2006, 2008). Some of the extant debris-covered glaciers in the ADV may have formed during this time, as long ago as 8.1 Ma (Marchant et al., 2002). These provide important insight into the interpretation of glacial deposits in the northern mid-latitudes of Mars and may lead to a better understanding of the behavior of ice sheets with time and how they behave in the distinctive mid-latitude topography of the dichotomy boundary.

Under what conditions might these features have formed on Mars? Recent GCM analyses show that the major accumulations of water ice in the equatorial regions (to form the Late Amazonian tropical mountain glacier deposits) most likely involved precipitation and deposition during periods of high obliquity. We examined the fate of tropical mountain glaciers formed at ~45° obliquity (Forget et al., 2006, 2007) following a return to lower obliquity (~35°) (Madeleine et al., 2007, 2009) and found that a meteorological consequence of this large equatorial reservoir was the formation of a thick cloud belt in the northern mid-latitudes of Mars. The thermodynamic state of the atmosphere results in increased meridional circulation, a strong eastward jet during northern winter, and associated stationary planetary waves. If the atmosphere is relatively dusty, a condition expected in this configuration, then this new water cycle favors condensation and precipitation and preservation of water ice in the areas described above to depths approaching 1000 m during a ~50 ky high obliquity cycle (Fig. 8). Guidelines from the GCMs can be used to model the snow and ice accumulation and flow behavior in this latitude region and assess the characteristics and evolution of accumulating ice in terms of flow patterns (Fastook et al., 2008a,b) in a manner similar to analysis of tropical mountain glaciers (Fastook et al., 2008b). Accumulation in alcoves produces local downslope flow, in time leading to convergence and coherent down-valley flow, and the formation of a well-developed valley glacier system extending to the mouths of the major valleys. The glaciers eventually extend out of the valleys and into the adjacent northern lowlands, in a configuration comparable to observations of the deposits (e.g., Fastook et al., 2008a,b). Expansion of the model clearly shows reproduction of local flow patterns (Fastook et al., 2008a,b) observed in images (Figs. 3–7). These analyses provide strong support for the interpretations and help to assess the time scales and velocities involved in the valley glaciation processes. The broad distribution of snow and ice accumulation mapped out by the GCM simulations (Madeleine et al., 2009) (Fig. 8A) raise the question of whether the LDA and LVF developed solely as alpine-type valley glacial landsystems (e.g., Benn et al., 2003), or whether they might represent the distal valley glacial components of higher altitude local or regional plateau glacial landsystems (e.g., Rea and Evans, 2003). Preliminary analysis of the relationships of the plateau margins and the valleys (Fig. 8D) suggests that plateau icefields existed in at least some cases, and perhaps regionally (Fig. 8).

In conclusion: 1) An array of terrestrial analogs for glacial processes that are applicable to the range of conditions on Mars has been developed (Marchant and Head, 2003, 2004a,b, 2006, 2007; Head and Marchant, 2003); 2) This has been used to test for the presence of deposits and sites of former valley glaciation and debris-covered glaciers (cold-based ice) in two specific areas of Mars (Head et al., 2006a,b); 3) From these analyses, general criteria for the recognition of debris-covered glacial deposits have been outlined as described above (Fig. 2); 4) Application of these criteria to the northern mid-latitudes (Fig. 1) reveals the presence of widespread cold-based glaciation in valleys and mountains and along scarps, in the 30°–50° N latitude band (Fig. 1); 5) The global-scale latitudinal distribution of these deposits (Fig. 1) suggests an extensive period in the Amazonian when ice was stable in this latitude band; 6) A plausible explanation for this configuration is the formation of an extended period of spin-axis obliquity at ~35°, following the formation of tropical mountain glaciers at ~45° (Forget et al., 2006, 2007). Under these conditions, the northern mid-latitude band becomes the locus of deposition of ice mobilized from equatorial latitudes with sufficient accumulation to produce glaciers (Madeleine et al., 2007, 2009); and 7) Glacial flow models predict the general configuration and morphology of the observed deposits interpreted to be integrated glacial valley landsystems (Fastook et al., 2008b). Recent SHARAD data have shown evidence for significant quantities of buried ice in mid-latitude LDA and LVF deposits (Holt et al., 2008; Plaut et al., 2009), adding confidence to this interpretation.

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