PROBING THE NEAR SURFACE OF GLACIAL DEPOSITS ON MARS. David M. H. Baker[1] and Lynn M. Carter[2], [1]NASA Goddard Space Flight Center, Greenbelt, MD 20771 (david.m.hollibaughbaker@nasa.gov); [2] Lunar and Planetary Lab, University of Arizona, Tucson, AZ 85721.

Introduction: Abundant evidence exists for the presence of debris-covered glaciers (DCGs) in the mid-latitudes of Mars [e.g., 1]. The near surface of these DCGs consists of a debris cover, or supraglacial debris, that is likely composed of a combination of headwall rock fall material, sublimation lag, and superposed mantling sequences [1,2]. Although radar sounding and crater morphology have provided some constraints on the physical characteristics of this supraglacial debris [3-5], much is unknown about its thickness, sedimentary structure and origin, and depositional and erosional evolution.

Impact craters <1 km in diameter can help to evaluate the material properties of the top tens of meters of DCGs. A diversity of crater types exist on DCGs, with few well-preserved examples [1,3,6]. So-called "ring-mold craters" (RMCs) have been hypothesized to have formed their concentric ridge and central plateau morphologies during impacts into mostly glacial ice [3]. In contrast, smaller bowl-shaped craters were hypothesized [3] to have formed mostly within the supraglacial debris; the underlying ice did not affect their final morphology. Alternatively, RMCs have been hypothesized to result from a degradation sequence of superposed mantle units [7].

To provide additional constraints on the properties of supraglacial debris and to test the hypothesized origins of DCG impact crater morphologies, 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 and superposed impact craters, measuring the depths and diameters of well-preserved craters, and assessing materials exposed by the craters.

Morphologic Mapping: A mosaic of CTX images at 6 m/pixel resolution was generated for regional mapping using USGS ISIS tools. Glacial deposits cover 22% of the region (166,035 km^2) and were mapped based on their topographic and textural characteristics at 1:50,000 scale in ArcMap.

Crater Mapping: Due to the relative youth of the DCGs (< 1 Ga crater retention age; [1,2]) and their highly modified surfaces, we increased our sampling size of craters over previous studies by mapping and recording the rim-crest diameters and morphologic types of all craters >75 m in diameter on all mapped DCGs. We have currently mapped over 20,000 craters on ~60% of the DCG area. In addition, we have measured the rim-crest diameters of 1,398 well-preserved craters >75 m on 100% of the DCG area.

Observations of Modified Craters: CTX images reveal a range of crater morphologies on DCGs that likely have a variety of origins [2] (Fig. 1). Many craters exhibit sharp rims and interior plateaus of layered sediments that appear to have been emplaced after formation of the crater (Fig. 1a). HiRISE images of RMCs also provide details on the relationships between DCG surface textures and crater landforms. Fig. 1b shows a typical morphology where a central depression is located within a textured plateau. The plateau has the same "brain-terrain" texture as the surrounding DCG surface and is encircled by a moat that defines the crater's outer boundary. The central depression also contains layered fill material that displays brittle fractures.

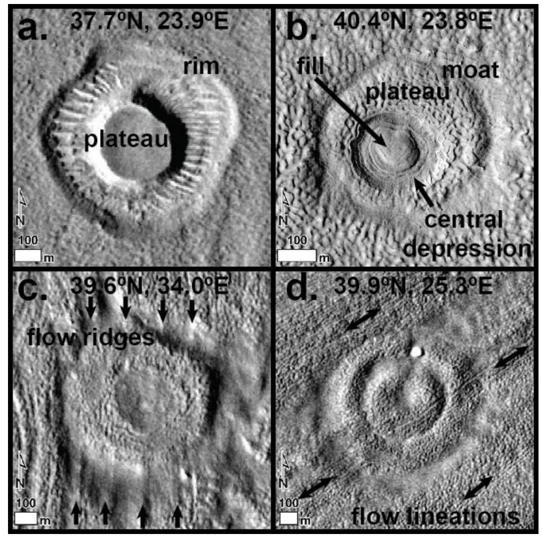

Fig. 1. Variety of modified crater morphologies discussed in the text (a,c,d: CTX image mosaic, b: HiRISE image PSP_009799_2205).

We also observe important relationships between modified craters and DCG flow lineations. In one example (Fig. 1c), flow lineations cross-cut the moat of a crater structure that shows morphologic similarity to the example in Fig. 1b . Since the crater is not sheared and likely formed after formation of the flow ridges, these observations suggest that the original rim-crest likely falls within the inner perimeter of the moat. Other observations show flow lineations completely cross-cutting crater structures that are not sheared by glacier flow. The lineations in these cases are probably inherited through modification of superposed mantling deposits [6]. Additionally, since the lineations are integrated with the crater structure, the crater itself appears to have similarly formed within the mantle.

Additional observations and a complete synthesis are ongoing. We plan to further test the hypotheses of RMC formation, especially considering recent landform modeling of perturbations to ice-rich targets at similar latitudes [8].

