GLACIAL FLOW TIMESCALES OF MARTIAN LOBATE DEBRIS APRONS IN EASTERN HELLAS.

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Introduction: Lobate debris aprons (LDAs) are broad, thick accumulations of ice-rich material that are commonly found at the base of prominent topographic features such as massifs (Fig. A). Based on Shallow Radar (SHARAD) observations, Martian LDAs likely correspond to debris-covered glaciers comprised of at least 90% water ice [1,2]. Inferring LDA evolutionary histories—which span a wide range of Amazonian ages (e.g., [3])—requires interpretation of present-day LDA shapes, which is greatly complicated by the surface debris cover that protects the underlying ice from rapid sublimation-driven loss. As part of a recently funded MDAP study, we are testing various hypotheses for the source of LDA debris cover and simulating overall LDA evolution using a model that for the first time incorporates a dynamic debris cover and surface mass exchange analogous to true glacial flow (as described in [4]). We first apply this model to aprons in Eastern Hellas (EH), in order to determine whether the flow history of EH LDAs is consistent with multiple episodes of glaciation.

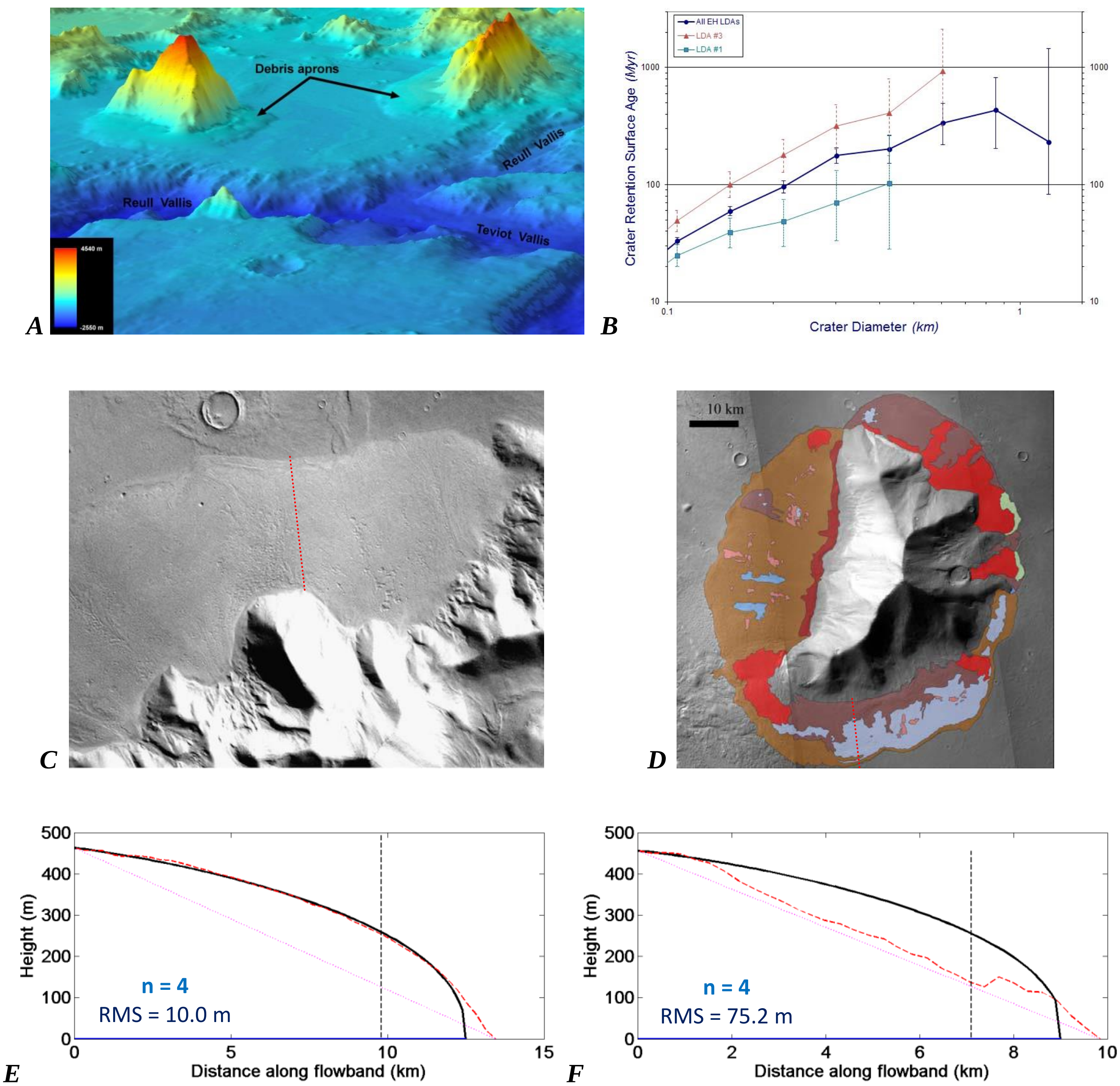
Crater Count Analysis: *Berman et al.* [3] counted 3800+ craters with diameters ranging from 5 m to 1.4 km on 17 different LDAs (designated "LDA #1"-"LDA #17") spanning 1.4 x 10^{10} m^2 in Eastern Hellas. The blue line in Fig. B shows the diameter-dependent crater retention age (CRA) for all 17 of these EH LDAs; the error bars represent 90% Poisson confidence intervals [5]. Excluding craters at lower diameters (D < 300 m), which appear to have been affected by active resurfacing, the five largest size bins are broadly consistent with an average CRA of 300 ± 130 Ma for all EH LDAs. (Note that "± 130 Ma" refers to the fundamental randomness associated with a stochastic process such as impact cratering; there is also a factor of 2-3 uncertainty due to potential errors in applying the lunar-derived isochron system to Mars [6]).

