RECENT PROCESSES AND TIMING OF EVENTS IN HIGH-LATITUDE PATTERNED GROUND ON MARS. M. A. Kreslavsky\textsuperscript{1}, J. Korteniemi\textsuperscript{1,2} and J. W. Head\textsuperscript{3}, \textsuperscript{1}Earth and Planetary Sciences, University of California - Santa Cruz, Santa Cruz, CA 95064, USA (mkreslav@ucsc.edu). \textsuperscript{2}Astronomy, University of Oulu, Oulu, Finland, \textsuperscript{3}Geological Sciences, Brown University, Providence, RI 02912, USA.

Introduction: Polar regions of Mars equatorward from the polar layered deposits (PLD) are covered by small-scale polygonal patterns and are almost devoid of small impact craters, which suggests surprisingly intensive permafrost processes. Here we try to correlate morphological observations and age constraints from crater counts against recent evolution of spin and orbit, which force significant climate change. We used the history of orbit eccentricity, spin axis obliquity, and season of perihelion \cite{1} to calculate the insolation regime of the polar regions. Fig. 1 shows the evolution of the year-maximum day-average insolation, a good proxy for summer surface temperatures.

Decameter-scale craters: We used relatively fresh (with sharp edges) craters in $D = 5 - 20$ m range to assess ages of the most recent small-scale resurfacing \cite{2,3}. Such craters are absent above $\sim 57^\circ$N, which means that resurfacing is occurring now or occurred very recently (a few ka) under the present spin/orbit configuration. We suggest that the nature of this resurfacing is (1) deposition of icy mantle due to migration of water vapor from the southern PLD (SPLD) to the northern polar region \cite{4}, when the perennial CO$_2$ deposit at SPLD was absent \cite{5} and intensive summer-time sublimation occurred and/or (2) desiccation of uppermost layer in response to a sharp decline in atmospheric water vapor content, after the perennial CO$_2$ deposit has formed a few 100s years ago \cite{6}.

For the 60$^\circ$S - 70$^\circ$S zone in the southern polar region such craters form an accumulation population with an age of about 20 ka (with high inherent absolute uncertainty) \cite{2}. We interpret this as a result of an inverted situation (A in Fig.1), when perihelion was during northern summer, water vapor migrated from the northern polar area to the southern polar area \cite{4} and produced the most recent mantle layer there.

There is a sparse population of sharp small craters below 57$^\circ$N; the size-frequency distribution does not suggest any distinctive resurfacing event (it has a gentle slope), and thus does not supply any well-constrained age, however, typical crater densities are higher than in the 60$^\circ$S - 70$^\circ$S zone. Small-scale resurfacing at the highest latitudes is generally faster than at moderately high latitudes, while the seasonal temperature amplitude is lower. This suggests that ice deposition and removal processes rather than thermal cycling are responsible for small-scale resurfacing in the circumpolar areas.

Hectometer-scale craters: All craters in $D = 100$ m - 1 km range that we see in our survey in 60$^\circ$ - 70$^\circ$N zone are heavily degraded \cite{7,8}; they have subtle topography and can be recognized due to circular arrangements of polygonal patterns. Given the cratering rate \cite{9} of $D > 100$ m craters, the youngest crater in our survey area is younger than $\sim 0.8$ Ma (90% confidence). This places very intensive resurfacing not later than point B in Fig. 1. The nature of this resurfacing is enigmatic. Seasonal freeze-thaw cycle is able to modify the surface very quickly and effectively, however climate models \cite{10} predict its onset at insolation levels that correspond to point D ($\sim$7.7 Ma ago) in Fig. 1. Absolute cratering rates are poorly constrained (significant variations of projectile flux at 100s ka to 10s Ma time scales are possible) and point C ($\sim$4.2 Ma) in Fig. 1 can be a viable candidate.

