Time will tell: temporal evolution of Martian gullies and paleoclimatic implications

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Introduction

To understand Martian paleoclimatic conditions and the role of volatiles therein, the spatio-temporal evolution of gullies needs to be deciphered. While the spatial distribution of gullies has been extensively studied, their temporal evolution is poorly understood. Given the widespread occurence of latitude-dependent-mantle deposits (LDM) and glacial landforms in gullied craters, we hypothesize that the temporal evolution of Martian gullies is strongly linked to ice ages.

Objectives

(1) Investigate how time and associated climatic variations have affected gullies.

(2) Provide a conceptual model for the temporal evolution of gullies.

We obtain these objectives by comparing the size of gullies in 19 craters, extracted from HiRISE DEMs, and their morphology, with host-crater age obtained from crater counting on CTX images.

Study sites

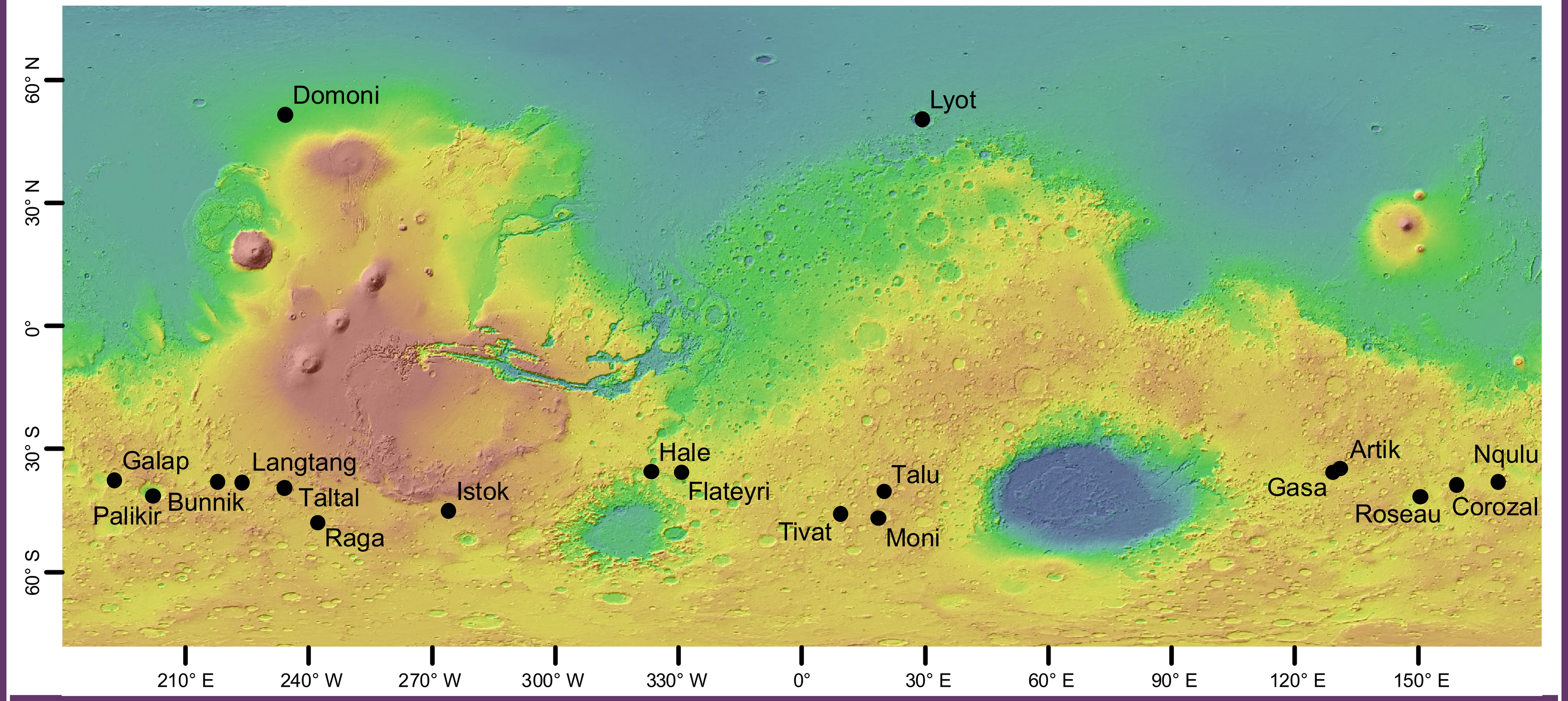

Fig. 1: Study crater locations. Background, color-keyed and relief-shaded, topography is from the Mars Orbiter Laser Altimeter (MOLA, red is high elevation, blue is low elevation).

