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INITIATION AND FLOW CONDITIONS OF CONTEMPORARY FLOWS IN MARTIAN GULLIES.

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Introduction: Over the last decade, new flow deposits have formed within multiple gullies across Mars. Monitoring of these gullies has highlighted that these new flows form when seasonal frost is present.

The recent flows that have been observed often originate from a point source and are morphologically diverse: they can be relatively light, neutral or dark, colorful or bland, and range from superficial deposits to 10 m-scale topographic changes [1]. The flows can substantially erode their channel and form terraces, transport boulders, form new channel segments, migrating sinuous curves and lobate deposits. An important observation is that many of these flows, despite the absence of liquid water, are more mobile and deposit on substantially lower slopes than would dry grainflows [1]. This suggests that these flows must have been fluidized, that is, something must have reduced the intergranular friction in these flows.

At present, we do not know the initial conditions and flow conditions of these flows. For example, we do not know their initial failure volume, degree of fluidization, and flow parameters such as flow velocity, flow depth, and erosion rate. Deciphering these conditions may inform us of the climatic conditions, i.e., amounts of CO₂ that need to precipitate from the atmosphere to trigger and sustain these recent flows. The lack of a terrestrial analog to compare to recent flows in Martian gullies inhibits resolving these climatic conditions through comparative studies. Therefore, numerical modeling of these flows might be the key.

We modified the RAMMS (RAPid Mass Movement Simulation) debris flow and avalanche model [2] to permit its use under Martian conditions, and then used this model to back-calculate and infer initial and flow conditions in recent flows in Martian gullies. In particular, we aim to: (1) constrain initial failure conditions; (2) determine flow properties including flow velocity and flow depth; (3) define the rate of fluidization within the flows; (4) and test whether CO₂ sublimation could account for the inferred fluidization. To do so, we back-calculate three recent flows in Hale crater, where a HiRISE digital terrain model is available.

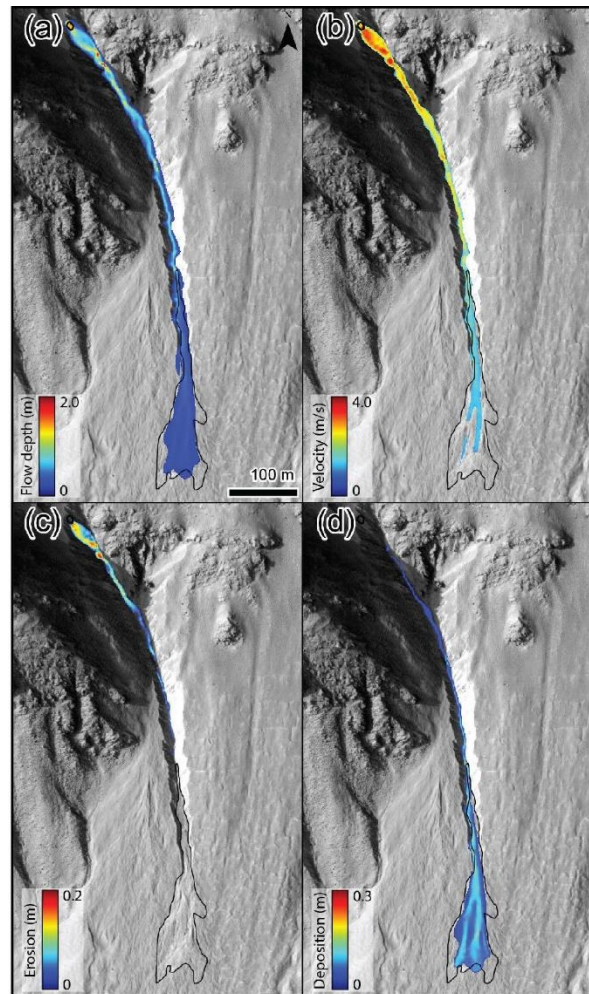


Figure 1: *Maximum flow depth (a), maximum flow velocity (b), maximum erosion depth (c), and final deposit thickness (d) for a flow with a release depth of 1.5 m, a dry-Coulomb friction of 0.10 and a viscous-turbulent friction of 100 m s⁻².*

Methods:

We use RAMMS under martian gravity conditions, to back-calculate the initial and flow conditions of three flows that occurred in Hale crater between March 2007 and September 2014. These flows were selected because they have an identifiable release area, have a long travel distance, have a well-defined and identifiable

depositional area, and are of considerable size, eroding material in the upper parts of the flow route and transporting multiple boulders. We back-calculate combinations of initial flow volume, dry-Coulomb friction (μ) and viscous-turbulent friction (ξ) by comparing model outputs to three types of observations made on the orthorectified HiRISE images. These are (1) total travel distance; (2) erosion distance (the distance from the release area to the most downstream point where erosion is observed); and (3) the flow depth estimated from boulder diameters transported in the flows. Calculations were performed on a HiRISE elevation model created with SocetSet.

