GROUND-ICE EXTREMES IN MARTIAN PERMAFROST AS REVEALED BY PERIGLACIAL LANDFORMS. Michael T. Mellon[1], William C. Feldman, Candice J. Hansen[2], Raymond E. Arvidson[3], and Hanna G. Sizemore[2], [1]Dept. of Space Studies, Southwest Research Institute, Boulder, CO 80302, [2]Planetary Science Institute, Tucson, AZ 85719, [2]Dept. of Earth and Planetary Sciences, Washington University, St Louis, MO 63130.

Introduction: Water on Mars has been central in most aspects of the planet's surface geology, geochemistry, climate, and potential habitability throughout history. In the modern martain climate water continues to play no small role. Ground ice is a major reservoir of modern water and is able to actively exchange with the atmosphere-polar-cap system on relatively short timescales.

The high-latitude regions of Mars are generally understood to be extensively underlain by ice-rich permafrost. The Mars Odyssey Neutron Spectrometer (MONS) and Gamma Ray Spectrometer (GRS) provided direct confirmation of the permafrost's ice-rich status [1,2,3]. The geographic extent and depth distribution of the observed ground ice are consistent with prior predictions of ground ice stability [4,5,6]. This correlation indicates we understand the climate factors that control its present day extent.

On the other hand, the observation of high ice concentrations (ice exceeding the soil pore volume) in many regions is an ongoing puzzle [2,3]. For example between 60° to 70° south latitude the ice concentration varies over 90° of longitude between extremes of "low" 20-40% by volume (consistent with matrix-supported ice-cemented soil) and "high" 75-90% by volume (essentially dirty ice). This excess ice was unexpected and currently remains unexplained.

Such a contrast in ice content raises many questions about the details of its historical origin and implications for the modern Martian climate and the role of liquid water.

Unfortunately, the geographic resolution of these observations is relatively poor. The nominal full width half maximum foot print of MONS is about 600 km [3]. In contrast, the Phoenix mission observed ground ice variations on a very small scale [7,8]. The Phoenix lander excavated the permafrost at a high northern latitude location and exposed patches of ice cemented soil and nearly pure ice (>90%) within less than 1 m of separation. But data on intermediate scales is lacking.

Both MONS and Phoenix were only able to observed ice at depths less than a few cm into the ice-rich zone (limited by either mean free path of neutrons in ice, or by excavation capabilities). Data on greater depth scales within the ice-rich zone is also absent.

To understand the origin and history of the ice and in particular the excess concentrations of ice, we need to understand the distribution of ice on a variety of spatial scales.

To this end we use the characteristics of the periglacial geomorphology to probe the distribution of ground ice at spatial scales not achievable with the MONS data or the Phoenix mission.

Polygonal Patterned Ground: Polygonal patterned ground is a ubiquitous landform in terrestrial permafrost forming by seasonal thermal-contraction cracking in permanently ice-cemented ground [9]. They develop slowly to a mature stage in 10^4-10^5 years [13] and are sensitive to the rheological properties (ice content) of the upper meters of the permafrost [8,11].

On Mars, high-latitude polygons have been observed from orbit since the Viking missions. And have since been found to be equally ubiquitous [10,11,12]. Close up analysis by the Phoenix lander showed that active sand-wedge formation is responsible [8].

In this work we examined the geomorphologic characteristics of polygons on Mars between 60°-70° South and 0°-160° East, as seen in High Resolution Imaging Science Experiment (HiRISE) images. This region covers low and high ice content, as well as the transition between them, as observed by MONS. The limited latitude range avoids the effects of zonal climate differences on polygons morphology. We specifically examined the polygon size-frequency distribution and aspects of trough morphology. We then compared these results with the MONS-derived ground ice concentration at each location. Figure 1 shows examples of the range of polygon sizes observed over the region.

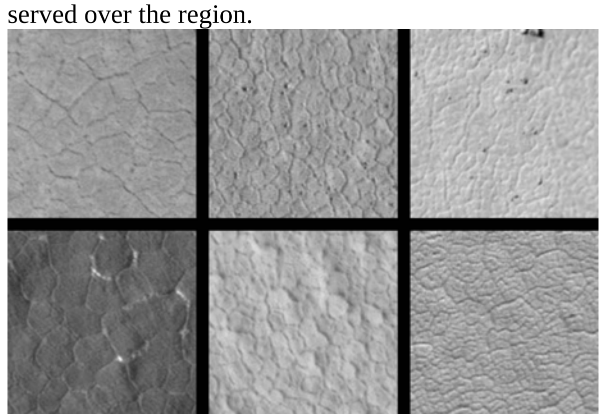

Figure 1. Examples of polygonal patterned ground in the study region. Each frame is a 50 x 50 m subframe of HiRISE images at 25 cm/pixel. Large polygon examples are on the left and small polygon examples are on the right.

