

**THE GLACIAL DEPOSITS OF THE NORTHERN MID-LATITUDES: REMNANTS OF LARGE-SCALE PLATEAU GLACIATION.** David R. Marchant<sup>1</sup> and James W. Head<sup>2</sup>, <sup>1</sup>Department of Earth Sciences, Boston University, Boston, MA 02215 [marchant@bu.edu](mailto:marchant@bu.edu), <sup>2</sup>Department of Geological Sciences, Brown University, Providence, RI 02912

**Introduction:** The martian polar caps are the dominant active reservoir in the present water cycle on Mars. Transport of water-ice during the late Amazonian occurs as planetary obliquity shifts [1,2]. Geological mapping [3,4], along with results from martian GCM's [5-8] and recent data from SHARAD [9-10], implicate mountainous terrain in the northern mid-latitudes as ideal settings for water-ice deposition and cold-based glaciation at higher-than-present obliquities during the late Amazonian. Indeed, mapping along the dichotomy boundary [11; Fig. 1] reveals an integrated network of ancient debris-covered glaciers fringing dissected plateau surfaces. The strong similarities between these debris covered-glacier systems with modern debris-covered glaciers alongside active plateau ice fields in the Antarctica (Earth's closest cold-desert analog for Mars) has led us to reexamine the extent of cold-based glaciation in the northern mid latitudes of Mars, and to critically assess the potential for extensive ice accumulation on plateau summits.

**The western Dry Valleys Region: A terrestrial analog for cold-based glaciation across the martian dichotomy boundary.** To a first order, the large-scale bedrock geomorphology of the Antarctic Dry Valleys (Transantarctic mountain rift-margin upwarp) approximates the martian dichotomy boundary: the valleys occur within, and dissect, a series of broad, coast-facing escarpments (total relief of up to 3000 m) separated by isolated inselbergs. In the middle Miocene, sometime between 14.8 and 12.5 Ma [12], all but the highest mountains in the Dry Valleys were overrun by a major expansion of East Antarctic ice. A modern-day counterpart for the maximum-overriding stage is seen inland of the ADV, where glacier ice still overrides stepped bedrock topography (Fig. 2,3). During the maximum phase of overriding, non-erosive, cold-based ice covered even the highest plateaus; without basal erosion and without exposed bedrock sources for supraglacial debris, evidence for ice expansion across plateaus is limited, and is inferred only from reconstructing the lateral extent of glacial deposits fringing plateau escarpments [13]. This approach, however, generally underestimates ice expansion, as debris-covered glaciers typically form only during the waning stages of glaciation. A typical sequence for the formation of debris-covered glaciers in Antarctica as follows: Following glacial maxima, and during ice recession, plateau surfaces are typically the first to emerge via ice sublimation. Emergent peaks provide sources for rockfall and ultimately supraglacial debris. With continued ice-surface lowering, ever-larger exposures of bedrock are revealed; in areas of steep bedrock scarps, rockfall typically produces extensive debris-covered glaciers that are best developed along the margins of former plateau ice fields (Fig 4). Although several factors play a role in determining the lateral extent of debris-covered glaciers, one central issue involves the extent of topographic relief on plateau surfaces. Plateau surfaces with considerable relief tend to provide abundant rockfall debris at early stages during the deglacial sequence. This rockfall produces extensive debris-covered glaciers, even as ice still occupies portions of plateau surfaces. As such, the lateral extent of these debris-covered glaciers most closely approximates maximum ice values. However, for those plateau summits with relatively smooth (low relief) surfaces, fringing debris-covered glaciers likely form only

during the very last stages of ice recession; therefore mapping the lateral extent of these glaciers will likely underestimate significantly the maximum values for plateau glaciation.

