Investigating the POLEWARD TREND OF SOUTHERN DUNE FIELD STABILIZATION on Mars Using Thermophysical Observations

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Synopsis

Dune fields in the southern Martian hemisphere have morphologies indicating a **poleward progression toward stabilization** starting near 50-60° S. Separately, near-surface ground ice is suspected to span the hemisphere poleward of ~50° S. We hypothesize that the southward increase in stabilization may be **caused by an intradune ice table** that is shallower at higher latitudes, a linkage that would make dune morphology a **tracer of local climate**. We use thermal inertia measurements and multi-layer thermal modeling to infer near-surface properties, including ice table depth. We have begun analyzing the largest 171 southern dune fields with well-defined morphologies. So far, we've found the dune thermal behavior to be consistent with crust overlying dust, rather than sand over ice, indicating there is more to the picture than initially suspected.

The Hypothesis

It's known that **ice can cement sand** in place [5], and Fenton and Hayward's dune morphology transition begins about where ground ice becomes prominent [see **The Evidence**, below]. It's suspected [4] that this correlation is a causation: at more balmy, northern latitudes, dunes are solely loose sand, swept about by wind that keeps them looking fresh and sharp. Closer to the poles, rising ground ice **freezes the dunes in place**, subjecting them to non-aeolian **erosion** that rounds and eventually flattens the dunes.

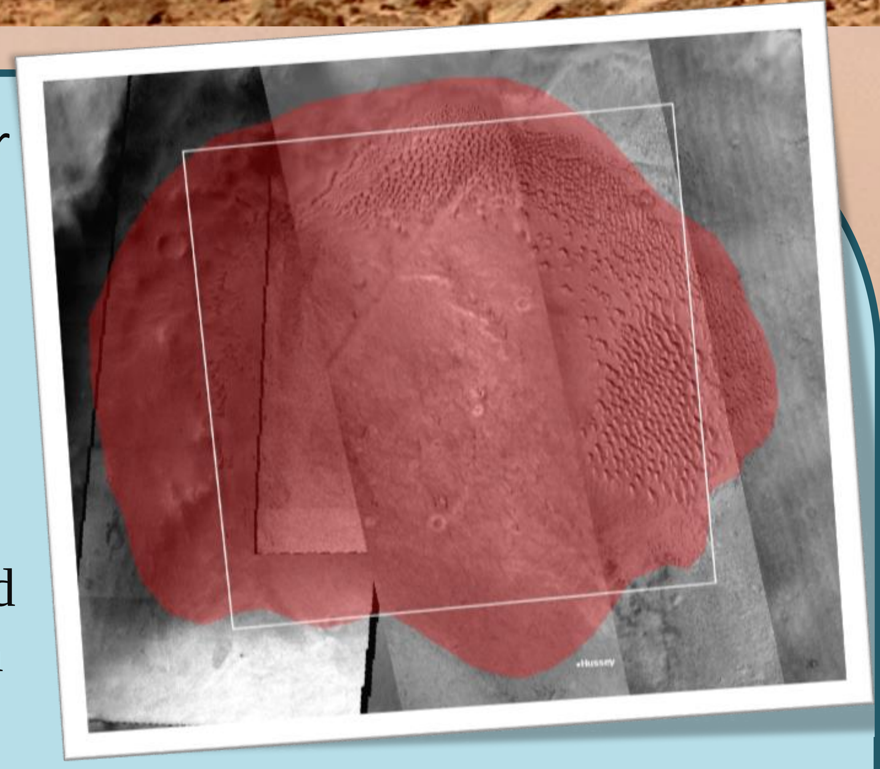
High-resolution images do not reveal any craters on these frozen-in-place dune fields, indicating the dune surfaces are young, perhaps even under 100 years old [6]. This suggests that, if morphology and ground ice are linked, dune morphology is a direct indicator of **current climatic conditions.**

