HIRISE OBSERVATIONS OF PATTERNED GROUND ON MARS. M. T. Mellon [1], M. L. Searls [1], S. Martinez-Alonso [1,2], and The HiRISE Team, [1] Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder 80309, [2] Department of Geological Sciences, University of Colorado, 80309.

Introduction: HiRISE observations of the martian surface provide unprecedented clarity for the study of potential periglacial landforms. Small scale topographic relief and rock distributions commonly associated with patterned ground in terrestrial permafrost can be clearly resolved by HiRISE at up to 25-32 cm/pix. Identifying, characterizing, and mapping these features can provide insight about the distribution, state, and history of water in the martian subsurface.

In this work we present an examination of HiRISE images for the presence of polygonal-patterned ground, including their geographic distribution and detailed morphology.

Terrestrial Polygonal-Patterned Ground: Polygons are the most ubiquitous form of patterned ground in terrestrial permafrost. Seasonal cooling of cohesive, ice-rich soils results in tensile stress and, under favorable conditions, tension fractures. These thermal-contraction fractures in permanently-frozen ice-rich permafrost form a honeycomb network of cracks just millimeters wide, meters deep, and typically 10's of meters in spacing (Lachenbruch, 1962). The depth and spacing of fractures are controlled in large part by the depth penetration of the seasonal thermal wave, similar to depths in martian ice-rich soil. Other factors such as soil texture and mean temperature also play a role.

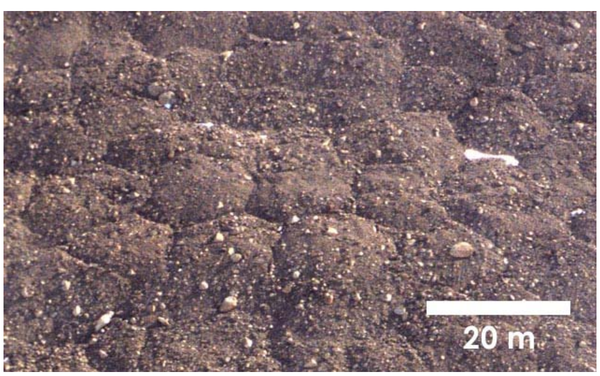

Figure 1. Antarctic sand wedge polygons. Aerial view.

Annually-repeated fractures (typically following zones of weakness from the previous year's fractures) allow for growth of the fracture network. In arid regions (analogous to Mars) loose surface soil falls into the open cracks and incrementally build up a subsurface wedges of sand and fine soil material (Pewe 1974). Subsequent seasonal warming results in compression and subtle, incremental surface uplift adjacent to the fracture and in the polygon interior. Over many yearly cycles, the development of microtopography and redistribution of surface rocks (too large to fall into the open fractures) result in clearly defined surface patterns. In wet climates, water (spring melt) often fills the open cracks and refreezes to form ice wedges (Black 1976) and similar microtopography through repeated cycles.

Surface expressions can vary depending on the polygon history (e.g., Sletten et al., 2003). Initially fractures relieve stress in a more rectilinear pattern, but over time with fracture migration the pattern becomes increasingly hexagonal. The sizes of terrestrial polygons are most typically on the order of 10-20 m, but can be larger or smaller. In addition, larger polygons and initial "megafractures" can become subdivided by episodic "cold snaps". Expression of this originally larger network which cracks more often than the smaller network, sometimes results in an apparent bimodal size distribution.


Figure 2. Antarctic sand wedge polygons. Close up of rock accumulation at intersection of 3 troughs.

At the fracture zone, a trough develops from the repeated annual consumption of loose surface soils. The trough can be V-shaped where loose soil actively funnels into the crack opening, or U shaped where subsequent degradation and mass wasting rework the trough. Both shapes are often observed in the same trough. Rocks can also accumulate in the trough (Fig 2), convected from the polygon interior (Sletten et al., 2003).

Over the scale of a polygon, surface relief is varied, consisting of high or low centers relative to trough depth. High-center polygons exhibit more deeply cut troughs and greater central uplift. Low-center polygons form a shoulder adjacent to the trough with little central uplift.

