WIND AND DRY ICE: AGENTS OF CHANGE ON MARS' NORTH POLAR ERG. C. J. Hansen[1] , S. Diniega[2], N. Bridges[3], S. Byrne[4], C. Dundas[5], A. McEwen[4], G. Portyankina[6], [1]Planetary Science Institute, 1700 E. Fort Lowell, Suite 106, Tucson 85719, cjhansen@psi.edu, [2]Jet Propulsion Lab / California Institute of Technology, [3]John Hopkins University / Applied Physics Lab, [4]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, [5]US Geological Survey, Flagstaff, AZ, [6]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO.

Introduction: Images have been collected by the High Resolution Imaging Science Experiment (HIRISE) on the Mars Reconnaissance Orbiter (MRO) of three northern spring seasons spanning Mars Year (MY) MY29 – MY31. In order to explore the processes responsible for changes observed on the dunes such as new alcoves and debris aprons [1] the third northern spring campaign featured an earlier start and more complete temporal coverage than in earlier years. Competing hypotheses have been proposed – that wind is solely responsible for changes [2], or that seasonal processes involving the sublimation of the seasonal CO_2 ice layer are responsible [3, 4]. The two possiblilties can be tested by observing when changes take place. We compared ice-free images to identify changes from one Mars year to the next, then went through the entire image sequence to establish when the change took place.

Dry Ice Mechanism: Every year dynamic seasonal sublimation activity occurs on Mars' vast north polar erg. As the seasonal CO_2 ice cap sublimates a variety of phenomena are observed. The Kieffer model, developed to explain seasonal activity in the southern hemisphere cryptic terrain [5], appears to also form a good framework for our understanding of northern seasonal processes. In the Kieffer model penetration of sunlight through translucent CO_2 ice warms the surface below, which leads to basal sublimation of the ice layer. Trapped gas escapes through ruptures at weak spots, entraining surface material which then settles out in fan-shaped deposits oriented by wind or slopes on top of the ice. Hansen [1] attributed formation of new alcoves to the destabilization of the dune brink via this gas escape. As shown in Figure 1 this may occur, however our new analysis shows that this is not the dominant process each year.

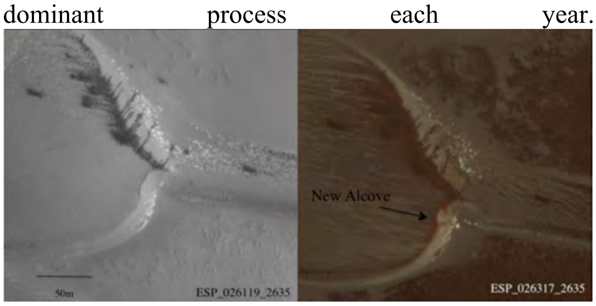

Figure 1. This new alcove formed between L_s 74 and L_s 80. The dune was partially covered with ice.

Eolian Mechanism: Horgan and Bell [2] proposed that the formation of alcoves is driven solely by the eolian sequence of deposition, oversteepening of the slipface, followed by localized failure and dry granular flow, due to summer winds. One challenge with this hypothesis however is that we might expect to see similar alcove formation rates at all latitudes, but even on very active dune fields at more equatorial latitudes formation of a new alcove is a rare event [2, 6]. In the north polar erg images no changes were detected on the dunes in the summer. That may simply mean that autumn winds are responsible, not summer winds which are expected to be weaker.

New Findings: Figure 2 shows a very typical sequence, applicable to most of the new alcoves we found. A new alcove identified in ice-free images with similar illumination has already occurred by the time of the first image taken in spring. Examination of the last image acquired in the previous summer does not show the change, eliminating summer winds as the cause. This pre-dawn timing also is inconsistent with the models proposed in [3] and [4] that invoke CO_2 gas destabilization of the dune due to absorption of solar energy and basal sublimation of the ice.

Figure 2. The ice-free left and right images were aquired with similar lighting to enable identification of changes from one Mars year to the next. The center image shows that the new alcove had already formed by the time the first image was taken in spring at L_s 2. It is also the site of very early spring sublimation-related activity.

Another time period that showed a concentrated set of changes occurred in very late spring when the dune slipfaces were largely ice-free, suggesting sand may have been held in place by the seasonal ice, but that as soon as that ice sublimated the sand was free to flow.

