The dynamics of CO_2-driven flows in Martian gullies

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Introduction

Martian gullies (Fig 1) have been hypothesized to be formed by various processes. Recent activity and new flow deposits in Martian gullies have shifted the leading hypothesis from water-based to **CO_2-driven flows**.

Due to a lack of in-situ observations, the following questions remain: **(1)** If and how the sublimation of CO_2 ice can fluidize granular material? **(2)** How much CO_2 ice needs to sublimate to explain the observed changes? **(3)** How CO_2-driven granular flows on Mars create landforms that are identical to landforms created by water-driven debris flows on Earth?

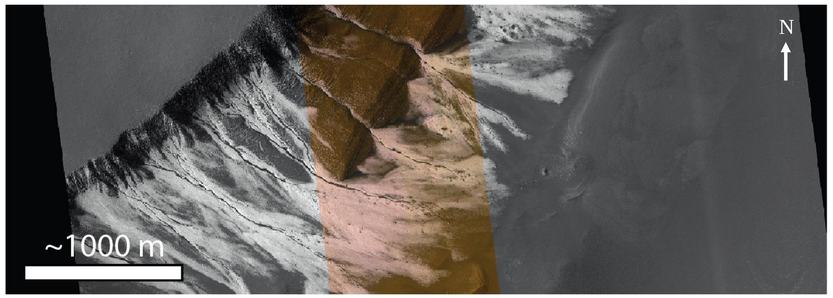

Fig 1 Martian gullies in Sisyphi Cavi (HiRISE image, ESP_039114_1115, Ls 243°), where defrosted surfaces appear red and frosted surfaces white.

Method

- Experiments in 2 flume set-ups (Fig 2c-d) of different sizes in different environmental chambers: the **Mars Chamber, The Open University (UK)** (Fig 2a) and the **Mars Simulation Wind Tunnel, Aarhus University (DK)** (Fig 2b).
- In the experiments mixtures of sediment and CO_2 ice were released into the flume under Martian atmospheric conditions (~8mbar).
- 1D atmosphere and subsurface column model (Mars PCM) to study where and when slope conditions are favorable for this process.

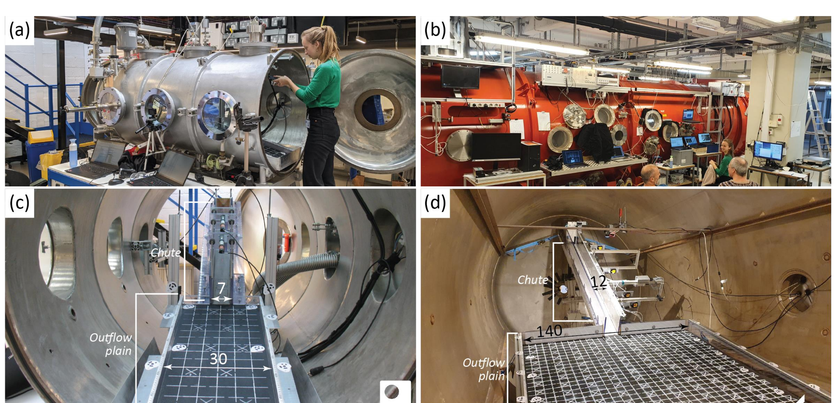

Fig 2 Photos of environmental chambers (a-b) and flume set-ups (c-d), at the Open University (a,c), referred to as small-scale, and Aarhus University (b,d), referred to as large-scale. Measurements are in cm. Preprint JGR-Planets Roelofs et al., 2024. .

Flow dynamics

- Fluidization due to high pore pressures from the sublimation of CO_2 ice in the granular mixture (0.8—1.3% of the total flow mass).
- Flow velocities of 2-3 m/s and flow depths of 1 -3 cm (Fig 3a-b).
- Gas pressure carries between 20-60% of the flow mass (Fig3c).

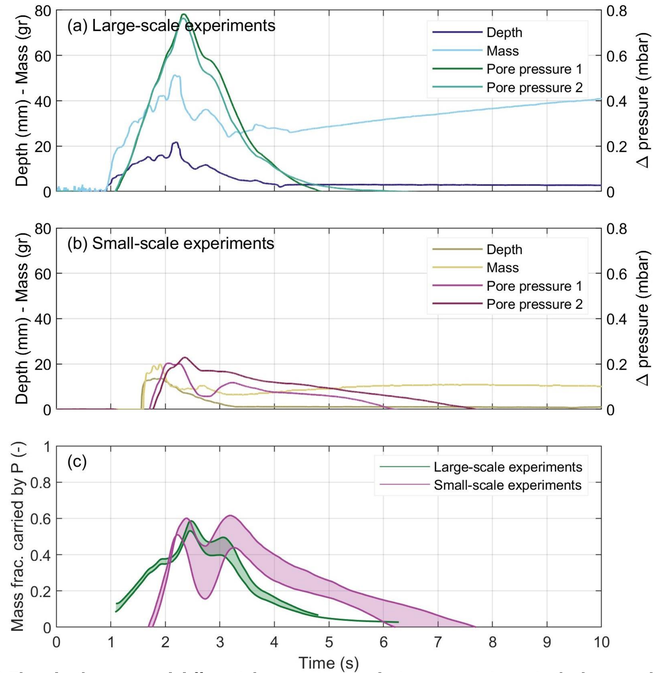

Fig 3 Flow depth, mass, and differential pore pressures during an experiment in the large-scale set-up (a) and small-scale set-up (b); initial CO_2 mass fraction of 0.23 and flume angle of 20°. Panel (c), shows the mass fraction of the flow carried by the gas pressure for the experiments depicted in panels (a) and (b). Preprint JGR-Planets Roelofs et al., 2024.

