ORIGIN OF MARTIAN NORTHERN HEMISPHERE MID-LATITUDE LOBATE DEBRIS APRONS.

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Introduction: To understand the formation and evolution of Martian debris aprons, thirty three MOLA topographic profiles across debris aprons from various locations in the northern hemisphere (Tantalus Mensae, Protonilus Mensae, Deuteronilus Mensae, and Acheron Fossae) and one profile across Valles Marineris landslide were collected. These data are compared with profiles calculated from simple plastic and viscous power law models. Our analysis supports previous interpretations that debris aprons are formed due to deformation of ice rich mixtures and therefore indicate Martian permafrost/glacial conditions during their formation. Deviations from a plastic equilibrium state as exhibited in longitudinal profiles of some debris aprons indicate that these ice-lubricated flows have experienced post-emplacement modifications in general, possibly primarily due to loss of internal ice through sublimation and secondarily due to basal sliding as ice melt at the bottom of deposits due to temperature increases from loading.

Background: Martian lobate debris aprons are masses with distinctive lobate and convex upward profiles which have developed at the foot of kilometer high scarps [1]. These features are concentrated in two latitudinal bands 25° wide centered on 40°N and 45°S, specifically the fretted terrain and fractured highlands of the northern hemisphere and areas surrounding the Argyre and Hellas Basins in the southern hemisphere [2,3,4]. Various workers have proposed that lobate debris aprons are flows of ice-rock mixtures [e.g. 4-6], implying large reservoirs of subsurface ice at that time of formation. Gamma Ray Spectrometer on-board the 2001 Mars Odyssey spacecraft measured the distribution of hydrogen in the near surface, thus provided evidence for ground ice in the top meter of the Martian regolith [7]. From the GRS data it is apparent that lobate debris aprons are found in areas with mid- to high near surface hydrogen concentrations, which are locations favorable for ground ice to exist. Analysis of five MOLA profiles of debris aprons in Protonilus and Deuteronilus Mensae based on ice rheological models provide further evidence that such features are due to deformation of solid ice [6]. We compared the topography of two prominent lobate debris aprons in the eastern Acheron Fossae region (36° latitude) with rheological models to understand their formation and implications for stability of ground ice in this region.

Rheological models: As suggested by [6], two rheological models, assuming simple plastic and viscous power law behavior are applicable to the study of the shape of ice-rock mixtures. In both models, the basal shear strength τ_b can be expressed as [8]: $\tau_b = -\rho g h \, dh/dx$, where h is the thickness of the ice sheet, ρ is the density of ice or ice-rich regolith and g is the gravitational acceleration (3.7 m/s^2 on Mars). The profile of the ice sheet is represented by [8]:

$$(h/H)^2+(x/L)=1$$

in the case of plastic equilibrium, or

$$(h/H)^{2+2/n}+(x/L)^{1+1/n}=1$$

in general, where H and L are the maximum thickness and maximum radial length of the ice sheet, respectively. The n is a constant mainly depends on applied stress and ice purity. It has been suggested that for pure ice, n equals 3 when stresses exceed 100 kPa [1, 8, 9]. To reach this level of stress at the base of Martian ice sheets requires a thickness at least 30 meters. All the flows in this study have thicknesses exceeding 30 meters, therefore a value of 3 is assigned to the parameter n. How ice purity affects the creep of ice is not fully understood and more studies are needed [8]. Laboratory experiments show that when ice content exceeding 90%, the value of n does not vary much from that of pure ice [10, 11]. However, at higher concentrations of solid inclusions, the creep rate of ice decreases exponentially with debris concentration (d) [12], and n should be modifie:

$$n=3-d \qquad 0.1<d<0.6.$$

When d exceeds 0.6 and solid particles in the ice touch each other, the stiffness of the ice increase greatly [13] and an ice creep model is no longer appropriate. In fact, the effect of n on the shape of the profile is very small, thereby assuming n to be constant with a value of 3 suffices this study.

