PRESENT-DAY FROST-DRIVEN GEOMORPHIC CHANGES ON MARTIAN NORTHERN DUNES.
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Introduction: Over the last ~decade, many small-scale geomorphological changes on martian sandy slopes have been identified and studied, occurring on ~annual timescales. In some sites where the timing of activity has been constrained to a portion of a Mars year, the formation of features has been tied to periods when frost is accumulating or sublimating [1-8]. This, together with other data such as location of these features within areas that are covered seasonally by frost [4,9-10], strongly suggests that martian CO2 frost and ice, especially when interacting with a granular surface, is an effective geomorphic agent (at least during ‘Late Mars’) and should be considered, with wind and impacts, when interpreting martian geomorphology. Additionally, some estimates of present-day rates of activity have led to the suggestion that CO2-driven processes may account for many features that have previously been hypothesized to be ‘fluvial’ features [e.g., 4].

This work will summarize current results and ongoing studies of martian landforms found on dunes in the northern hemisphere (i.e., dune alcoves and ‘troughs’) observed to be active over seasonal-to-decadal-timescales and hypothesized to have activity connected to the accumulation and/or sublimation of seasonal frost. Potential connections of these features to active landforms in the southern hemisphere (e.g., dune gullies, linear gullies, araneiforms) will be noted and implications regarding hemisphere- or regional-scale CO2 frost/ice condition differences will be discussed.

The northern landforms:
• Alcove-apron features have been observed to form annually in the north polar [6-8,11] and mid-latitude [12] dune fields (Fig. 1). In at least the polar fields, this mass-wasting is thought to account for 2-20% of the overall sand movement over the dunes [8]. Within the north polar erg, alcove formation has been constrained to the frost-ed seasons, but unlike active martian dune-gullies in the southern hemisphere which is tied to sublimation in late winter/early springtime [2-5], appears to occur during early autumn [8,13].
• ‘Troughs’ are also found to form annually, extending from the crests of the north polar dunes (Fig. 2). It is not yet clear if these features are more similar to linear gullies which form due to sliding/rolling of a CO2 ice block downslope [14] or if they are more similar to dune furrows [15-16] extending from the margins of north polar dunes or araneiforms [17] seen in the southern hemisphere, both of which are hypothesized to form due to gas flow beneath a translucent CO2 ice slab [16-21].

Figure 1. Dune alcoves in a northern mid-latitude (A) and polar (B) dune field. Examples shown here are from Lyot Crater dune field (50.3ºN, 28.9ºE, ESP_044334_2305) and Palma dune field (76.2ºN, 95.4ºE, ESP_018525_2565).

CO2 frost and ice surface-interactions:
In this and many previous works, we have focused on CO2 frost and ice as a driver for observed geomorphic activity as this volatile makes up 96% of the martian atmosphere [22]; accumulates on the martian surface in significantly greater amounts than water frost/ice (e.g., compare [23] with [24]); and – when information is available – coincides better with the timing of surface landform activity. Solid CO2 can interact with the martian surface via these forms:
- As the autumn season cools, transient (diurnal) frost can condense on the martian surface. Such frost has been observed in low latitudes [25] and laboratory experiments have shown it can induce at least small-scale mass-wasting within granular material at or below the angle of repose [26].
- Seasonal frost accumulates within latitudes poleward of ~30° [27], with depths increasing up to tens of centimeters in the polar regions [22].
- As winter progresses, the CO₂ frost anneals into denser slab ice [28]. The formation of slab ice across our studied dunes is supported by the appearance of cracks across the frosted dunes surfaces in the spring.
- In the spring, blocks of CO₂ ice can be cold-trapped in alcoves, while ice on the dune slipface sublimes. When these ice blocks break free, they can slide over the warmer exposed dark sand. Such blocks have been observed on the martian surface [e.g., 3]; terrestrial field experiments have shown that such blocks can easily ‘hovercraft’ down dune slopes, carving out a track [14,29]; and laboratory experiments under martian winter-time conditions show that stationary subliming blocks can create pits [16].
- Snowfall also occurs in the polar regions [30] and may influence some large-scale mass-wasting activity observed on north polar dunes [13]. Several CO₂-frost driven mechanisms have been proposed as possibilities for the types of present-day martian surface activity discussed in this presentation, but generally the exact drivers/process(es) for feature formation are still under investigation.

In our study, we are monitoring and measuring dune alcove and furrow activity within both the polar and mid-latitudes [12,31] so as to to identify latitude- variations in the timing/magnitude of frost formation and use these to constrain the relevant frost environment for causing the observed geomorphic changes.


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Figure 2. Image of a ‘trough’ – extending down the stoss slope (middle arrow, at dune brink). Note that it curves (lower arrow) and cuts across the ripple pattern on the stoss slide. On the lee side, a slump/track extends from the same point, ending in an area of the apron that appears to have been cleared (top arrow). This example is from Kolhar dune field (84.7°N, 0.7°E, ESP_017895_2650).