CORRELATING PRESENT-DAY SURFACE AND SUBSURFACE FROST CONDITIONS WITH GEOMORPHOLOGIC ACTIVITY ON MARS.

S. Diniega[1], J.M. Widmer[2], C. Gary-Bicas[3], A.A. Fraeman[1], P.O. Hayne[3], S. Piqueux[1]. [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109, USA (serina.diniega@jpl.nasa.gov), [2]University of Maryland, [3]University of Colorado, Boulder.

Introduction: Dune-alcoves are triangular erosional features found at the top of a dune brink, that often grade into broad depositional fans that extend down the steeper downwind dune slopes (Figure 1). In the north polar region, dune-alcoves have been observed to form annually over the last ~decade, with their timing of formation constrained to the frosted portion of the year [1-3] – thus suggesting that dune-alcove formation is driven by specific frost conditions within the present-day martian environment. Constraining specific environmental drivers for the formation of these dune-alcoves would allow these small-scale landforms to be used as proxy records of the present-day local-scale martian surface environment. Such a proxy record would be complementary to existing surveys of present-day frost conditions – which tend to be based on coarse-resolution, global datasets (e.g., based on MOLA and THEMIS [4], ODY GRS [5], and MCS and TES data [6]).

However, limitations in the observational record available for the north polar dune fields do not allow for the formation conditions of these features to be fully determined. Two ways to address this gap and further this investigation are to observe analogous features within other martian regions (specifically, the northern mid-latitudes) and consider observational data beyond visible images.

Thus, our study aims to characterize the surface frost environment within northern mid-latitude dune fields, and then compare specific frost types and timing to the formation (or not) of dune-alcoves. We have surveyed 38 northern mid-latitude dune fields to determine which of these contained alcoves (which can then be compared with the 7 polar fields previously studied [1]). We focus on six specific fields (3 with dune-alcoves and 3 without, Table 1) that have higher coverage in visible (HiRISE, CTX), near-IR (CRISM), and thermal (THEMIS, MCS) datasets; by detecting frost through visible appearance (i.e., transient brightness), spectral signatures of frost compositions, and surface temperatures, we are better able to characterize the frost environment over these sites [7].

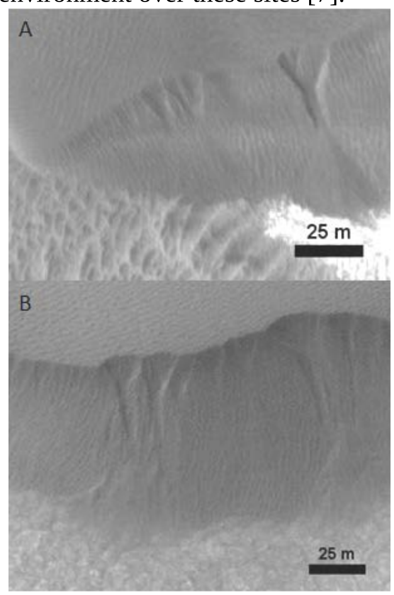

Figure 1. *Dune-alcoves are found in many (but not all) north mid-latitude and polar dune fields, such as Lyot Crater (A: 50.3ºN, 28.9ºE) and Palma dune field, (B: 76.2ºN, 95.4ºE). In both HiRISE images, the dune brink (which marks a change in dune slope) extends through the upper half of the image and exposed inter-dune substrate at the bottom. The dune-alcoves (i.e., triangular "bite" from the dune brink) extend downslope, often ending with an apron. Illumination is from left. HiRISE images: (A) ESP_044334_2305, MY33* L_s *93.5; (B) ESP_018525_2565, MY30* L_s *116.1.*

Study sites (dune field ID/crater)	Lat/Lon	Alcoves	HiRISE	THEMIS		CTX	CRISM FRT
				IR	VIS		
9	64.5°N, 315.9°E	Y	15	45	8	18	8
43	63.8°N, 292.1°E	Y	5	36	17	29	8
86	58.3°N, 89.6°E	N	27	28	12	29	3
47/Milankovic	54.5°N, 213.5°E	N	4	52	15	8	7
3/Lyot	50.0°N, 28.9°E	Y	18	71	42	30	10
10/Moreux	42.0°N, 44.1°E	N	5	59	13	26	8

Table 1*. Observations of the six study sites (ordered by latitude). Sites containing dune-alcoves are highlighted. MCS data counts are not shown - all sites have >100 MCS observations within ~100km (most have several 100s).*

