THE CAUSES OF VISCOUS FLOW SURFACE PATTERNS AT CRATER GREG AND DAO VALLIS

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Introduction: In relating the surface patterns at Dao Vallis and Crater Greg to high elevation glacier crevasses, foliation, and ogives, we assume sublimation is the dominant ablation component. We present interpretations (see Figure) of ablation patterns of GLF (glacier-like flow or feature) on the Greg south wall (upper left) and the North wall of the neck of Dao Vallis (bottom left). The chevron patterns at Greg Crater may be the related to crevasses and foliation, visible in our high elevation terrestrial glacier analog Theri Kang, Bhutan (upper right, please zoom in) or ogives, visible at Gilkey Glacier, AK (right), with possible foliation ablation patterns stronger on Mars examples.

Theri Kang is also a good analog for the Dao Vallis crevasse-like zone, with crevasses and longitudinal foliation as possible components. The Figure also shows where the patterns seen in the adjacent ice-rich material may have been placed down on the surface, albeit much subdued, as ice that gives the bold three dimensional character that was lost to sublimation, until only an echo of the patterns in the sublimation till remained. Sublimation till can sometimes preserve supraglacial and englacial structures like foliation.

Hartmann et al. [1] suggests this texture is remnant of glacial flow down the river-carved valleys, after ~90% sublimation of glacial ice fill, formed during high-obliquity periods. In keeping with this line of thinking, it seems possible that the chevron patterns at Greg and similar patterns at Dao represent foliation. Formation of foliation occurs as ice becomes oriented by the effects of stresses induced by ice flow on the variations of ice crystal size and debris content within the glacier. Then, melting or sublimation causes variable ablation across the glacier surface, resulting in patters of relief that reflect foliation and flow.

The Figure (lower left) presents an image of the area adjacent to the large tributary located on the Dao Vallis north wall seen in the Figure. It shows some similarities to the chevron flow patterns in Greg, but the material is located in more of an alcove than a valley. Given that the viscous flows of the Greg chevrons more constrained by narrower valleys, there definitely seems to be some similarity. Our thought is that they are the later remnants left after aggressive sublimation --- what you'd see if you sublimed away the top 70 or 90 % of the Dao Vallis flows. Particularly, the craggy surface of the ice seen in the Figure, could be a surface that has evolved, with sublimation and with flow, from the knobby terrain into the kind of chevron textures seen in the Figure. It is possible that the processes of genesis at Greg and Dao are related by the similar accumulation, flow, and ablation processes of ice, yet vary by topography and climate histories. We believe that foliation, flow, and ablation can explain some of the patterns we see in the more ice-rich and through to the more ablated glaciers.

Theri Kang: (Figure: upper right) At Theri Kang, preferential sublimation acting on crevasses is the source of most of the sublimation pattern, and a mostly longitudinal foliation component is less obvious as a secondary pattern. "The lower portion of the glacier is debris covered along the lateral margins, but the clean ice portion has an interesting pattern that is typical of a glacier in a drier climate where sublimation dominates over melting. The crevasse pattern becomes a series of prominent crests, almost waves, that persists in the absence of the crevasses that formed them. This persistence would not occur in a zone dominated by melting." [2]. The foliation ablation pattern mostly runs up and down the length of the glacier at approximately right angles to the crevasses and is caused by ablation of longitudinal foliation. These are narrow parallel ridges and are reminiscent of snow layering, but are composed of what had been englacial ice.

Greg: (Figure: upper left) A Crater Greg enigma is why the S wall features have such dramatic V-shaped chevron texture. Analysis indicates [3] average slopes as high as 14.7 deg on the upper walls where dendritic valley networks are found. Some of the strongest chevron texture is in lower valleys shows slope only 6.9 deg. One idea is that dendritic networks fed or feed into the single narrower valley causing unusually rapid flow, creating the chevron fractures and texture. One possibility is that if a glacier sublimates nearly entirely, the dirt load in the ice between the original fractures could be left behind, deposited on the original floor of the fluvial valley, and we see the pattern that shows up on the valley floors on Greg S wall. Those ridges might be a mixture of soil and ice, or mostly soil, deposited ultimately from original ogives (Figure: lower right), for instance.

The upper part of Figure inset shows an ablation pattern consistent with radiating longitudinal foliation somewhat like the Theri Kang ablated foliation, while the lower portion shows a more scalloped-like pattern that fairly resembles the Theri Kang ablated crevasse pattern. At Greg, ablation patterns, of what may reflect foliation, are continuous from the longitudinal zone to

the transverse zone, curving in a step-like manner as much as 90 degrees. Longitudinal foliations are aligned parallel to glacier flow and sometimes form patterns that run the length of a glacier. Longitudinal foliation may be the most relevant to the chevron pattern because they express the effects of slower moving ice nearer the flanks of the glacier and faster moving ice nearer the center. Here, like at Dao Vallis, there is a transition zone where the radiating longitudinal pattern changes to a transverse pattern. However, at Greg, the transverse pattern does not disappear downflow as it does at Dao. This difference may be explained by the fact that the viscous flow at Greg does not merge with a main-valley flow that imparts shear forces to it, but rather joins a large and mostly stagnant deposit of viscous material on the flatter crater floor in a manner that allows the transverse pattern to be retained across the crater floor. The transverse pattern itself could reflect strongly ablated transverse foliation and/or crevasses.

