ACTIVE MASS WASTING OF ICE LAYERS AND SEASONAL CO_2 FROST IN THE NORTH POLAR REGION OF MARS.
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Introduction: HiRISE has discovered two significant forms of mass-wasting in the north-polar region. One is that bright layers of the north polar basal unit (immediately underlying the north polar layered deposits, NPLD) retreat scarpward by fracture-controlled and undercutting-assisted piecewise failure of layer edges, resulting in rockfalls and rockslides [1-3]. The other, completely unexpected and caught in-action during imaging, comprises falls and avalanches of frost and dust over a steep NPLD scarp during early spring CO_2 frost sublimation [4]. Here we report the latest findings in both of these dramatic and currently active processes in the north polar region.

NPLD and basal-unit mass wasting: The basal unit [5-7] is clearly subdivided into two main types of materials in HiRISE data [3]: a bright material expressed in outcrops as thin resistant layers, steep cliffs, and plateaus within the section, and intervening, dark material exhibiting lower slopes. Most bright layers are cut by fractures or joints, delineating polygonal blocks. This type of fracturing is also typical of the overlying lower PLD. Shadowing indicates that fractures between blocks become wider and deeper towards the layer edge, and some blocks here have rotated slightly away from the scarp face. Isolated clusters of loose blocks and fragments on shallower slopes below indicate that pieces of the layer edge eventually break off and fall away. This process is termed block-wasting here for brevity. A polygonally shaped recess in the edge of the fractured bright layer often indicates where a block has fallen away.

We have surveyed 166 HiRISE images covering ~63 individual basal unit-outcrop sites around the NPLD. Of these sites, 16 showed evidence of recent block-wasting activity in the form of scattered blocks and debris on basal-unit slopes. Other sites were characterized by a lack of blocks and loose debris and significant dark-sand cover. In general, the [potentially] active outcrops generally had a higher overall slope from outcrop top to bottom than the [potentially] quiescent outcrops. Most of the active outcrops also showed signs of debris likely detached from the above NPLD, in the form of wider patches and accumulating aprons of debris, more numerous and denser fields of individual blocks, and debris emplaced all the way up to the foot of the NPLD scarp [1,3,8], detailing a process of NPLD erosion proposed from MOC images [6]. Qualitatively characterizing the 16 potentially active outcrops into three groupings of 'likelihood of recent mass-wasting activity' (Fig. 1), and determining the overall slope of the local, overlying NPLD scarp from MOLA, we find that the outcrops with the most debris correlate generally with the steeper NPLD scarps. This further suggests that NPLD material is contributing to basal unit-outcrop debris, and that this type of mass-wasting is what is maintaining (and possibly creating) these steep scarps (often 45°-65°, with sections approaching vertical). An alternative for apparent lack of mass-wasting activity at basal-unit outcrops is a significantly higher rate of block destruction and/or a significantly higher rate of sediment (dark sand) through-transport by the wind.

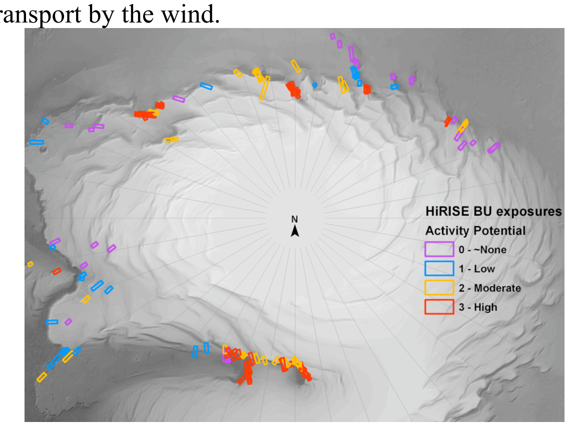

Fig. 1 Qualitative groupings of basal-unit outcrops with respect to likelihood of recent mass-wasting activity.

Finding only one instance of a newly appeared block-wasting event sourced in the basal unit within the first season of MRO observation [2,9], we present here the results of a survey of images of the same outcrops in the second season of MRO observation, in which several minor block-wasting events are identified, restricted largely to a few scarps. The most impressive example of mass-wasting is identified by a new deposits consisting of fine-grained dark material and resolvable, bright boulders encompassing an area ~ 160 m wide, covering the full ~250 m length of the basal-unit outcrop from head to toe, and marked with a pronounced, distal lobate front. Directly upslope, comparison of before and after images reveals the absence of a massive pre-fractured slab of the lowermost NPLD cliff, measuring roughly 4 m x 2-4 m x 20-40 m. This is the best confirmation of NPLD mass-wasting processes described by [1,6,8].

While the number of observations is still small, we attempt to place loose constraints on the rate and effectiveness of this important form of north polar erosion.

CO_2 frost-dust falls and avalanches: Nine frost-dust avalanches were observed in northern spring, Mars Year 29 (2008), between Ls 27° and 39° [4] (Fig. 2). Only one image is available from earlier in the season (Ls 14°). Coincident timing with local and polar regional CO_2 frost sublimation suggests a causal relationship. This and an apparent origin location on the scarp face suggest the events are triggered by sublimation-related or scarp-proximal atmospheric (e.g., wind gusts) disturbances.

