3.1.1. Direction of flow in LVF

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

3.1.2. Detailed structure of LDA

New high-resolution THEMIS, MOC and HRSC data show much more detail than Viking (Fig. 3B) and reveal that aprons are composed of multiple individual lobes derived from local indentations (alcoves) in the massif (Fig. 3B) and valley walls (Fig. 3C); 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 (Fig. 3B, C) are similar to ridges on debris-covered glaciers (Levy et al., 2006; Marchant et al., 2007).

3.1.3. Relationships between LDA and LVF

Where massifs face outward to plains (Fig. 3B), 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. 3C), and 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. 3F) and local LVF. Where massifs are close together, LDA converge in the middle of the valley, turn and flow laterally, often forming divides (Fig. 3E). In some cases (Fig. 3D), 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. 3A). Thus, at least in these numerous cases, LDA becomes LVF and vice versa.

3.1.4. 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 (Fig. 3A–C, E–F); these are very similar to the debris-covered glacier source alcoves seen in the two regions interpreted to represent integrated valley glacial landsystems (Head et al., 2006a,b). Detailed HRSC 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, but since has sublimated.

3.2. Mamers Valles (Fig. 2, location 4; Fig. 4)

Analysis of MOLA data in this area (Carr, 2001) revealed slope reversals in Mamers Valles, a Hesperian fretted valley, suggesting that down-valley flow of lineated terrain was minor. LDA were interpreted by Carr (2001) as debris flows lubricated by ground ice in material undergoing wall-slope-related mass wasting. In this area we analyzed LDA, LVF, and their relationships along >900 km^2 of the length of Mamers Valles from the crater Cerulli north to the area just south of Deuteronilus Colles (Fig. 1, location 4), and also assessed its distribution in along-valley and intersecting craters (Fig. 4).

Mamers Valles can be subdivided into its lower reaches, where it averages <10 km in width, and its upper reaches where it is 20–30 km in width (Fig. 4A). The upper reaches are characterized by linear LDA; high-resolution images show that LDA are composed of dozens of parallel lobes that originate in alcoves in valley walls and extend onto the valley floor, creating a marginal ridge, and abutting similar parallel lobes emerging from the opposite wall (Fig. 4B). LDA can also emerge from theater-like remnant crater rims (Fig. 4B) and from tributary valleys intersecting the main valley wall (Fig. 4C); the tributaries are commonly characterized by LVF that merges with the LDA, producing a larger than average lobe and/or unusual pitted surface texture (Fig. 4C). Asymmetry in LDA development is commonly observed, with south-facing LDA more extensive. In narrower areas of the valley floor, lobes from opposite sides meet and their distal ridges form parallel linear ridges (Fig. 4B); in wider areas, LDA do not meet (Fig. 4C), and unusual surface textures and features suggestive of ice-related periglacial processes are observed (Fig. 4C, D), including lobe-shaped depressions trending in the same direction as the LDA lobes (arrows in Fig. 4D). Where some LDA meet in the central part of the valley, they are distorted along-valley (Fig. 4E) in a common flow direction, become complexly folded (north part of Fig. 4E) and begin to merge into LVF. In some cases (Fig. 4F) LDA derived from wall alcoves rapidly deform, lose their individual identity and merge into LVF. In the much narrower southern part of Mamers Valles (Fig. 4A), LVF forms in the narrow tributaries from coalescing alcove-fed flow and emerges into the main channel (Fig. 4G), where it joins other tributary-fed LVF and linear channel-wall LDA, compressing and deforming to produce ever-narrower folds until it becomes LVF. The unusual nature of superposed impact craters (Fig. 4B, D) suggests that the substrate contained significant ice (e.g., Kress and Head, 2008) and that deformation has been minimal since its emplacement (Carr, 2001). Along-valley slope reversals (Carr, 2001) are caused by local divides, where flow is away from broad accumulations in different directions (Fig. 4A). Where narrow, along-valley integrated LVF flow opens into a significantly larger part of the valley (such as a large depression; Fig. 4A) the distinctive along-valley flow terminates in a broad piedmont-like lobe (Fig. 4H), further contributing to the along-valley variations in topography described by Carr (2001).

3.2.1. Direction of flow in LDA

LDA flow direction is normal to valley walls where valleys are wide and LDA from opposite walls are separated (Fig. 4C) or simply abut (Fig. 4B).

3.2.2. Relationships between the LDA and LVF

Where LDA meet and begin to merge, LDA flow direction is distorted down-gradient (Fig. 4E); continued merging causes LDA to compress (Fig. 4E, G), lose their individual identity (Fig. 4F), and merge into and become true LVF (Fig. 4F–H).

3.2.3. Direction of flow in LVF

As noted by Carr (2001), topographic gradients are variable along-valley; these topographic slope reversals commonly reflect observed variations in LDA/LVF flow directions derived from detailed analysis of folds and deformed surface textures (Fig. 4A). Along-valley slope reversals tend to occur at flow divides, and distinctive slope changes occur where LVF empties into wider depressions (Fig. 4H).

3.3. Ismeniae Fossae region (Fig. 1, location 6; Fig. 5)

In this area we analyzed LDA surrounding several isolated mesas adjacent to the dichotomy boundary in the area (41° E, 45° N) north of Ismeniae Fossae, the northernmost part of the dichotomy boundary. The region is characterized by two major mesas and a series of smaller satellite mesas and hills with surrounding LDA. The current mesa topography is characterized by a series of bite-like 5–10 km wide alcoves along their margins (Fig. 5A). In contrast to the broadly lobate nature of LDA seen in Viking images, linear lobate debris aprons along the dichotomy boundary scarp (Fig. 5A) are composed of numerous parallel ridged lobes (Fig. 5B) emerging from alcoves in the scarp wall (Fig. 5G) and flowing downslope, compressing and deforming to form the broad apron seen at Viking resolution. Distal, medial, and looping concentric ridges are common, as are pits and depressions (Fig. 5B). Where downslope obstacles are encountered (Fig. 5G) flowlines are