Observations of Well-Preserved Craters: While more limited in number, well-preserved craters provide the best locations for characterizing more recently exposed near-surface material and evaluating primary crater morphology. Well-preserved craters were recognized by their sharp rim-crests and their lack of significant interior fill (Fig. 2). We measured the

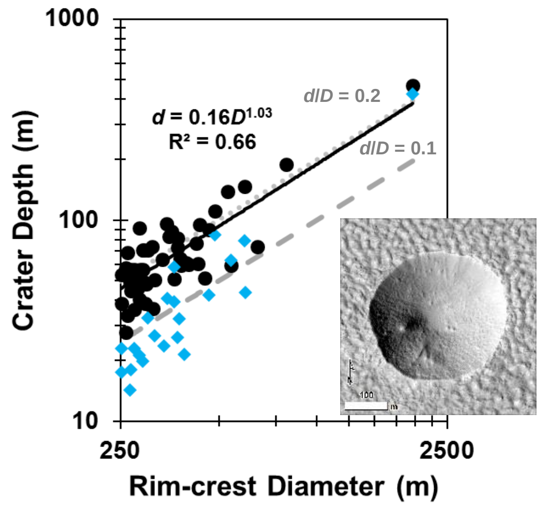

Fig. 2. Log-log plot of well-preserved crater depth (*d*) versus rim-crest diameter (*D*). Shadow-length measurements are shown as black circles; DEM measurements are blue diamonds. Well-preserved craters on DCGs (e.g., inset HiRISE image) have *d*/*D* ratios of ~0.2, typical for simple craters on Mars [6,8].

depths (*d*) of well-preserved craters >250 m in diameter using wall shadow lengths observed in CTX images with 55-80º incidence angles (total of 56 craters). Measurements were calculated from equations appropriate for their assumed geometry [9] and were averaged where multiple images overlapped. Digital elevation models (DEMs) at 18 m/pixel were also generated from available CTX stereo pairs [10] using the Ames Stereo Pipeline (ASP) [11]. Depths for 25 craters with DEM coverage were calculated as the difference between an average of rim-crest elevations and the first percentile of all interior elevations.

Results: Most well-preserved craters show typical bowl-shaped morphologies (Fig. 2). 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.

Craters measured from shadow-lengths have an average *d*/*D* ratio of ~0.2 (Fig. 2), which is consistent with the general trend of other simple craters on Mars [9,12]. If we extend this *d*/*D* ratio to all craters and assume a maximum depth of excavation $d_e \approx 0.084D$ [13], we find that all craters >75 m on DCGs have depths that exceed ~10-m thickness, with 35% exceeding depths of 25 m. Depths measured from CTX DEMs are systematically shallower (~70% on average) than the shadow-length measurements (Fig. 2). We attribute these shallow depths to inaccuracies in the DEM products at the ~15 to 20 DEM-pixel scale of the craters we measured. Some dominant wall shadows likely precluded accurate stereo matching of crater interiors. The percent difference between DEM and shadow-length measurements also generally increases with decreasing size of the crater

Well-Preserved Crater Survival Timescale: Incremental size-frequency distributions for well-preserved craters were compared to Hartmann (2005) [14] isochrons to estimate a survival timescale for these crater types. Based on a best-fit to the crater distribution, the fresh crater population on DCGs has a survival timescale of ~10 Myr.

Discussion/Summary: Hundreds of craters excavated and displaced material tens of meters into DCGs and possibly into glacial ice [4,5], yet still retain their simple, bowl-shaped morphology and *d*/*D* ratios typical of simple craters on Mars. This is at odds with a hypothesized formation of “ring-mold craters” [3] and should be a focus of further testing. From our observations, the various modified craters on DCGs, incuding RMCs, likely have a range of origins, including components established both syn- and post-crater formation.

In addition, the 10-Myr survival timescale for well-preserved craters on DCGs is greater than predicted from recent modeling of crater-like forms in ice-rich targets [8]. Dundas et al. [8] show shallowing and substantial widening and rounding of the rims of craters subjected to sublimation on timescales of tens to hundreds of thousands of years. Crater forms in pure-ice targets also show extreme slope asymmetries due to slope-dependent insolation differences; some type of debris cap from intitial slumping or eolian deposition is likely needed to stabilize the craters [8]. Considering this and the timescales of modification, 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 probably on the order of tens of meters and is likely heterogeneous across the DCGs. Well-preserved craters also show apparently fine-grained sediments in their walls and highly erodible ejecta that are consistent with the surfaces of DCGs being highly modified by tens of meters thick mantling materials through their history [e.g., 2]. Our observations in at least some modified craters (Fig. 1) also support this interpretation.

References: [1] Head, J.W., *et al.* (2010) *EPSL* 294, 306–320. [2] Baker, D.M.H. and Head, J.W. (2015) *Icarus* 260, 269–288. [3] Kress, A.M. and Head, J.W. (2008) *GRL* 35, L2306. [4] Holt, J.W. *et al.* (2008) *Science* 322, 1235–1238. [5] Plaut, J.J. *et al.* (2009) *GRL* 36, L02203. [6] Mangold, N. (2003) *JGR* 108(E4), 8021. [7] McConnell et al. (2007) *7th Int. Conf. on Mars*, no. 3261. [8] Dundas, C.M. *et al.* (2015) *Icarus* 262, 154–169. [9] Daubar, I.J. *et al.* (2014) *JGR* 119, 2620–2639. [10] Becker, K.J. *et al.* (2015) *LPSC 46*, no. 1832. [11] Moratto, Z.M. *et al.* (2010) *LPSC 41*, no. 2364. [12] Watters, W.A. *et al.* (2015) *JGR* 120, 226–254. [13] Melosh, H.J. (1989) *Impact Cratering: A Geologic Process*, 253 pp. [14] Hartmann, W.K. (2005) *Icarus* 174, 294–320.