DICHOTOMY BOUNDARY GLACIATION MODELS: IMPLICATIONS FOR TIMING AND GLACIAL PROCESSES. J. L. Fastook[1], J. W. Head[2] and D. R. Marchant[3]. [1]Climate Change Inst., Univ. Maine, Orono, ME 04469 (fastook@maine.edu), [2]Dept. Geol. Sci., Brown Univ. Providence, RI 02912. [3]Dept. Earth Sci., Boston Univ., Boston MA 02215.

Introduction: A 30,000 km^2 valley system at ~34E, 41N in the Deuteronilus-Protonilus Mensae (DPM) region has been interpreted as a relict integrated debris-covered valley glacial system (Fig 1a) [1] and is typical of dozens of fretted valleys along the dichotomy boundary [2]. In order to assess this hypothesis, we compare results from the University of Maine Ice Sheet Model (UMISM) to the features described in [1] to further analyze potential timing and flow processes responsible for candidate glacial features.
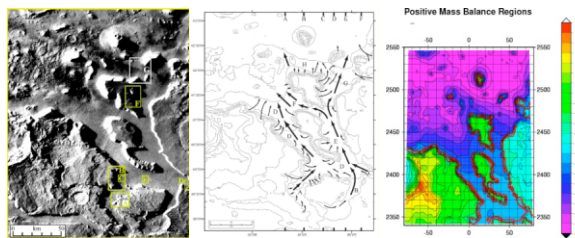

Fig. 1: (a:left) Viking image of model area, (b:center) Interpreted unified debris-covered glacial flow regime [1], and (c:right) alcove regions with +1 mm/year within red outline and -0.1 mm/yr elsewhere.

Background: A progression of fretted terrain geomorphic features has been described in the region of DPM along the dichotomy boundary (Fig. 1) [3]: these begin as sinuous valleys in highlands, transition to upland mesas at lower elevations, and terminate as broad lobes extending into surrounding lowlands. Lineated-valley fill (LVF) is one of the distinctive features of this terrain, and has been interpreted as ice-assisted downslope movement of debris from valley walls [e.g. 4] or deposits analogous to those formed by glaciers [e.g., 5]. Using recent high-resolution image data, Head et al. [1] identify evidence for a number of features interpreted to be indicative of glacial flow. These include: 1) localized alcoves from which emanate narrow, lobate concentric-ridged flows interpreted to be remnants of debris-covered glaciers; 2) alcove depressions perhaps interpreted to represent sublimation of material from relict ice-rich accumulation zones; 3) plateau-ridge remnants between alcoves typical of glacially eroded aretes; 4) horseshoe-shaped ridges upstream of topographic obstacles; 5) convergence and merging of LVF fabric in the down-valley direction; 6) deformation, distortion and folding of LVF in the vicinity of convergence; 7) LVF with pits and elongated troughs in distorted areas; 8) distinctive lobe-shaped termini with associated pitting where the LVF emerges into the northern lowlands. These features, taken as a whole [1], indicate that the boundary area was subjected to very large-scale regional glaciation during the Amazonian [2].

This evidence is interpreted to define a coherent, unified flow regime extending from the upper valley reaches down to the northern lowlands (Figure 1b); lobes emerging from the alcoves (indicated by small arrows) turn and merge with an along-valley flow regime (larger arrows). Additional support for the glacial hypothesis comes from a GCM for a dusty-atmosphere Mars with obliquity set to 35° and a water source in the Tharsis region. The GCM generates a pattern of ice accumulation in good agreement with these geological observations [6]. This modeled climate is what one might expect to follow a high-obliquity excursion of the type thought to build ice caps on the flanks of the Tharsis volcanos [7-9].

Modeling: The UMISM, as used here, is a thermo-mechanically coupled shallow-ice approximation terrestrial ice sheet model used for time-dependent reconstructions of Antarctic, Greenland, and paleo-icesheet evolution in response to changing climate on Earth [10], and adapted for the Mars environment [11-13]. Topography from MOLA was used to generate a grid with resolution in this ~30,000 km^2 region of approximately 1.5 km (12544 nodes and 12321 elements, 112X112 rows and columns).