Results and discussion:

Observations of the recent flows in Hale crater indicate that they are generated by restricted release areas, erode bed and bank sediments when traversing down the gully and form deposits with restricted thickness estimated to be in the order of a few decimeters at maximum. We are able to successfully reproduce these observed initial and flow conditions through simulations with RAMMS (Fig. 1) [3]. We back-calculate that the three studied recent flows in Hale require minimum release depths of 1.0-1.5 m, and initial release volumes of 100-200 m³. These flows grow in size by a factor ~2.5-5.5 by entraining bed materials. Entrainment is necessary to meet the observed travel distance and deposits - in the absence of entrainment and bulking the flows have a travel distance that is too short. The reproduced mean cross-channel flow velocities are in the range of 3-4 m s⁻¹ near the release area where channel slopes are large, and decrease to ~1 m s⁻¹ near the flow termination point. Mean cross-channel flow depths generally decrease from 0.5-1 m near the release area to 0.1-0.2 m near the flow terminus. The mean cross-channel erosion depth and deposition thickness are generally subtle, in the order of 0.1-0.2 m, in line with observations of limited erosion depth and deposit thickness.

We are able to reproduce the observed flow properties for flows with a dry-Coulomb friction in the range of 0.1-0.25 and a viscous-turbulent friction of 100-200 m s⁻². These friction values are similar to those found by back-calculation of a wide range of terrestrial debris flows, while they differ from the friction values found by back-calculation of a wide range of rock avalanches, ice-rock avalanches, snow avalanches and a pyroclastic flow that have larger dry-Coulomb and viscous-turbulent friction values (Fig. 2). Our model results thus suggest that the fluidization obtained by CO₂ sublimation is of the same order of the fluidization obtained by water in terrestrial granular debris flows – thereby potentially explaining their morphological resemblance to terrestrial debris flows.

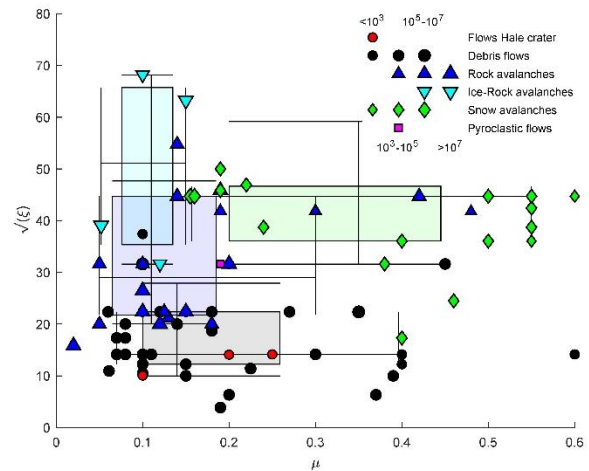


Figure 2: *Vöellmy friction parameter combinations of the modelled recent flows in Hale crater and terrestrial values back-calculated from a wide range of debris flow, rock avalanche (also containing debris avalanches and landslides), ice-rock avalanches, snow avalanches and a pyroclastic flow.*

Through a quantitative novel model for mass-flow fluidization by CO₂ sublimation, we further test if our back-calculated flow conditions can be explained by CO₂ sublimation fluidizing the flow under Martian atmospheric conditions. In short, our model shows that CO₂ sublimation may indeed fluidize recent flows in Martian gullies. These calculations show that even very small volumetric fractions of CO₂ of <1% within mass flows may yield gas fluxes that are large enough to fluidize and enhance the mobility of recent flows in Martian gullies. The fluidization effect of CO₂ sublimation is so strong under Martian conditions that changes in permeability by several orders of magnitude would not affect these conclusions. For an extensive overview of this work see de Haas et al., 2019 [3].

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