

MODIFICATION OF THE WALLS OF A NOACHIAN CRATER IN NORTHERN ARABIA TERRA (24°E, 39°N) DURING NORTHERN MID-LATITUDE AMAZONIAN GLACIAL EPOCHS ON MARS: NATURE AND EVOLUTION OF LOBATE DEBRIS APRONS AND THEIR RELATIONSHIPS TO LINEATED VALLEY FILL AND GLACIAL SYSTEMS. J. W. Head¹ and D. R. Marchant², ¹Dept. Geol. Sci., Brown Univ., Providence, RI 02912 (james_head@brown.edu), ²Dept. Earth Sci., Boston Univ., Boston, MA 02215.

Introduction: Fretted terrain and fretted channels are very well developed in the northern part of Arabia Terra [1] and are the site of development of lineated valley fill (LVF) and lobate debris aprons (LDA) [2-3]. The detailed geological history and chronology of this region provide [4] a framework for the interpretation of modification processes operating on and near the dichotomy boundary. This study [4] underlines the conclusion that fretted channels and valleys formed early in Mars history (prior to middle Hesperian) and that the associated LVF and LDAs represent Amazonian-aged modification of the fretted topography. The LDA and LVF are characterized by very low slopes and thus have historically been interpreted to be related to viscous gravity flow of debris lubricated by groundwater or ice, with ice thought to have been supplied by vapor diffusion and condensation in slope talus. Uncertain has been 1) the direction of flow in LDA and LVF, either normal to the valley [2], or possibly parallel (down-valley) [5]; 2) detailed structure and texture of the LDA; 3) the relationships between the LDA and the LVF; 4) the relationship of LDA and LVF to adjacent walls; 5) the origin of the lubricating agent; 6) the mode of origin of the LDA and LVF (e.g., ice-assisted rock creep, ice-rich landslides, rock glaciers, debris-covered glaciers) [2-6]; and 7) the implications for the geological history of Mars. Recently, regional analyses of LVF [7-8] have shown evidence for local sources of LVF in alcoves in valley walls, down-valley flow, merging of flowlines into broad trunk valleys, extensive along-valley flow, and termination in lobate deposits, all features that are similar to valley glacial landsystems on Earth. In this analysis we mapped a ~50,000 km² area just north of an area of LVF interpreted to be a valley glacial landsystem (Fig. 1) and addressed the questions listed above. We found it useful to subdivide LDAs into *linear* (occurring along valley walls and crater interiors) and *circumferential* (aprons generally surrounding isolated massifs).

1) Direction of flow in LVF: In the mapped region, flow directions are away from the massif walls in circumferential LDA (Fig. 2) and away from valley and crater walls in linear LDA (Fig. 3); however, when massif/wall LDA/LVF meets in central valley floors (Fig. 4) or between massifs (Fig. 5) it merges and commonly follows the local topographic gradient to create along-valley flow, forming complex folds and other deformation patterns (Fig. 4). In some places, flow divides can be established, where flow patterns diverge from a local high and extend down-valley in opposite directions (Fig. 5, middle; Fig. 4, lower right).

2) Detailed structure of LDA: New high-resolution THEMIS, MOC and HRSC data show much more detail than Viking (Fig. 2) and reveal that aprons are composed of multiple individual lobes derived from local indentations (alcoves) in the massif (Fig. 2) and valley walls (Fig 3); pitting suggests loss of ice by sublimation and marginal ridges are reminiscent of moraines. Localized convex-outward ridges in the proximal parts of the aprons (Figs. 2-3) are similar to ridges on debris-covered glaciers.

3) Relationships between LDA and LVF: Where massifs face outward to plains (Fig. 2), debris aprons spread out as lobes from alcoves and deform in relation to their neighbors; where they meet obstacles, they compress and flow around the obstacles (Fig. 3), in some cases where the obstacle is parallel to the crater wall, they converge and flow through a low point in the obstacle to create a piedmont-like lobe (Fig. 6) and local LVF. Where massifs are close together, LDAs converge in the middle of the valley, turn and flow laterally, often forming divides (Fig. 5). In some cases (Fig. 4), LVF flows from two different valleys, converges, incorporating a LDA from the southern valley wall, and forms a huge broad fold more than 25 km in length that becomes part of the linear LDA in the southern part of the valley wall (Fig. 1). Thus, at least in these numerous cases, LDA becomes LVF and vice versa.