Morphology

Outflow deposits of experiments with CO_2 contain:

- Multiple lobes formed by different surges (Fig 4f,k). Some are stacked.
- Some of the deposits show levees (Fig 4b). They form when one surge overrides the next.

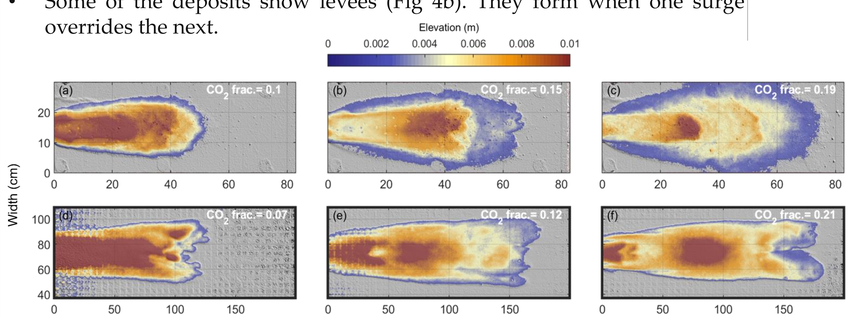

Fig 4 DEMs of deposits of 6 experiments, in the small (a-c and h-i) and large set-up (d-f and j-l) Preprint JGR-Planets Roelofs et al., 2024. .

Favorable conditions

Schematized slope & climate conditions in a 1D-PCM test for 2 flow mechanisms where and when these could occur. The modelled occurrence envelops observed activity (Fig 5).

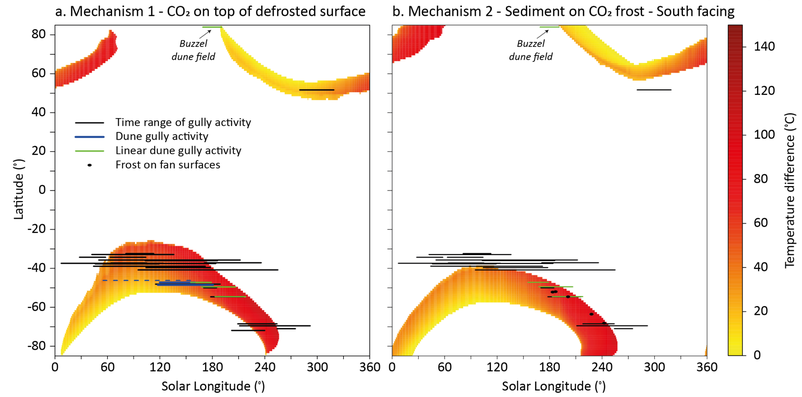

Fig 5 Climate model results with observed gully activity superimposed. Color indicates the maximum daily temperature difference between frosted and unfrosted surfaces for (a.) mechanism 1 and (b.) mechanism 2 for south-facing slopes for different latitudes over a Martian year. Conditionally accepted Comm. Earth & Environment, Roelofs et al., (2024)

Discussion & Conclusions

- Under Martian atmospheric pressure (~8 mbar), **the sublimation of small quantities of CO_2 ice**, 0.8—1.3% of the total flow mass, **can fluidize large volumes of granular material** on various slopes. The fluidization is made possible by high pore pressures.
- **CO_2-driven flows are dynamically similar to terrestrial two-phase granular flows** (Fig 6), explaining the similarity in morphology (levees, and lobes, Fig 4).
- 1D climate model results show that **the schematized favorable conditions for these types of flows align with observed activity** (Fig 5).

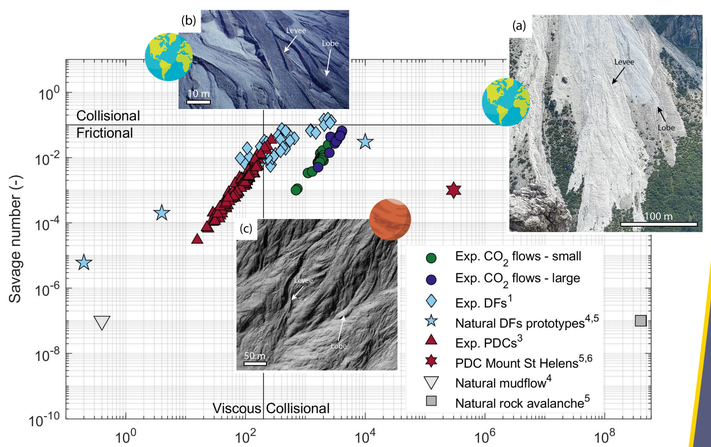

Fig 6 Dimensionless numbers quantifying forces in different types of granular flows, both experimental and field data with photos of their deposits; debris flow (a), pyroclastic flow (b), Martian fan in Istok (c). See preprint JGR-Planets Roelofs et al., 2024.

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