ICY POLAR CLIFFS: STRESSED OUT AND FALLING TO PIECES. S. Byrne[1], P. Russell[2], A. Pathare[3], P. Becerra[1], J. Molaro[1], S. Mattson[1], M.T. Mellon[4] and the HiRISE Team[1]. [1]Lunar and Planetary Lab, Tucson, AZ. (shane@lpl.arizona.edu) [2]Smithsonian Institution, Washington, DC. [3]Planetary Science Institute, Tucson, AZ. [4]Southwest Research Institute, Boulder, CO.

Introduction: The martian North Polar Layered Deposits (NPLD) and their southern counterpart are layered stacks of dusty water ice a few km thick and several hundred km across. The layers have long been thought to represent a climatic record akin to terrestrial ice cores [1,2] with dust content varying from layer to layer, but being minor overall [3]. The NPLD likely wax and wane in thickness with variations in orbital parameters and obliquity; however, strong local effects on erosion and deposition patterns can also be seen. The spiraling troughs that pervade the NPLD interior were initiated partway through NPLD history and have migrated poleward [4]. Chasma Boreale has persisted throughout NPLD history while other large depressions have been filled in by accumulation [5].

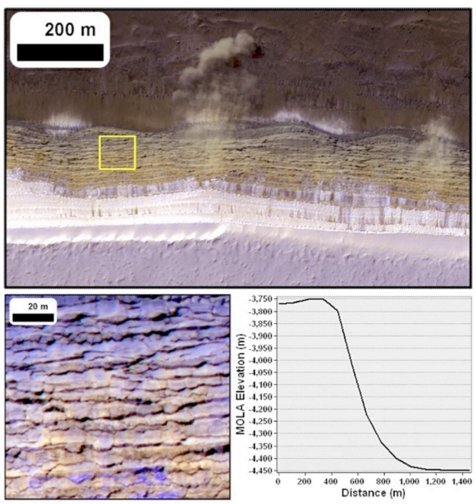

Figure 1. HiRISE image (PSP_007338_2640, L_s 34) of 70° scarp (MOLA topography at bottom right) at 84°N 235°E with avalanche in progress [10]. Yellow box shows location of scarp texture in bottom left.

The NPLD margins in contrast have received less attention. In places, the NPLD are bounded by steep scarps of up to 800m in relief and 70° in slope (figure 1). These steep scarps typically overlie exposures of a sandy basal unit [6,7] and it may be that removal of this friable material is undermining the NPLD and leading to the steepness of these bounding scarps [8].

The steep equatorward facing orientation of these cliffs mean that, in contrast to surrounding flat terrain, they defrost early and receive intense summertime insolation with a strong diurnal cycle and low incidence angles. They are also distinguished from troughs in the NPLD-interior by their unusual surface texture. These scarp faces appear heavily fractured with jagged slab-like fragments (figure 1) and lack the thick slumping dust covers seen on the troughs [9].

Evidence for mass wasting of these steep cliffs is common with fresh basal debris appearing even over the period of HiRISE operations [8]. Exfoliation of large slabs (figure 2) indicates the prevalence of sheeting joints in addition to fractures perpendicular to the surface. Additionally, multiple frost and dust avalanches (figure 1) have been observed by HiRISE in early spring each year [10].

The absence of a thick dust cover and their geometry mean these icy scarps are subject to high ablation rates. Springtime avalanches likely scour these scarps of any dust lags acquired the previous summer. However, HiRISE color and albedo values show dust of some thickness exists on their surface.

Here, we examine the unique thermal environment of these scarps and the thermally-generated stresses they endure. We show fractures are easily generated and that scarp-curvature also likely leads to sheeting joints and exfoliation of slab-like fragments.

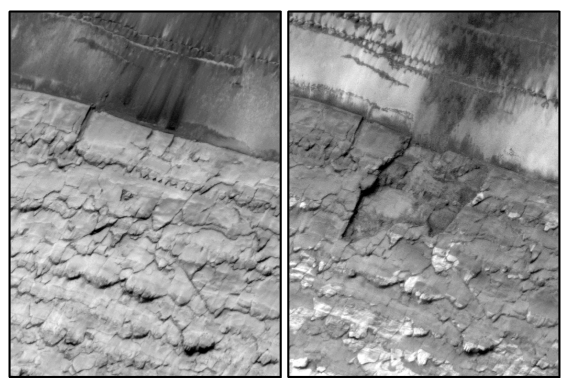

Figure 2. HiRISE images ESP_016292_2640 (left) and ESP_024639_2640 (right) show collapse of a 70m wide slab during MY30.

Thermal Behavior: We simulated the thermal behavior of these steep scarps with a standard 1D semi-implicit thermal diffusion code with radiative boundary conditions at the top surface and negligible heat flow from beneath. The steepness of these slopes means that they exchange reflected and emitted radiation with surrounding flat terrain as well as open sky. We separately simulated the temperatures of the surrounding terrain (assumed to be dark sand, albedo

0.15, thermal inertia [TI] 225) to calculate the upwelling fluxes onto the scarp face. Downwelling radiation from the sky was assumed to be 4% of the noon flux and adjusted for the portion of sky visible.

