PHYSICAL PROPERTIES OF SUPRAGLACIAL DEBRIS ON MARS.

David M. H. Baker and Lynn M. Carter, NASA Goddard Space Flight Center, Greenbelt, MD 20771, david.m.hollibaughbaker@nasa.gov.

Introduction: Important to understanding the recent climate history of Mars and current water budget is an understanding of the exchange of water vapor between polar and non-polar regions under various orbital forcing scenarios. The mid-latitudes of Mars are host to a class of features thought to be debris-covered glaciers (DCGs) [e.g., 1]. Although surface ice is currently unstable in the mid-latitudes, current sublimation rates of ice at DCGs have been substantially reduced by a protective layer of supraglacial debris that is hypothesized to be on the order of 10 m thick and covers nearly pure glacial ice hundreds of meters in thickness [2-4].

Although radar sounding and crater morphology have provided some constraints on the physical characteristics of this supraglacial debris [2-4], much is unknown about its thickness, sedimentary structure and origin, and depositional and erosional evolution. In addition, mid-latitude ice deposits are potential water resources for future missions to Mars. Understanding their near-surface structure and accessibility has important bearing on the viability of these sites for future exploration.

To improve constraints on the physical properties of martian supraglacial debris, we conducted a detailed analysis of the near-surface of DCGs within Deuteronilus Mensae (36-48.5ºN, 13-36ºE). We used MRO CTX (6 m/pixel) and HiRISE (25 cm/pixel) images for mapping of DCGs, measuring fresh crater depths and diameters, and assessing materials exposed by the craters. SHARAD radar sounding data (vertical resolution: 15 m in free space; horizontal footprint: ~0.3-1 km along-track and ~3-6 km cross-track) was used to assess DCG thicknesses and search for evidence of near-surface layering.

Morphologic Mapping: A full-resolution mosaic of CTX images was generated for regional mapping using USGS ISIS tools. Glacial deposits were mapped based on their topographic and textural characteristics at 1:50,000 scale in ArcMap.

Results: Glacial deposits cover 22% of the region (166,035 km^2) and always occur adjacent to steep slopes. A variety of surface textures at the tens of meters scale are present, which result from a combination of primary flow-related terrain and secondary resurfacing textures, including mantling and inherited topography from preferential fracturing and aeolian erosion [e.g., 5]. Typically, the surfaces consist of relatively “fine-grained,” sub-meter scale material based on HiRISE images.

Crater Depths and Diameters: We mapped and measured the rim-crest diameters (D) of 1,398 fresh craters >75 m on DCG surfaces. Fresh craters were recognized by their sharp rim-crests and their lack of significant interior fill. We also measured the depths (d) of fresh craters >250 m in diameter using wall shadow lengths observed in CTX images with 55-80º incidence angles (total of 56 craters) and assuming parabolic crater shapes [6].

Results: Most fresh craters show typical bowl-shaped morphologies (Fig. 1). All of the craters lack ejecta blankets, suggesting that excavated material was highly erodible or volatile, consistent with fine-grained material and/or ice-rich subsurface debris. The walls of the craters also typically lack boulders and layering at the >1-m scale where HiRISE images were available.

Measured craters have an average d/D ratio of 0.20 (Fig 1), which is consistent with the general trend of other simple craters on Mars [6,7]. If we extend this d/D ratio to all craters and assume a maximum depth of excavation $d_e \approx 0.084D$ [8], we find that all craters >75 m on DCGs have depths that exceed the proposed ~10-m thickness for the supraglacial debris layer (Fig. 2), with 35% exceeding depths of 25 m.

Furthermore, comparisons of crater size-frequencies with Hartmann (2005) [9] isochrons, show that this fresh crater population has a survival timescale of approximately 10 Myr.

