SOLIFLUCTION AND THAW ON MARS? 3D COMPARISON OF MARTIAN HILLSLOPE LOBES WITH TERRESTRIAL SOLIFLUCTION AND ATACAMA LOBES. S. J. Conway[1], R. Gastineau[1,2], A. Johnsson[3], J. Eichel[4], C. Dundas[5], N. Mangold[1], P. M. Grindrod[6] and T. Izquierdo[7], [1]Laboratoire de Planétologie et Géodynamique CNRS UMR 6112, Université de Nantes, France (susan.conway@univ-nantes.fr), [2]Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, IRD, IFSTTAR, ISTerre, France. [3]Department of Earth Sciences, University of Gothenburg, Sweden. [4]Karlsruhe Institute of Technology (KIT), Institute of Geography und Geoecology, Germany. [5]U.S. Geological Survey, Astrogeology Science Center, Flagstaff AZ, USA. [6]Department of Earth Sciences, The Natural History Museum, London, UK. [7]Instituto de Investigaciones Científicas y Tecnológicas de la Universidad de Atacama (IDICTEC-UDA), Copiapó, Chile.

Introduction: Downslope oriented lobate forms of tens to hundreds of meters in scale are found on hillslopes at mid- to high-latitudes on Mars [e.g., 1]. In planview images these lobes resemble solifluction lobes on Earth, which are features caused by differential creep of soil undergoing freeze-thaw cycling [e.g., 2]. On Mars the generation of liquid water via thaw is considered problematic at the present-day and under recent climatic conditions [e.g., 3,4] when these lobes are thought to have formed. Here, we study the 3D properties of martian lobes and compare them to the 3D properties of solifluction lobes in five different terrestrial sites [5]. We also compare them to lobate forms in the Atacama Desert – one of the driest places on Earth – whose origin is thought to be via seismic shaking [6] – a mechanism that would avoid any problems with generating liquid water on recent Mars. Our objective is to ascertain whether these comparisons uphold the current hypothesis that lobate forms on Mars are analogous to terrestrial solifluction lobes, or not.

Approach: We used digital terrain models (DTMs) at better than 2 m/pix to perform our measurements. For each site we digitized the length and width of each lobe as lines. For this task we used ortho-images and hillshaded relief maps. By extracting the elevations along the longitudinal axis line we were able to calculate the slope and orientation of each lobe. We digitized the nearest upslope ridge (with aid from the compound topographic index) for each suite of lobes in order to quantify their positions within the hillslope. On Mars we made measurements at five sites (see [5] for details) and used 1 m/pix DTMs derived from HiRISE stereo images using the Integrated Software for Imagers and Spectrometers (ISIS3) and Socet Set 5.6.0 workflow [7]. On Earth we used five sites with solifluction lobes (Svalbard, Iceland, Sweden, Greenland, and French Alps) and one site with lobate forms in the Atacama. DTMs were generated from the High Resolution Stereo Camera - AX (HRSC-AX), two suites of airborne LIght Detection And Ranging (LIDAR) data, a terrestrial laser scanner and stereo Pléiades satellite imagery (see [5] for details).

Results: We analyzed 5148 lobes in total, with 1901 on Mars, 2759 solifluction lobes and 488 Atacama lobes. Martian lobes are found on slopes between 10° and 38° (median 25°) compared to solifluction lobes which are found on all slopes up to 35° (median 16°) and the Atacama lobes from 5° to 30° (median 17°). Martian lobe dimensions generally fall within those expressed by terrestrial solifluction lobes (up to hundreds of meters), but are on average longer and wider. In contrast, the Atacama lobes differ from both as they do not exceed 20 m-wide and 20 m-long. Field observations reveal they express little relief [e.g., 6] in contrast to the martian and solifluction examples. The three populations differ as to where they occur in the hillslope: martian lobes tend to occur near the ridge, solifluction lobes on mid- to lower slopes and Atacama lobes can occur in any position.

Discussion: Our 3D comparison reveals that the Atacama lobes are morphometrically dissimilar to the martian lobes. Previous studies concluded martian lobes resemble solifluction lobes [e.g. 1 and references therein] and our results generally agree. The major difference lies in our slope measurements – martian lobes are located nearer the ridge where slopes are >10° whereas solifluction lobes tend to be located further downslope and thus predominantly occur on lower slopes. We do not think this could be attributed to differences in gravitational acceleration because both resisting and driving forces would be attenuated to the same degree on Mars – cancelling each other out. On Earth the formation of solifluction lobes is favored by a larger upslope drainage area which promotes saturation by meteoric input [2] – a factor which is not expected to be relevant on Mars in the Amazonian and could be part of the explanation. Boulder movement is observed to be active near some of the lobes [8] and opens the possibility of a different lobe-forming process active on Mars today with no Earth analog, perhaps related to frost or ice processes.

Conclusions: Martian lobes have similar 3D morphometric properties to solifluction lobes on Earth. Lobes in the Atacama caused by seismic shaking are dissimilar to the martian lobes. Martian lobes are found higher on the hillslope and at correspondingly higher slopes than terrestrial solifluction lobes, which we attribute to the lack of meteoric water input on Mars,

although we cannot rule out the action of CO_2 or H_2O frost/ice processes with no known terrestrial analogue.