Results: We find that polygon sizes vary significantly over this region, between the smallest sizes of 2-4 m and the largest of 7-12 m, by a factor of three. The polygon troughs appear well developed with a propensity for equiangular junctions – indicates mature stage, greater than 10^4-10^5 yrs by analogy to terrestrial counterparts [13]. In addition, large polygons sometimes exhibited pitting along troughs, suggestive of subsurface mass loss.

Figure 2a,b shows a comparison of polygon size and ice content as a function of longitude. It is evident that large polygons are more common where the MONS ice content is high. It can also be seen that images dominated by small polygonal forms are intimately interspersed in the excess-ice region.

Figure 3 shows a cross comparison of MONS ice content with polygon diameter for each image location. While small polygons are found throughout, larger forms are limited to locations of excess ice.

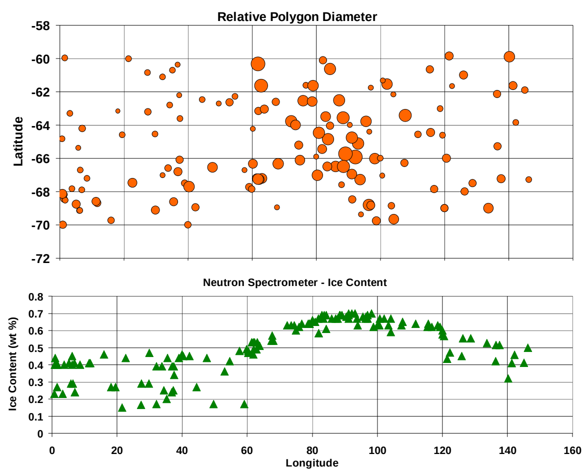

Figure 2. A) Relative polygon diameter vs latitude and longitude across the study region (larger circles indicate images dominated by larger polygons). B) MONS derived ice content at each image location.

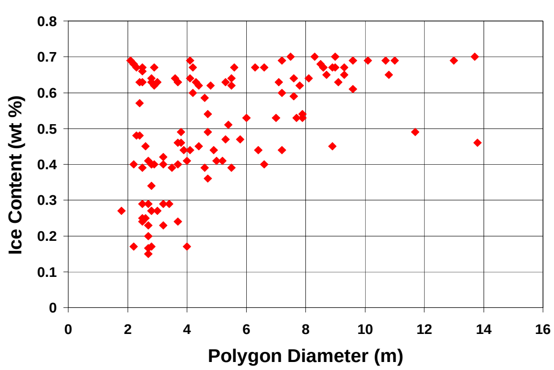

Figure 3. Cross correlation of MONS ice content as a function of polygon diameter for each HiRISE image location.

Other factors such ice table depth, soil thermal inertia, albedo, and small scale regolith morphology (mantles, bedforms, etc.) are not observed to vary substantially across the region.

Conclusions:

- The characteristic diameter of polygon patterned ground is expected to depend on both ice table depth and ice concentration.
- Patterned ground is generally understood to depend on the presence of ice-rich permafrost in the upper few meters depth.
- Polygons are slow to develop and long lived, thus provide indication of the presence and distribution of ice over recent millennia.
- In the southern high latitudes of Mars the observed ground-ice concentration is well correlated with the diameter of polygonal patterned ground.
- The presence of abundant patches of small polygons with the excess-ice zones indicate small scale (10's km) variability in ice content unresolved by MONS or GRS.

Implications: The correlation between excess ice and polygon diameter indicates:

1) The ice is present at greater depths than the upper cm's of the ice table sensible by MONS. Polygon development is typically sensitive to rheological properties within the thermal active layer of the permafrost, more so nearer the surface. This dependence suggests they excess ice may extend to several meters depth.

2) The ice has persisted in its present state for at least 1000's of yrs for polygons to develop. The morphological characteristics of relatively narrow size frequency distributions and the propensity for equiangular trough junctions both indicate a mature stage of polygon formation. During that time the ice content (and the ice table depth) would not have varied substantially or the polygons would develop into irregular patterns which is not observed [e.g.,13]

3) Whatever process has resulted in the deposition of excess ground ice it would have acted in the recent past due to obliquity-driven desiccation of the upper 1-2 m of the regolith [5], but long enough ago to allow the polygonal patterns to develop.

References: [1] Boynton et al, *Science*, 2001; [2] Prettyman et al, *JGR*, 2004; [3] Feldman et al, in *The Martian Surface*, 2008; [4] Leighton and Murray, *Science*, 1966; [5] Mellon and Jakosky, *JGR*, 1993; 1995; [6] Mellon et al, *Icarus*, 2004; [7] Smith et al, *Science*, 2009; [8] Mellon et al, *JGR*, 2009; [9] Lachenbruch, *Spec. Pap. Geol. Soc. Am.*, 1962; [10] Mangold, *Icarus*, 2005; [11] Mellon et al, *JGR*, 2008; [12] Levy et al, *JGR*, 2009; [13] Mellon et al, *Antarc. Sci.*, 2013.