Geomorphological Evidence of Local Presence of Ice-Rich Deposits in Terra Cimmeria, Mars. S. Adeli[1], E. Hauber[1], G. Michael[2], P. Fawdon[3], I. B. Smith[4], and R. Jaumann[1,2]. [1]Deutsches Zentrum fuer Luft- und Raumfahrt (DLR), Institute für Planetenforschung, Rutherfordstr. 2, 12489 Berlin, Germany (Solmaz.Adeli@dlr.de). [2]Freie Universität Berlin, Institute of Geological Sciences, Malteserstr. 74-100, 12249 Berlin, Germany. [3]Birkbeck, University of London, Malet St, London WC1E 7HX. [4]Planetary Science Institute, 1546 Cole Blvd Ste 120, Lakewood, Colorado, USA.

Introduction: Global circulation models suggest that obliquity oscillations caused the mobilization of ice from polar regions and its re-deposition at lower latitudes [1, 2]. They show that during high obliquity periods, ice can be deposited almost anywhere in the mid-latitudes and during low obliquity ice is transported back to the poles [2-4]. Although the obliquity variations are not predictable for periods more than 20 Ma ago [6], it is likely that the surface of Mars, during Amazonian, has repeatedly undergone such climate changes leading to deposition and sublimation/evaporation of ice-rich material [e.g., 3, 6, 7]. Evidence of shallow ground ice has been widely observed in the north and south mid-latitude regions of Mars such as: geomorphological evidence of debris-covered glaciers [e.g., 8, 9] and SHARAD observation [e.g., 10] of ~70 m thick ice deposits. This study describes well-preserved glacial-like deposits in Terra Cimmeria, which are defined here as valley fill deposits (VFD) (Fig. 1-a). They are located on the floor of a valley system which bears a record of Amazonian-aged fluvial and glacial processes [11].

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 kilometers, (2) convex-upward surface topography (Fig.1-b), and (3) pits and crevasses on their surfaces. These valley fill deposit (VFD) are located a few tens of kilometres east of the Tarq impact crater. Several of the VFDs are situated within the visible ejecta blanket of the Tarq Crater (Fig.1-a). The crater ejecta are observable on the surface and surrounding area of those VFDs. The VFDs have individual surface areas of a few km^2 to a few tens of km^2 (Fig1-b). 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 the VFD in the thickest part has a thickness of ~30 meters. The latitude dependent mantle (LDM) is also partly covering the VFD, and the surface of the VFD is outcropped where the LDM has been degraded or sublimated.

The surface of VFD shows only few impact craters, with diameters equal or smaller than ~700 m. Craters larger than 70 m are mostly degraded, their rims show almost no positive relief (at CTX resolution) and they have flat floors. Smaller modified craters have been observed, but there are also a few small fresh impact craters (smaller than 70 m in diameter) which do not show any modification of their rims and walls. On the surface of several VFD, we observe some craters a few hundred meters in diameter, that are bowl-shaped and rimless, with a flat floor. They have very similar characteristics to impact craters on LDA and LVF surfaces in mid-latitudes, which are termed ring-mold craters by [12] and are thought to be a result of impacts into shallow buried ice.

Where higher resolution data are available, we can observe linear features, cracks, and crevasses (lateral

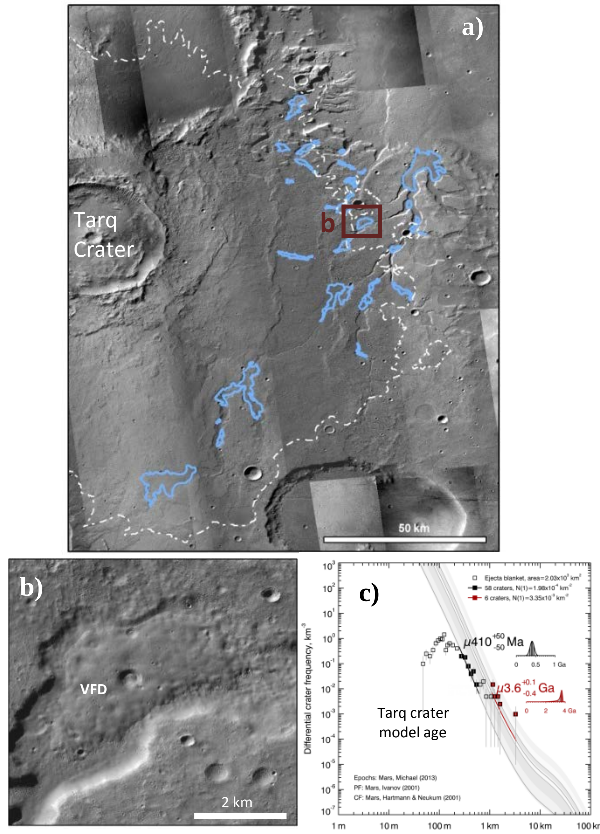

Fig. 1: a) An overview of the study area. The solid blue line represents the VFD locations. The dashed white line shows the Tarq Crater ejecta blanket. b) Zoom to one of the VFD, on the floor of a fluvial valley. c) Absolute model age corresponding to the ejecta blanket of Tarq crater. μ is a function representing the uncertainty of calibration of the chronology model [5].