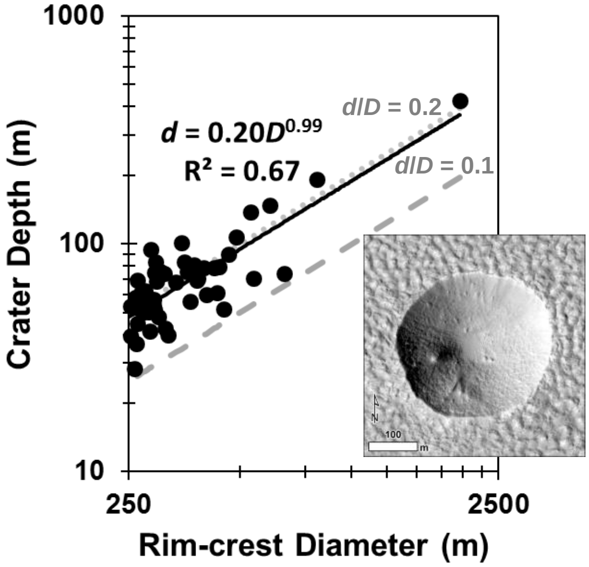

Fig. 1. Log-log plot of measured crater depth (d) versus rim-crest diameter (D). Craters on DCGs (e.g., inset HiRISE image) have d/D ratios of ~0.2, typical for simple craters on Mars.

Comparisons with Glacier Thicknesses: The identifications of strong, radar-bright radar reflectors at the bases of DCGs provide evidence that DCGs contain massive, low-loss, relatively pure ice bodies [3]. We identified 48 craters >250 m with adjacent SHARAD tracks that showed DCG basal reflectors, which allowed for estimates of DCG thicknesses, as in [3,4].

Results: DCG thicknesses range from 104-761 m with a mean of 396 m (Fig. 2). Crater depths, on average, extend to ~20% of the DCG thickness, with excavation depths reaching ~10% of the DCG. These depths are well beyond 10 m and should have extended into glacial ice (Fig. 2).

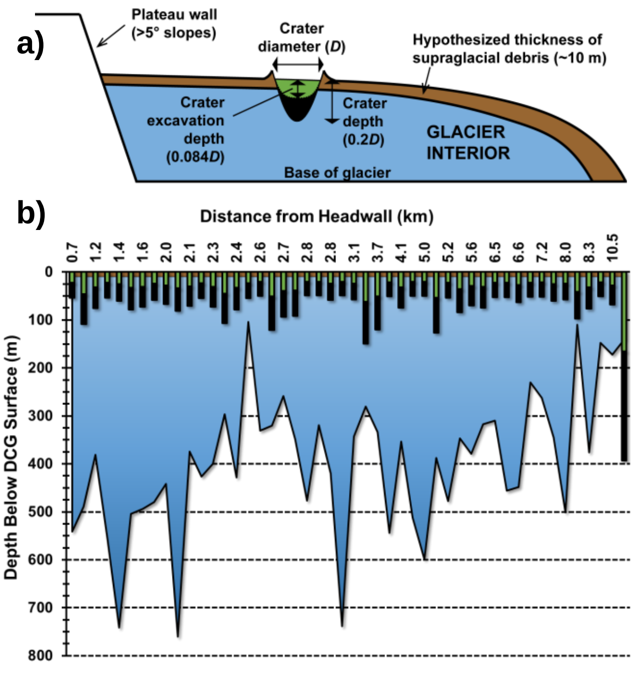

Fig. 2. (a) Hypothesized structure of a martian debris-covered glacier, showing superposed crater geometry. (b) Depths of excavation (green) and crater depths (black) compared to glacier thicknesses (blue) and a 10-m debris thickness (brown). Measurements for 48 craters >250 m are shown, arranged by distance from the glacier headwall.

Near-Surface Layering in SHARAD: A survey of SHARAD radargrams covering DCGs in the study area was conducted to identify possible evidence of near-surface layering. However, as for other areas on Mars [e.g., 10], definitive evidence of near-surface layering was not readily observed and difficult to separate from other components of the radar signal. Most of the observed returns occurring at time delays near the main surface reflection are attributed to surface clutter from the closely spaced headwalls of DCGs and also sidelobe patterns resulting from range compression. The few radargrams not dominated by surface clutter and sidelobes also did not show clear near-surface returns.