The thermophysical properties of the scarpface were taken to be those of water ice at 200K (TI 2130) overlain by a thin dust cover (albedo 0.25, TI 85). The thickness of this dust cover is a crucial controlling factor on the thermal behavior of the ice and it strongly affects the L_s on which the scarp losses its CO_2 frost cover. Specially targeted early HiRISE images show the scarp has already defrosted by L_s 350 and so the dust cover has negligible thickness. We continue to use a dusty albedo for the scarp surface though.

Mechanical Behavior: We follow the approach of [11] to solve for the time varying stress in a viscoelastic solid. No lateral strain can occur so surface-parallel thermal expansion and contraction is opposed by elastic stresses over short timescales that decay over longer timescales due to viscous effects. The thermal history at each depth can be used to calculate these stresses, as well as surface-normal displacement. The ice's viscous strain rate is grain-size dependent. We use the Zenner pinning approach of [12] with NPLD dust abundances [3] to constrain ice grain sizes to be 10-1000μm.

During much of the northern summer diurnal temperature oscillations in the ice are large and associated surface stress can vary by several MPa and alternate between extensional and compressive (e.g. figure 3). Compressional stresses occur during warmer periods and are thus more effectively viscously relaxed than extensional stresses. Colder ice allows for the accumulation of greater extensional stress during polar night.

Discussion: The tensile strength of water ice ranges from 1-2 MPa. Peak extensional stress at the surface (figure 3) exceeds this by an order of magnitude. Thus these steep scarps with thin or absent dust covers cannot remain unfractured. Stresses exceed the strength of ice down to depths of 5-10m depending on ice grain size and cracks are expected to these depths.

Once fractures have formed, surface-parallel strain is possible (through opening and closing of cracks) and stresses can be further reduced. The fracture spacing should decrease until all points on the scarp face are near enough to a crack to avoid further fracturing.

In addition to these fractures, surface-parallel compression, in concert with surface curvature, can generate extensional stresses below (and normal to) the surface [13]. This effect is thought responsible for large surface-parallel sheeting joints forming on terrestrial granitic domes. High compressional stresses on these martian scarps are relatively easy to generate and so only modest surface curvature is required to overcome the increasing pressure with depth [13]. Peak compressive stresses (figure 3) and potentially sheeting joint formation occur in the upper few meters in early spring and coincide with the seasonality of avalanche activity.

Shallower polar slopes (e.g. the spiral troughs) appear unfractured. Our modeling suggests this is due to thicker dust covers, possibly because they do not experience the scouring avalanches of steep slopes.

References: [1] Thomas et al., Mars, Univ. AZ Press, 1992. [2] Byrne, Ann. Rev. Earth & Planet. Sci., 2009. [3] Grima et al., GRL, 2009. [4] Smith et al., Nature, 2010. [5] Holt et al., Nature, 2010. [6] Byrne & Murray, JGR, 2002. [7] Fishbaugh & Head, Icarus, 2005. [8] Russell et al., LPSC, 2012. [9] Herkenhoff et al., Science, 2007. [10] Russell et al., GRL, 2008. [11] Mellon, JGR, 1997. [12] Durand et al., JGR, 2006. [13] Martel, GRL, 2011.

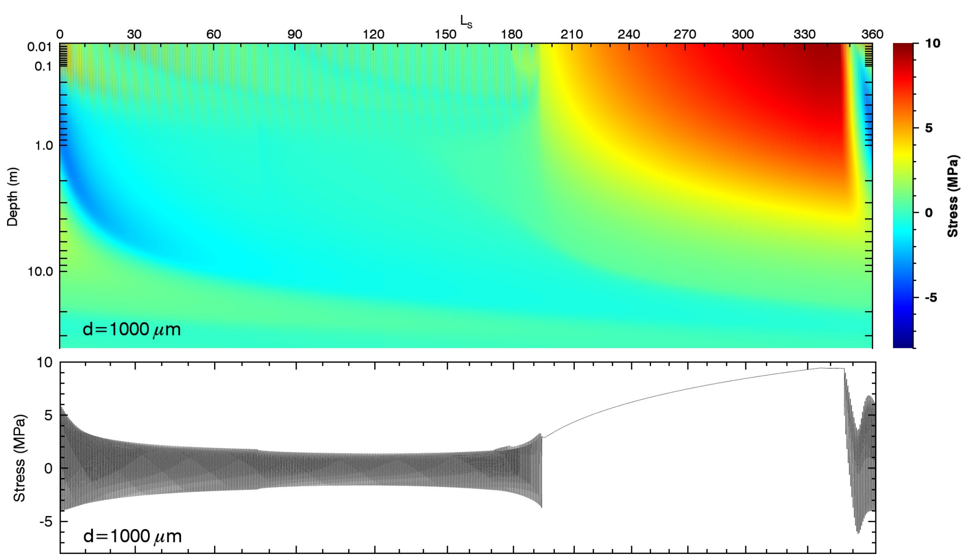

Figure 3. (Top) Thermoelastic stresses (positive is extension) on a southwest facing 70° slope as a function of depth and season. (Bottom) Stresses at the surface. Results shown for an ice grain size of 1mm.