

## NEW EVIDENCE FOR REGIONAL GLACIAL MODIFICATION OF PLAINS UNITS IN DEUTERONILUS MENSÆ, MARS.

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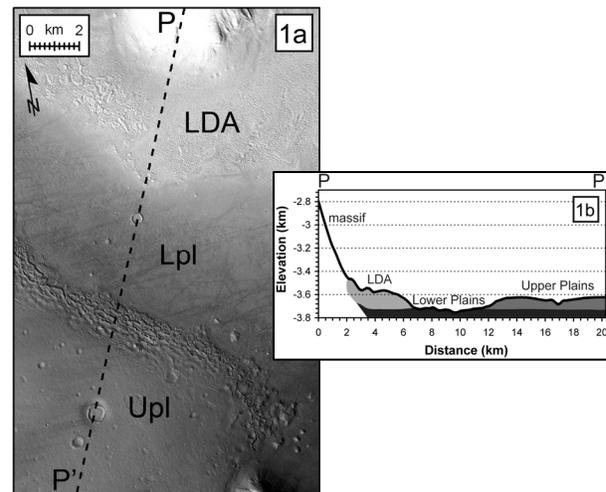
**Introduction:** Lobate debris aprons (LDA) (Fig. 1) are Late Amazonian in age, and are found to completely surround escarpment walls such as isolated plateaus and massifs in both the northern and southern mid-latitudes (~30° to 50°) on Mars [1]. While it is clear that flow of ice and debris formed these features [1-9], a growing body of morphological and geophysical evidence suggest that LDA are linked with lineated valley fill (LVF) and were largely formed as debris-covered glaciers in the Middle to Late Amazonian [e.g., 5-9]. More recent evidence has suggested that this glaciation may have been more extensive in the past [10-11]. Plausible snow and ice accumulation rates are predicted by atmospheric general circulation models for Mars [12], and these rates have been used to develop glacial flow models that suggest that LDA are the preserved remnants of the retreat and downwasting of a much more regional glacial landsystem [11].

In order to assess the likelihood of former glacial maxima, we investigated the morphology and topography of plains units distal to LDA in Deuteronilus Mensae (39.6°N to 50.2°N and 13.6°E to 35.4°E) [see also, 13] using image data from the Mars Reconnaissance Orbiter (MRO) Context (CTX) camera at ~6 m/pixel resolution and topographic data from High Resolution Stereo Camera (HRSC) digital terrain models (DTMs). Here, we focus on the characteristics and models of formation of an Upper plains unit (Upl) (Fig. 1a) and its age and stratigraphic relationship with LDA and other plains units.

**Upper plains unit characteristics:** An Upper plains unit (Upl) covers much of the intermediate areas between plateaus and surrounding LDA north of ~43°N in Deuteronilus Mensae (Fig. 1a). The unit is relatively smooth at Viking and CTX resolution but is pockmarked with numerous muted impact craters and depressions formed by surficial collapse. Irregular fractures <20 m in width and isolated elongate pits with raised rims are also observed in Upl. Some fractures widen and form concentric and radial patterns, appearing to be controlled by underlying structures such as impact craters and knobs of older terrain (Fig. 1a). Topographic measurements of Upl also indicate a unit thickness of around 100 m (Fig. 1b), and initial observations of potential subsurface reflections in radar data from the MRO Shallow Radar (SHARAD) (e.g., observation ID# 1190203) are consistent with this thickness estimate.

**Stratigraphic relationships:** Upl and LDA are superposed on an older Lower plains unit (Lpl), which exhibits a variety of textures and albedos with erosional remnants of older terrain. The contact between LDA and Lpl is generally sharp (Fig. 1a-b), with the steep convex-upward topography of the LDA termini abruptly transitioning to the flatter Lpl at lower elevations (Fig. 1b). The contact between Upl and Lpl is similarly sharp; the margins of Upl also have convex-upward profiles transitioning to a flatter Lpl (Fig. 1b).

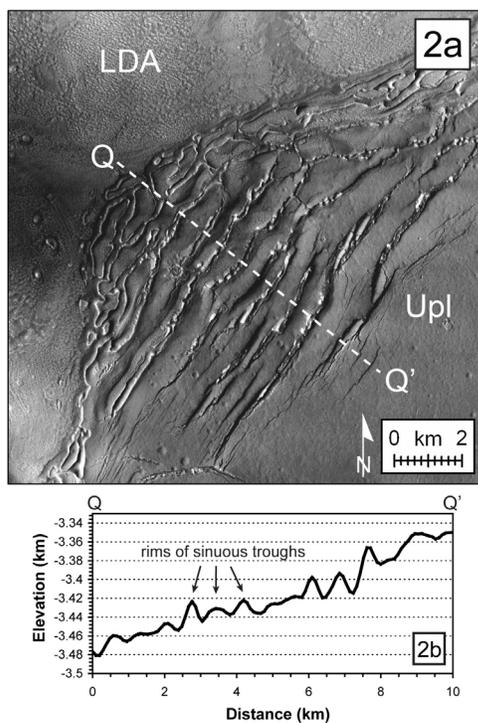
The stratigraphic relationship between Upl and LDA is more complex. Where Upl is within proximity of LDA, surface fractures and elongated pits within Upl widen and link to form large, irregularly patterned sinuous troughs that are <500 m in width and extend for tens of kilometers (Fig. 2a). The sinuous troughs are restricted to the margins of Upl and areas in contact



