GEOGRAPHIC VARIATION AND SEASONAL EVOLUTION OF STEEP NORTH POLAR SCARPS ON MARS.
P. S. Russell[1], S. Byrne[2], and A. Pathare[3], [1]Center for Earth and Planetary Studies, Smithsonian Institution, P.O. Box 37012, MRC 315, Washington, DC, 20013 (russellp@si.edu), [2]Lunar and Planetary Lab, Tucson, AZ, [3]Planetary Science Institute, Tucson, AZ.

Introduction: The north polar layered deposits of Mars (NPLD) are a stack of ice layers mixed with variable, yet minimal [1], amounts of dust, reaching up to several km in thickness. Under a large portion of the NPLD is a basal unit (BU) of interlayered dark sand and bright icy layers [2-6], up to several 100 m thick. Layering is thought to result from variations in deposition and erosion reflecting paleoclimate conditions. While this is largely attributed to relative availability and rates of deposition and sublimation of ice, mass-wasting processes likely play a significant role in eroding and shaping the peripheral bounding scarps of the NPLD and BU [3, 5, 7, 8], influencing both polar landscape evolution and surface-atmosphere volatile exchange cycles.

Mass-wasting processes identified include rock fall and rock avalanche-like shedding of slabs from NPLD scarps/cliffs [3, 5, 9], rock fall and rock slide-like detachment of blocks from fractured icy BU bright layers [5, 10], granular flow of sand in the BU [7], and powder avalanche-like cascading of fine material (some combination of dust, CO_2 frost, and NPLD material) from the face of the NPLD scarps/cliffs [8, 11].

Our present goal is to relate these mass-wasting processes to the physical scarp environment. We present two lines of investigation: the first is to characterize scarps by a set of physical metrics; the second is an intense study of the evolution of two scarps of particular interest over the spring and summer seasons for ~3 Mars years. The first addresses the large-scale current state of the scarps, the second addresses the surficial changes and current processes occurring in this setting.

Scarp Metrics: The scarps on which the above mass-wasting processes have been identified are distinct from the polar troughs in being steeper, located generally around the periphery of the NPLD, overlying an outcrop of BU, and hosting a fractured NPLD surface. In order to be objective and to compare these scarps to those scarps without the features described above, we select all scarps for which at least 2 pixels of a MOLA-derived slope map (~117 m/pxl) have values >30°. This includes the scarps in Chasma Boreale and around the periphery from ~90-270° E Lon, reflecting the extent of the BU, as well as peripheral trough faces from ~310-90° E Lon, where none of the above mass-wasting processes or fracturing have been observed (Fig. 1).

In order to make useful measurements from the MOLA data, which is coarsely gridded relative to the area of the scarps (typically ~0.5-2 km perpendicular to strike), and to achieve a concise representation of elevations, thicknesses, and slopes, which may vary significantly along strike, we use the following approach, within ArcGIS® software. The scarps are traced along strike at four levels, sampling the elevation every 20 m and then averaging to get a single value for each of these levels: lower scarp-plains contact, BU-NPLD contact, upper scarp lip/edge, plateau ~400 m back from the scarp. This yields average elevations, heights, and thicknesses. Length, orientation, and curvature are measured with distances between the two end points and the point on the scarp most convex/concave from a line connecting the end points. A scarp's slope is summarized with two values: the highest-value MOLA-slope pixel on the NPLD scarp, and the average of all slope pixels on the NPLD scarp.

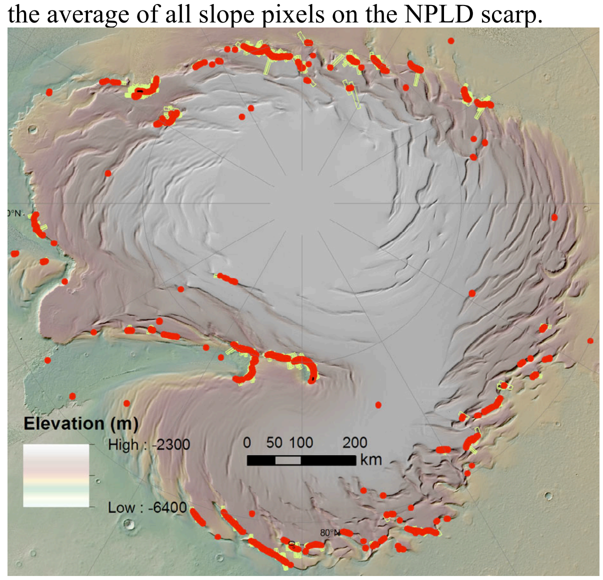

Fig 1. Distribution of slopes > 30° in the north polar region (red dots; from MOLA 512 px/deg gridded data) and HiRISE image footprints covering these points (yellow outlines).

Qualitative characteristics reflecting the processes of interest are the degree of mass-wasting activity, indicated by the amount and density of ice blocks and aprons on and below the BU, and the presence and expression of fractures and slabs on the NPLD.

