PRESENT-DAY GULLY ACTIVITY (DARK FLOWS AND BLOCK MOVEMENTS) IN SISYPHI CAVI, MARS.

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Introduction: We present the final results of our study regarding contemporary gully activity in the Sisyphi Cavi region on Mars [1]. We choose this specific region due to a high number of active gullied slopes [2, 3], as well as a former detailed study of ongoing activity of one specific gully [2].

Our study is mainly based on multi-temporal HiRISE (n = 212) and CTX (n = 382) imagery. In addition, we used HRSC, THEMIS-IR, CaSSIS, MOLA DTM, and TES datasets for our intensive survey of all gullies in the Sisyphi Cavi region.

Study region: The study region (340° to 10° E and 66° to 76°S) comprises the complete Sisyphi Cavi region, an area with numerous polar pits up to ~1000 m deep [2] (Fig. 1). It is proposed that the south polar pitted terrains (including Sisyphi Cavi) were formed by collapse induced by basal melting of volatile-rich surface layers [4]. The complete study region is covered in a decimeter thick seasonal CO_2 slab ice during winter with extensive surface defrosting during mid-spring and summer [2]. The steep slopes of the numerous pits host fresh-looking gullies, some with ongoing present-day activity [1-3].

Methods: We mapped and measured the orientation of all gullies (n = 17,760, based on the identification of a clearly visible alcove) in Sisyphi Cavi based on CTX images. We used multi-temporal HiRISE imagery for detailed analyses of active gullies.

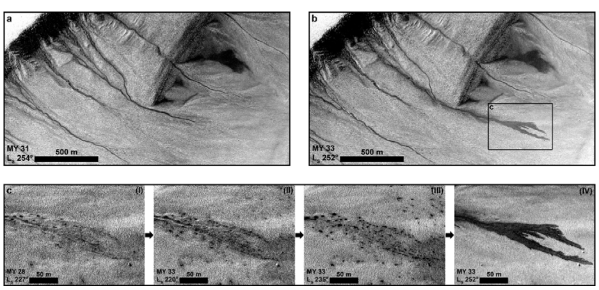

Fig. 1: (a, b) Before and after image of an active gully. (c) A dark flow-like feature formed between L_S 235° and 253° of MY 33 [from 1].

We identified 35 active gullies in the study region, identified with the web-based tool MUTED [5]. Activity can be grouped into: (I) dark flow like features (n = 22) (Fig. 1) and (II) block movements within gullies (n = 16), whereas three are combined features, which makes 35 active gullies in total. 10 of the 35 active gullies could be narrowed down to occur in a specific time interval during one martian year (MY), due to a high frequency of HiRISE images.

To identify small-scale movements like creep as precursors of gully activity, we used Digital Image Correlation [e.g., 6]. This method has been used in other morphological studies on Mars [e.g., 7, 8], but in our case no small-scale movements could be identified.

To investigate the thermal seasonal frost coverage we analyzed maximum daytime surface temperatures (TES) binned into 2° latitude groups within the study region. We plotted the mean values against solar longitude (L_S). The defrosting period is readily identifiable as a rise in mean temperature accompanied by a high variability around the mean, caused by partial frosted and defrosted surfaces being present at the same time (Fig. 2).

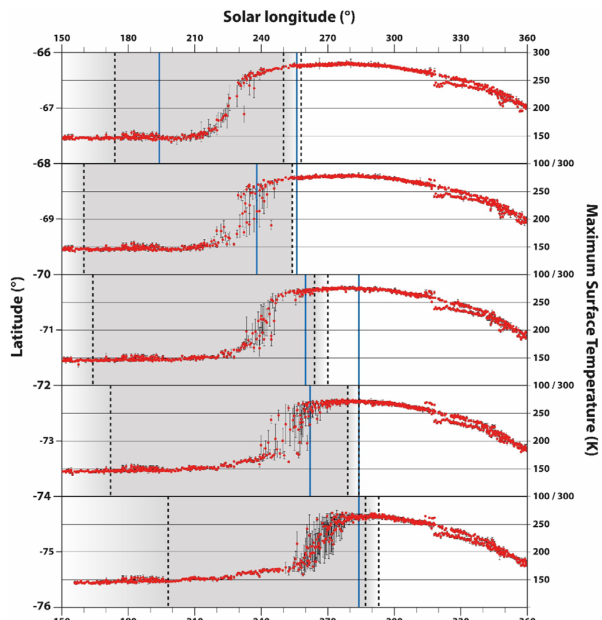

Fig. 2: Diagram of average annual defrosting of the study region in 2° latitudinal bins (left axis) and temperature (right axis) vs. time (end of winter to end of summer). Red dots represent the average of all taken TES maximum daytime surface temperatures at the same time between MY 24 to 26 with standard deviation (black bars). Grey areas represents a fully frosted surface. Surface defrosting took place between the last two dashed lines (based on CTX) and blue lines (based on HRSC) [from 1].