**Glacial deposits along the dichotomy boundary:** Lineated valley fill (LVF) and lobate debris aprons (LDA) in fretted terrain at the dichotomy boundary are most probably glacial in origin [#]. However, unknown is whether glacier ice could have covered fringing plateau surfaces as well. To address this question, we examined an integrated LVF glacial landsystem in the Coloe Fossae region [14] (Fig. 5) and used our understanding of debris-covered glaciers in the ADV to guide our inquiry. We find evidence for significantly greater volumes of ice in the fretted valleys of the Coloe Fossae region, and elsewhere along the dichotomy boundary, than at present. For example, the elevation difference between the upper limit of glacial deposits and the current LVF surface in Coloe Fossae region is ~920 meters [14]. We interpret this difference to reflect the minimum amount of ice-surface lowering during retreat. Given that these glaciers likely formed well after recession began, we consider plateau glaciation a reasonable possibility. As for the case on Earth, however, physical evidence for glacial overriding of the plateaus themselves is sparse. The evidence includes: 1) lobes descending down from the plateau surfaces, 2) unusual crater forms on the plateaus, and 3) predictions from the GCMs [8].

Finally, we argue that the indiscriminant areal distribution of LDA (i.e., without regard to equatorward/poleward slopes) is suggestive of plateau glaciation. If the LDA formed solely by snowfall, then the features would typically be restricted to protected alcoves along poleward facing slopes, yet LDA circumscribes plateau surfaces. One explanation for this widespread distribution is that calving margins of plateau ice fields, rather than local accumulation of snowfall, provided the ice source.

**Conclusions:** Analysis of the areal distribution of debris-covered glaciers and plateau ice fields in the western Dry Valleys region of Antarctica provides insight into the origin of debris-covered glaciers in similar topographic settings on Mars. The Dry Valley analogs strongly suggest that the dichotomy boundary was largely covered by plateau ice fields during parts of the Amazonian. Subsequently, recession caused bedrock exposure, rockfall, and debris-covered glaciers to form; the current LVF/LDA configuration represents the terminal stages of this phase. The areal distribution of deposits is similar to that found in high-latitude terrestrial settings, in which physical evidence for cold-based glaciation on plateau summits is rare [15] but is abundant in fringing, low-lying valleys.

**References:** 1) M. Carr, *Water on Mars*, 1996; 2) J. Laskar et al, *Icarus* 170, 343, 2004; 3) J. Head et al. *EPSL* 241, 663, 2006; 4) J. Head et al., *GRL* 33, L08S03, 2006; 5) M. Richardson and J. Wilson, *JGR* 107, 5031, 2002; 6) M. Mischna et al., *JGR* 108, 5062, 2003; 7) F. Forget et al. *Science* 311, 368, 2006; 8) J-B Madeleine et al, *LPSC* 38 1778, 2007; 9) J. Holt et al., *Science* 322, 1235, 2008; 10) J. Plaut et al., *GRL* 35, 36379, 2008; 11) J. Head and D. Marchant, *LPSC* 37 #1126, 2006; 12) Marchant et al. *Geografiska Annaler* 75, 269-302, 1993; 13) Denton et al. *Geografiska Annaler* 75, 155-204 (1993); 14) J. Dickson et al. *Geology* 36, 411, 2008; 15) Kleman, J. *Geomorphology* 9, 19-32, 1994; Kleman, J. and Stroeven, A.P. *Geomorphology* 19, 35-54, 1996; Kleman et al. *Ann. Glaciology* 28, 189-194, 1999; Fabel et al., *Earth and Plan. Sci. Let.* 201, 397-406, 2002.

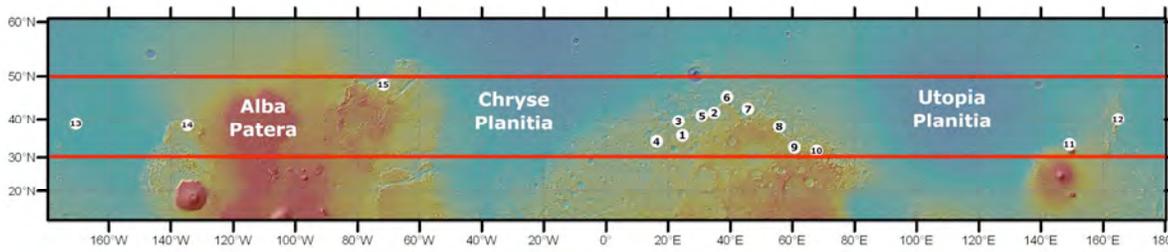


Figure 1. Distribution of study areas summarized in Head and Marchant (2006).