Seasonal Control: Most (but not all) new alcoves form in the period of time that HiRISE cannot image: autumn when light levels are too low to see subtle details on the dark sand dunes, and the polar hood is encroaching, and winter, when polar night falls. The dominance of change in that period suggests a seasonal control.

Once the dunes are blanketed with frozen CO_2 winds will not have an effect. That means that there is a fairly constrained window for winds to be effective agents of change, given that summer winds do not seem to be adequate. Fierce autumnal winds would have to be the culprit.

A seasonal control involving sublimation of CO_2 ice would be consistent with well-established results from the changes observed on the dunes and gullies in the southern hemisphere [7, 8]. Given the very low rate of alcove formation on dunes at more equatorial latitudes a process involving CO_2 ice that would only be effective at high latitudes is logical. So a new avenue of investigation is to model what sorts of forces would be in effect in the fall and winter that could cause new alcoves to form. For example is there a point at which simply the additional weight of the CO_2 causes a sand avalanche?

Interannual variability: A great deal of interannual variability in alcove formation has been identified across the three northern spring seasons, MY29 – MY31, observed. Figure 3 shows sites of new alcoves at one of our study locations, indicated by white (MY28-29), red (MY29-30), and yellow (MY30-31) dots.

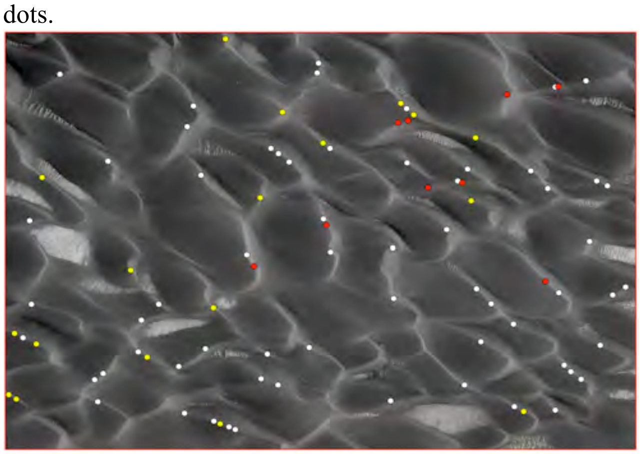

Figure 3. This region of a dune field known informally as "Tleilax" is about 2 x 3 km. The vast majority of new alcoves formed in the winter of MY28 (white dots). Only a handful (red dots) formed in the winter of MY29.

An interesting possibility inspired by this finding is that interannual variability in alcove formation can be traced to interannual variability in the amount of CO_2 deposited and/or wind speeds. Although we tend to think of Mars meteorology in broad climatic terms, it is possible that differences in regional weather is responsible for this variability. Comparing Mars years and study sites the trends are not the same - this implicates meteorological phenomena associated with regional storms, rather than for example global dust storms.

The comparison of images across Mars years also gives us a sense of the timescale for degradation of new alcoves. Degradation occurs rapidly. Most of the new alcoves identified in MY28-29 had been erased two Mars years later.

Conclusions: Our results show that formation of alcoves should not be attributed to solely one process. It is likely that "all of the above" is the correct answer – that autumn winds oversteepen the dunes such that when the frost begins to condense the crest is destabilized and new alcoves form early in winter, covered by continued frost accumulation. In early spring there are the occasional mass wasting events as blocks of ice fall and trigger sand avalanches. In late spring the weight of the ice on the stoss and sublimating gas destabilizes the ice-free slipface.

HiRISE is uniquely suited to studying dynamic processes, including the migration and seasonal changes of dunes and ripples. Now into its 4th martian year of observations, HiRISE has accumulated a detailed record of changes over multiple seasons. We still have much to learn about the dynamic nature of Mars, slowly being revealed.

References: [1] Hansen, C. J. et al. (2011) *Science, 311, 575-578*. [2] Horgan, B. H. and J. F. Bell (2012) *GRL 39, L09201*. [3] Hansen, C. J. et al. (2012) *Icarus, 225, 881-897*. [4] Cedillo-Flores, Y. et al. (2011) *GRL, 38, L21202*. [5] Kieffer, H. (2007) *JGR, 112*, E08005. [6] Chojnacki, M. et al., (2013) *Icarus, in press*. [7] Diniega, S. et al. (2010) *Geology, 11, 1047*. [8] Dundas, C. et al. (2012) *Icarus, 220, 124.*

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