Dao Vallis: (Figure: bottom left) A stacked card-like nature is suggested by portions of the surface of the GLF in the Figure. This could be explained by unequal ablation acting on transverse foliation and generating a surface that is similar to the unequal erosion that acts on tilted strata in rock, which gives a similar expression. Possibly, the ice experiences compressive forces as the ice sheet in the wider, upper section of the alcove becomes channeled through the narrower section below, causing the viscous flow to thicken. The foliation, which is not unlike strata, could become rotated from longitudinal to transverse in orientation as different stress fields are applied to the ice, resulting new flow velocity regime may be oriented transversely rather than longitudinally across the viscous flow. As far as crevasses are concerned, it would be expected that fractures underlying the formation of crevasses could exploit foliation, especially strongly formed foliation that has significantly weakened the ice along particular planes oriented to the stress field responsible for the crevassing. Conceivably, a co-evolution of foliation and crevassing may be an underlying element in the formation of the type of transverse patterns seen in the Figure. On the other hand, the transverse pattern may entirely result from crevasses, with the possible longitudinal foliation pattern being masked upon entering the crevasse flow regime below.

The loss of the transverse pattern at the confluence of the wall GLF with the main-valley GLF at Dao Vallis might be caused by what could be interpreted as closure through crevasse healing, icy mantles muting the landscape, or by the reorientation of foliation plane angle, as the wall GLF merges to become one with the main-valley GLF. When a plane of the foliation is reoriented nearer to that of the surface of the viscous flow, the pattern will become more weakly expressed. However, faint patterns of very closely spaced bands related to the less closely spaced pattern of the crevasse-like zone are visible on the main-valley flow, which supports an interpretation of healing.

Conclusion: We suggest that some of the variations of ablation patterns observed (on both Earth and Mars) result from the combining of various varieties and expressions of crevasses, foliation, and ogives reacting to flow and sublimation-driven ablation. And that while crevasses are usually the dominant underlying factor on Earth, foliation or ogives may sometimes rule the expressions of the ablation patterns on Mars.

References: [1] Arfstrom, J.D. and Hartmann, W.K. (2005) Icarus, 174, 321-335. [2] https://glacier-change.wordpress.com/tag/theri-kang-glacier-retreat/ . [3] Hartmann, W.K. et al. (2014) Icarus 228, 96–120.

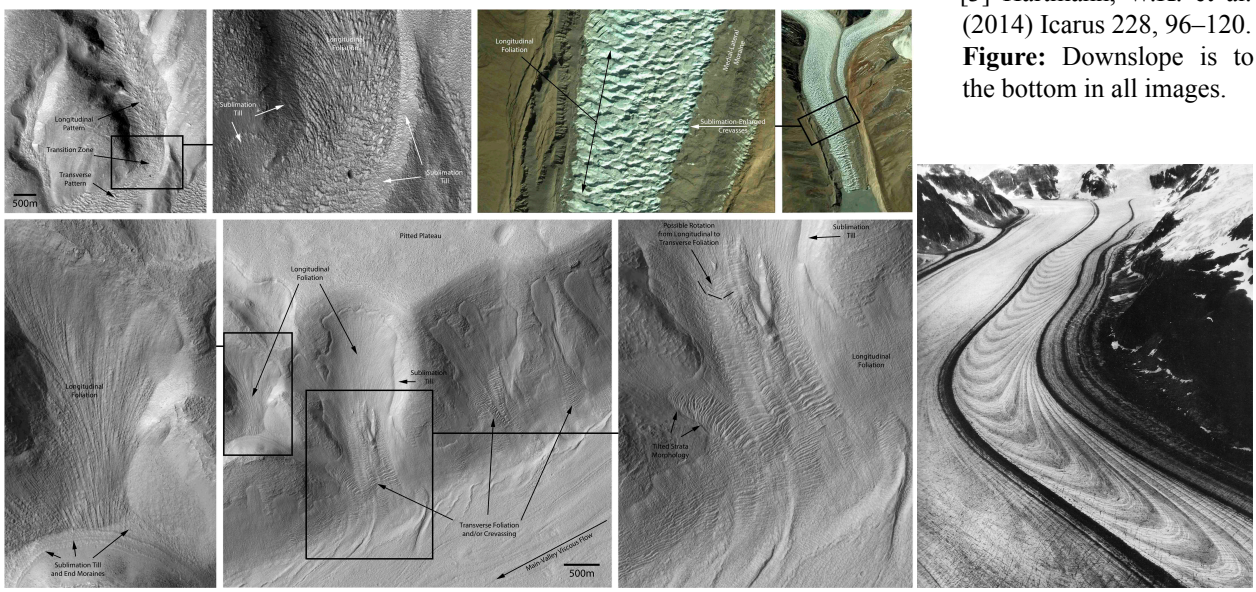

Figure: Downslope is to the bottom in all images.