SEASONALLY ACTIVE DUNE SLIPFACE AVALANCHES ON MARS: EVIDENCE FOR A WIND-RELATED ORIGIN. B. Horgan[1], R. Sullivan[2], J. F. Bell III[1], [1]School of Earth and Space Exploration, Arizona State University (briony.horgan@asu.edu), [2]Center for Radiophysics and Space Research, Cornell University.

Introduction: The north polar erg of Mars is one of the largest sand seas in the solar system, and appears recently active, as most dunes exhibit crisp or minimally degraded brinks, low dust cover (suggesting recent saltation), a minimum crater retention age, and changes in some stoss and lee slopes consistent with migration rates on the order of 1 meter/year [1]. Recently, [1] reported observations of seasonally active mass wasting on dune slipfaces in the uppermost region of Chasma Boreale (Tenuis Cavus) concurrent with springtime CO_2 sublimation, as well as the appearance of features on slipfaces having alcove and fan morphologies. Because the features are apparent on the slipfaces after the CO_2 frost is gone but not in images from early in the previous summer, the origin of these features was attributed to mass wasting during sublimation. However, in this study we have used high-resolution images (25 cm/pixel) from HiRISE to show that the alcoves and fans are apparent under the CO_2 frost prior to sublimation, and that the morphology and orientations of the features are instead consistent with an aeolian origin in mid- to late summer.

Alcove and fan morphologies: Alcoves are the most common slipface features we observed in the north polar sand sea. Alcoves are wedge-shaped sloped depressions above fan-shaped deposits [1] (Fig. 1). Alcove widths are typically on the order of ~2-10 m, but range up to several hundred m. Regardless of size, alcoves are easily identifiable under favorable lighting conditions because of their surface relief. Individual alcoves commonly cluster or overlap on slipfaces, producing a sawtooth morphology (Fig. 1). Most fan deposits appear to be conical, smooth, and symmetric, without evidence for lobate flow features or multiple flow events, and generally do not extend far beyond the base of the slipface. Alcoves are found throughout the north polar sand sea, but vary in areal density: most dune fields exhibit scattered, isolated alcoves, but barchan dune fields adjacent to polar scarps commonly exhibit many alcoves per slipface. Overall, the relative freshness of the alcoves and fans mimics that of the slipfaces on which they occur. Most alcoves exhibit signs of degradation through modification by ripples, perhaps indicating less recent formation. Exceptions include fresh-looking alcoves and fans in Tenuis Cavus, which have been recently active [1].

Seasonal changes: Slipface alcoves are actively forming under modern climatic conditions. [2] reported observations of new, isolated alcoves forming between consecutive summers in Mars Years (MY) 28 and 29 in the mid sections of Chasma Boreale, and [1] reported observations of abundant new alcoves forming in Tenuis Cavus between early summer of MY 29 and spring of MY 30. Based on a strong association between these new alcoves and spring mass wast-

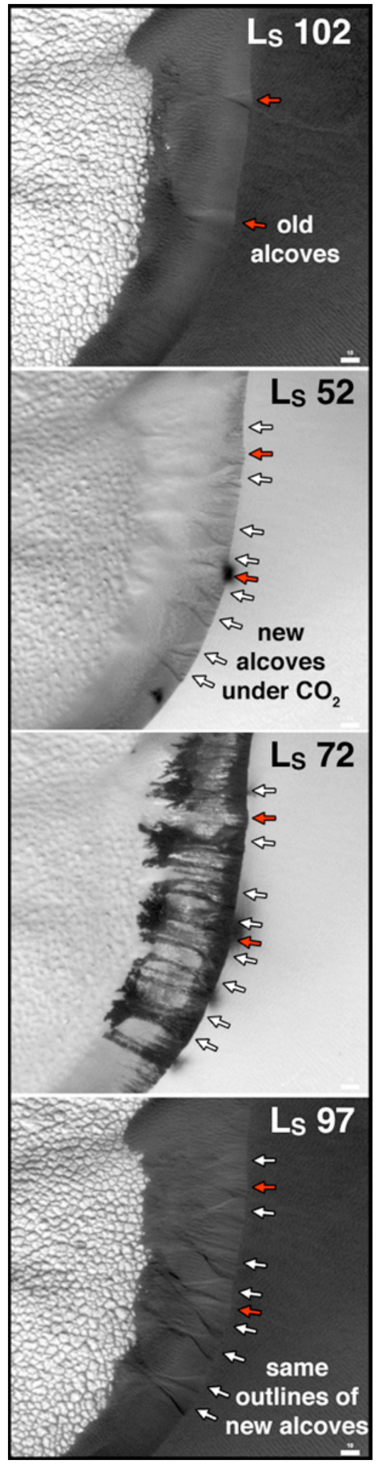

Figure 1: Alcove formation between early summer of MY29 and early spring of MY30 in Tenuis Cavus (3°E, 84°N). While some modification does occur during CO_2 sublimation, the new alcoves (white arrows) and their associated fan deposits are already apparent beneath the thinning CO_2 frost by L_s = 52° (mid-spring), implying formation prior to CO_2 deposition in the fall. Where they are present, old alcoves (red arrows) appear to undergo overprinting and modification due to formation of new fans. All scale bars are 10 meters. HiRISE images from top to bottom: PSP_009324_2650, ESP_016682 _2650, ESP_017249_2650, ESP_017974_2650.