Crater morphology types

Type 1: No LDM, no glacial landforms

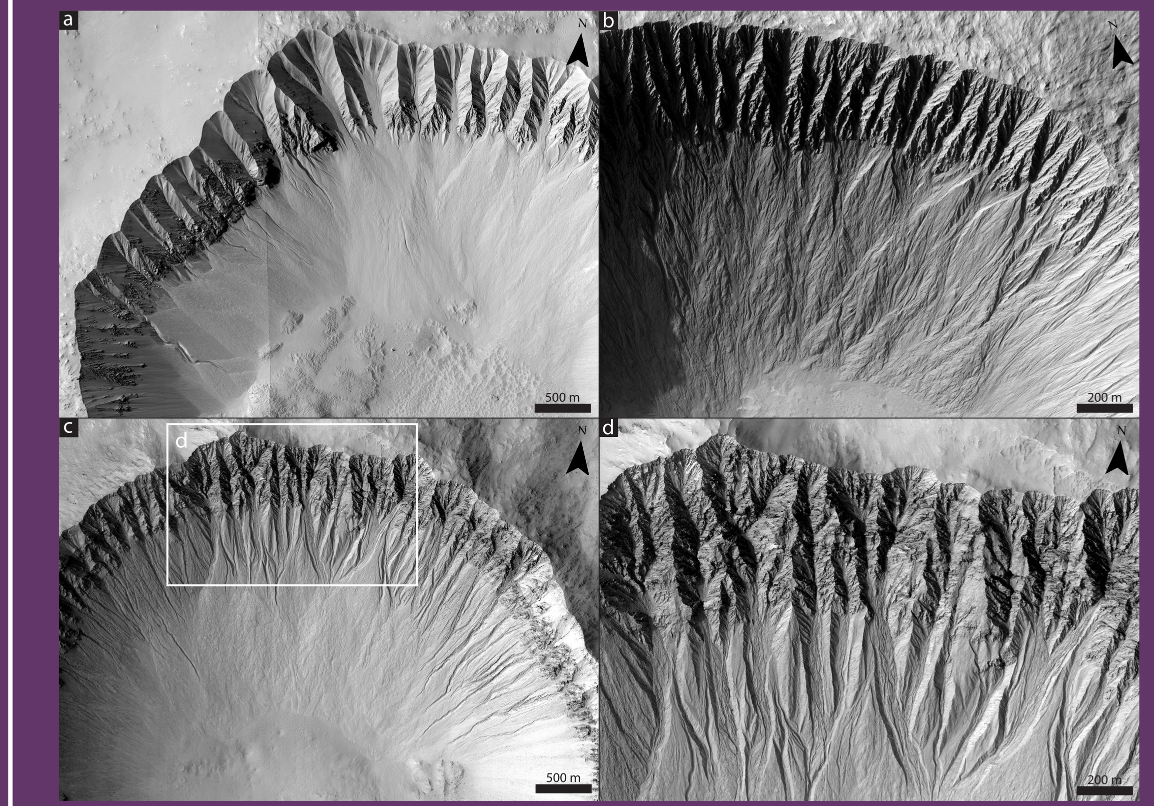

Fig. 2: Morphology of young craters. The gully-alcoves have a crenulated shape and cut into the upper crater rim, exposing fractured and highly brecciated bedrock containing many boulders. (a) Gasa crater (HiRISE images ESP_014081_1440 and ESP_021584_1440). (b) Istok crater (HiRISE image PSP_006837_1345). (c) Galap crater (HiRISE image ESP_012549_1420). (d) Detail of Galap crater alcoves.

