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Geomorphological evidence of localized stagnant ice deposits in Terra Cimmeria, Mars

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Introduction:

The presence of snow and ice at mid-latitudes of Mars cannot be explained by current climatic conditions, as surface ice is unstable. However, a large variety of debris-covered glaciers have been observed at both mid-latitudes [e.g., 1, 2]. Global circulation models suggest that obliquity oscillations caused the mobilization of ice from polar regions and its re-deposition at lower latitudes [3, 4]. Although the obliquity variations are not predictable for periods more than 20 Ma ago [6], it is likely that the surface of Mars, during the Amazonian, has repeatedly undergone such climate changes leading to deposition and degradation of ice [e.g., 6, 7, 8]. Here, we report the presence of local, small-scale, and debris-covered stagnant ice deposits on the floor of a valley system in Terra Cimmeria (Fig.1).

1. Morphological characteristics:

Several deposits on the flat floors of S-N trending valleys south of Ariadnes Colles (34°S, 172°E) are characterized by (1) widths and lengths of a few kilometres, (2) convex-upward surface topography, and (3) pits and crevasses on their surfaces. They are referred to, in this study, as valley fill deposits (VFD). A total of 38 VFD have been observed and mapped in the study area. These VFD are located a few tens of kilometres east of Tarq impact crater (Fig.1). Tarq is a central-pit crater where the pit is ~4 km in diameter and located within a central peak. Several of the VFD are situated within the visible ejecta blanket of Tarq crater (Fig.1). The crater ejecta streaks are observable on the surface and surrounding area of some of those VFD. The VFD have individual surface areas of a few km^2 to a few tens of km^2. In some cases they are located in the centre of the valley floor, whereas in other cases they cover the entire width of the host valley, indicating their post-valley formation. The valley width could reach up to a few kilometres, in some areas. Using a HiRISE DEM, we observed that one VFD has a thickness of ~30m. The

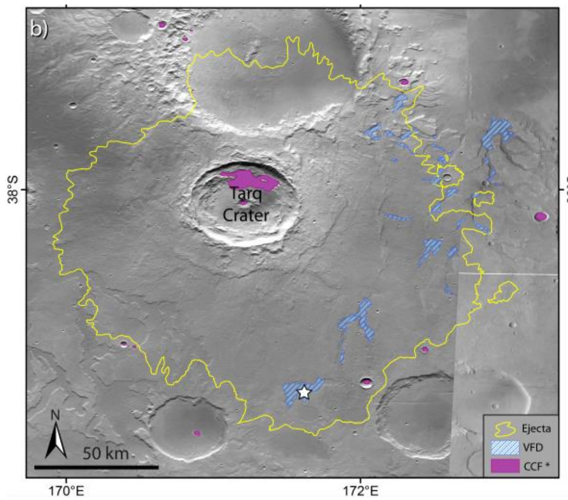

Fig. 1: An overview of the study area. The VFD indicated in hachured blue lines, *the pink filled polygones represent the location of glaciers mapped by [5]. The boundary of mapped ejecta blanket from Tarq crater is shown in yellow line (detail of HRSC nadir image, orbit number 12939 and 4198).

host valley system floors, as well as areas surrounding the VFD are partly covered by a thin mantle that appears to have a relatively smooth texture at HiRISE scale. This mantle is superposed by only very few impact craters smaller than a few meters, indicating a recent formation.

The surfaces of VFD show only few impact craters with diameters equal or smaller than ~700m. Craters larger than 70m are mostly degraded, their rims show almost no positive relief (at CTX resolution) and they have flat floors. Where higher resolution data are available, we can observe linear features, cracks, and crevasses (lateral and transverse) on surface of VFD. Transverse crevasses may indicate tensile stress caused by local collapse of the deposit. In several cases, in front of the VFD margins there is a zone up to ~3km of length, where the valley floor is covered by rough sediments. We interpret this rough zone as sediment accumulation similar to ablation morainelike material in front of a glacier. At the contact between the VFD and the valley walls, we observe several pits which most likely formed due to ice sublimation. These pits are aligned along the border of the VFD.

Absolute model age estimation: In order to understand the absolute model age (crater retention age) of the VFD, we analysed crater size-frequency distributions (CSFD) on CTX and HiRISE (where available) images using the method described in [9]. It should be noted here that there are uncertainties to derive a confident absolute model age of these deposits due the small area and small number of craters on VFD, in addition to the resurfacing phase(s) which may have most likely modified the crater morphology and their visible dimensions. We suggest that the model age of the VFD surface is ~µ25 (±10) Ma, which corresponds to very late Amazonian (µ is a function representing the uncertainty of calibration of the chronology model [9]). In addition to the VFD, we also measured the CSFD on the ejecta blanket of Tarq crater, using a mosaic of CTX images. The result shows two model ages of µ410 (±50) Ma (mid-Amazonian) and µ3.6 (+0.1/-0.4) Ga (late-Hesperian). In order to constrain the most likely absolute model age of Tarq crater, we need to combine this result with geomorphological evidence of the impact crater morphology and its ejecta blanket.

2. Discussion and conclusion: The VFD were observed within the limits of the ejecta blanket of the Tarq impact crater, the ejecta streaks of which are partly covering the areas surrounding the VFD as well as the surface of a few VFD. The central pit of this impact crater points to a potential impact into an ice-bearing substrate. Our geomorphological observations indicate that the VFD are small-scale debris-covered stagnant ice deposits, and are currently in degradational stage. These observations include: 1) the convex-upward morphology, 2) the infilling, in some cases, of the entire valley depth, 3) crevasses on their surface, and in some cases traces of volume loss of the deposit, and 4) sublimation pits. Our crater-size frequency distribution results, however, show two major resurfacing events in the area, and therefore two possible formation times for the Tarq crater: Late Hesperian or Middle Amazonian. In order to clearly address this ambiguity, we described two plausible scenarios for the emplacement of the VFD:

<u>Scenario I</u>: The Tarq impact took place during the Middle Amazonian, into an icy target substrate. Impact into subsurface ice should result in a mixture of ejected solid particles and water ice distributed over the impact crater periphery. The material deposited on the floor of the host valley system has then been preferentially protected against sublimation by a wind-blown lag deposited in the topographic lows of the valley system, covering the VFD. This scenario fits our geomorphological observation, but can hardly be explained by the model age estimation.

<u>Scenario II</u>: The Tarq impact took place either during the Late Hesperian or Middle Amazonian. After the impact, the VFD were emplaced in this area by precipitation as a wide-spread surficial ice layer, which was later modified and degraded. In this case, we would expect the deposit to have a less localized distribution and more importantly, to cover the ejecta blanket of Tarq crater. This is, however, not the case as some ejecta streaks are on top of the VFD. This scenario, although inconsistent with most of our geomorphological observations, would however be consistent with the estimated model ages.

We favour scenario I —VFD distribution due to impact into an icy substrate— because it is consistent with all of our geomorphological observations. Valley fill deposits (VFD) are debris-covered stagnant ice deposits with a likely age of Middle Amazonian, which were not reported in the previous studies (such as in [5] (Fig. 1)). These deposits have been preserved most likely due to a lag of dust and debris deposited in the valley's topographic lows, and are currently in a degradational phase. They highlight the importance of local geologic conditions (i.e., impact into icy strata; ice emplacement in topographic lows) for the current distribution of ice deposits on the surface of Mars. Although the VFD have a local presence but they hint to a likely possibility of present of more wide-spread buried ice deposits in the mid-latitudes, which require detailed investigations of high resolution data.

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