4) Relationship of LDA/LVF to adjacent walls and origin of the lubricating agent: Numerous local alcoves appear to be the source of the concentric outward ridges that are the hallmarks of the LDA deposits (Figs. 2,3,5,6); these are very similar to the debris-covered glacier source alcoves seen in the two regions interpreted to represent integrated valley glacial landsystems [7-8]. Detailed topography often shows evidence for depressions at the head of the ridges and the base of the massifs, suggesting that ice and snow once accumulated there to form debris-covered glaciers.

5) Mode of origin of the LDA and LVF: These relationships suggest that the LDA and LVF are intimately related in morphology and modes of origin. Formation of LDAs by accumulation of snow and ice in alcoves along the flanks of massifs and valley walls, led to the formation and outward flow of glacial ice; debris falling from the talus slopes above became concentrated and deformed to create the lineated glacial debris cover. As LDAs grew and coalesced, they merged between massifs (Figs. 5,6) and in valley centers, and began to flow down-gradient, forming LVF, creating local piedmont type glaciers (Fig. 6) or larger valley glaciers with divides (Fig. 5), and very large glacial landsystems (Fig. 1, 4) [7,8].

6) Implications for the geological history of Mars: This interpretation implies that significant snow and ice accumulated for a sufficient period of time in the Amazonian [4] to produce the LDAs and lead to their coalescence to produce extensive LVF valley glacial landsystems. A plausible explanation for these relationships is that water ice was mobilized from polar reservoirs during periods of obliquity higher than present [9-12] and was deposited preferentially in the 30-50° N latitude band, an interpretation supported by the widespread nature of similar deposits at these latitudes [13].

References: [1] R. Sharp, *JGR*, 78, 4073, 1973; [2] S. Squyres, *Icarus*, 34, 600, 1978; [3] S. Squyres, *JGR*, 84, 8087, 1979; [4] G. McGill, *JGR*, 105, 6945, 2000; [5] B. Lucchitta, *JGR*, 89, B409, 1984; [6] T. Pierce and D. Crown, *Icarus*, 163, 46, 2003; [7] J. Head et al., *EPSL*, in press, 2005; [8] J. Head et al., *GRL*, in press, 2005; [9] J. Laskar et al., *Icarus*, 170, 343, 2004; [10] F. Forget et al., *JGR*, 104, 24155, 1999; [11] M. Mishna et al., *JGR*, doi:10.1029/2003JE002051, 2003; [12] R. Haberle et al., *Icarus*, 161, 66, 2003; [13] J. Head and D. Marchant, *LPSC* 37, 2006.

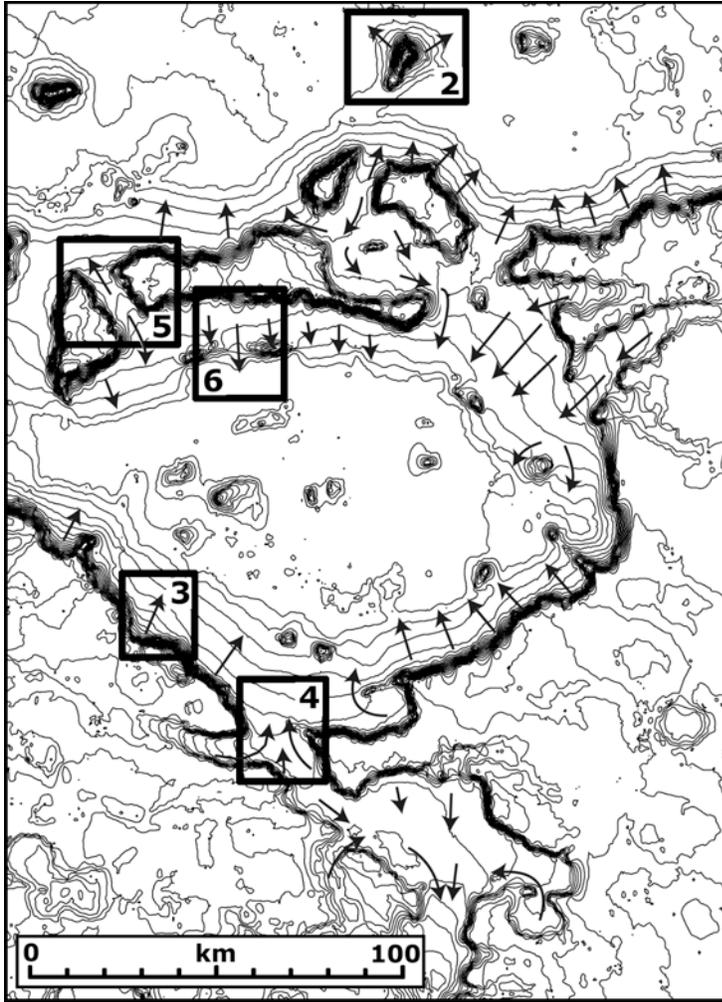


Fig. 1. Topographic contour map of study region: 100 m contour interval. Arrows show mapped directions of flow.

