VOLUMETRIC ESTIMATES OF AMAZONIAN LOBATE DEBRIS APRONS (LDA) IN THE MID-LATITUDES OF MARS: SUPPORT FOR THE PRESENCE OF SIGNIFICANT WATER-ICE. L. R. Ostrach and J. W. Head, Department of Geological Sciences, Brown University, Providence, RI 02912 USA (Lillian_Ostrach@brown.edu).

Introduction: Lobate debris aprons (LDA), believed to have formed by ice-assisted debris flow, are located in the northern and southern mid-latitudes of Mars [1-11]. These landforms exhibit distinctive morphological features such as convex upward longitudinal profiles and various surface textures suggestive of erosional and sublimational processes [1-9]. Analysis of these features has provided unanimous agreement that water-ice has played some role in the mobilization of material to form these deposits, but it is unclear whether ice-filled regolith pores or glacial ice is the primary constituent. At present, determining the type and/or amount of ice entrained in the deposit is the focus of many workers [1-9] (Fig. 1-2).

We address this question through the use of MOLA topography data and high-resolution imagery data. The MOLA data provide an excellent source of LDA measurements by allowing the topography of the deposit to be determined. From the longitudinal profile, we can measure apron parameters of the deposit, such as the length and height, and use these estimates in quantitative analyses of the LDA sample as a whole and compare these results to terrestrial analogs. In addition, the various high-resolution image datasets (e.g. THEMIS, MOC, CTX) can be used to provide a visual analysis of the deposits to identify distinctive surface features suggestive of sublimational processes and other degradational processes. In this study, we used MOLA topography data to observe LDA deposits in the Deuteronilus Mensae region of Mars and characterize these deposits according to measured parameters. We also analyzed high-resolution images of the study area in an attempt to discern whether the results and interpretation from topography analysis and subsequent parametric measurements were consistent with the morphological observations.

Prior Analyses: Previous work has examined apron profiles [4, 7-9], which strongly suggest the presence of significant ice content within the LDA deposits through the comparison of the longitudinal profile to a simple plastic flow model [e.g. 4, 8]. Using the MOLA data, we estimated the absolute height and length of these deposits and used basic physical comparisons to infer relationships. Using a sample set of 74 LDA, we found: 1) the sample does not exhibit a single yield stress, 2) lengths and heights for isolated LDA and deposits emanating from mesa complexes exhibit characteristic ranges, and 3) length to height ratios for isolated, circumferential LDA deposits are of the same magnitude as for combined mesa complex LDA. These findings strongly support the presence of significant ice content entrained within the deposits and suggest that these features likely formed under similar physical conditions. These results prompted us to explore derived parameter measurements, specifically height of the escarpment (Hs) and escarpment slope angle (S), in an attempt to further characterize these deposits and distinguish between different modes of origin.

Data and Methods: In this study, the derived parameters Hs and S were used in conjunction with the absolute height (H) and length (L) to derive estimated volumes for the deposits using cross-sectional areas. Physical relationships between the basic parameters and the derived parameters allowed us to revise our model LDA profile. Two volume estimates were calculated: 1) the estimated real volume of the deposit and 2) the estimated volume of a deposit with debris solely contributed by rock-fall. The estimated real volume, represented by the equation $Vg=(2/3)*H*L-(H^2/2\tan S)$ [4] relies on the relationship between the area of the profile per one scarp unit and ratio between the apron height and escarpment slope angle. The rock-fall volume estimate, represented by $Vr=Hs^2/2\tan S$, assumes a vertical escarpment prior to deposition and a gradual depositional process [4].

A sample of 74 LDA were used, scattered across the Deuteronilus Mensae region in the latitude band 38°-48°N and longitude range 16°-49°E, for which both basic and derived parameters were measured in order to estimate volume (Fig. 1). The MOLA orbit tracks for these aprons had previously been identified and processed for the continuation of the study in [7], and all MOLA orbits used in this study were projected perpendicular to the escarpment face for measurement accuracy.