and transverse) on surface of VFD. Transverse crevasses may indicate tensile stress caused by viscous flow of the deposit. In several cases, in front of the VFD margins, there is a zone up to 3 km of length, where the valley floors are rougher than further down the valley. We interpret this rough zone to correspond to sediment accumulation similar to moraine-like material in front of a glacier that moves down the valley. At the contact between the VFD and the valley walls, we observe several sublimation pits a few tens of meters wide and aligned along a preferential direction on 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 [5]. The data are plotted as a differential presentation of CSFD. It should be noted here that there are uncertainties to derive a confident absolute model age of these deposits, which correspond to the small area and small number of craters on VFD, in addition to the resurfacing phase(s) having most likely modified the few craters morphology and visible dimensions.

We suggest that the model age of the VFD surface is ~µ25 (±10) Ma, which corresponds to late Amazonian (the µ factor is a function representing the uncertainty of calibration of the chronology model [5]). The resurfacing event has roughly a recent age of ~µ3.4 (+2/-1) Ma and corresponds to late emplacement(s) of a thin layer of dust, airfall, and/or ice-rich material (e.g., LDM) covering the VFD.

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 a model age of ~µ410 (±60) Ma for the impact crater (Fig.1-c), which corresponds to the end of the middle Amazonian (epoch boundaries from [13]), and a model age of ~µ3.6 (+0.1/-0.4) Ga for the base age.

Discussion: The VFD have been observed on the floor of a valley system with traces of early to middle Amazonian fluvial activities [11] and our observations point to a post-valley formation for the VFD. The VFD is characterized by a convex-upward shape, transverse crevasses, sublimation pits, and association with moraine-like deposits. These characteristics, together with evidence of ring-mold craters, suggest that VFDs are ice-rich deposits with a thickness of a few tens of meters. The VFD was later partly covered by LDM, which shows evidence of degradation, such as retreating boarders, sublimation pits, and scalloped surface.

Our geomorphological observation suggests a link between the ejecta blanket of Tarq crater and the VFD distribution. It is, however, unclear whether the VFD formed 1) prior to the impact event, 2) contemporary to the impact, or 3) posterior to the impact and replacement of the ejecta blanket. In the 1st case, the emplacement of the ejecta blanket on a widespread ice layer would result in ice melt and mobilization into the valley. This case explains the VFD distribution but not the VFD model age. In the 2nd case, the impact event may have occurred in ice-rich strata, which, subsequently, may have distributed a mixture of ejected material and ice, in other words, icy ejecta in the surrounding area. The ejected material which were deposited on the valley floor have been preserved by the valley wall and therefore agrees with our interpretation. This case justifies the VFD distribution, our geomorphological observation, and younger model age than the ejecta blanket. In the 3rd case the VFD deposition may have taken place long after the Tarq impact event. This case is in agreement with our model age, but does not fully support our observation. Therefore, the 2nd scenario of impact into icy strata resulting in ice distribution in the area, and ice deposits been preserved by the valley wall fits our geomorphological interpretations.

We conclude that the glaciation and deposition of VFD, regardless of the formation mechanism, should have taken place under different climatic conditions in the past, and that the presence of ice-rich VFD is a local evidence of an episodic and multi-event process of ice emplacement in the mid-latitude regions of Mars during the Amazonian period.

Future work: Our next step is to look at the SHARAD radargrams of the VFD, aiming to observe presence or lack of subsurface reflection. It should be noted here that the VFD covers a relatively small area which may not be in favor of a clear SHARAD observation. Additionally, the VFD location on the valley floor may as well cause topographical obstacle in a radargram.

References: [1] Forget, F., et al. (2006), *Science*. *311*, p. 368-371. [2] Madeleine, J.-B., et al. (2009), *Icarus*. *203*, p. 390-405. [3] Smith, I.B., et al. (2016), *Science*. *352*(*6289*), p. 1075-1078. [4] Levrard, B., et al. (2007), *Journal of Geophysical Research: Planets*. *112*(*E6*), p. E06012. [5] Michael, G.G., et al. (2016), *Icarus*. *277*, p. 279-285. [6] Laskar, J., et al. (2004), *Icarus*. *170*, p. 343-364. [7] Head, J.W., et al. (2005), *Nature*. *434*, p. 346-351. [8] Head, J.W., et al. (2003), *Nature*. *426*, p. 797-802. [9] Hubbard, B., et al. (2014), *The Cryosphere*. *8*(*6*), p. 2047-2061. [10] Stuurman, C.M., et al. (2016), *Geophysical Research Letters*. *43*(*18*), p. 9484-9491. [11] Adeli, S., et al. (2016), *Icarus*. *277*, p. 286-299. [12] Kress, A.M. and J.W. Head. (2008), *Geophysical Research Letters*. *35*. [13] Michael, G.G. (2013), *Icarus*. *226*(*1*), p. 885-890.