The feedback between scarp characteristics and processes are potentially many and complicated. The presence of the sandy BU beneath the NPLD appears to lead to undercutting [3, 5, 7, 8], promoting steepening of the scarp, and this is likely important in initiating steep scarps from shallower ones when the BU becomes exposed and starts to erode. A steeper face at this latitude means more direct insolation, in which case both sublimation and thermal stresses (leading to fracturing and potentially accelerating mass wasting) may increase. Our results will help constrain modeling of these thermal stresses and fracturing, from which initial results actually suggest that very steep slopes may be less prone to fracturing [12, this conference].

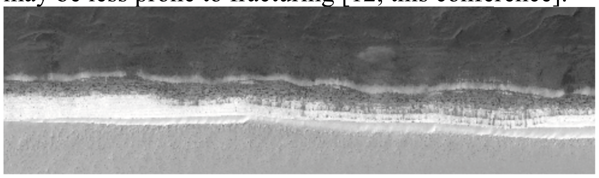

Fig. 2. North polar scarp at ~235 E Lon, with frost covering the plateau (bottom of image) and upper reaches of the NPLD scarp, a steep (darker) fractured cliff (slopes 30-70°), a band of fine-material accumulation at the NPLD base at the BU contact, and an active powder avalanche cloud rolling down the BU out onto the low plains (top of image). The NPLD cliff section is ~400 m high and only ~230 m wide (from foot to top). Portion of HiRISE PSP_007140_2640.

Seasonal Evolution: The two scarps investigated in this aspect are the scarp at ~235° E Lon at which powder avalanches were first discovered and at which the majority of them have been observed, and the eastern headscarp of Chasma Boreale, where mass-wasting debris fans and scattered blocks on the BU are among the most well developed and plentiful of all scarps.

The distribution in time of all HiRISE images at these two scarps is given in Table 1. Many images taken during the spring, when frost cover is evolving quickest and the powder avalanches are active, are available over 3 Mars years. However, due to a spacecraft safing and the timing of the avalanches discovery, there are images between Ls ~0-30° in only one year. Summer coverage, in which layering, mass-wasting deposits, and other features are best distinguished, extends over 4 years due to the arrival of MRO at Mars in late northern summer.

Location	Season	MY 28	MY 29	MY 30	MY 31	Total
SS	Spring	-	14	17	21	52
	Summer	2	4	5	9	20
CBHS	Spring	-	4	5	8	17
	Summer	2	2	3	3	10

Table 1. Number and image distribution in time at the Steepest Scarp (SS) and the easternmost Chasma Boreale Headscarp (CBHS). Spring is Ls 0-80°, Summer is Ls 80-170° as most of the CO_2 frost cover is gone by Ls 80°.

Images are normalized with basic corrections for incidence angle and the atmosphere. Because diffuse sky light illuminates shadowed regions (sufficiently for HiRISE to detect), the minimum image value from a shadowed region is subtracted from the whole image, yielding a better measure of the light reaching the camera that is due to reflected sunlight. This value is then divided by the cosine of the angle that the incident sunlight makes with an ideal Mars ellipsoid at the center of the image. This normalizes all images for illumination, but does not normalize all surfaces within an image (with each other). Thus, caution must be used in comparing the brightness on the steep scarps with shallower slopes and flat surfaces, yet relative change at one location from image to successive image may be tracked. Absolute values recorded by HiRISE are limited to accuracies of ~20% between images and ~5% within an image (between individual ccd segments) [13]. Because of this, ratios of brightness (between two locations) are better compared between images than single values. Scarp coverage in HiRISE's 3 broad color bands is less consistent as it is limited to the center 20% of the image width and targeting foorprints aren't perfectly aligned. The BG and IR typically have poorer SNR, yet color comparisons are insightful. We focus on qualitative patterns and trends through a series of images, keeping the above limitations in mind.

CRISM images of these two scarps exist, although seasonal coverage including spring coverage is much more sparse, existing in only one year. These data, in which CO_2 frost can be distinguished from H_2O ice (unlike with HiRISE), are processed with the current CRISM software and provide a compositional as well as regional check on HiRISE data (the CRISM footprint includes much more of the surrounding low plains and NPLD plateau than that of HiRISE).

The key determination to be made from this analysis is the Ls at which CO_2 frost clears from the NPLD scarp and BU. This serves as a test of whether CO_2 on the scarp may be a source for the powder avalanches. It also has significant implications for cycling of the seasonal, solar-driven thermal wave into the icy scarp face, influencing temperatures throughout the year, the stresses likely responsible for fracture formation [see 12], and possibly the detachment of blocks and slabs from the scarp face. In addition, the CO_2 accumulation on the BU, increased by material shed from the NPLD, may shorten the period of the year during which mass-wasting processes in the BU (hastened by wind- or sublimation-driven removal of dark sand and undercutting of icy layers [3, 5, 7, 8]) are active.

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