We address several outstanding or poorly constrained issues with current imaging in this northern spring, Mars Year 30. Although there is direct evidence of wind gusts on the plateau above the scarp (in the form of localized, entrained, near-surface particle clouds seen in CTX and HiRISE data), no instances of particle clouds going over the scarp lip were ever observed, and plateau-gust and scarp-event observations were in mutually exclusive seasons. New observations will help constrain the source of these events by continuing or disrupting this trend.

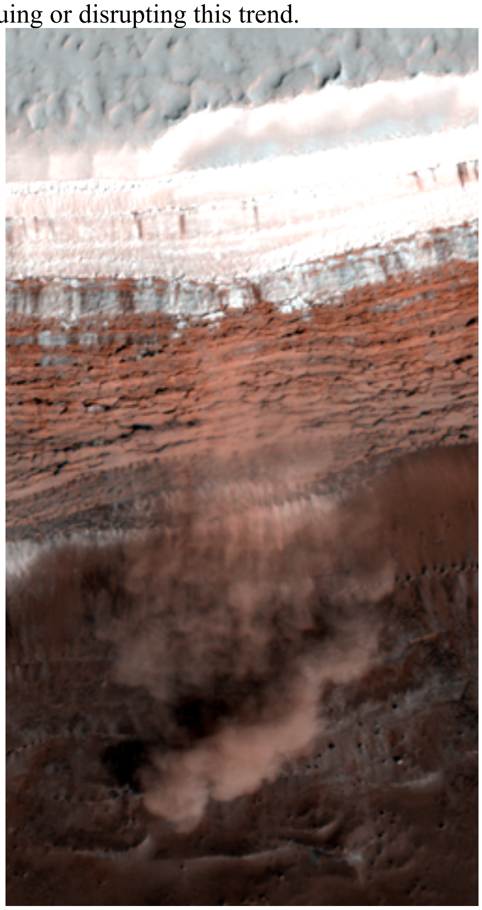

Fig. 2. Frost-dust avalanche observed in HiRISE PSP_007338_2640, Ls 34°, false color. White at top is CO_2 frost-covered polar plateau; light red mid-image is fractured NPLD; dark at image bottom is basal unit outcrop. This is the most well-developed of the observed clouds.

The Increasing confidence in the starting Ls and ending Ls (especially the former) of these events will help constrain the formation and trigger mechanisms as well as provide boundary conditions for thermal models of surface CO_2 balance and sublimation rate, enabling testing of the hypothesis of formation by disturbance due to expansion of sublimating CO_2 gas. Mechanisms of heat retention or CO_2 pressure within or just under a surface layer may be required to create such a disturbance, perhaps paralleling processes proposed for seasonal CO_2 activity elsewhere [10-13].

The speed of the most prominent avalanche cloud (Fig. 2) at the base of the scarp is estimated theoretically (considering a moving mass of particles with low equivalent coefficient of friction) to be ~ 40 m s^{-1}. The maximum settling velocity of individual particles, e.g., stripped from the margins of this moving body, is calculated at 0.25 m s^{-1}. This value could be altered by local turbulence, but relative to the speed of the advancing mass, explains why we see the trailing clouds (8 examples) and why this is more commonly observed than the well developed fronts (1-2 examples).

No missing NPLD blocks on the scarp face or new blocks below the scarp face in subsequent images have been unequivocally attributed to or associated with these events. This suggests that these seasonal events may not play a large role in NPLD mass wasting described above and elsewhere [1-3,6]. However, the appearance, within a window of 29 days and after an avalanche, of two new blocks a few meters below an apparent disturbance in a basal-unit bright layer, suggests that the passing avalanche cloud disrupted blocks at the edge of basal-unit bright layers that were on the verge of falling already. This would tend to accelerate the type of mass-wasting discussed above.

Prolonged MRO safe-mode has precluded imaging the polar region at first spring light, before and around Ls 0°, so the earliest potential start date for this activity can not be determined this Mars year. However, imaging at Ls 25° and after will still help to further constrain many aspects of the above, with imaging to the end of February covering the whole activity period observed in the first year. Another line of investigation tests the geographic extent of these events during their activity period, monitoring several scarps within ~100 km of the original discovery scarp, and several scarps scattered around the margins of the NPLD.

References: [1] Russell P. S. et al. (2007) *LPSC XXXVIII* #2358. [2] Russell P. S. et al. (2008) *LPSC XXXIX* #2313. [3] Herkenhoff K. E. et al. (2007) *Science, 317*, 1711-1715. [4] Russell P. S. et al. (2008) *GRL 35,* L23204, doi:10.1029/2008GL035790. [5] Byrne S. and Murray B. C. (2002) *J. Geohys. Res., 107 E6*, 5044. [6] Edgett K. S. et al. (2003) *Geomorph., 52*, 289-297. [7] Fishbaugh K. E. and Head J. W. (2005) *Icarus, 174*, 444-474. [8] Russell P. S. et al. (2007) *7th Int. Conf. Mars* #3377. [9] McEwen A. et al. (2010) *Icarus*, in press. [10] Kieffer H. H. (2000) *LPI Contribution* #1057. [11] Hansen C. J. et al. (2010) *Icarus*, in press. [12] Portyankina G. et al. (2010) *Icarus*, in press. [13] Hansen C. J. et al. (2010) *LPSC XL*, this conf.