Distribution and Origin of Oriented- and Non-Oriented Polygonally Patterned Ground in Mullins and Central Beacon Valleys, Antarctica: Interaction of Glacial Flow and Sublimation in a Mars-Analog Environment.

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To understand the origin and evolution of polygonally patterned ground on a debris-covered glacier in the Antarctic Dry Valleys, we map the distribution of five morphological units of polygonally patterned ground in Mullins and central Beacon. Mapping is based on surface morphology and morphometric parameters such as trough intersection angle. Where Mullins Valley debouches into Beacon Valley (Figure 1), polygonal patterning transitions from radial orthogonal-intersections to non-oriented hexagonal-intersections, providing a time-series of polygon evolution under uniform microclimate conditions [1]. Based on surface morphology, ice flow rates, cosmogenic nuclide exposure ages, and stress analyses, we conclude that the most likely explanation for the variety of polygon morphologies observed in Mullins and central Beacon Valleys is a model which combines initial thermal contraction-crack formation oriented radially to glacier flow in areas of rapid horizontal ice flow, modified over ky-timescales by sublimation and deformation, and ultimately dominated by non-oriented thermal stresses in areas of stagnant buried ice.

Mullins Valley (77°54'S, 160°35'E) is a tributary valley to Beacon Valley (77°49'S, 160°39'E) and is located in the stable upland zone of the McMurdo Dry Valleys [2]. Climatically, Mullins Valley is hyper-arid, with an annual water-equivalent precipitation of < 10 mm/year (Marchant and Head 2004). Air temperatures range between -48°C and approximately 0°C in adjacent Beacon Valley, with brief hour- to day-scale excursions above 0°C, and a mean annual temperature of -22°C [9].

The floor of Mullins Valley is dominated by Mullins glacier, a debris-covered glacier approximately 3 km long and 0.8 km wide. The glacier is composed of several distinct lobes which are nested axially down-valley. We map five distinct morphological units on Mullins glacier: (Zone 1) nascent, radial crack formation (RC), (Zone 2) radial polygons (RP), (Zone 3) deformed radial polygons (DRP), (Zone 4) non-oriented ("hexagonal") polygons (NOP), and (Zone 5) no polygons (NP) (Figure 1). For a complete

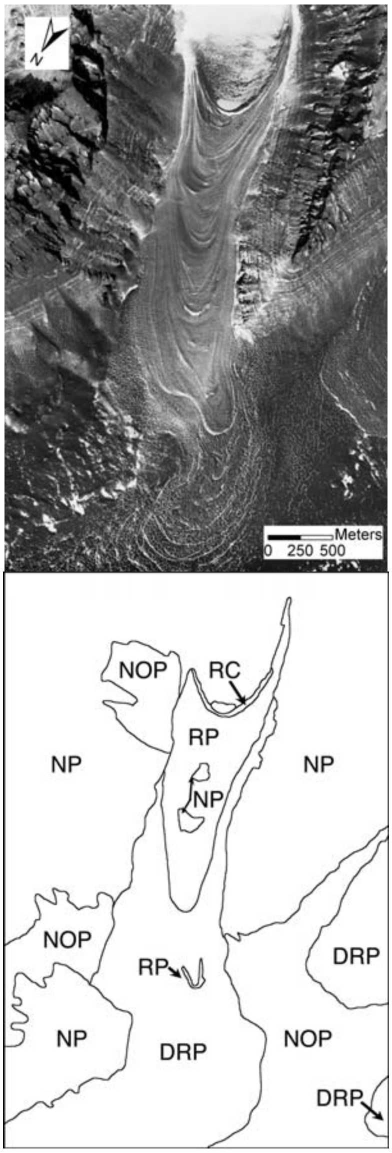

Figure 1 – (Above) Mullins Valley debouching into central Beacon Valley. Lobes of Mullins glacier are clear visible flowing towards the image bottom. (Below) Sketch map of morphological units of polygonally patterned terrain in Mullins Valley.

discussion and description of morphological units see Levy et al. (2005, in review). Our mapping program, based on field excavation and mapping,