Type 2: LDM, no glacial landforms

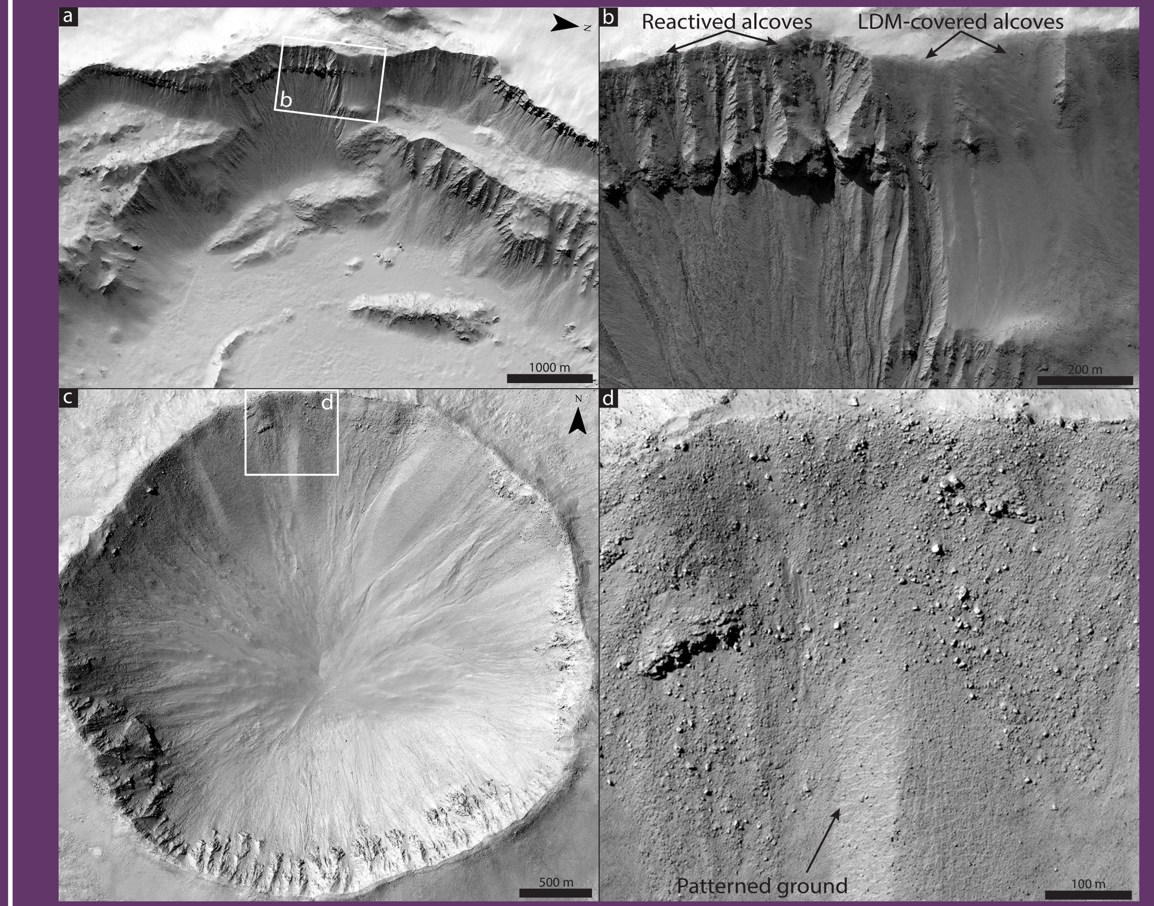

Fig. 3: Interaction between gullies and LDM in Domoni, Raga, Roseau and Tivat craters. (a) Western wall of Domoni with abundant gullies. Evidence for former glaciation is absent (HiRISE image: ESP_016714_2315). (b) Detail of gully-alcoves: the gully-alcoves in the right side of the images are covered by LDM deposits, whereas the gully-alcoves on the left side of the image have been reactivated since the last episode of LDM emplaced and therefore these alcoves are largely to completely free of LDM deposits. (c) Raga crater (HiRISE image: ESP_014011_1315). (d) Detail of gully-alcoves in Raga crater with softened topography and patterned ground.