The Science

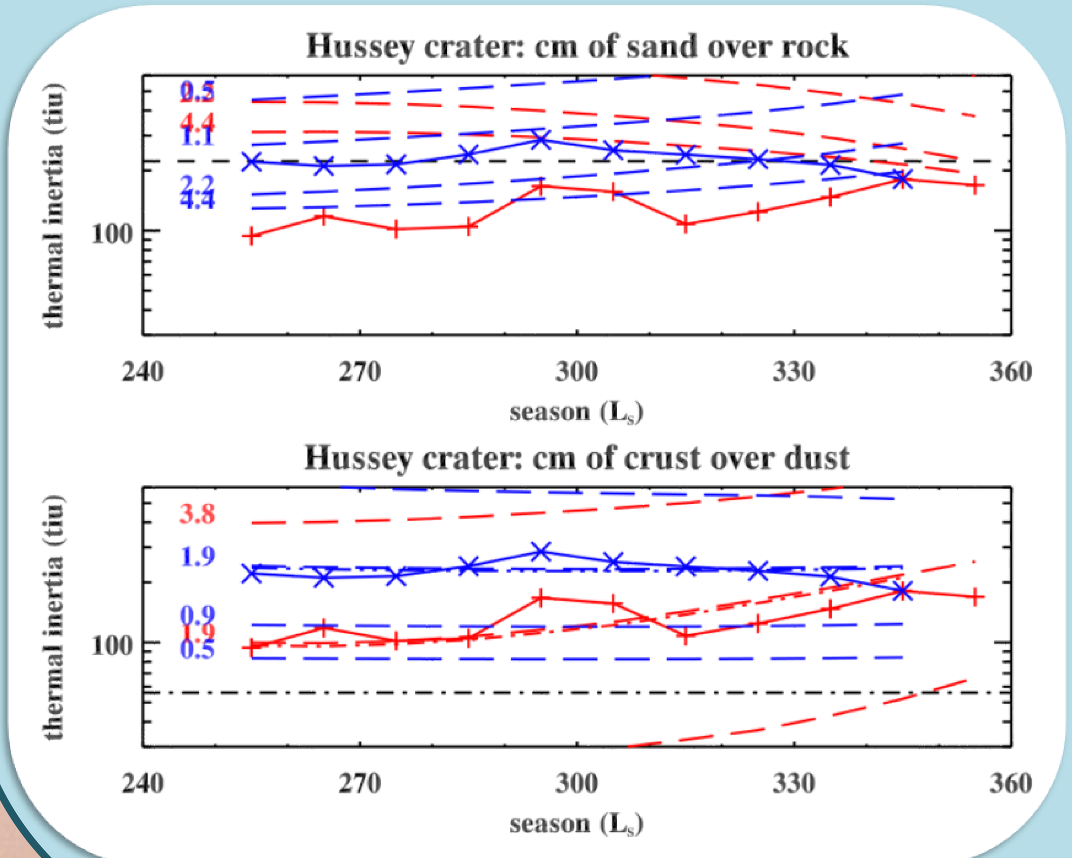
Thermal Inertia

Thermal inertia is a bulk material property dominated by thermal conductivity [7], and it varies by two orders of magnitude from dust to rock/ice. Heterogeneity in a surface causes **seasonal** and **diurnal variation** in apparent thermal inertia [8,9].

We derive thermal inertia from **TES** [B] and **THEMIS** [C] IR data and model-generated lookup tables, assuming a homogeneous subsurface [10,11]. The derived thermal inertia curves are compared to **model curves** of lateral mixtures and **layerings** of different materials (dust, sand, duricrust, rock/ice) to find the best-fit surface properties.

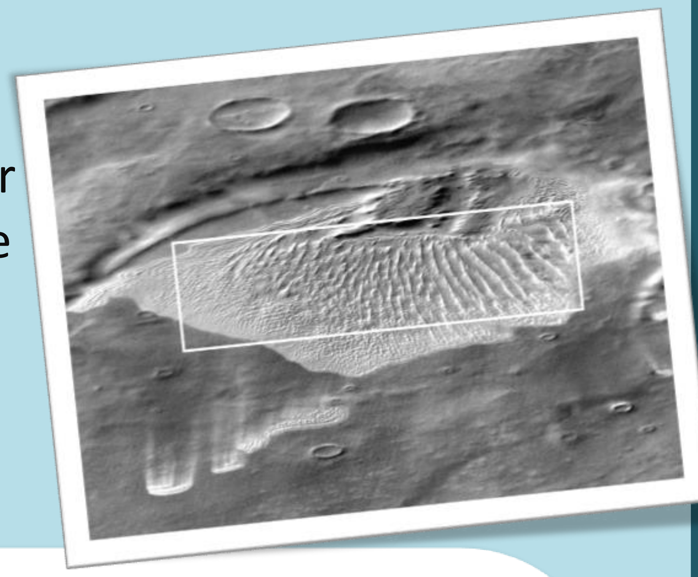


Right: The bounds of the Hussey Crater dune field in red, and the region of analysis within the box (30 by 30 km).