Results and Conclusions: *Timing of activity:* On HRSC and CTX images, we identified defrosting of the surface (Fig. 2) based on: (1) visible frosted/defrosted ground (high albedo of frosted ground), (2) dark defrosting spots, and (3) dust devil tracks (which can only form on defrosted, loose material). The observed defrosting is correlated to the rise of maximum surface temperature: the complete surface defrosting happened about 10-15° L_S after the rapid rise of surface temperature. All observed gully activity occurred during these last phases of surface defrosting between L_S ~225° and ~260° (Fig. 3).

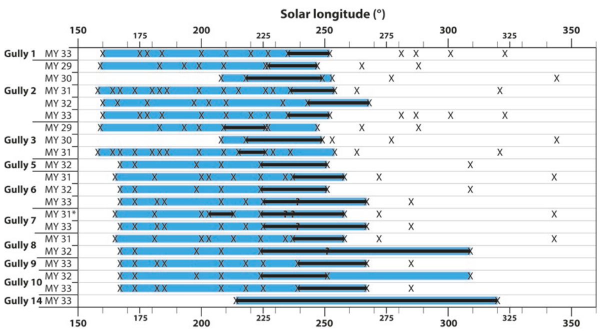

Fig. 3: Diagram of the 10 active gullies with visible changes within one MY. Six of the 10 gullies show periodic activity within different martian years (y-axis). The crosses represent single HiRISE images; the blue bars represent the identified surface frost coverage from the beginning of surface frost (beginning of blue bar) to the first image without any identifiable surface frost (end of blue bar). Black bars represent identified activity from between the "before" and "after" HiRISE images [from 1].

Orientation: Gullies in the study region tend to be orientated north-south with a slight bias towards south-facing (pole-facing) slopes. In contrast, active gullies tend to be oriented towards the northwest and to a lesser extent the southwest, with a lack of directly north-south facing active gullies.

Erosion/origin of material: We identified the origin of transported material in some active gullies. First, material was eroded from the walls of gully channels and accumulated during very early defrosting stages. Here, there was a direct link to dark spots [e.g., 6, 7] and, if the surface was inclined, dark flows [e.g., 8, 9]. Both features share the same morphologies, timings, and occur in the same regions, therefore the same triggering mechanism is likely. Our observations reinforce the theory of the origin of material proposed by Raack et al. [2]:

- sediment is sourced from gully channel and alcove slopes,
- material is eroded during early defrosting stages by basal sublimation onto the still available seasonal CO_2 slab ice,
- the transported material accumulates in the gully channels and flows down the gully if enough material has accumulated.

In addition, material was eroded in the active alcove of an active gully by headwall erosion (Fig. 4). This mechanism was observed in one specific gully. The same gully was investigated in detail by [2], but headwall erosion and the origin of transported material was not observed due to the lack of HiRISE coverage in 2015.

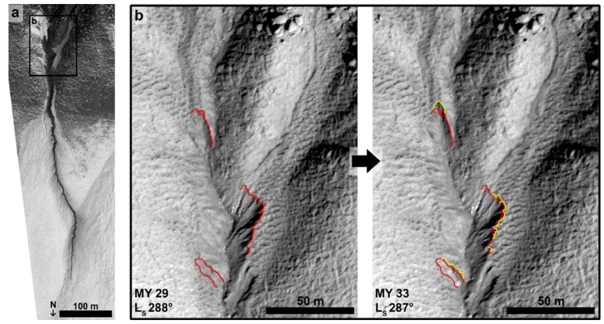

Fig. 4: Headwall erosion of the active gully presented in [2]. (a) Overview image. Before and after images: (b) Detail of gully alcove in MY 29 at L_S 288°, red lines represent clearly identifiable outlines of the headwall of the alcove (small active alcove in larger, older and inactive alcove). (c) Erosion of some meters of material in MY 33 (L_S 287°), yellow lines represent the new headwall of the alcove [from 1].

Possible formation mechanism: Based on our investigations, we identify a strong temporal and morphological relationship between gully and dark spots/flows activity. We also observed erosion on gully channel slopes where dark spots/flows where the likely cause of the transported material. Our work confirmed the potential transport mechanism of active gullies in Sisyphi Cavi proposed by [2]: dry flows of sandy/dusty material over a sublimating translucent seasonal CO_2 slab ice, with the added caveat that activity only occurs at the very end of surface defrosting.

References: [1] Raack, J. et al. (2020) *in prep.* [2] Raack, J. et al. (2015) *Icarus* 251, 226-243. [3] Dundas, C.M. et al.(2015) *Icarus* 251, 244-263. [4] Ghatan, G.J., Head, J.W. (2002) *JGR* 107, E7, 5048. [5] Heyer, T. et al. (2018) *PSS* 159, 56-65. [6] Cantor, B. et al. (2002) JGR 107, 5014. [7] Piqueux, S. et al. (2003) JGR 108, 5084. [8] Horváth, A. et al. (2009) Astrobiology 9, 90-103. [9] Jouannic, G. et al. (2019) GSA Spec. Pub. 467, 115-144.

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