Type 3: LDM and glacial landforms

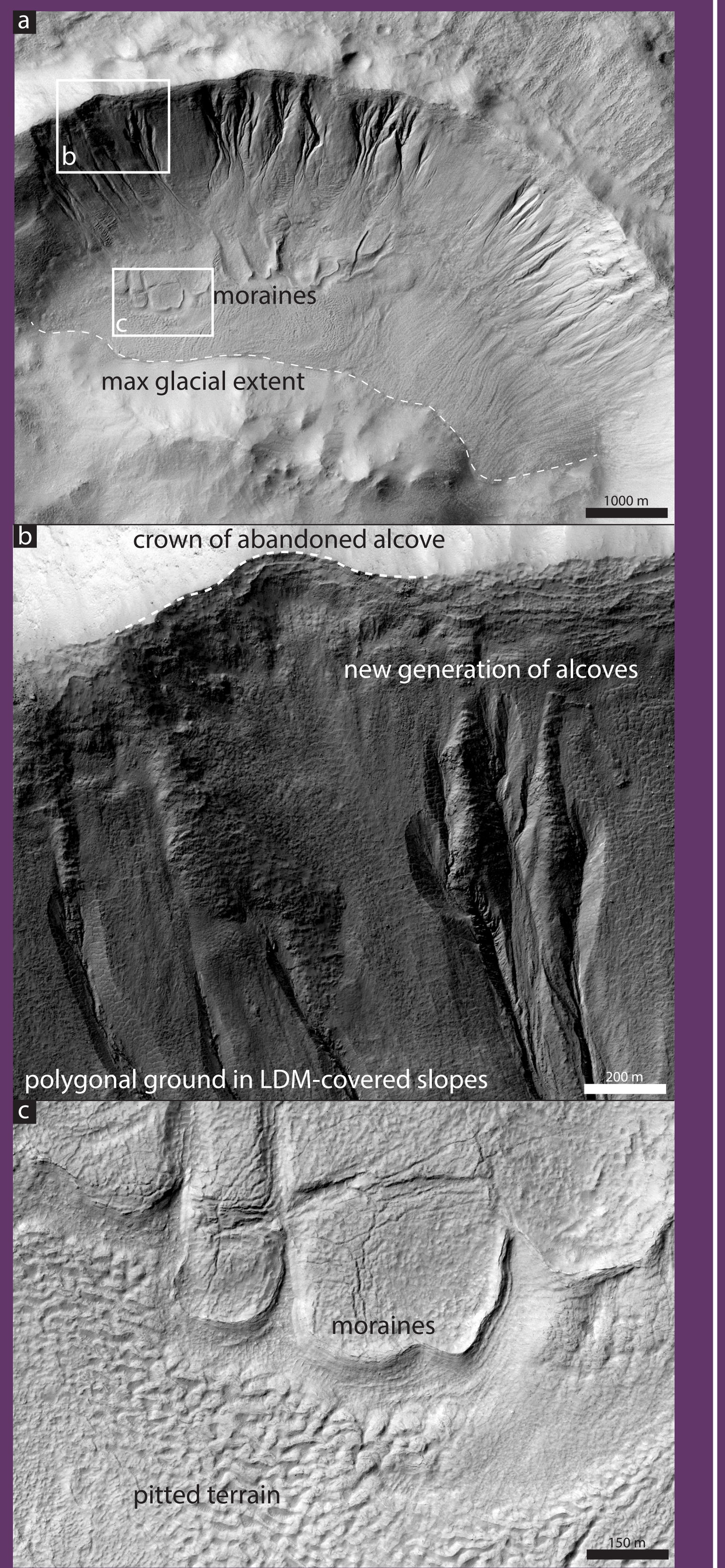

Fig. 4: Multiple generations of alcoves and glacial advances in Langtang crater. (a) Glacial extent. CTX image F10_039752_1419_XI_38S142W. (b) Detail of the crater slope, showing the crown of a former, now abandoned, alcove and younger smaller generations of alcoves. The crater slope is covered by a thick layer of ice-rich material, as demonstrated by the shape of the youngest alcove incisions and polygonal patterned ground on top of the crater wall. The new alcove incises by more than 25 m into the crater wall. HiRISE image: ESP_023809_1415.
(c) Detail of the moraine deposits and the pitted terrain, which originates from sublimation till. HiRISE image: ESP_023809_1415.