However, inspection of crater counts for individual LDAs indicates that ***there have likely been multiple episodes of glacial activity*** and lobate debris apron formation/modification in Eastern Hellas throughout the Amazonian [3]. For example, the green line in Fig. B corresponds to CRAs derived from crater counts of LDA #1 (a.k.a. Euripis Mons), which is clearly younger than the combined "All" population. This can be more formally established with Poisson statistics [5]: the CRA derived from the LDA #1 diameter bin centered at 300 m is 95% likely to be less than 130 Ma (upper green error bar), but the CRA of the corresponding "All" bin is 95% likely to be greater than 150 Ma (lower blue error bar). Therefore, we can state with 95% certainty that LDA #1 either formed or was resurfaced more recently than the rest of the EH LDAs. Similarly, the red line in Fig. B shows that the surface of LDA #3 (Fig. C) is significantly older than the other EH LDAs; its CRA of 930 Ma (in its largest diameter bin) imposes a key constraint on our flow modeling of LDA #3 (Fig. E).

Flow Model Simulations: Previously, *Pathare et al.* [7] applied a simplified isothermal steady-state flow model to EH LDA #3, and found that an n = 4 rheology provided the best fit to MOLA topography (Fig. E). (The poor fit near the terminus in Fig. E is likely due to mass wasting along the steeper terminal slopes [8].) These preliminary calculations suggest that this particular LDA has remained close to its present-day shape (undergoing minimal relaxation) for the vast majority of its Gyr-history [7]. We are developing a temperature-dependent debris-covered glacial flow model (e.g., [4]) to assess whether the morphology of different LDAs is consistent with multiple episodes of glacial activity in Eastern Hellas (as implied by Fig. B).

We are also constraining our glacial flow simulations of LDAs with systematic surface texture mapping (as detailed in [9]). *Joseph et al.* [10] correlated crater counts to surface textures (Fig. D), finding for example that the Upper Smooth Material is the least degraded LDA texture, while the Lower Knobby texture appears to be the most modified unit, exhibiting a narrower range of superposed craters than other LDA textures. Intriguingly, the "quality" of our initial steady-state glacial flow model fits [7] to actual LDA profiles may be correlated to surface textures: compare the Fig. E simulation of an Upper Smooth Material surface on LDA #3 (RMS = 10.0 m) to the Fig. F simulation of a Lower Knobby surface on LDA #2 (RMS = 75.2 m). We will analyze such deviations from our full model in order to estimate the total ablation experienced by individual LDAs, ***thereby constraining regional LDA resurfacing rates throughout Eastern Hellas.***

References: [1] Holt et al. (2008), *Science* 322, 1235. [2] Plaut et al. (2009), *GRL* 36, L02203. [3] Berman et al. (2015), *PSS* 111, 83. [4] Koutnik et al. (2016), *LPSC* 47, Abs# 1059. [5] Pathare et al. (2005), *Icarus* 174, 396. [6] Hartmann (2005), *Icarus* 174, 294. [7] Pathare et al. (2013), LPSC 44, Abs# 2687. [8] Pierce and Crown (2003), *Icarus* 163, 46. [9] Joseph et al. (2016), *LPSC* 47, this volume. [10] Joseph et al. (2013), *LPSC* 44, Abs# 2774. [11] Bleamaster et al (2005), *LPSC* 36, Abs# 2164.



CAPTION: (A) Shaded-relief perspective of LDAs near Reull Vallis in Eastern Hellas. Vertical exaggeration is 5x. From [11]. **(B)** Diameter-dependent crater retention ages of LDAs in Eastern Hellas. Markers denote midpoints of *D* to *D**sqrt(2)-sized bins; error bars are 90% Poisson confidence intervals. **(C)** HRSC image H0440-000-ND3 of "LDA #3" (denoted by right arrow in Fig. A). Dashed red line indicates MOLA profile segment used in Fig. E. **(D)** Surface texture map of EH "LDA #2" (denoted by left arrow in Fig. A), from [10]. Unit key: red = Upper Smooth Material, salmon = Upper Pitted, maroon = Upper Ridge & Valley, dark brown = Pitted and Ridge & Valley, brown = Pitted, Ridge & Valley, and Knobby, periwinkle = Lower Knobby, light blue = Lower Smooth, light green = Blocky. Dashed red line indicates MOLA profile segment used in Fig. F. **(E)** Steady-state glacial flow simulations (black line) of LDA #2 (shown above in Fig. C) MOLA altimetry (red dashed line) across Upper Smooth Material texture conducted for stress exponent of $n = 4$. Magenta line is initial surface used for mass balance calculations. Vertical black dashes denotes equilibrium line. **(F)** Flow simulation (black line) of LDA #3 (shown above in Fig. D) MOLA altimetry (red dashed line) across a variety of surface textures on southern slope for $n = 4$ rheology: largest deviation from model fit corresponds to middle of highly-eroded Lower Knobby texture.