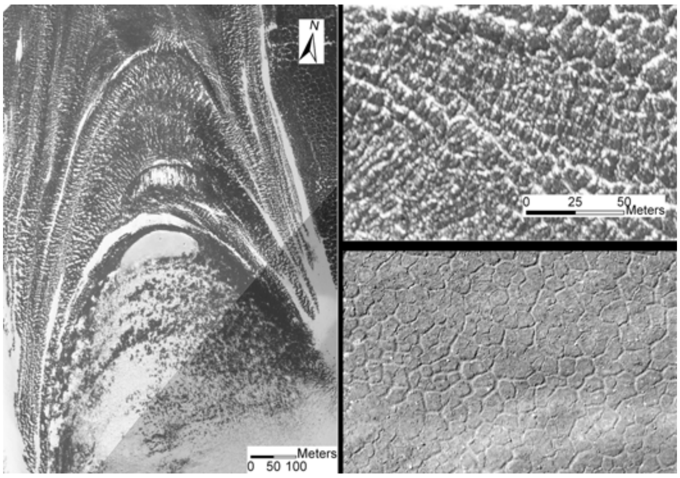

Figure 2 – (Left) Orthogonal-intersection polygons forming radially along glacial lobes in upper Mullins Valley (RP). (Upper Right) Deformed radial polygons in Mullins Valley (DRP). Non-oriented polygons in lower Beacon Valley (NOP). NOP are approximately 20 m in diameter.

as well as analysis of high-resolution air-photography, modifies the traditional theory of polygonal patterning--classically described by [5] and [6] as roughly hexagonal networks of thermal contraction cracks. In contrast, our model integrates the morphological characteristics of each zone of polygonal patterning to generate a model which traces the development of polygon morphology as influenced by stress associated with glacier flow, sublimation, and thermal contraction.

Additionally, ice ages give maximum constraints on the time required to produce the observed morphological units. We correlate synthetic aperture radar interferograms from Rignot et al. (2002) with our polygon morphology map of Mullins and central Beacon Valleys. We find that there are distinct spatial relationships between relatively “fast” surface velocities ($\geq$ 5 mm/year) and the formation of radial polygons as well as between slow/stagnant flow rates and areas showing hexagonal non-oriented polygons.

Cosmogenic nuclide exposure ages for the Mullins Valley glacier are reported in clusters of 13 ka, 136 ka, 300 ka, and 730 ka (Marchant, personal communication), which correlate well with polygon morphology and interferogram analysis. The youngest exposure age (13 ka) was measured near the contact between Zones 2 and 3. 136 ka cosmogenic nuclide samples were collected from the Zone 2, near contacts with Zone 5. The 300 ka samples were collected in the Zone 3. The oldest cosmogenic nuclide samples (730 ka) were measured deep in the zone of deformed radial polygons. These observations are consistent with rapidly flowing ice in the up-valley reaches of Mullins Valley and a significant stagnation or slowing of ice as it enters Beacon Valley.

We present the following conceptual model to account for the morphological, age, and flow data observed in Mullins and Beacon Valleys. The troughs of oriented, orthogonal-intersection polygons, which initially arise from cracks that form through a combination of flow-oriented glaciel stress and thermal cracking, are modified by sublimation of near-surface ice during down-valley transport. Some polygon troughs re-seal by the time of arrival in Beacon Valley, particularly by slumping of till, resulting in the removal of inherited sites of material weakness and the exposure of new sites for preferred cracking. The near-stagnant ice in Beacon Valley is largely subjected to thermal stress, in the absence of glacial stress, which is adequate to produce contraction cracks that produce non-oriented hexagonal.

This work enhances our ability to interpret polygonal patterning ubiquitously observed on Mars at high latitudes and interpreted as indicators of thermal contraction phenomena (e.g., Mangold et al, 2004; Mellon, 1997). By unraveling the morphological effects of thermal and structural stress in a competent icy layer, we can better understand climate and deformation history recorded in martian polygonally patterned terrain.

References

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