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Northern mid-latitude glaciation in the Late Amazonian period of Mars: Criteria for the recognition of debris-covered glacier and valley glacier landsystem deposits

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ABSTRACT

Lobate debris aprons (LDA) and lineated valley fill (LVF) have been known to characterize the mid-latitude regions of Mars since documented by Viking; their flow-like character suggested that deposition of ice in talus pile pore space caused lubrication and flow during an earlier climatic regime. A number of factors have remained uncertain, however, including the detailed structure and texture of LDA/LVF, the relationships between them, their direction of flow, the origin and abundance of the lubricating agent, and their exact mode of origin (e.g., ice-assisted rock creep, ice-rich landslides, rock glaciers, debris-covered glaciers). We use new High-Resolution Stereo Camera (HRSC) image and topography data, in conjunction with a range of other post-Viking data sets, and new insights provided by cold-based terrestrial glacial analogs, to assess the characteristics of LDA/LVF in the northern mid-latitudes of Mars. We find evidence that the characteristics and flow patterns of the LDA and LVF are most consistent with Late Amazonian debris-covered glacial valley landsystems. The broad distribution and integrated characteristics of the LDA/LVF systems suggest that earlier in the Amazonian, climatic conditions were such that significant snow and ice accumulated on mid-latitude plateaus and in valleys, producing integrated glacial landsystems, the remnants of which are preserved today beneath residual sublimation till derived from adjacent valley walls. Atmospheric general circulation models suggest that these climatic conditions occurred when Mars was at a spin-axis obliquity of ~35°, and the atmosphere was relatively dusty. Glacial flow modeling under these conditions produces patterns similar to those documented in the LDA/LVF, and SHARAD radar data suggests that significant amounts of ice remain sequestered below the sublimation lag today.

1. Introduction

Mars is currently a cold, hyper-arid global desert (Baker, 2001); water is currently sequestered in the regolith-cryosphere, with the major surface reservoir residing in the extensive polar caps, and very small amounts in the atmosphere (Carr, 1996). Evidence is growing that in its past history, Mars has been characterized by significant variations in its spin-axis/orbital elements (obliquity, eccentricity and precession) (Laskar et al., 2004) and that these variations have led to the redistribution of water in the polar ice deposits to lower latitudes to create ice ages and their related deposits (e.g., Head et al., 2003). This has led to a renewed interest in the development of criteria to recognize non-polar ice-related, glacial and periglacial deposits that might represent the record of these excursions. Topographic and imaging data acquired by recent spacecraft have revolutionized our understanding of these deposits, providing detailed information that helps to characterize their key parameters (structure, morphology, slopes, elevations, morphometry, stratigraphic relationships, etc.) that are essential to interpreting these deposits. In particular, the High-Resolution Stereo Camera (HRSC) on board the Mars Express Spacecraft has provided image data and high-resolution digital elevation models (Neukum et al., 2004a,b; Gwinner et al., 2005; Scholten et al., 2005) that, together with complementary data from HiRISE, CTX, THEMIS and MOLA, have permitted the assessment of these types of features in the northern mid-latitudes of Mars.

Fretted terrain and fretted channels are very well developed in the northern part of Arabia Terra (Sharp, 1973) and were clearly identified in Viking data as the site of development of lobate debris aprons (LDA) (Fig. 1B) and lineated valley fill (LVF) (Fig. 1C) (Squyres, 1978, 1979). The detailed geological history and chronology of this region (McGill, 2000) provide a framework for the interpretation of modification processes operating on and near the dichotomy boundary. McGill (2000) underlines the conclusion that fretted channels and valleys formed early in Mars history (prior to middle Hesperian) and that the associated LDA and LVF represent Amazonian-aged modification of the fretted topography. Carr and Schaber (1977) analyzed the early Viking Orbiter images and concluded that frost creep and gelifluction were the primary processes in LDA formation. Squyres (1978) documented the fact that in the fretted terrain, debris aprons (LDA), characterized by sharply-defined flow fronts and convex-upward

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