Patterned Ground On Mars: Since the Viking spacecraft returned high resolution images of the martian surface polygonal patterned ground has been reported (Evans and Rossbacher, 1980; Brooke, 1982; Lucchitta, 1983; Mutch et al., 1977) with sizes from 50 to a few hundred meters, limited by the image resolution. Comparison between Earth and Mars climates and the process of polygon formation shows that thermal contraction polygons can easily form in present day conditions and should be abundant (Mellon, 1997). MOC observations have allowed for the identification and mapping of numerous polygonal patterns similar in scale to terrestrial permafrost polygons (e.g., Seibert and Kargel, 2001; Mangold, 2005).

HiRISE Observations: In HiRISE images, numerous small scale polygonal features are clearly identified and their detailed morphology can be examined. A wide array of patterns are observed, linked by a number of similarities: locally, narrow size distributions; hexagonal patterns make up some fraction, if not all, of the polygon field (many 3-way intersections); depressed perimeter troughs; central uplift (shoulders and interior mounds). Figures 3 and 4 show typical examples. Other patterns are observed with irregular size distributions and complex long parallel-to-subparallel lineations in two or more preferred orientations. These appear consistent with jointed bedrock and are excluded from this study.

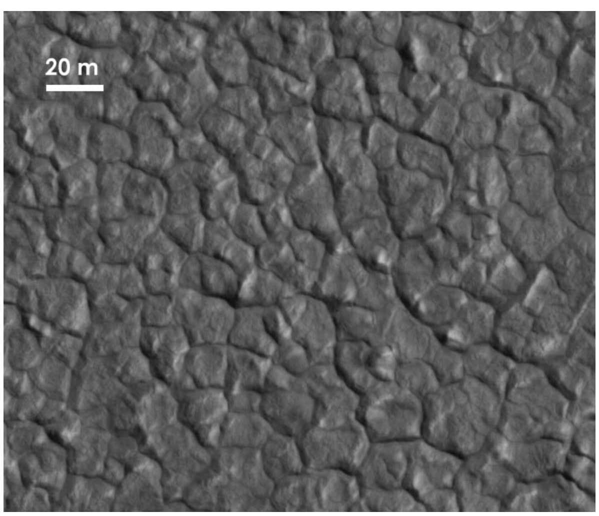

Figure 3. Polygons with generally V-shaped troughs and irregular high centers. HiRISE image PSP_001334_2645.

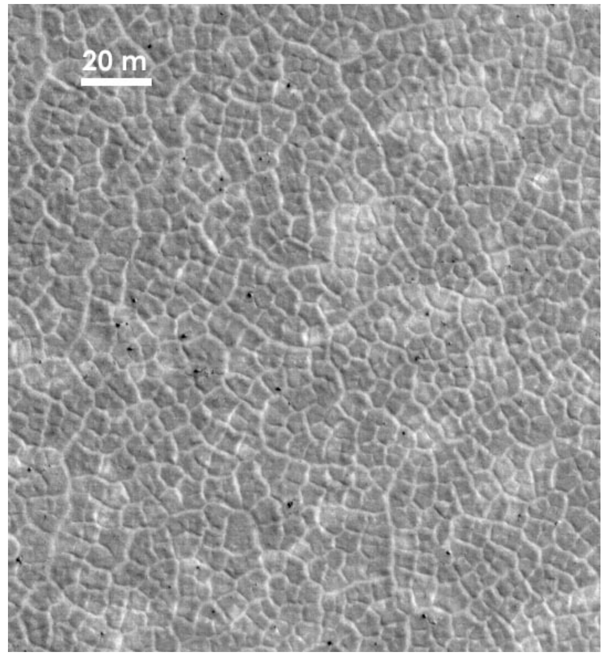

Figure 4. Polygon field on Mars. Light toned troughs are due to a combination of illumination with some dust accumulation. Dark spots are the shadows of surface rocks. HiRISE Image PSP_001418_2495.

Polygon perimeter troughs exhibit both U-shaped and V-shaped profiles. In some cases (Fig 4), perimeter shoulders on one or both sides of the troughs are observed, with the polygon interior being relatively flat or slightly depressed. In other cases (Fig 3) polygons exhibit rounded or complex and irregular high centers.

