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Earth-like aqueous debris-flow activity on Mars at high orbital obliquity in the last Ma

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1. Introduction

At present Mars is very cold and dry and its thin atmosphere makes liquid water at its surface exceptionally rare. However, climatic conditions differed during periods of high orbital obliquity in the last few millions of years [4]. In these periods liquid water was probably more abundant, as testified by the presence of numerous mid-latitude gullies, which are small catchment-fan systems. Obliquity on Mars has varied between 15^0 and 35^0 in the last 5 Ma, in cycles of approximately 120 Ka [3]. The obliquity threshold for snow and ice transfer from the poles to lower latitudes is estimated at 30^0 [1], whereas the threshold for melting and associated morphological activity is probably higher but unknown [5].

Key questions that remain unanswered are how much water could potentially melt during these high-obliquity periods? And how frequent was the aqueous activity within the gullies? Here, we address these questions by quantifying debris-flow size, frequency and associated liquid water contents on Mars, in the very young Istok crater in Aonia Terra (Fig. 1) (0.1-1 Ma; best-fit age: ~0.19 Ma [2]).

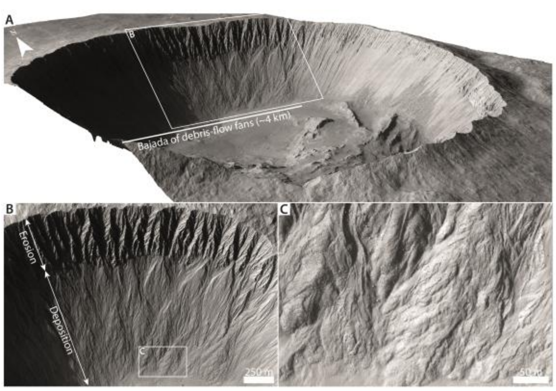

Figure 1: Istok crater. (A) Bajada of remarkably pristine debris-flow fans on the pole-facing slope (45.11^0S; 247.2^0E). (B) Eroding alcoves supply sediments to the downslope bajada of fans. (C) The fans are composed of debris-flow deposits [2].

2. Debris-flow and liquid water volume and frequency

The pole-facing slope of Istok crater hosts a bajada, a series of coalescing fans, with abundant debris-flow deposits, which are among the best preserved found on Mars to date [2].

Debris flows contain approximately 20 to 60 percent water by volume. They form deposits with paired levees and distinct depositional lobes that often incorporate large boulders. We use the distinct morphology of these deposits to estimate individual debris-flow volumes from a HiRISE DEM with a sampling distance of 1 m. Estimated individual debris-flow volumes roughly range from 400 to 5100 m^3 (Figs. 2A-C).

We estimated the total number of debris flows by comparing the volume of a single, modal-sized, debris flow to the total volume of sediment eroded from the catchments. In total, around 28000 modal-sized debris flows were needed to form the entire bajada and ~1900 debris flows originated from each catchment. From this we calculated the cumulative time above a specific obliquity threshold for melting and then determined the debris-flow frequency within the gullies, expressed as their return period. Debris-flow return periods ranged between 4-15 yr on the bajada, and 64-221 yr in the catchments for a conservative obliquity threshold for melting of 30^0. A melting threshold of 35^0, implies return periods of 0.2 to 0.8 yr for the bajada and 3 to 12 yr for the catchments (Fig. 2D-E).

Using the known range of water concentrations of terrestrial debris flows in combination with the measured debris-flow volumes in Istok crater, we estimate the amount of liquid water required for each flow. The associated liquid water volume yields a minimum estimate of snow/ice deposition and subsequent melting within the alcoves. Between 3 and 9 mm of liquid water uniformly spread over an average-sized alcove is required for the formation of modal-sized debris flows, and 16 to 50 mm of liquid water is required for the formation of large, 95 percentile-sized debris flows. The actual thickness of the snow/ice layer must have been much larger due to the porosity of the snowpack, potential sublimation and evaporation losses, and the fact that uniform melting over an entire alcove will generally not occur. Therefore, we estimate that centimeters to decimeters of snow must have accumulated in the alcoves to form the observed debris-flow deposits.

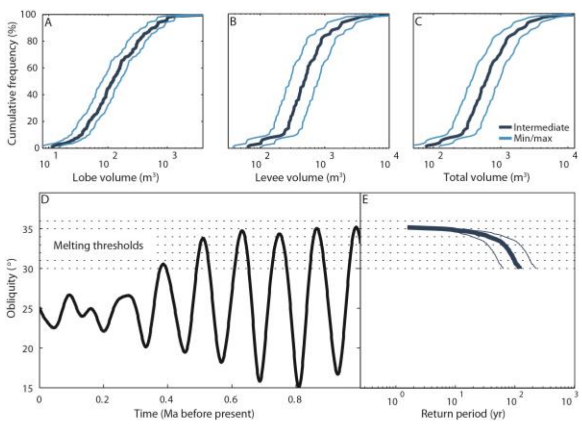

Figure 2: Debris-flow return periods and size in Istok crater. (A-C) Cumulative frequency distributions of lobe, levee and total debris-flow volume, respectively. (D) Obliquity in the last Ma on Mars, and potential thresholds for melting on mid-latitude pole-facing crater walls. (E) Debris-flow return periods averaged per catchment [6].

3. Discussion

The surprisingly short debris-flow return periods at high orbital obliquity in Istok crater are very similar to those in various environments on Earth [4] (Fig. 3). Current climatic models do not explain the amounts of liquid water needed for the formation of the debris flows in Istok crater [5]. This implies that melting of snow/ice in high-obliquity periods must locally have been much larger and more frequent than currently predicted by these models.

4. Conclusions

- Debris flows occurred at Earth-like frequencies in Istok crater during high-obliquity periods in the last million years on Mars.
- Local accumulations of snow/ice within gullies were much more voluminous than currently predicted
- Melting must have yielded centimeters to decimeters of liquid water in catchments.
- Recent aqueous activity in some mid-latitude craters was much more frequent than previously anticipated.

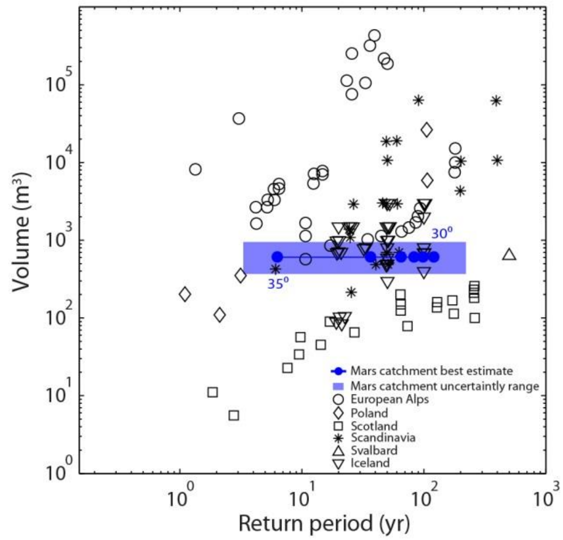

Figure 3: Comparison between debris-flow volumes and return periods in Istok crater, Mars [6], and examples from Earth [4].

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