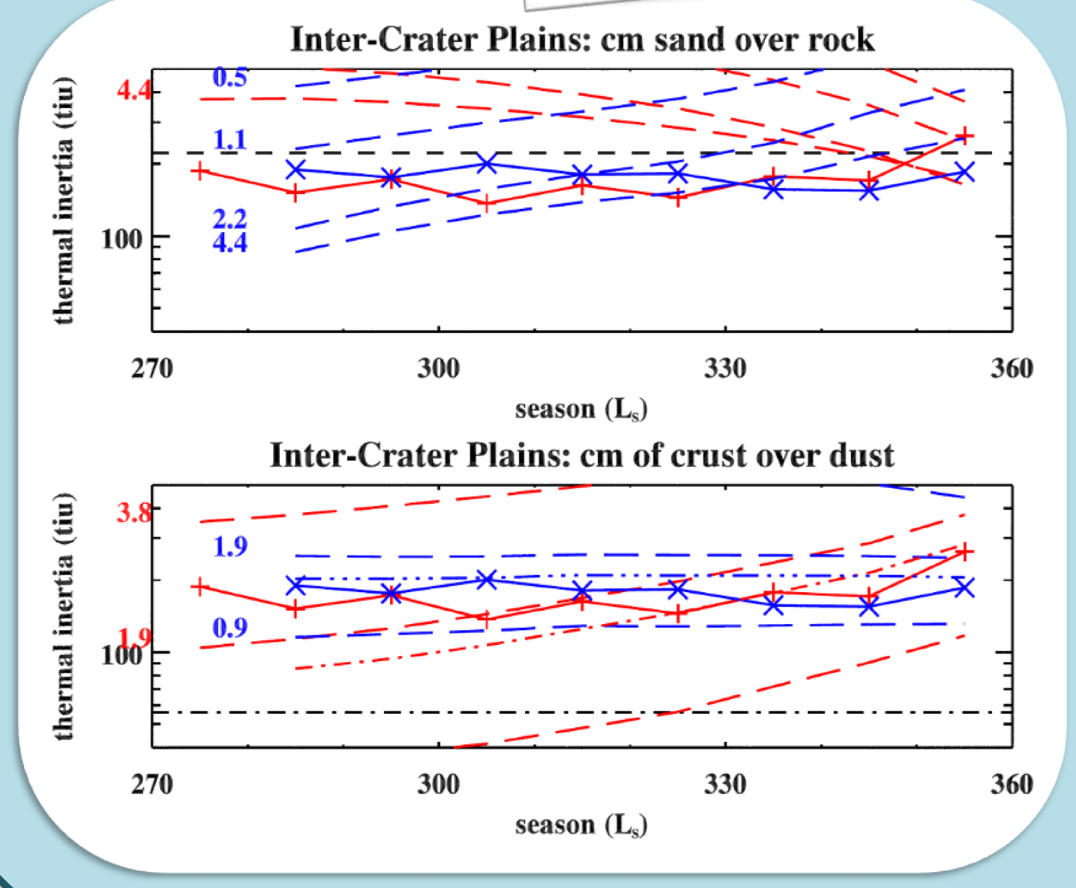


Under the ice-enabling-erosion hypothesis, we would expect consistency with models of **sand over ice** (where ice is thermally equivalent to rock). We've so far surveyed 23 of the 171 largest southern dune fields from [4] and found them all **inconsistent** with sand-over-ice models. Instead, a plurality of fields are consistent with crust-over-dust models. We're continuing to expand our survey and investigate this unexpected conclusion. In particular, we're anticipating updated software to model 3+ layers. Perhaps ice is underneath multiple layers of material, with its lower position partially masking its thermal signal.

Left: TES thermal inertia data (daytime and nighttime) for Hussey Crater (marked on the map below), typical of the dune fields we've studied, overplotted on dashed model curves for different upper-layer thicknesses in two different layering scenarios.



Right: A 25 x 35 km field in the inter-crater planes (marked on the map to the left). *Below*: Plots for that field, another typical example.



