BOULDER SIZE DISTRIBUTIONS ON MARTIAN DEBRIS-COVERED GLACIERS: FLOW HISTORY AND TIMESCALE.

J. S. Levy[1] C. I. Fassett[2], M. White[1], P. M. Chaffey[2] [1]University of Texas Institute for Geophysics, 10100 Burnet Rd., Austin, TX 78758, joe.levy@utexas.edu [2]Dept. of Astronomy, Mount Holyoke College, South Hadley, MA 01075.

Introduction: Remnant glacial landforms (CCF, LVF, and LDA) are very common in the martian mid-latitudes and cover 7×10^5 km^2 of the martian surface between ±~30-50º latitude, with current thicknesses of several hundred meters [1]. In total, this represents a global water-equivalent layer 0.9-2.6 m thick [1,2].

Crater statistics demonstrate that LDA, CCF, and LVF were mostly formed in the last 100 Myr to 1 Gyr [e.g., 3-7]. Stratigraphic relationships between craters and the glacial deposits also require that glacier emplacement and evolution occurred over an extended period of time: many large (D ≥ 2.5 km) craters have ejecta which is superposed over adjacent CCF and LDA deposits, but these superposing craters are also filled by ice, indicating that there was at least a ~600 Myr period in which glacial deposits were actively forming [7]. Small craters (diameter D≤ 0.5-1 km) are poorly retained on the surface of CCF, LDA, and LVF, and, since the glacial landforms are geologically young, it is challenging to reliably constrain individual ages of features using impact crater size-frequency data. Modeling investigations of ice flow under martian conditions suggest that LDA could accumulate and flow to their full extent in as little as ~500 kyr [8] or could require over 100 Myr [9], depending on different assumptions about ice accumulation rates and important unknown rheological factors such as the temperature and grain size of the ice.

Crater statistics and flow modeling have thus largely been unable to distinguish whether ice deposition occurred episodically during a few, short instances, or whether glacial flow was quasi-continuous and occurring slowly over this period. Other measurements are required to differentiate between these two endmember scenarios. Remarkably, HiRISE allows direct measurement of the size of boulders entrained in the glacial debris. This enables us to directly measure boulder populations on remnant glacier surfaces to address this topic, and constrain their flow history.

The most likely source for these boulders is erosion off the steep escarpments and slopes in the glacial accumulation zone (e.g., at LDA headwalls) and transport of these boulders as supraglacial till. This is directly analogous to how rocks are delivered onto debris-covered glaciers on Earth. Because rocks exposed on Mars' surface are known to breakdown and weather to a finer grained regolith [10-12], we hypothesize that surface boulders decrease in size down-glacier, since the surface age increases with distance from the accumulation zone of these glaciers to their termini. Debris movement and boulder breakdown thus acts as a "ticker tape" advancing out of the accumulation zone such that boulder population on the debris surface is sensitive to the episodicity and intensity of glaciation as a function of time. Populations of different sized boulders arise from a variety of geological processes on Earth and Mars, but are well described by an exponential distribution of boulder frequency as a function of size [e.g., 13-15], meaning population statistics of boulders could be used to infer changes in erosion mechanism and rate, or glacier flow.

Hypotheses: Differences in boulder distribution with distance down-glacier can distinguish whether flow is continuous or episodic, and whether glacial flow primarily occurred in the earliest part of the glacial period on Mars or occurred throughout (Fig. 2). A uniform boulder size distribution down-glacier is the null hypothesis and might arise if (1) if boulder size on the surface is unaffected by weathering (i.e., if weathering is very slow relative to the flow rate), or, (2) if a stable population of boulders developed only after glacial flow ceased. A smoothly decreasing size distribution would indicate glacier flow at modest rates compared to boulder breakdown rates. A stepped size distribution would suggest glacier advance was episodic; boulders weather in place and become smaller during hiatuses, so during each period of glacial advance new boulders that are emplaced are much larger than the preceding ones that were long exposed and eroded in situ. Finally, if the boulder population increases in size or has the largest boulders near the toe, it may indicate a englacial transport of a significant number of rocks.

Method: We measured boulder size distributions on a series of CCF, LVF, and LDA deposits using HiRISE images as well as on terrestrial debris covered glaciers (Mullins and Friedman glaciers, Antarctica) using high resolution airborne imaging and LiDAR (e.g., Figs. 1-2).

Results: Three major classes of glaciers have emerged from this study: landforms with clearly decreasing boulder size downslope (median and 95th percentile) (Fig. 1), landforms with more peaked distributions, and landforms that are too mantled to derive a clear signal. Antarctic debris covered glaciers are in the first class, and decrease down to a uniform size distribution at ages >~1.5 Ma.

Implications: Preliminary analysis of the catalog suggests that debris covered glacial processes on Mars are similar to those on Earth*:* debris is heterogeneous and commonly occurs in enriched bands. Some martian remnant glaciers appear to be older than the timescale of boulder breakdown, while others preserve a -clear "ticker tape" indicating relatively recent glaciation and slow erosion. These results tentatively would suggest that glaciation was episodic in some locations on Mars, and has not tapered off from an early period of glaciation in the late Amazonian.