Patterns: Observations: We performed a systematic survey of patterned ground terrain at high northern latitudes (50$^\circ$ - 70$^\circ$N) of Mars with HiRISE images \cite{15}. We avoided steep slopes, large craters, etc. Typical patterned ground at high latitudes often has two distinctive scales (Fig. 2a). The larger scale (10s of m spacing) is formed by gentle topography, typically, a polygonal network of smooth gentle troughs with smooth intervening mounds. (Fig. 2a,b) We refer to polygonal patterns made by smooth gentle topography as Type 1 pattern. We found that the Type 1 pattern is present in almost every image. In classification of \cite{11} our Type 1 corresponds to S1, S2 and S3 patterns. The appearance of Type 1 polygons varies widely. In places troughs are outlined by gentle albedo variations due to concentration of thin sand sheets in troughs. In places mounds are marked by distinctive rubble piles, which also produces a specific pattern known as "basketball terrain". Patterns of smaller scale (<10 m spacing) are formed by narrow lineaments, obviously, cracks. We used the presence of narrow cracks as a defining characteristic of the Type 2 pattern. The Type 2 pattern is superposed over the Type 1 pattern (Fig. 2a) and occurs predominantly north of 57$^\circ$N. The morphology of this pattern also varies widely; it generally corresponds to "high-relief", "flat-top small", and "irregular" polygon types from \cite{12}. In places cracks form hierarchical structures with small cells formed by very narrow cracks that subdivide larger cells outlined by more pronounced cracks. In places the largest cracks are associated with double ridges; such features are limited to
north of 64°N. The southern boundary of Type 2 occurrence is gradational: in a few images, in addition to the Type 1 pattern, there is a barely distinguishable patchy small-scale pattern with spacing typical for Type 2, but without sharply defined cracks (Fig. 2b).

**Patterns: Interpretation:** The southern boundary of Type 2 approximately corresponds to the southern boundary of the present-day shallow ground ice detected by neutron spectrometers [13], within the inherently low resolution of that remote sensing technique. We interpret cracks forming the Type 2 pattern as presently active seasonal thermal contraction cracks in the icy permafrost. The latest crack formation cannot date earlier than the summer insolation maximum 20 ka ago (A in Fig. 1).

The Type 1 pattern extends equatorward from the current shallow ground ice stability boundary and is stratigraphically older than Type 2. It is reasonable to associate the Type 1 pattern with earlier epochs, when shallow ground ice was stable at lower latitudes. When summer insolation was higher, the atmosphere was more humid, which overwhelmed the effect of increased year-average surface temperature and expanded the ice stability to lower latitudes [e.g., 14]. Thus, it is natural to associate formation of the Type 1 pattern with peaks of summer insolation. It is not clear on what time scale these observations apply; the recent summer-time pericenter (20 ka ago, A in Fig. 1), recent obliquity peak (0.7 Ma ago, B), or very high obliquity (C or D), however, the latter seems very improbable, because patterns cover all degraded craters. It is probable that formation of Type 1 polygonal patterns was not synchronous over the entire polar regions.

If other circumstances are the same, high summer temperatures lead to shorter spacing of thermal cracks. The longer spacing of the Type 1 pattern is naturally explained in two principally different ways. (1) Warmer summers mean a thicker ice-free layer over stable ground ice, which increases spacing. (2) Cracking may not be seasonal, but result from secular cooling. The latter can occur in response to a decrease of obliquity from its maximum, or due to increase of surface albedo (deposition of bright dust or frost), or due to increased soil thermal conductivity as a result of filling pore space with ice or increase of air pressure [16].

**References:**


![Fig. 1. Evolution of year-maximum day-average insolation on horizontal surfaces at 60°N and 60°S for the last 0.5 Ma and at 60°N for the last 10 Ma and](image1.png)

![Fig. 2. Examples of patterned ground. HiRISE images PSP_001611_2485 (a) and PSP_010382_2445 (b).](image2.png)