Intense Glacial Erosion Could Have Erased Gullies on Mars

Conference or Workshop Item

INTENSE GLACIAL EROSION COULD HAVE ERASED GULLIES ON MARS. S. J. Conway[1], F. E. G. Butcher[2], T. de Haas[3,4], A. A. J. Deijns[4] and P. M. Grindrod[2], [1]CNRS, Laboratoire de Planétologie et Géodynamique, Université de Nantes, France (susan.conway@univ-nantes.fr), [2]School of Physical Sciences, Open University, Milton Keynes, MK7 6AA, UK, [3]Department of Geography, Durham University, South Road, Durham DH1 3LE, UK, [4]Faculty of Geoscience, Universiteit Utrecht, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands, [5]Department of Earth Sciences, The Natural History Museum, Cromwell Road, London SW7 5BD, UK.

Introduction: The mid-latitudes of Mars are host to a wide variety of ice-related landforms, including those that resemble glaciers on Earth – collectively known as Viscous Flow Features (VFF) [e.g., 1,2] and a blanketing deposit often called the Latitude Dependent Mantle (LDM) [e.g., 3,4]. The same latitude band is shared by martian gullies, erosion-deposition systems up to several kilometers long that comprise a source alcove, and depositional apron connected by a channel [e.g., 5,6]. Gullies are known to form within the LDM deposits that are found on steep slopes [7], but evidence for gullies being formed before the LDM was laid down is sparse [8]. In our previous work we hypothesized that glacial erosion/burial may have erased previous generations of gullies [9]. Here, we explore that hypothesis in more detail and find that intense glacial erosion has significantly contributed to down-wasting and was likely promoted by pore water within substrate beneath glaciers.

Approach: We performed a survey of High Resolution Imaging Science Experiment (HiRISE) images at 25-50 cm/pix based on the gully-database of [5] to identify those where gullies interact with LDM. Widths of the incisions into the LDM were measured to provide an estimate of the depth of the unit. We also noted the presence of arcuate ridges at the base of the crater wall, as these were previously interpreted to be moraines and therefore glacial in origin [10,11]. We used topographic data derived from HiRISE stereopairs at 1-2 m/pix in order to measure the slope angle of the bedrock exposed near the crater rim – we found this typically extends to ~350 m from the rim crest. We measured slopes in eight "glacial" (Fig. 1) craters and seven "non-glacial" craters with diameters ranging between 2.5 and 20 km which were not superposed on other relief-forming structures (older craters, graben, mesas, etc.). We used superposed crater-size frequency distributions [12] on crater ejecta blankets to estimate a crater's age where an age had not already been published.

Texturally disrupted bedrock: Our first key observation is that LDM or "pasted-on terrain" is almost always found downslope of texturally disrupted bedrock (Fig. 1d,e). Bedrock exposures near fresh crater rims usually take the form of a series of "spur and gully" type alcoves and the bedrock itself is usually mas-

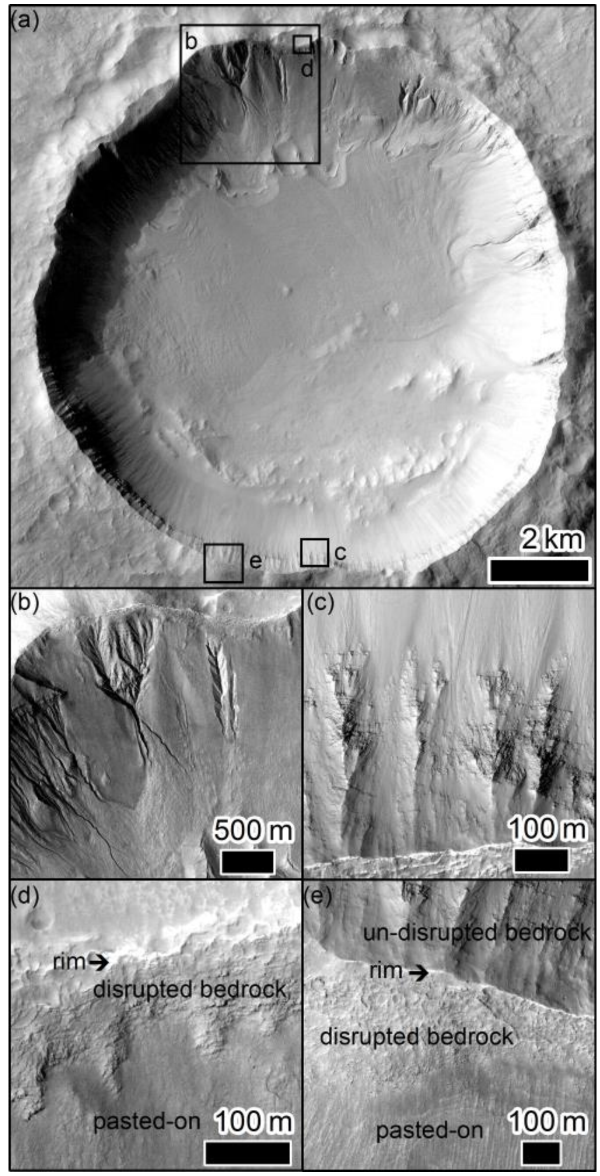

Figure 1: *Crater Niquero on Mars with gullies and evidence of glaciation (N is up). (a) Overview in CTX image P03_002383_1417 with boxes indicating: (b) gullies, (c) unmodified bedrock alcoves, (d) inner wall and (e) outer wall in HiRISE image ESP_030443_1410.*

sive, sometimes identifiably layered, breaking off downslope into decameter-sized blocks (Fig. 1c). The texturally altered bedrock we report here usually has no alcoves, but if they are present they are hundreds of meters in width and shallow. Its exposure is smooth at the 1:25,000 scale, yet rubbly at the 1:5,000 scale with rarely any massive or layered outcrop visible. We find this relationship between pasted-on terrain and texturally disrupted bedrock on the inner and outer walls of impact craters as well as other sloping terrains.