References: [1] Levy et al. (2014) *JGR-Planets* 119**,** 2188–2196. [2] Karlsson et al. (2015) *GRL,* 42**,** 2627–2633. [3] Berman et al. (2015) *PSS*, 111**,** 83–99. [4] Mangold, N. (2003) *JGR* 108**,** doi:10.1029–2002JE001885. [5] Head et al. (2006) *EPSL* 241**,** 663–671. [6] Baker et al. (2010) *Icarus* 207**,** 186–209. [7] Fassett et al. (2014) *Geology* doi:10.1130/G35798.1. [8] Fastook et al. (2014) *Icarus* 228**,** 54–63. [9] Parsons et al. (2011) *Icarus* 214**,** 246–257. [10] Malin, M. (1974) *JGR* 79**,** 3888–3894. [11] Arvidson et al. (1979) *Nature* 278**,** 533–535. [12] Viles et al. (2010) *GRL* 37, doi:10.1029/2010GL043522. [13] Malin, M.C. (1988) NASA Tech Memo., TM-4041, 502–504. [14] Golombek & Rapp (1997) *JGR*, 102, 4117–4129. [15] Golombek et al. (2003) *JGR,* 108, 8086, 10.1029/2002JE0020

a

b

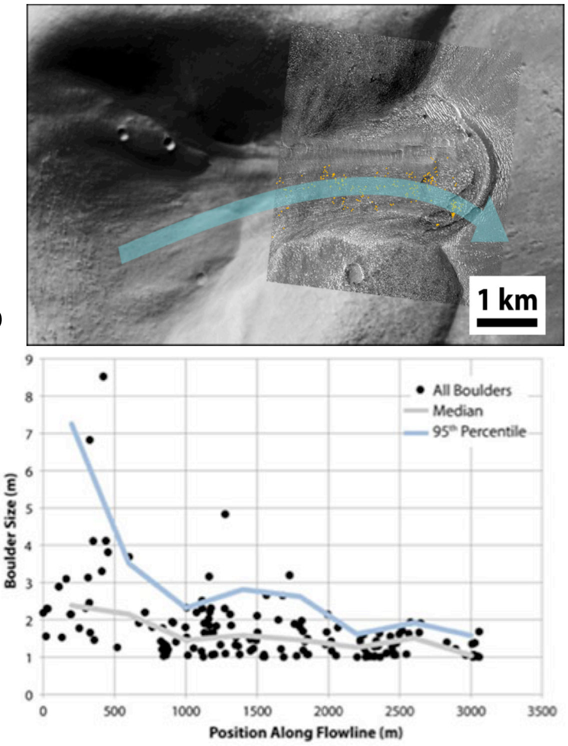
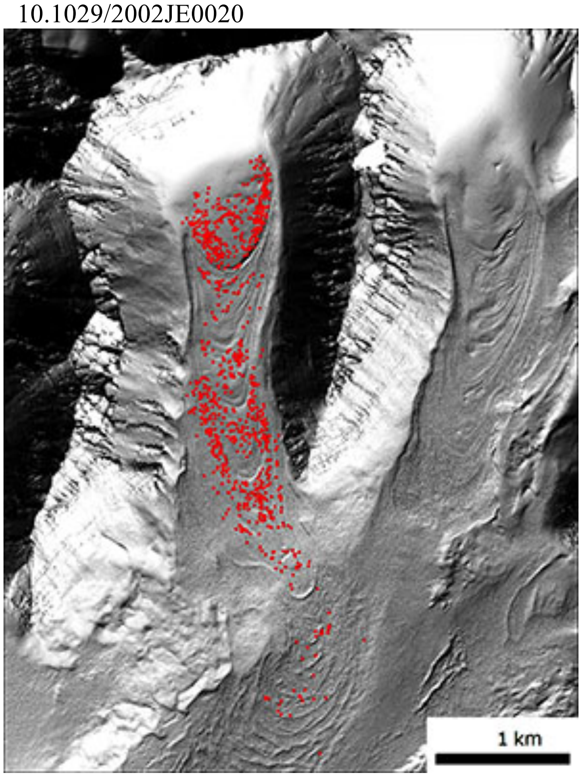


Fig. 1. (a) Image showing pilot study location, G16_024552_1394, overlaid by HiRISE image ESP_023497_1395. Boulders are marked in orange, flowline in blue. (b) ≥1m boulder diameter versus distance measured down-glacier using ESP_023497_1395. Both the largest boulders and the median size decrease down-glacier. The rate of this decrease is fastest closest to the accumulation zone, which could reflect faster breakdown of large boulders relative to small ones. Solid lines show the trend of the median and 95th percentile in 400-m long bins downglacier.



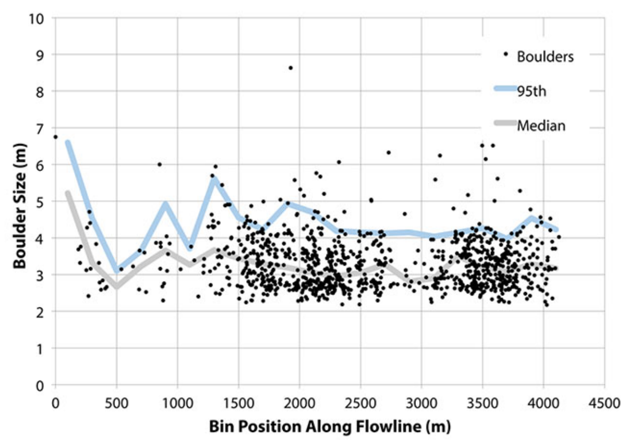


Fig. 2. Boulder size distributions on the Mullins Valley debris covered glacier, Antarctica. (Left) Boulder locations over LiDAR hillshade. (Right) Boulder size distribution along with median size and 95th percentile boulder size.