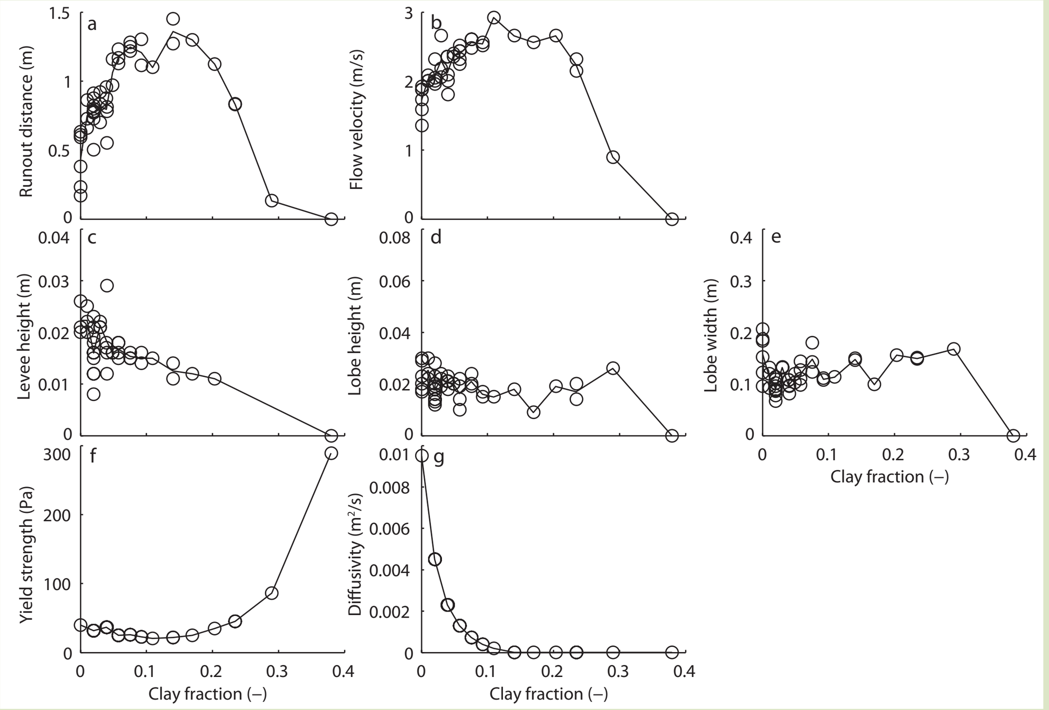

Fig. 6) Flow, morphological and geotechnical properties as a function of clay fraction in otherwise the same conditions. The solid line connects the values averaged by clay fraction class.

Discussion

- Sediment sorting and morphology of the experimental debris flows is similar to natural debris flows (Fig. 7).
- Width-to-depth ratio of the experimental debris-flow channels is in the range of natural debris flows. Runout length (or travel distance) is relatively restricted and at the lower range of natural debris flows (Fig. 8).
- Lobe height generally determined by the frontal accumulation of coarse particles, not by yield strength.

Fig. 7) Comparison between sediment sorting of experimental (a,c) and natural (b,d) debris flows.

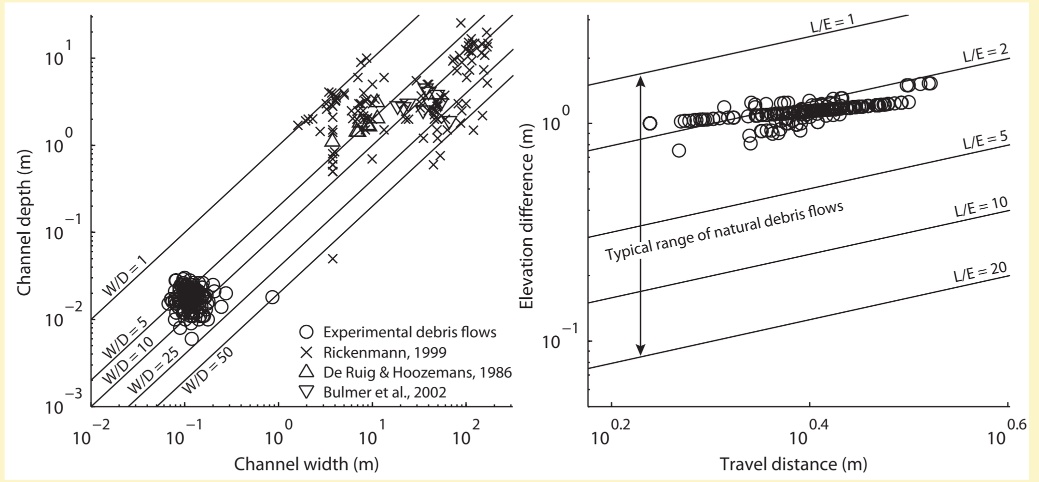

Fig. 8) Comparison of the dimensions of experimental and unconfined and confined natural debris flows.

Future experimental work:

- Debris-flow fans: studying the autogenic dynamics of debris-flow fans (Fig. 9).
- Debris-flow erosion: studying the erosive potential of debris-flows of various composition (Fig. 10).

Fig. 9) Debris-flow fan after 54 stacked debris flows.

Fig. 10) Debris-flow erosion experiment. We use an initial bed layered with colored sand, in order to determine the erosive depth in the runout zone.

Conclusions

- We experimentally created unconfined small-scale debris flows with self-formed levees and a marked depositional lobe.
- Flow dynamics, deposit morphology and sediment sorting were similar to natural debris flows.
- Debris-flow composition has a profound effect on runout distance and depositional mechanism. Therefore, compositional effects should be incorporated in runout distance predictors.
- There is an optimum runout distance for gravel and clay fraction, whereas runout increases with water fraction (latter result not shown on this poster).
- Debris-flow deposition is primary governed by friction at the flow front in most debris flows, but in debris flows with a very high clay content high viscosity and yield strength govern deposition.

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