In earlier reconstructions of Tharsis Montes ice caps, we either used a parameterization of mass balance as a function of height [11-12] or GCM results [13] as the source of mass in the continuity equation. Here we have chosen instead the expedient of specifying a positive mass balance of 1 mm/yr in the alcoves and a negative mass balance of 1/10th of this value outside the alcoves (Fig. 1c). Starting with no ice, the model is run for 2 million years. While this time interval is longer that expected for a steady climate to hold on Mars [14], it delivers a flow pattern that can be compared to the integrated glacial flow interpretation [1].

Ice thicknesses and velocities are shown in Fig. 2, with superimposed surface elevations at four times: 1) at 300Ka the flow from the sides has not yet merged along the center of the valleys. This configuration would not yet produce the turning flow observed [1]. 2) By 500Ka the beginning of a coherent down-valley flow is observed. The ice flowing from each side of the valley has merged in the center. Note the velocities are not yet appreciable. 3) By 1000Ka there is a well-established valley glacier extending to the mouths of the valleys. Velocities are as high as 250 mm/year. 4) As we move further to 1500Ka, the glacier extends out of the valleys onto the northern lowlands. Either 1000Ka or 1500Ka would clearly be producing the kinds of landforms observed [1].
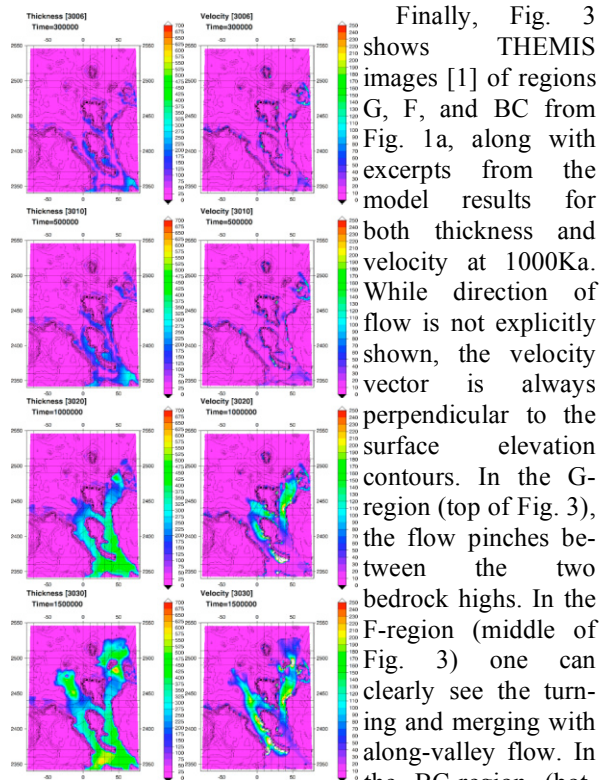
Fig. 2: Color-coded thicknesses (m) and velocities (mm/a) at 300, 500, 1000, and 1500 Ka. Contours indicate surface elevation.

Finally, Fig. 3 shows THEMIS images [1] of regions G, F, and BC from Fig. 1a, along with excerpts from the model results for both thickness and velocity at 1000Ka. While direction of flow is not explicitly shown, the velocity vector is always perpendicular to the surface elevation contours. In the G-region (top of Fig. 3), the flow pinches between the two bedrock highs. In the F-region (middle of Fig. 3) one can clearly see the turning and merging with along-valley flow. In the BC-region (bottom of Fig. 3), which is the region furthest from the valley mouths, extremely low surface slopes are observed (surface contours are only 50 m) and the flow is directed away from the alcoves with less turning down-valley.