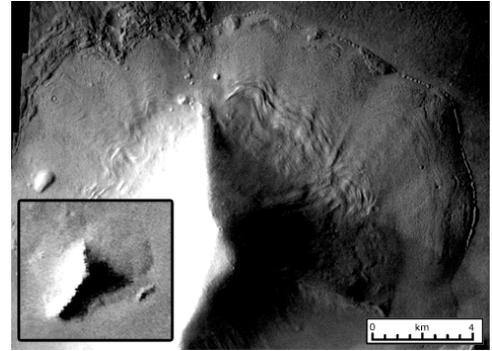


Fig. 2. Massif with circumferential LDA. Themis V13879005 with Viking inset for comparison.

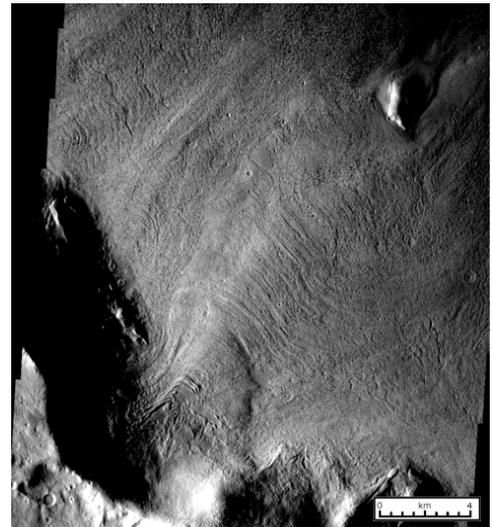


Fig. 3. Linear LDA along crater wall. Note alcoves, lobes, obstacle divergence. Themis V10834007.

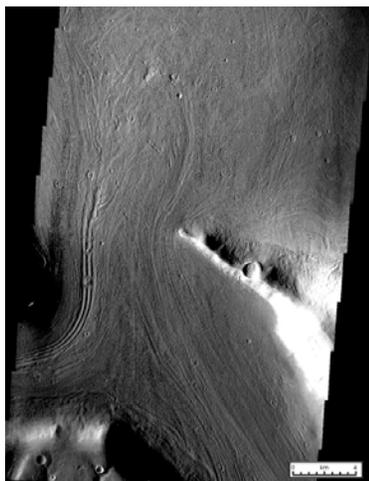


Fig. 4. Large fold where LVF converges and becomes LDA. Themis V11433004.

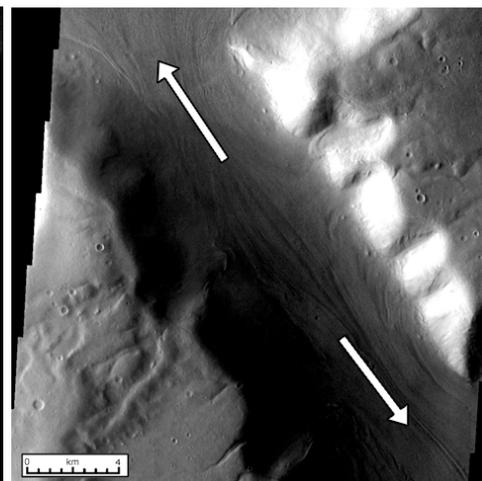


Fig. 5. Massif LDAs meet and flow laterally from a divide, forming LVF. Themis V14216012.

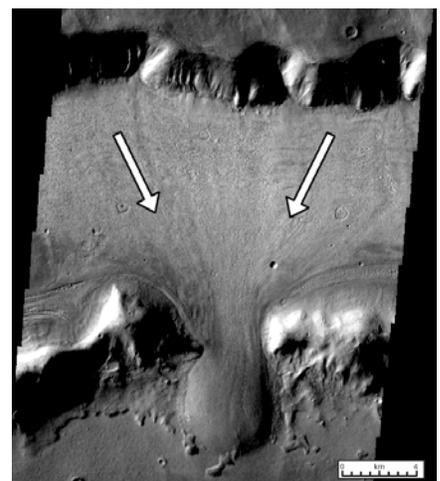


Fig. 6. Linear LDA blocked by parallel ridges, merges to form LVF and piedmont lobe in gap. Themis V12057009.