Gully size and morphology vs time

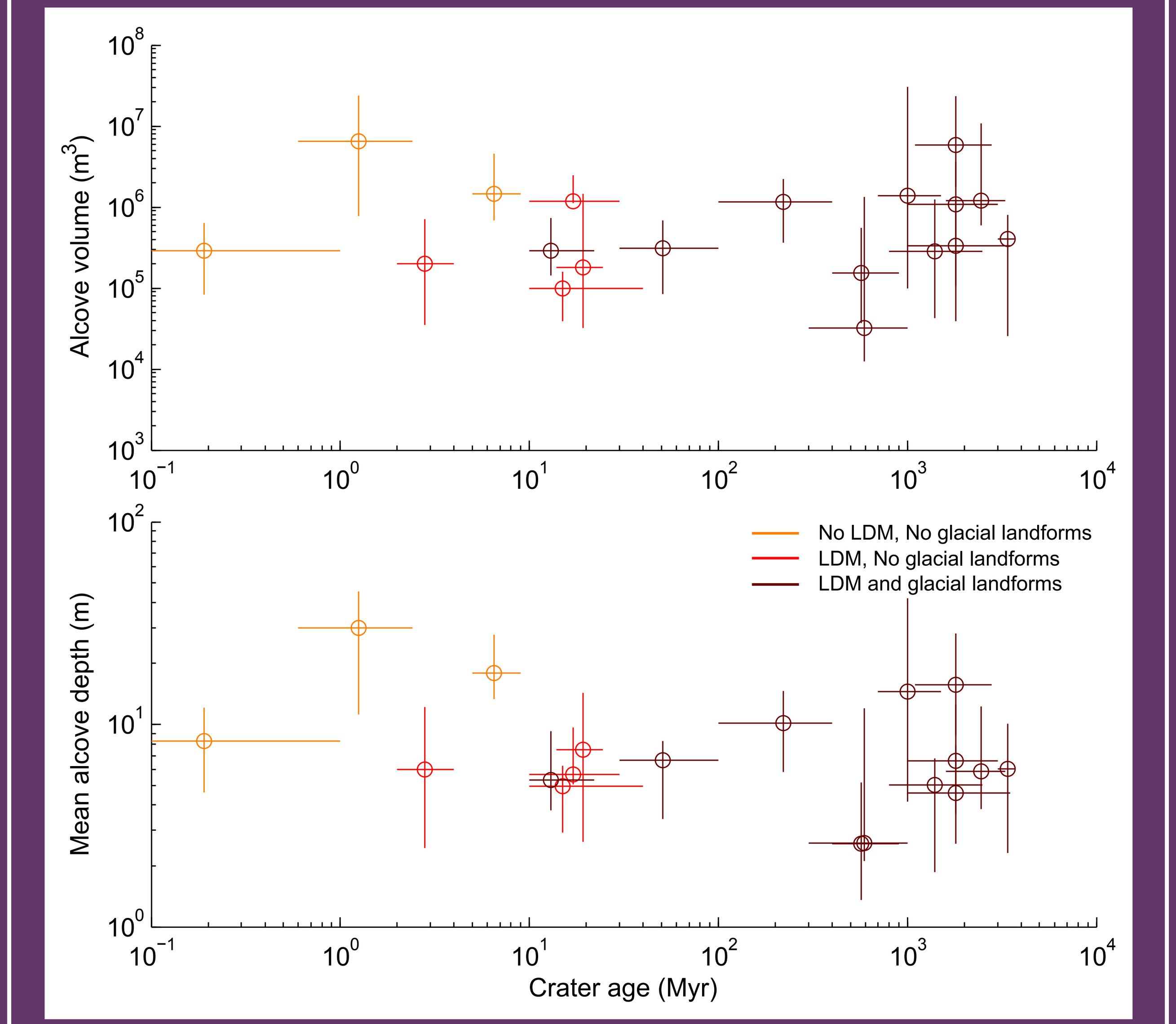

Fig. 5: Gully-alcove size as a function of crater age. (a) Crater age versus alcove volume. (b) Crater age versus mean alcove depth. The circles are the best fit crater ages and the median backweathering rates per crater. Bars denote minimum and maximum crater age and the 10th and 90th percentile alcove size of the measured gully-alcoves within each crater.

Fig. 6: Conceptual model of the temporal evolution of gullies on Mars. (t=1) The highly-fractured and unstable walls of newly formed impact craters are prone to gully formation. (t=2) As a result, large gullies may rapidly form. Such gullies may typically cut into the crater rim. (t=3) During high-obliquity periods the gullies may be covered by LDM deposits, which impedes further gully-alcove growth. Subsequently, gullies may reactive and transport the LDM deposits in the gully alcoves to the gully-fan until a new mantling episode commences. Gullies may experience multiple repeats of these cycles. (t=4) During favorable obliquity periods glaciers may form on the crater wall removing or burying the gully deposits, and forming a moraine deposit at the toe of glacier. (t=5) Following glacial retreat a smoothed crater wall and moraine deposits remain. (t=6) New gullies may now form within the formerly glaciated crater wall. Such gullies typically have v-shaped and elongated alcoves and do not extend to the top of the crater wall. The gullies may enlarge until there is another episode of LDM emplacement or glaciation.

Conclusions

Contrasting gully morphology, depending on host-crater age:

- Craters < a few Myr old: gullies are free of LDM and glacial deposits.
- Craters > few Myr and < few tens of Myr old: gullies affected by LDM only.
- Craters > few tens of Myr: gullies affected by LDM and glacial activity.

Over time gullies experience sequences of (1) LDM deposition and reactivation and (2) glacier formation and removal, and the formation of new gullies.

Conceptual model