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Evidence for very recent melt-water and debris flow activity in Istok crater, Mars

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Abstract
We report on very young (~0.2 Ma) and well-preserved deposits of water bearing debris flows in Istok crater, Mars. Debris flows postdate the latest dust-ice mantle emplacement. A model of melting of recent snow packs is proposed as a water source in Istok crater. Asymmetry in slope degradation demonstrates that insolation-controlled slope processes (including gully formation by debris flows) are surprisingly efficient on Mars under very recent climate conditions.

1. Introduction
Gullies on Mars are known to display a range of different morphologies but typically include an alcove, channel and apron [1]. Several processes have been invoked to explain their genesis ranging from dry granular flows [2], debris flows [3] to fluvial erosion with alluvial deposition [4]. Albeit there is a general consensus that the medium involved is water, more attention is now drawn towards the dominant depositional processes of the gully fan formation. The observed range of fan morphologies asks for several depositional mechanisms which likely vary at different sites due to regional and local differences in climate and source material. Studies indicate that the common mechanism is fluvial deposition [5] in contrast to debris flow-like deposits which have only been documented at three sites [5,6,7]. These sites formed deposits of seemingly fine dusty mantle material. Here we report on unusually well preserved Martian debris flows in Istok crater which is rich in clastic material that forms pristine debris lobes, debris plugs and lateral levees. It also displays numerous fresh looking rock falls with distinct boulder tracks. This raises the following questions: Why does so well-developed debris flows occur here and not in other nearby craters? What role does the clastic material play in debris flow initiation and development?

2. Observations and results
The Istok crater is a well preserved 4.7 km-diameter crater located in the Aonia Terra region (centered at 45.11°S; 274.2°E). Istok is superposed on the ejecta blanket of a much larger 17 km-diameter rampart crater. The nighttime THEMIS-image of Istok's ejecta point to a surface of either blocky or consolidated sediments (Fig 1).

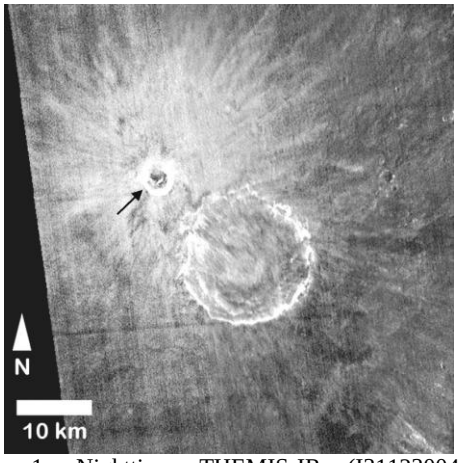

Figure 1. Nighttime THEMIS-IR (I31123004RDR) highlights the rayed ejecta which suggest unconsolidated, blocky material with limited aeolian deposition and reworking. Image credit: NASA/JPL Caltech/Arizona State University.

Due to the underlying unconsolidated ejecta the former is favored. Numerous debris flow deposits are present at the pole facing inner wall of the crater (Fig. 2A) forming a bajada. Distinct, meters high levees are seen (Fig 2B), overlapping lobe fronts (Fig. 2C), and more recent fan structures (Fig 2D). Within debris flow channels debris plugs with rounded termini are clearly visible (Fig. 2E). The crater floor display numerous fresh appearing rock falls, with sizes ranging from less than a meter to ~2.5 m. The pole facing deposits display a high fraction of clastic material.

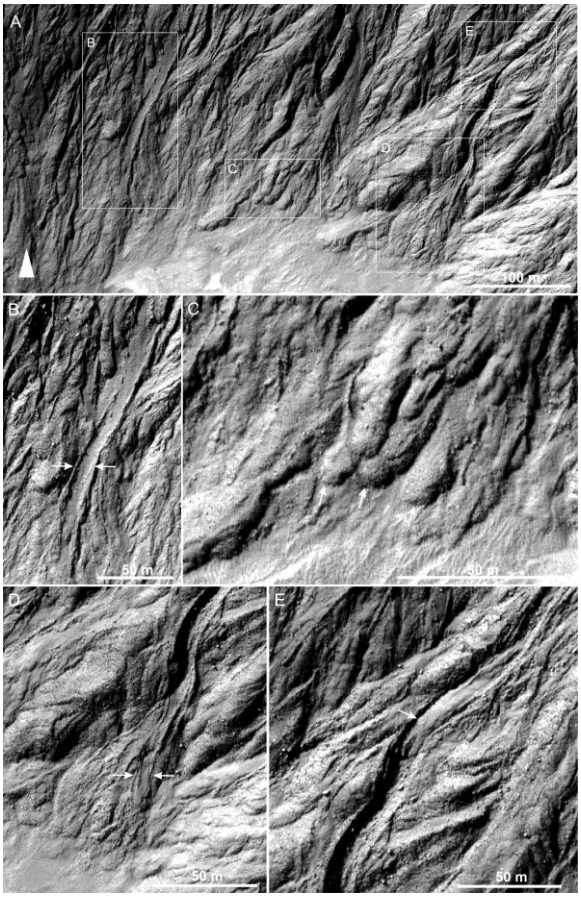

Figure 2. A) Overview of the pole-facing bajada of debris-flow fans (HiRISE image PSP_006837_1345). B) Distinct lateral levees. C) Overlapping debris lobes. D) Younger debris flow fan. E) Debris plug (medial deposit). Image credit: NASA/JPL/UofA for HiRISE

The rayed ejecta of the study crater, in combination with few superposed impact craters, its sharp crater rim, and the limited infill suggest a young age of the study site. Crater size–frequency distribution indicates an absolute model age for the study crater between 0.1 and 1 Ma. The best-fit absolute model age is 0.19 ± 0.04 Ma.

3. Discussion

Istok crater displays a spectrum of slope degradation ranging from debris flow dominated (pole facing) to single-channel gullies (west facing) and talus cones (equator facing). This suggests that distinct morphological characteristics are influenced by solar insolation rather than local climate differences. Numerous rock-falls in the crater suggest an active weathering environment, which may play a critical role in debris flow initiation and morphology. The lack any significant layer of dust-ice mantling deposits or evidence of water conduits leads us to propose a model of top-down melting of snow pack's as a water source. In synergy with previously studied regions these deposits suggests that they add important insight into the formation and hydrological significance of Martian debris flows.

6. Conclusions

Based on their plan-form morphology, the presence of key morphological attributes, their location on slopes favorable for snow deposition, and by comparison to known periglacial debris-flow landforms in Svalbard we conclude that the studied deposits are best explained as water-bearing debris flows.

The highly unconsolidated outcrops on the crater rim together with the preserved steep slopes cause; (1) an abundant sediment supply of varying grain sizes and (2) slope instability. This makes the conditions particularly favorable for high-energy debris flows.

The rare occurrence of debris flows, in contrast to modeling attempts and slope-area analyses, may be explained by a later superposition and melting of more recent LDM during the last Martian ice age which has obscured preexisting debris flows.

The comparison to other mid-latitude impact craters of similar age and size suggests that latitude (Zumba crater is located at lower latitudes) and availability of clasts (Gasa crater dominated by fine-grained particles) may have been important factors limiting the formation of debris flows.

The North-South asymmetry in degradation demonstrates that insolation-controlled slope processes (including gully formation by debris flows) are surprisingly efficient on Mars under very recent climate conditions.

Acknowledgements

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