Results: Real volume estimates and rock-fall estimates were calculated for the LDA identified in an attempt to discover the nature of the material composing the LDA deposits. Using the maximum escarpment slope value calculated to provide maximum estimates, the real volume of the LDA sample has a maximum estimate of ~25km^2 and a minimum estimate of ~0.1km^2, with a range of ~25km^2. The estimated rock-fall volume has a range of ~4km^2, with a maximum estimate of ~4km^2 and a minimum of ~0.3km^2. For this sample, using the maximum escarpment slope angle, in 50% of the cases the real volume exceeds the maximum volume estimated due to rock-fall (Fig. 3). The volume estimates for the LDA population studied show that when a maximum value for slope is used, approximately half the deposits contain debris that could be accounted for in a maximum-rock-fall emplacement scenario. Interestingly, the LDA with the largest real volumes and positive Vg-Vr difference are often associated with mesa complexes and the largest isolated LDA samples while a preliminary comparison of negative Vg-Vr differences correspond to smaller isolated LDA and mesa complex deposits exhibiting significant modification and degradation. The positive Vg-Vr difference within the sample suggests the debris must be emplaced by a process other than simple talus accumulation. One candidate is debris-covered ice.

Geomorphic Applications: Given the intriguing volume estimates of the LDA population, it is worthwhile to analyze images to test for the presence of buried ice. Observations of THEMIS VIS imagery for relatively large-scale surface features indicate textures interpreted to be 1) large sublimation pits, 2) ring-mold craters (RMC) [12], 3) large compressional ridges typical of debris-covered glaciers (Fig. 4). These morphological features support the quantitative and morphometric analyses suggesting significant amounts of subsurface ice, in excess of that typical of ice-assisted creep and more typical of debris-covered glaciers.

Conclusions: 1) Several lines of evidence indicate that LDA are the remains of significantly ice-rich features of varying degradational states. 2) The volume of the LDA deposits cannot be accounted for using a simple rock-fall mechanism and subsequent deposition of pore ice; instead, a mechanism inclusive of primary glacial ice appears required. 3) Morphology analyses suggest that secondary, diffused pore ice cannot explain the large-scale textures (e.g., pits, RMC's, etc.) observed in the central deposit. 5) Further analysis of RMC's suggests that shallow buried ice is wide-spread in LDA's [13].

References: [1] S. Squyres (1978) *Icarus*, 34, 600. [2] S. Squyres (1979) *JGR*, 84, 8087. [3] T. Pierce and D. Crown (2003) *Icarus*, 163, 46. [4] N. Mangold and P. Allemand (2001) *GRL*, 28, 407. [5] A. Colaprete and B. Jakosky (1998) *JGR*, 103, 5897. [6] N. Mangold (2003) *JGR*, 108, 8021. [7] L. Ostrach and J. Head (2007) *LPSC 38*, Abst. #1100. [8] H. Li *et al.* (2005) *Icarus*, 176, 382. [9] H. Li *et al*. (2006), *LPSC 37*, Abst. #2390. [10] J. Head *et al*. (2005) *Nature*, 434, 336. [11] J. Head *et al.* (2006) *GRL*, 33, L08S03. [12] A. Kress *et al.* (2008) *LPSC 39*, Abst. #1273, #1293. [13] L. Ostrach and J. Head (2008) *LPSC 39*, this volume.

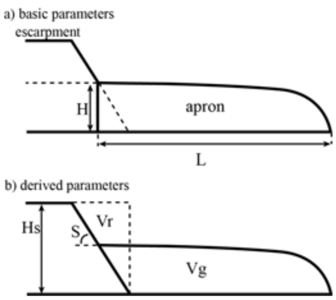

Fig. 1: Typical LDA showing a) the basic parameters: maximum length, L, and height, H, for an apron and b) the derived parameters: escarpment height, Hs, and escarpment slope, S. The basic and derived parameters can be used to derive the real volume of the apron, Vg, and a maximum estimate of material due to rock-fall, Vr (Fig. 2).