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References: [1] A. Johnsson et al. (2018) Chapt 8 in *Dyn. Mars*, (Eds: Soare, R. J. et al.) [2] N. Matsuoka (2001) *Earth-Sci. Rev.*, *55*, 107–134. [3] M.A. Kreslavsky et al. (2008) *Planet. Space Sci.*, *56*, 289–302. [4] M.T. Mellon and R.J. Phillips (2001) *JGR - Planets*, *106*, 23165–23179. [5] R. Gastineau et al. (2020) *Icarus*, *accepted*. [6] S.M. May et al. (2019) *Geomorphology*, *344*, 46–59. [7] R.L. Kirk et al. (2008) *JGR. Planets*, *113*, doi:10.1029/2007JE003000.

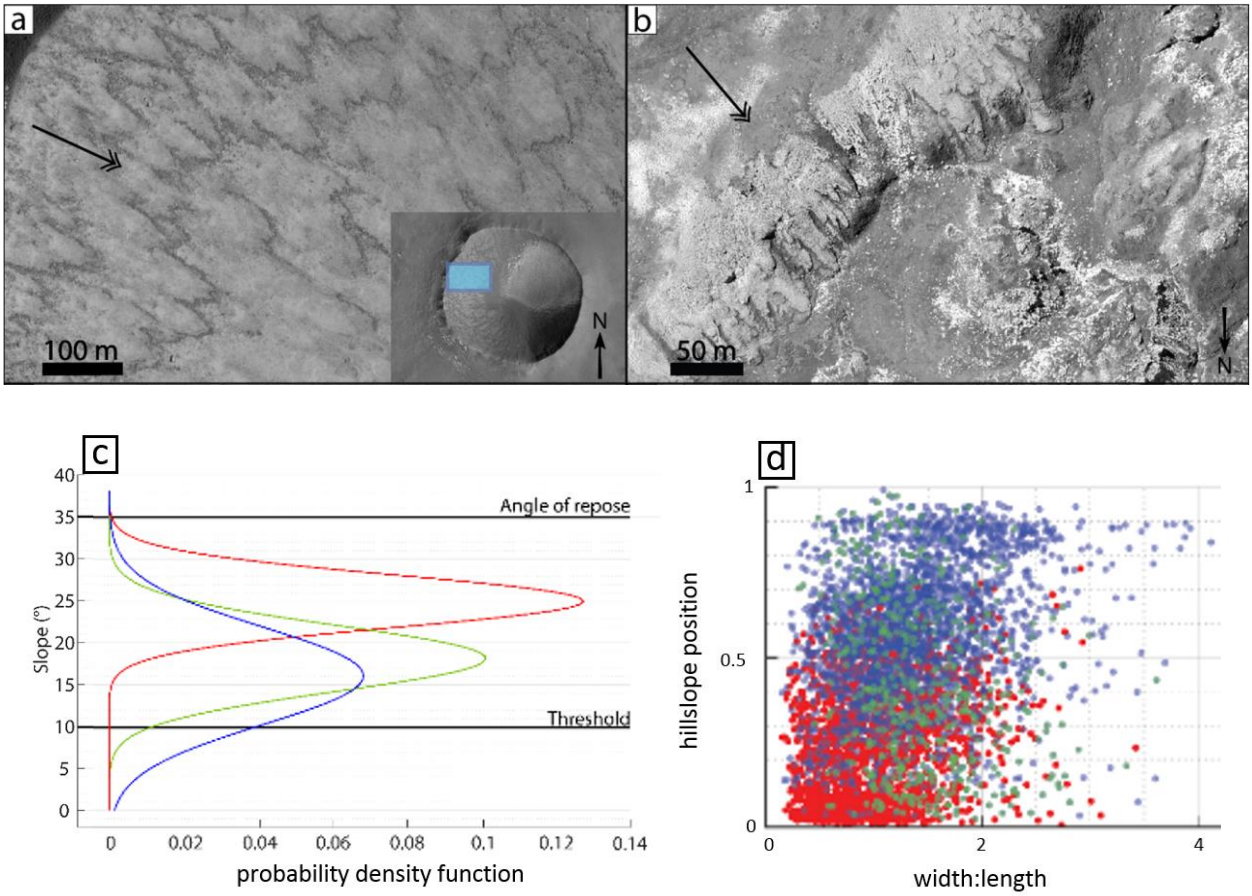

Fig. 1: a) Martian lobes in a 1-kilometre-crater at 72.44°N, 126.46°E, HiRISE image: ESP_027768_2525. Blue box in inset shows the position of the main image. Double-headed arrow is downslope. b) Non-sorted solifluction lobes near Termignon in the French Alps, France. Credit: IGN BD ORTHO. Double-headed arrow is downslope. c) Probability Density Function (PDF) of slopes for lobes on Mars and Earth showing this distribution with a 95% confidence intervals. d) Scatter plot of the normalized distance from each lobe to its nearest upslope ridge (the closer the value is to 0, the closer the lobe is to the ridge) versus its width to length ratio. In c and d: red is Mars, blue is solifluction and green is Atacama.