The Evidence

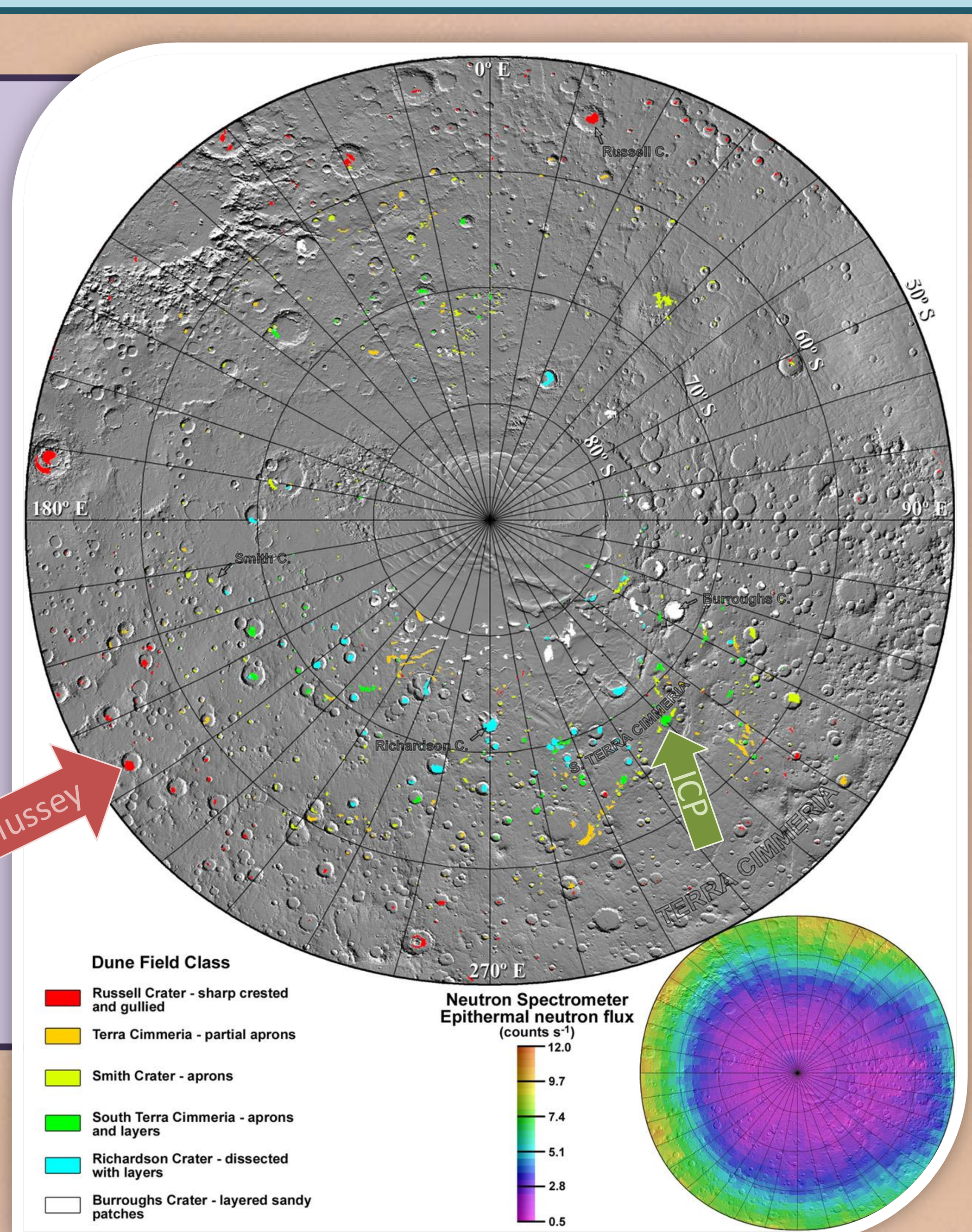
Ground Ice

Evidence for ubiquitous, high-latitude ground ice includes:

- Excavation of ice by fresh, mid-latitude craters only **decimeters deep** [1]
- Temporal variations in apparent thermal inertia of the northern polar erg consistent with **ice-cemented sand** under decimeters of dry sand [2]
- Neutron spectrometry data from Mars Odyssey indicating deposits of 20–100% water-equivalent hydrogen by mass within a meter of the surface poleward of ±**50° latitude** [3]

Dune Morphology

Evidence for a poleward gradient in dune morphology comes from Fenton and Hayward [4], who categorized 1190 southern -hemisphere dune fields. They found sharp-crested dunes almost exclusively in the northern portion, while more rounded, or stabilized, dunes were **primarily south of 60° S**, progressing to flat sand fields near the pole.



Right: MOLA [A] shaded relief map of 50-90° S in an oblique equidistant projection. 1190 dune fields in six morphological classes progress southward from sharp-crested dunes (red) to rounded dunes (e.g. green) and then to flat sand fields (white). In the corner is the neutron spectrometry data indicating ground ice nearer the poles, which broadly matches the morphology transition. Fig. 18 of [4]

References: [1] Byrne, S. et al. (2009) Science, 325, 1674-1676. [2] Putzig, N. E. et al. (2014) Icarus, 230, 64-76. [3] Feldman, W.C. et al. (2004) JGR, 109, 13. [4] Fenton, L. K. and Hayward, R. K. (2010) Geomorphology, 121, 98-121. [5] Bourke, M. C. et al. (2009) Geomorphology, 109, 148-160. [6] Butcher, A. and Fenton, L. (2011) LPS XLII, Abstract #2091. [7] Jakosky, B. M. (1986) Icarus, 66, 117-124. [8] Mellon, M. T. et al. (2008) in: The Martian Surface, Bell, J. F., ed. (2008) Cambridge Univ. Press. [9] Putzig, N. E. and Mellon, M. T. (2007) Icarus, 191, 52-67. [10] Mellon, M. T. et al. (2000) Icarus, 148, 437-455. [11] Jakosky et al. (2006).

Footnotes: [A] Mars Orbiter Laser Altimeter (MOLA), Mars Global Surveyor [B] Thermal Emission Spectrometer (TES), Mars Global Surveyor [C] Thermal Emission Imaging System (THEMIS), Mars Odyssey