Results and discussions: Based on their longitudinal shape, debris aprons in this investigation can be classified into four main categories: category I, those which fall below both the simple plastic and power law models and are convex down in profile; category II, those which fall below both rheological models but have convex-up profiles; category III, those which have profiles matching closely with the simple plastic model; and category IV, those whose profiles fluctuate around the simple plastic model (Table 1 and Figure 1).

Eighty percent of all the debris aprons studied have convex upward profiles, which is expected for debris aprons. As a comparison, dry landslides on Mars have typical convex downward shape. The remaing twenty percent of debris aprons have convex downward profiles (type I), which are more similar to landslides. [14] studied the geometry of landslides in the Valles Marineris and found that it is best matched by pressurized fluidization model, which includes the contributions from pore pressure. Forty percent of the aprons have convex upward shape following the simple plastic mode (type III), indicating they formed as ice-rock mixtures or debris-covered ice. The remaining debris aprons have profiles falling below both simple plastic and viscous power law models (type II, and IV), indicating that although these features are due to deformation of ice, they are neither active ice sheets nor ice-rock mixtures in a plastic equilibrium state. Several processes could have modified their shapes: if basal sliding happened at the bottom of these ice rich rock deposits, the displacement could have caused the aprons to develop a less concave upward longitudinal profile; secondly, the loss of internal ice in the debris deposits could also contribute to the deflated appearance. The composite profile of all thirty three debris aprons is close to but slightly below the simple plastic model (Figure 2), indicating that sub-emplacement modification is a common process to these debris aprons.

Type	*Profile description*	*#*
I	lower than both rheological models convex downward shape	18%
II	lower than both rheological models convex upward shape	43%
III	close to simple plastic model	36%
IV	changes from convex upward to convex downward from upper to lower slope	3%

Table 1: Classification of lobate shaped aprons.

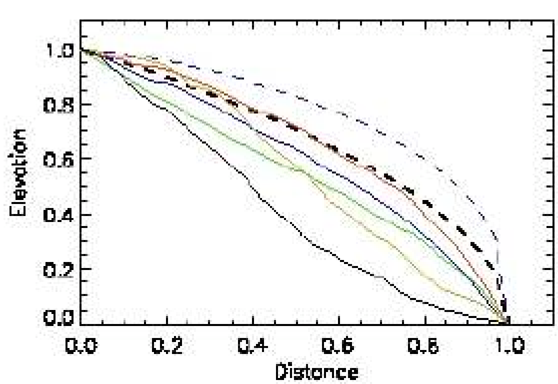

Fig. 1: Composite profiles of four categories of lobate debris aprons and Valles Marineris landslide, normalized to unit length and thickness. Green=type I, blue=type II, red=type III, brown=type IV, black=Valles Marineris. Blue and black dashed lines represent simple plastic and power law model, respectively.

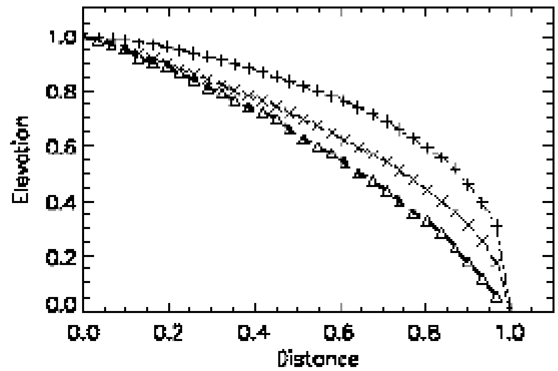

Fig. 2: Composite profile of lobate debris aprons, normalized to unit length and thickness. Triangle represents median elevation from thirty three profiles of lobate debris aprons in Acheron Fossae, Tantalus Fossae, and Deuteronilus and Protonilus Fossae. X=simple plastic model; +=power law model.

Conclusions: This study, based on topographic data, supports the formation of Martian lobate debris aprons by deformation of ice. Most of these features in the northern hemisphere are not in a plastic equilibrium state, therefore must have undergone varied degrees of modification since their emplacement, possibly due to loss of internal ice through sublimation. The existence of lobate debris aprons in the eastern Acheron Fossae region suggests that Martian climate was conducive to the formation of ice lubricated deposits in the northern Tharisis region as recent as the late Amazonian period.

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