

DOCUMENTING MICROCLIMATE VARIATION AND THE DISTRIBUTION OF ENGLACIAL DEBRIS IN MULLINS GLACIER, ANTARCTICA: IMPLICATIONS FOR THE ORIGIN, FLOW, AND MODIFICATION OF LDA AND LVF ON MARS. D.R. Marchant¹, S.L. Mackay, J.W. Head, III², D.E. Kowalewski³. ¹Boston University, Dept. of Earth Sciences, 685 Commonwealth Avenue, Boston, MA 02215; ²Brown University, Dept. of Geological Sciences, 324 Brook St., Box 1846, Providence, RI 02906; ³University of Massachusetts, Dept. of Geosciences, 233 Morrill Science Center, Amherst, MA 01003.

INTRODUCTION: Lineated valley fill (LVF) and lobate debris aprons (LDA) characterize most of the valley floors and walls along the dichotomy boundary. Their flow-like character suggests movement by ice-assisted creep, but unknown are the origins and ultimate concentrations of the deforming icy substrates (e.g., pore ice, excess ice, glacier ice) and the degree to which ice accumulation, burial, and/or variations in subsurface-debris concentration implicate changes in Martian climate. Interestingly, in terms of defining the origin, style of deformation, and climate significance of a wide variety of high-latitude near-surface flow features on Earth (including those tentatively described as gelifluction lobes, rock glaciers, debris-covered glaciers, and pro-talus ramparts) the terrestrial community is faced with similar uncertainty. To help address these questions, we focus on a single viscous flow feature, the Mullins Valley debris covered glacier, for which there is abundant evidence for preservation of ancient ice. We assess the spatial variation in its surface and subsurface debris as a guide to help predict the potential range of debris (concentration, layering, etc) that might occur in documented ice-rich lobes along the dichotomy boundary [1-3].

Geological Setting: To a first order, the large-scale bedrock geomorphology of the ADV (Transantarctic mountain rift-margin upwarp) approximates the Martian dichotomy boundary: the valleys occur within, and dissect, a series of coast-facing escarpments (the highest of which ~3000-m high); in places, the valleys are separated by isolated inselbergs. Mean annual temperatures at the Mullins Valley debris-covered glacier approach -25°C with relative humidity being as low as ~10%. Under these hyper-arid, cold desert conditions, melting of surface ice is minor and limited to the margin of solar-heated rocks that rest directly on exposed snow and/or ice. Data from instrumented soil pits and numerical-modeling studies show that in areas where ice is covered with at least 15 cm of debris, ablation is entirely from sublimation; hence, ice loss occurs only via sublimation and vapor diffusion for most of Mullins Glacier. It is this unique attribute, e.g., the absence of melting along the buried-ice interface, that makes interpretation of this system relatively straightforward, especially when compared to more complex viscous-flow deposits of the Arctic whose surface morphology and texture is strongly dominated by phase transitions and, especially, the liquid-water phase.

RESULTS: The Mullins Glacier descends from steep cliffs at the head of Mullins Valley and terminates ~8 km away out on the floor of central Beacon Valley (Fig. 1). Over most of its length, Mullins Glacier is covered with sublimation till >15 cm thick. Mullins Glacier has been the focus of interdisciplinary research ever since initial reports suggested it contained Miocene-aged ice (e.g., up to 7.9 Ma in age) and bacteria [4]. As a consequence, Mullins Glacier has served as a "type section" for slow-moving, cold-based alpine glaciers [5,6]; as a type locality for sublimation till and sublimation polygons (7); and, as the focus of ongoing studies aimed at reconstructing long-term

variations in greenhouse gasses. These interdisciplinary studies have all made important contributions in their respective fields, but several first-order questions remain: What aspects of vapor diffusion, atmosphere-surface interactions, and till characteristics encourage long-term ice preservation? How might sublimation tills and sublimation polygons influence subsurface ice loss and the composition of trapped gases in glacier ice? Do morphometric parameters of surface ridges and sublimation polygons (trough depth, angle of polygon slope and polygon asymmetry, [e.g. 6,7] shed light on the depth and purity of subsurface ice? If so, can these same morphometric parameters be used to map the concentration of buried-ice deposits elsewhere on Earth, and on Mars?

Thickness and internal structure of Mullins Glacier: On the basis of our preliminary ground penetrating radar (GPR) and shallow seismic reflection profiles, Mullins Glacier is ~100 m thick near the valley head, ~60-to-45 near the valley mouth, and ~150 m thick in Beacon Valley [8,9]. Horizontal ice-surface velocities, as measured from synthetic-aperture radar interferometry (inSAR) range from a maximum of ~40 mm y⁻¹ near the valley head, to < 1-2 mm y⁻¹ where Mullins ice occupies Beacon Valley [5]. Isotopic analyses show that δD and δ18O values fall along a precipitation slope, implying that the buried ice has an origin from recrystallization of snow (glacier ice) and that phase changes (if any) have not modified significantly the isotopic composition of the ice. We have inferred the concentration of englacial debris in Mullins Glacier from ground-penetrating radar and shallow-seismic reflection surveys (three transects [8,9]), as well as from direct examination of shallow ice cores (<20 m deep). Results show that englacial debris occurs: (i) as gravels and cobbles scattered throughout the glacier (<<1% by volume), (ii) as closely-spaced cobbles within inclined layers up to ~1 m thick, (iii) as widespread, rocky debris with concentrations of up to 50%, and (iv) as veins and wedges of oxidized sands that typically taper with depth (Fig. 1). Collectively, the concentration of englacial debris increases down valley, but we do not know if transitions from one type of debris to another (i-iv above) are abrupt or gradual, or if these changes result in morphologic variation at the glacier surface. We do know, however, that at one location near the valley headwall, inclined layers of concentrated englacial debris (in otherwise clean glacier ice) intersect the ground surface at the first major surface ridge to mark Mullins Glacier [9]. We postulate that other ridges may also be associated with dipping englacial debris bands.