Existing hypotheses: A study of seven polar dune fields over four Mars years has shown that dune-alcove formation most likely occurs after frost has started to form on the dunes, in early autumn [1]. Based on this timing, a connection to early diurnal frosts has been hypothesized [1], and laboratory experiments have shown that sublimation of a small amount of surface condensate can yield at least small-scale mass-wasting [8]. Alternatively, a control by CO_2 snowfall has been investigated [9-10], but a clear connection to total snowfall or early snowfall has not been found consistently through all fields. Based on this, a hypothesis that early snowfall interacts with early surface frost causes mass-wasting has been proposed [10].

Current results

1) Early snowfall and seasonal frost? Based primarily on MCS surface brightness temperatures [7,9,11], CO_2 snowfalls have been detected in 5 of these mid-latitude fields, over Mars Years 28-33. All 3 of the fields that contain alcoves have stable seasonal frost (i.e., CO_2 frost detected in ~3pm observations) as well as an observed snowfall that occurs within ~10 L_s of initiation of a frost layer. However, field 86, which does not contain alcoves, also exhibits this pattern of early snowfall. A potential mitigating factor is that we are currently considering data from all Mars years together (i.e., ignoring interannual variations); a next step is to consider frost conditions within individual years, which may clarify the controlling frost types and timing especially if an interaction between frost types is key.

2) A connection to subsurface ice? Of the categorized 38 fields, we note a potential anti-correlation between fields containing dune-alcoves and higher levels of subsurface water ice (Figure 2), suggesting that mid-latitude dune-alcoves may not form over larger amounts of near-surface ice. This could be consistent with an early frost-driven process as thermal inertia effects of subsurface ice close to the surface would delay the formation of CO_2 frost [12-13]. This also could be a moderating factor in the general alcove-formation model (and accounting for e.g., field 86). These ideas will be explored further.

Potential science advancement: If dune-alcoves can be interpreted as proxy records of specific frost types and amounts in the present climate, then the presence (or absence) of dune-alcoves could be used to identify local-scale, present-day frost environments across a broad swath of Mars. Thus, this work could yield a novel map, complementary to existing maps, of the present-day martian frost distribution based on geomorphic markers.

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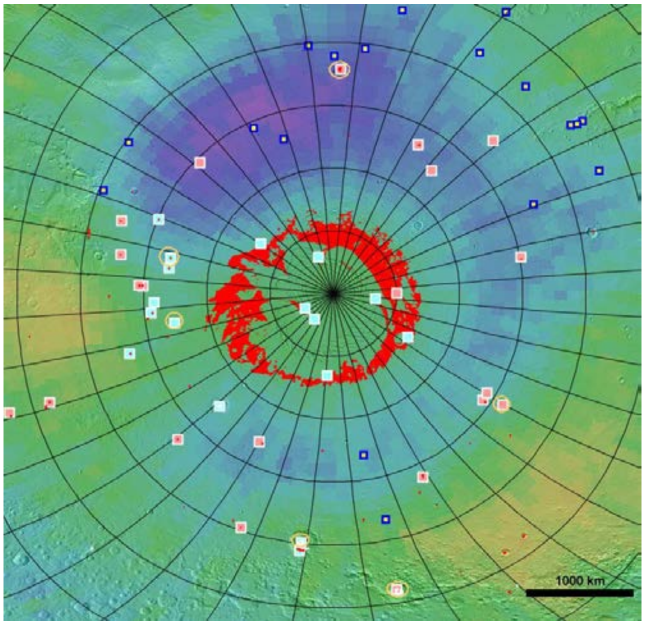

Figure 2. *Map of 38 mid-latitude and 7 polar dune fields, categorized as containing dune-alcoves (pale blue squares) or not (pink); orange encircles our six study sites. Polar [14] and mid-latitude dunes (pers. comm. Lori Fenton) are in red, overlaying a MOLA shaded map and Mars Odyssey Neutron Spectrometer (NS) epithermal counts [15]. The NS layer shows blue/purple with low neutron counts, interpreted as the presence of high amounts of water ice within the upper meter of the surface [16-17] (and this interpretation is consistent with the locations of fresh icy craters (dark blue) [18]). The water ice-richest areas appear anti-correlated with the locations of dune-alcoves. Lat/long lines are 10° apart; 0°E extends down.*

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