Discussion/Conclusions: We have documented evidence of 1,398 fresh craters >75 m that have depths that exceed the hypothesized ~10 m thickness of supraglacial debris on debris-covered glaciers (DCGs) within Deuteronilus Mensae. Many craters excavated and displaced material tens of meters into DCG surfaces and possibly into glacial ice, yet retain their simple, bowl-shaped morphology and *d*/*D* ratios typical for simple craters on Mars. This is at odds with the hypothesized formation of “ring-mold craters” that are suggested to have developed their unique interior morphologies due to impacting into an ice-rich target [2].

In addition, the 10-Myr survival timescale for craters on DCGs appears to be greater than predicted from recent modeling of the sublimation and viscous relaxation of craters formed into ice-rich targets. Dundas et al. [11] have shown a substantial widening and rounding of the tops of craters and shallowing of craters subjected to sublimation on timescales of tens to hundreds of thousands of years. Preliminary results from Dombard and Noe Dobrea [12] also suggest that substantial crater shallowing and widening can be achieved through viscous relaxation on timescales of a few million years. Considering these timescales, it is unlikely that many of the craters on DCGs have formed into pure-ice targets; a more debris-rich, ice-poor target material is more consistent with the observed fresh crater population.

The above observations suggest that the thickness of supraglacial debris is likely to be much greater than 10 m and probably on the order of tens of meters. The apparently fine-grained nature of the crater walls and erodibility of the ejecta also suggest that much of the supraglacial material may not be rockfall shed from DCG headwalls. However, we cannot rule out the possibility that headwall material is present with grain sizes < 1 m, which would not be resolved in HiRISE images. Overall, the observations are consistent with the surfaces of DCGs being highly modified by tens of meters thick mantling materials through their history [e.g., 13].

The observation that SHARAD radargrams do not show clear evidence of near-surface reflections suggests that the contact between the supraglacial debris and glacial ice may be gradational at vertical scales greater than ~10 m. However, if the contact is sharp with a strong dielectric contrast, as observed in some terrestrial debris-covered glaciers [14], it is also possible that the subsurface return coincides with time delays similar to those predicted for sidelobes patterns. Simple three-layer radar propagation models suggest that returns from contacts at ~15-25 m and ~30-40 m depths may overlap with these sidelobe patterns. A more detailed analysis of the returned powers at these depths and time delays with model predictions would further elucidate this problem.

References: [1] Head, J.W., et al. (2010) *Earth Planet. Sci. Lett.* 294, 306–320. [2] Kress, A.M. and Head, J.W. (2008) *Geophy. Res. Lett.* 35, L2306. [3] Holt, J.W. *et al.* (2008) Science 322, 1235–1238. [4] Plaut, J.J. *et al.* (2009) *Geophys. Res. Lett.* 36, L02203. [5] Mangold, N. (2003) *J. Geophys. Res.* 108(E4), 8021. [6] Daubar, I.J. *et al.* (2014) *J. Geophys Res.* 119, 2620–2639. [7] Watters, W.A. *et al.* (2015) *J. Geophys Res.* 120, 226–254. [8] Melosh, H.J. (1989) *Impact Cratering: A Geologic Process*, 253 pp. [9] Hartmann, W.K. (2005) *Icarus* 174, 294–320. [10] Putzig, N.E. *et al.* (2014) *J. Geophys Res.* 119, 1936–1949. [11] Dundas, C.M. *et al.* (2015) *Icarus* 262, 154–169. [12] Dombard, A.J. and Noe Dobrea, E.Z. (2016) *LPSC 47*, no. 1766. [13] Baker, D.M.H. and Head, J.W. (2015) *Icarus* 260, 269–288. [14] Mackay, S.L. *et al.* (2014) *J. Geophys. Res.* 119, 2505–2540.