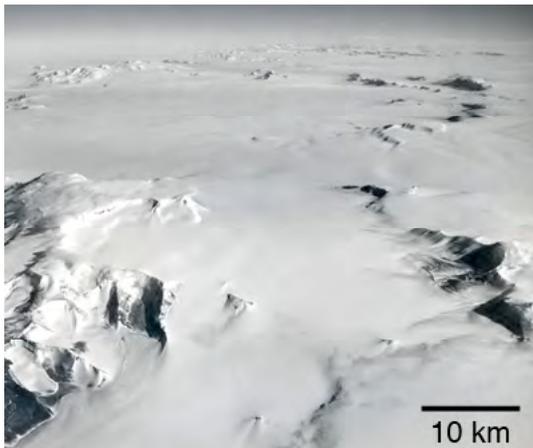


Fig. 2. Modern-day overriding of mountains inland of the ADV. Emerging nunataks show lee-side debris-covered glaciers. Inland ice shown passing over a broad plateau.

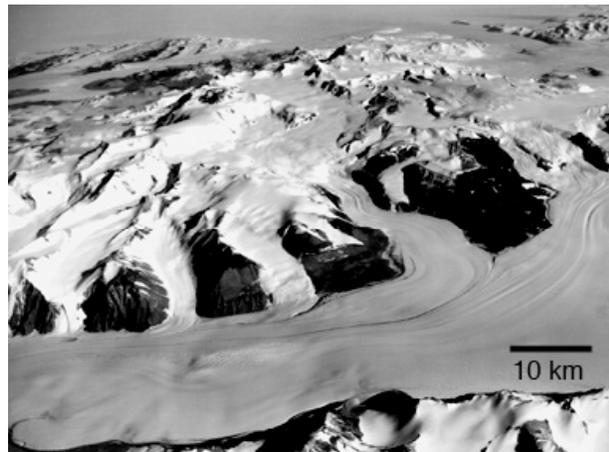


Fig. 3. Transitional stage from glacial overriding to ice-free ADV. Tributary glaciers merge with established trunk-glacier systems. Flow lines show ice deformation in association with compression from interaction and flow of merging glaciers.



Fig. 4. Formation of debris-covered glaciers. Small alpine glaciers emanating from alcoves are covered with debris via rockfall. This is the last phase of deposition associated with initial ice-sheet overriding of mountain topography.

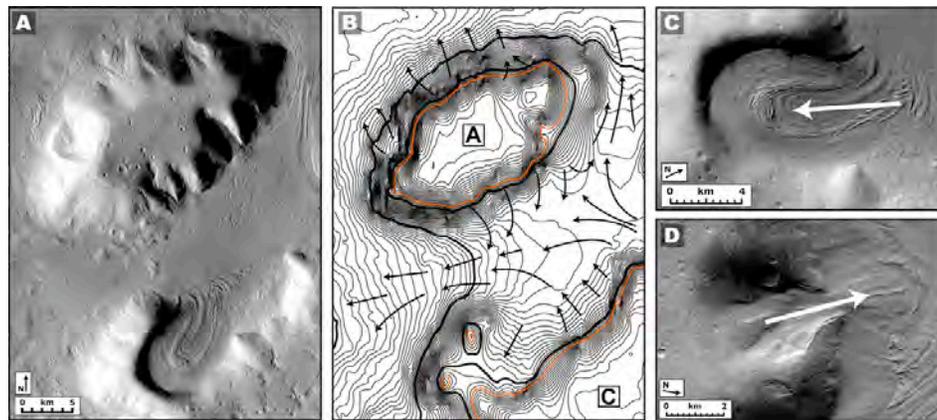


Fig. 5. a) MRO CTX image PO1\_001570\_2213. b) 100 m contour map. c) Loop-shaped lobe entering into the box canyon, with ice sourced from the main trunk valley. d) Tributary debris-covered valley glacier emerging from the northern slope of massif A and joining a main trunk valley.