Topographic analysis of the inner crater walls with texturally disrupted bedrock reveals that these walls are on average 5° lower than the conjugate crater wall and 14° lower than the average slope of "non-glacial" craters in our study. The same trend is observed for the outer crater walls; however, the slope-lowering is not statistically significant, probably because of the large variance in initial slope of the non-glaciated outer walls.

We converted these slope-reductions to headwall retreat rates using the known length of bedrock exposure and the estimated crater age. This revealed retreat rates of ~10^3 m Myr^{-1} equivalent to erosion rates of wet-based glaciers on Earth [e.g., 13] and to headwall retreat rates associated with extensive martian bedrock gully systems [14]. This is several orders of magnitude higher than estimates of erosion by VFF by Levy et al. [15] of 10^{-2}-10^{1} m Myr^{-1}, which are roughly equivalent to cold-based glaciers on Earth.

Pasted-on terrain and arcuate ridges: The pasted-on terrain is never found extending over the crater rim. It infills-in depressions in the crater wall (Fig. 1d) and one of its most common surface textures comprises downslope lineations. Given the material eroded from the texturally disrupted bedrock should be found downslope, we provide an alternate interpretation that this unit represents a glacial remnant or perhaps till deposit. The presence of the arcuate ridges where the pasted-on terrain is found on the headwall above an extant VFF supports a glacial origin for the pasted-on terrain. By comparison to terrestrial examples [16,17] we find that the arcuate ridges are likely the result of glaciotectonic deformation of sub-marginal and proglacial sediment. Conway and Balme [18] found that the pasted-on terrain contained between 46% and 95% ice by volume and our work shows that it tends to increase in thickness from ~10 m at 28-30° to 40 m at around 60°. Such volumes of till and the presence of glaciotectonic deformation are consistent with glacial motion on Earth under wet-based conditions . We note that pore-water driven glaciotectonic deformation is particularly effective within permafrost-confined substrates [16,17]. Equally the lack of other wet-based landforms (eskers, moraines broken by meltwater, meltwater lakes, etc.) argues that the quantities were limited to pore-water.

Timing: We found no convincing evidence that any gullies predate the pasted-on terrain. Dickson et al. [8] reported gullies emerging from underneath the LDM, but we interpret these as landforms emplaced atop glaciers now deformed/inverted by the loss of that glacial ice. The youngest "glacial" crater in our study has an age of ~0.5 (0.4-50) Ma, yet all the others are dated at >10 Ma, hence further work is needed to ascertain whether this glacial erosion coincides or not with the shift to lower mean obliquity at ~5 Ma [19]. Where dating is possible most gullies have been estimated to be < 5 Ma [9,20,21], hence the relative stratigraphy and absolute ages seem to agree.

Conclusions: (1) We have found evidence for significant glacial erosion on Mars with rates equivalent to those for wet-based glaciers on Earth, (2) we find morphological evidence for the presence of pore-water in the form of striae on till deposits and ridges formed by glaciotectonic deformation, (3) we interpret the pasted-on terrain as being glacial in origin and therefore not linked to the blanketing airfall deposit called the LDM, and (4) the glacial erosion rates we find are sufficient to erase even the youngest and most well-developed gully-systems, hence support the hypothesis of de Haas et al. [9].

Acknowledgments: SJC is supported for her HiRISE work by the French Space Agency, CNES. FEGB is supported by STFC grant ST/N50421X/1. TdH is funded by the Netherlands Organization for Scientific Research (NWO) via Rubicon grant 019.153LW.002.

References: [1] Milliken R.E. et al. (2003) *JGR, 108*, doi:10.1029/2002JE002005. [2] Squyres S.W. (1979) *JGR 84*, 8087–8096. [3] Mustard J.F. et al. (2001) *Nature, 412*, 411–414. [4] Kreslavsky M.A. and Head J.W. (2000) *JGR 105*, 26695–26712. [5] Harrison T.N. et al. (2015) *Icarus, 252*, 236–254. [6] Malin M.C. and Edgett K.S. (2000) *Science, 288*, 2330–2335. [7] Christensen P.R. (2003) *Nature, 422*, 45–48. [8] Dickson J.L. et al. (2015) *Icarus, 252*, 83–94. [9] de Haas T. et al. (2017) *Geol. Soc. Lond. Spec. Publ.*, 467 *doi: 10.1144/SP467.1*.[10] Berman D.C. et al. (2005) *Icarus, 178*, 465–486.[11] Arfstrom J. and Hartmann W.K. (2005) *Icarus, 174*, 321–335.[12] Hartmann W.K. and Neukum G. (2001) *Space Sci. Rev., 96*, 165–194. [13] Geirsdóttir Á. et al. (2007) *J. Geodyn., 43*, 170–186. [14] de Haas T. et al. (2015) *JGR 120*, 2169–2189. [15] Levy J.S. et al. (2016) *Icarus, 264*, 213–219. [16] Bennett M.R. (2001) *Earth-Sci. Rev., 53*, 197–236. [17] Fitzsimons S.J. (1996) *Ann. Glaciol., 22*, 68–74. [18] Conway S.J. and Balme M.R. (2014) *GRL 41*, 5402–5409. [19] Laskar J. et al. (2004) *Icarus, 170*, 343–364. [20] Schon S.C. et al. (2009) *Geology, 37*, 207–210. [21] Reiss D. et al. (2004) *JGR, 109*, doi:10.1029/2004JE002251.