Discussion and Conclusions: Recent GCM analyses have shown that Late Amazonian tropical mountain glaciers [7-9] occurred during periods of high obliquity (~45°). The fate of these huge glaciers was studied following a return to lower obliquity (~35°) [6]; it was found that a meteorological consequence of this large reservoir was the formation of a thick cloud belt in the northern mid-latitudes.

The thermodynamic state of the atmosphere results in increased meridional circulation, a strong eastward jet during northern winter, and associated stationary planetary waves. For an expected relatively dusty atmosphere the new water cycle favors precipitation and preservation of water ice in the D-P area to depths approaching 1000 m during a ~50 ky high obliquity cycle [6]. In this study we used guidelines from GCMs to model 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 [1-2]. Accumulation in alcoves produces local downslope flow, leading to convergence and coherent down-valley flow and 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., 1]. These analyses provide strong support for the interpretations and help to assess the time scales and velocities involved in the valley glaciation processes.

References: [1] J. Head et al. (2006) *GRL* 33, L08S03. [2] J. Head and D. Marchant (2006) *LPSC 37* #1127. [3] R. Sharp (1973) *JGR* 78, 4073. [4] M. Carr (2001) *JGR* 106, 23571. [5] B. Lucchitta (1984) *JGR* 89, B409. [6] J-B Madeleine et al. (2007) *LPSC 38* #1778. [7] J. Head and D. Marchant (2003) *Geology* 31, 641. [8] D. Shean et al. (2005) *JGR* 110, E05001. [9] F. Forget et al. (2006) *Science* 311, 368. [10] J. Fastook (1993) *Computational Science and Engineering* 1, 55. [11] J. Fastook et al. (2004) *LPSC 35* #1352. [12] J. Fastook (2005) *LPSC 36* #1212. [13] J. Fastook et al. (2006) *LPSC 37* #1794. [14] J. Laskar et al. (2004) *Icarus* 170, 343.
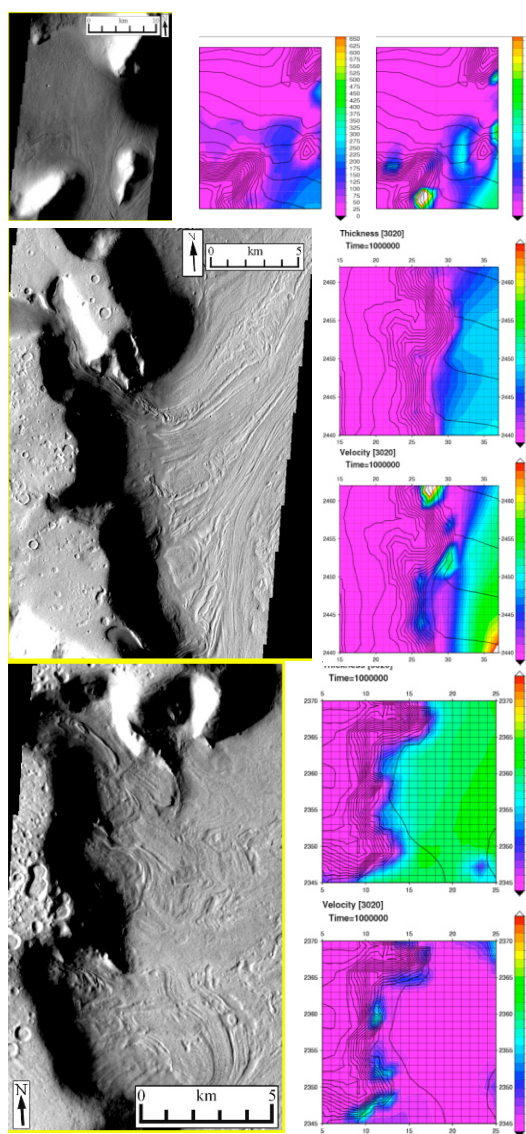

Fig. 3: Regions G, F, and BC of Fig. 1a (V11208010) with thickness and velocity at 1000Ka. Surface elevation contours are at 100 m intervals.