ing on slipfaces at L_s = 59°, [1] hypothesized that the alcoves form during this time period (mid-spring) due to mass wasting triggered by CO_2 sublimation. However, analysis of a sequence of images bracketing this date (Fig. 1) shows that the alcoves are clearly already present under the thinning CO_2 frost prior to exposure of the underlying sand and initiation of mass wasting, as identified by the outlines of their sharp sides and associated fan deposits. A search for new alcoves in a sequence of co-registered HiRISE images from MY 29 and 30 in the Tenuis Cavus dune field revealed that of the 228 slipfaces examined, 170 (75%) exhibited new alcoves, and in 140 (82%) of the changed slipfaces, the new alcoves are visible under the CO_2 frost. Thus, while CO_2 sublimation could cause additional mass wasting and minor modification of these features, our survey reveals that their primary formation mechanism does not appear to be related to CO_2 sublimation. The new alcoves appear to be preserved underneath the frost, and they most likely formed prior to deposition and annealing of the thick CO_2 slab, which begins near L_s = 170-180° (early fall) at the 84°N latitude of Tenuis Cavus [3]. The last MY 29 image of this dune field prior to formation of the new alcoves was at L_s = 102° (Fig. 1), placing the formation of the alcoves sometime during the mid to late summer.

Alcove orientations: The association noted above between fresh slipfaces and fresh alcoves suggests a relationship between alcove formation and dune activity. If alcove formation is related to recent dune activity, we might expect to see some correlation between alcove orientations and recent winds. Our detailed analysis of 17 HiRISE images in Olympia Undae (OU) reveals that alcoves have a strikingly uniform orientation within each image (Fig. 2), varying from SE-facing in Eastern OU to NW-facing in Western OU, consistent with contemporaneous formation during the most recent strong wind event. Furthermore, there is an apparent correlation between the orientations of dune brinks at the location of slipface alcoves and adjacent stoss slope ripples (Fig. 2), suggesting that the most recent sand-transporting winds flowed directly over alcove-bearing slipfaces.

Discussion: Based on our analysis, initiation of new slipface alcoves and fans in the north polar sand sea of Mars by CO_2 frost sublimation is inconsistent with observations from our extensive spatial and temporal survey of these features. Instead, the summer timeframe, association with dune activity, and relationship with recent winds that we demonstrate above, all support an origin for the alcoves related to aeolian processes. Indeed, the morphology of the alcoves is consistent with a dry granular flow created during localized collapse of the slipface, which on terrestrial dune slipfaces is triggered by over-steepening caused by deposition of saltating sand [4]. This type of failure occurs when a very small flow initiates on the slipface, creating an initial breakaway scarp, which expands laterally and moves upslope, forming an alcove at the dune brink [4,5] and a bottleneck at the point of greatest slope on the slipface [6] (Fig. 3). While martian north polar dune slipface alcoves and fans resemble terrestrial dune features, the scale is different. Terrestrial dune alcoves typically are ~50 cm wide and no more than a few cm deep [7], while martian alcoves typically are meters to tens of meters in width and appear to be meter-scale in depth. The difference in scale may be attributable to the effects of differerent gravity on the static and dynamic angles of repose, which are similar on Earth but predicted to be less so on Mars [8]. Although it has long been assumed that angles of repose do not vary with gravity, recent reduced gravity experiments have shown that the dynamic angle of repose is 20-30° less than the static angle of repose under Mars-like gravity [8]. If so, once failure is initiated on a martian dune slipface, the associated collapse will be much larger than on a terrestrial dune, and the associated fan deposits will run out much farther and at a shallower angle.

References: [1] Hansen, C.J. *et al.* (2011) *Science*, *331*, 575. [2] Horgan, B.H. *et al*. (2010) LPSC XLI, #1325. [3] Kelly, N.J. *et al.* (2007) *JGR*, *112*, E03S07. [4] Hunter, R.E. (1977) *Sedimentology*, *24*, 361. [5] Lindsay, J.F. (1973) *GSA Bull.*, *84*, 1799. [6] Anderson, R.S. (1988) *Sedimentology*, *35*, 175. [7] Lowe, D.R. (1976) *J. Sed. Petrol.*, *46*, 188. [8] Kleinhans, M.G. *et al*. (2011) *JGR*, 116, E11004.

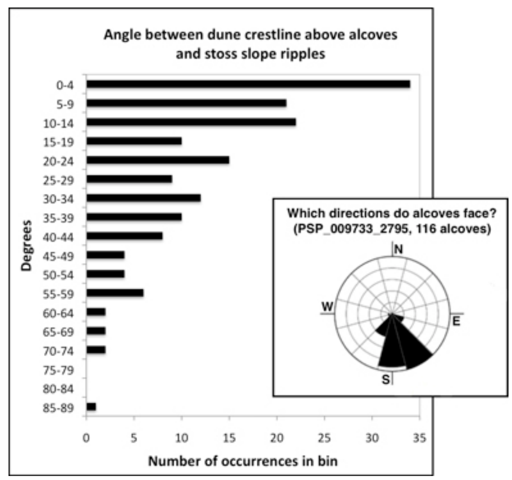

Figure 2: Alcove and ripple orientations in one image (PSP_009733_2795, Olympia Undae). Ripples are commonly parallel to sub-parallel to dune crests above alcoves. *Inset:* These alcoves only occur on ~S-SSE facing slopes.

Figure 3: Formation of alcoves in the White Sands dune field. Region of failure is about 3 m across, and typical alcove depths are a few centimeters (R. Sullivan).