**Fig. 1.** Morphology (a) and topography (b) of lobate debris aprons (LDA), the Lower plains unit (Lpl), and the Upper plains unit (Upl). Both LDA and Upl are superposed on Lpl and have convex-upward margins and sharp contacts with the flatter, low-lying Lpl. The thickness of Upl is estimated to be 100 m (b). Profile in (b) corresponds to the line of transect (P to P') in (a). CTX image P04\_002481\_2241 and HRSC DTM 1461 (elevation data relative to MOLA datum).

with or in proximity to LDA. The sinuous troughs have raised rims and separate intermediate, low-topography patches of Upl. Toward the LDA terminus, the sinuous troughs further widen and lose their raised rims. Widening of the troughs suggests removal of material from Upl, possibly fines or volatile-rich material. This progression produces isolated patches or platforms of Upl that can appear raised above the surrounding LDA surface [13]; the platforms are also found to seamlessly grade texturally and topographically with the dominant LDA surface textures (Fig. 2a).

**Crater size-frequency distributions:** Previous maps of Deuteronilus Mensae have used crater counts from Viking orbiter images to suggest an age of Mid Hesperian to Early Amazonian for units corresponding to Upl [e.g., 14]. In contrast to these ages, our revised crater size-frequency distributions on Upl using CTX images and all craters >100 m in diameter yield a best-fit age of ~520 Ma (Middle Amazonian, Hartmann [15] isochron) (Fig 3a). The difference in ages is due to our improved ability to recognize and exclude buried impact craters and collapse structures in our crater analyses using higher resolution images. Including buried craters in the crater size-frequency distribution yields a best-fit age of ~1.8 Ga (Early Amazonian, Hartmann [15] isochron), which is more consistent with the ages reported in previous maps. For comparison, a best-fit age of ~470 Ma was determined for nearby LDA (Fig. 3b), although with a less well-defined isochron that reflects removal of small crater sizes and effects of impacts into ice-rich substrates [16]. The similarities in ages between Upl and LDA suggest that these two units were formed nearly



**Fig. 2.** The contact between lobate debris aprons (LDA) and the Upper plains unit (Upl). (a) Brittle fractures in Upl widen to form parallel troughs with raised rims toward the LDA terminus. Further widening of the troughs produces isolated patches of Upl (CTX image P17\_007729\_2250). (b) Topographic profile (Q to Q' in a) of troughs and fractures in Upl. The ridge and furrow topography progresses upslope and exhibits asymmetric profiles that may be related to glacitectonic deformation. HRSC DTM 1201 (elevation data relative to MOLA datum).

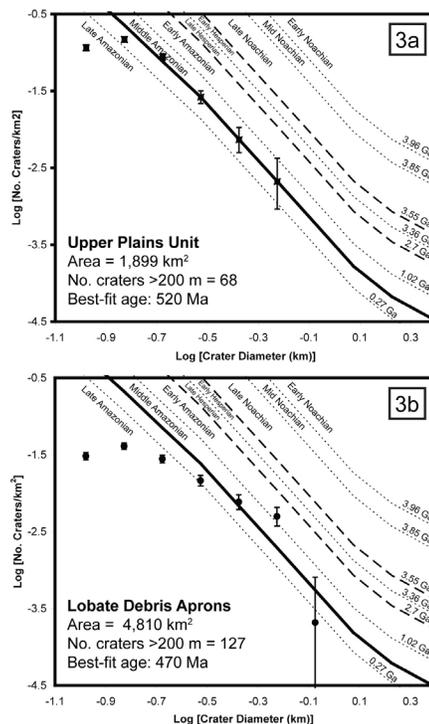
contemporaneously, and may help to explain their complex stratigraphic relationships.

**Models of formation:** The similarity in crater retention ages between LDA and Upl (Fig. 3) and the complex, often gradual transition from Upl to LDA point toward a link in the processes that formed or modified these two units. While traditional wet-based glacial depositional and erosional landsystems [17] are not overt in the plains surrounding LDA [13], it is possible that Upl may be related to deposition of glacially modified sediments with contributions from deformation by glacitectonic stresses under cold-based conditions [18]. Many unique landforms are known to be produced from processes resulting from the retreat and deposition of glacial sediments over down-wasting, buried glacial ice. Such landforms include controlled and hummocky moraines, with the details of moraine topography being largely related to the spatial pattern, distribution, and concentration of englacial and supraglacial debris concentrations over stagnant glacial ice at the glacier's terminus [18]. In addition, the mapped restriction of sinuous troughs in Upl to areas with steep surface gradients proximal to LDA (Fig. 2a) suggests that differential ice flow may also be important. The asymmetrical profiles of the rims of some parallel troughs, the brittle fracture patterns, and the ridge-and-furrow topography along Upl margins (Fig. 2a-b) are consistent with both compressive and extensional flow, with compressive

flow likely dominating early on, followed later by extension as sublimation-driven processes modify ice-surface slopes.

Further morphologic and topographic analyses of the Upper plains unit and its relationship with LDA will help to elucidate potential models for their formation. Additional analyses using SHARAD will help to better resolve the thickness and material properties of surficial units in Deuteronilus Mensae.

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**Fig. 3.** Crater size-frequency distributions for craters >100 m on the Upper plains unit (a) and proximal lobate debris aprons (b) (Hartmann [15] isochrons, dashed lines). (a) The Upper plains unit has a well-defined isochron and a best-fit age of ~520 Ma (solid line). (b) Lobate debris aprons have a less well-defined isochron with a best-fit age of ~470 Ma (solid line). Best-fit ages were determined using craters >200 m in diameter.