There are several sources for englacial debris bands, including (i) rocks falling onto the glacier accumulation zone, (ii) sifting of surface debris (Mullins till) into open thermal-contraction cracks [6,12], and (iii) windblown debris. Basal regelation is not a plausible source for the englacial debris, because of low ice temperatures (-25.7° C at 10 m depth) and minimal horizontal transport velocities (see also [10]).

Importance of microclimate variation: In addition to marked variation in debris content (Fig. 1), our initial studies show that local meteorological conditions vary appreciably along the length of Mullins Glacier. Key questions center on whether these local variations in meteorological conditions, which arise from (i) valley-side shielding, (ii) elevation effects, and (iii) meter-scale changes in the morphology of surface polygons, also impart first order changes in the morphology of Mullins Glacier. Ultimately, our aim is to identify surface morphologies that are diagnostic of subsurface ice concentrations (accepting and understanding the variation that arises from differing microclimate settings) and then apply these concepts to the study of similar viscous flow features in Antarctica, and potentially to those on Mars.

CONCLUSIONS:

Our results suggest that variations in both englacial-debris concentration and local environmental conditions impart first-order changes in the surface morphology of Mullins Glacier. Understanding these variations, and their causes, will help frame questions regarding the origin and debris concentrations within similar appearing viscous flow features on Mars, especially LFV and LDA for which recent data from SHARAD [11] and numerical modeling [12] suggest relatively pure subsurface ice.

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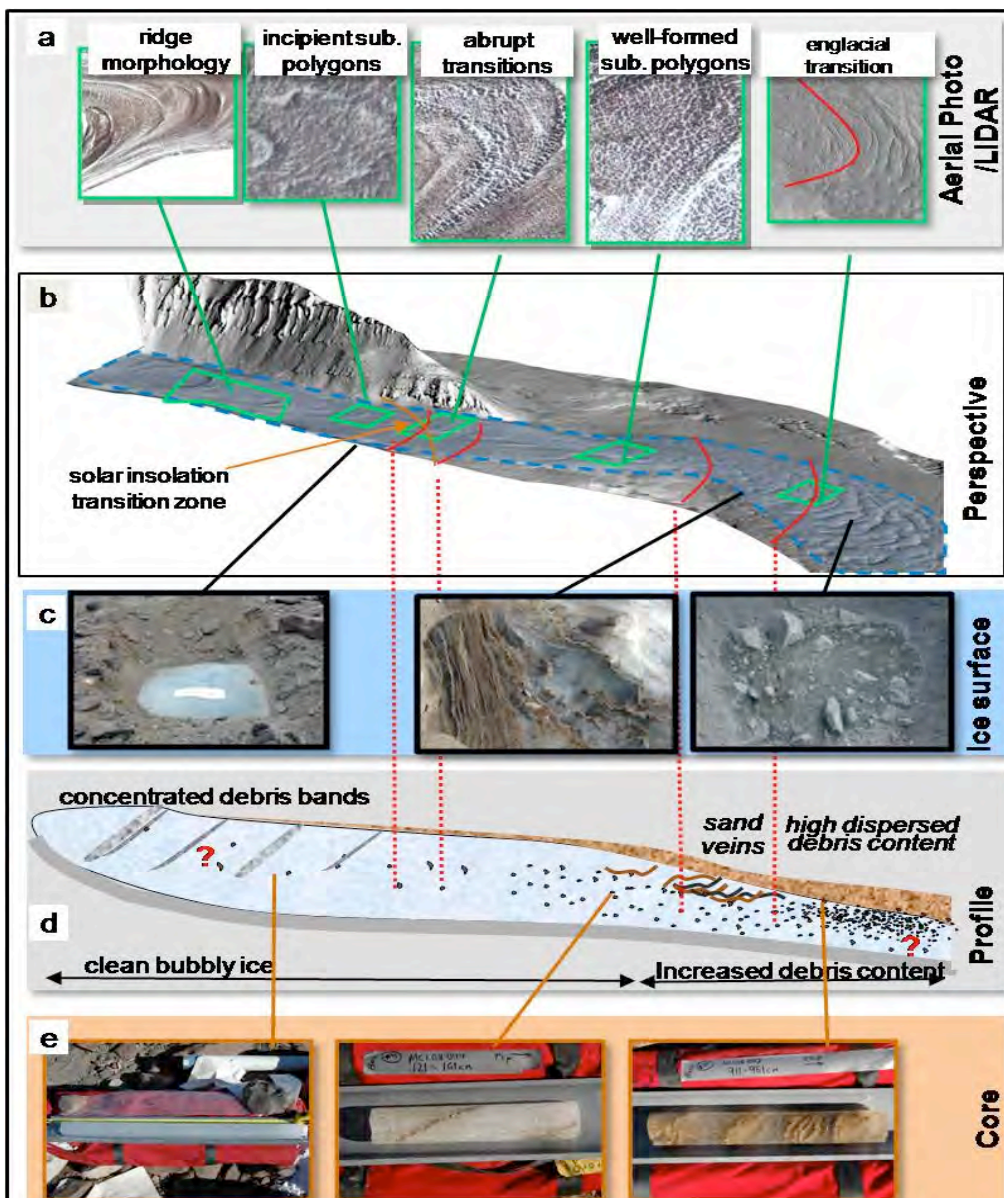


Fig. 1, a-e: inferred and measured variations in surface morphology, debris content, and microclimate thresholds (solid red lines) along the Mullins Valley debris covered glacier.