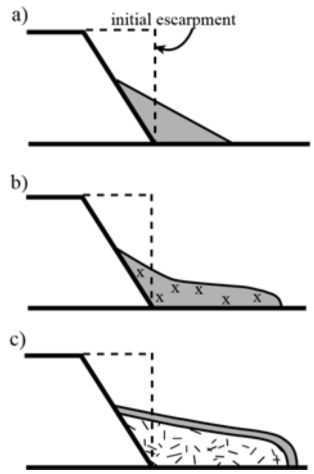

Fig 2: Deposits that would result from various origins for an LDA. a) In a rock-fall scenario, debris falls from the initial escarpment and forms a talus/debris pile at the angle of repose. b) When interstitial ice is present due to atmospheric diffusion, ice-assisted creep dominates and forms a concave-up, lobate deposit that is analogous to terrestrial rock glaciers. c) A large amount of primary ice entrained in the deposit accumulates a debris-cover that insulates the ice core; distinct sublimation features (pits, knobs, ridges) will be observed on the deposit surface.

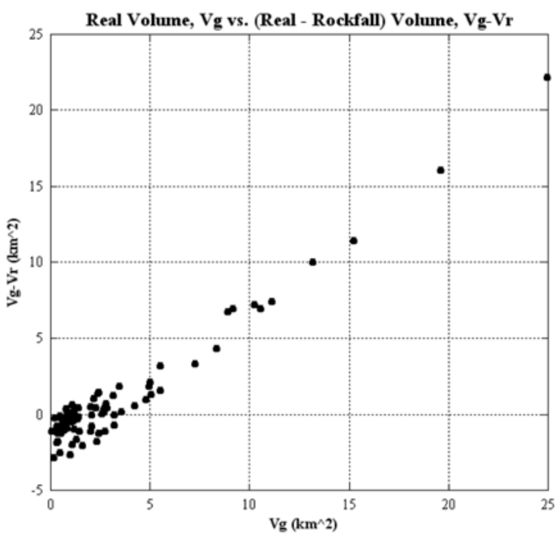

Fig 3: (above) Real volume compared to the difference between the real volume and rock-fall volume estimate. ~50% of the deposits have a real volume exceeding rock-fall estimates, indicating that a rock-fall origin is not feasible.

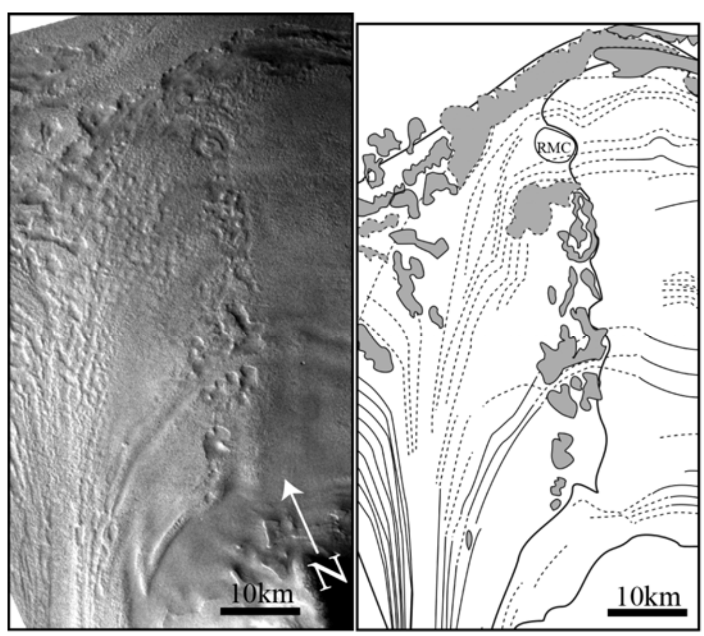

Fig 4: (right) Portion of THEMIS V18558008. Various sublimation textures are present on the surface of this LDA. Lineation/ridges indicative of compressional flow, knobby textures within the lineations; and abundant sublimation pits (in gray) are most notable. A ring-mold crater (RMC) is present which may indicate impact into an ice-rich surface [12].