Geographically, polygonal patterns are observed in a large number of images at mid and high latitudes. Generally polygons are found intermittently between about 35º and 45ºN latitude. And in nearly every image poleward of 45ºN. The area of the image dominated by polygons also increases dramatically between 50º and 60º N such that at the higher latitudes polygons cover 100% of most images, with the exception of polar layered deposits and polar dunes fields where polygons localized. (Polygons are also observed in the southern high latitudes, but presently images are statistically biased in the north due to seasonal constraints of the early MRO mapping mission.) Assuming that these patterns originate from thermal contraction in permafrost, this distribution is consistent with the expected distribution of shallow ground ice from GRS (e.g., Boynton et al., 2002) and theory (e.g., Mellon et al., 2004)

Within each image, or in a unique terrain within an image subset, the polygon size (crack-to-crack spacing and polygon diameter) are relatively uniform. Sizes vary from image to image (with geographic location). There is a notable propensity for smaller polygons at high latitudes relative to lower latitudes. At lower latitudes polygons are as small as ~10 m, while at high latitudes polygons can be as small as ~2 m. Mellon (1997) showed that very high tensile stresses can occur at high martian latitudes, facilitating the formation of small polygons. In some images a bimodal size distribution is observed where larger polygons (with wider troughs) are subdivided into 3-15 smaller polygons with less developed or narrower troughs.

Images with abundant rocks (meter to submeter) and boulders (multi meter) exhibit a mix of correlations with the polygonal patterns. In some cases no obvious correlation is apparent. However, sometime large boulders are congregated in the polygon centers (or at least less abundant in the perimeter regions). In other cases smaller rocks and sometime boulder are collected within the trough (see Fig 5), similar to Antarctic sand-wedge polygons (Fig 2).

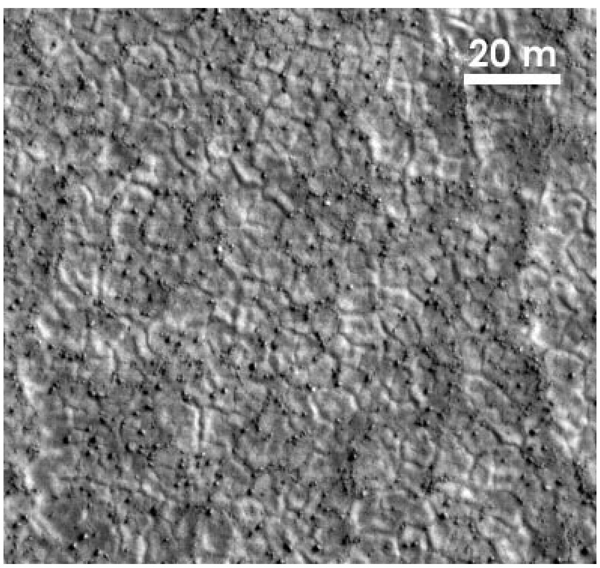

Fig 5 Rock distribution with polygons. Rocks are sometimes collected in the polygon troughs. HiRISE image PSP_001381_2485.

Interpretations and discussion: Many of the characteristics of martian polygonal-pattern ground are similar to the terrestrial permafrost polygons. Martian forms frequently exhibit regular sizes and a preference for hexagonal shapes and 3-way trough intersections. Perimeter trough, upturned perimeter shoulder, and general microtopography can be associated with compression of material fallen into the contraction crack, which differs in nature from desiccation or tectonic fractures (rock joints) which typically open once and do not undergo periodic compression of crack-filling material. Rock and boulder redistribution into the polygon troughs is consistent with Antarctic sand wedge polygons (Sletten et al., 2003), where long lived consumption of soil acts to convect rocks to the surface and creep gradually toward the trough. Such rock distributions are also observed on Earth in sorted stone circles, and form by freeze-thaw convection and frost heave. However, the freeze-thaw reworking tends to leave the soil surface relatively level rather than with upturned shoulders or irregular high centers.

Where polygons are not seen. As interesting as where polygonal patterns are observed is where they are not observed. Many dunes occur in regions of extensive polygonal-patterned ground where the dunes set atop a basal surface of extensive well developed polygons. However, polygonal patterns are absent from the dune surface – an example from the north polar erg is show in figure 6. At these latitudes, these dunes should start become ice cemented (cold trapped from atmospheric water vapor) below a few centimeters to decimeters depth in just a few thousand years. This absence may suggest that the process by which polygons form is inactive in these regions today, and existing polygons on the basal surface are relics from an earlier climate. However, Mellon (1997) showed that polygon formation should be more active in the higher latitudes and active in today's climate. Alternatively, the dunes may be presently active enough to prevent tough development to a level visible to HiRISE.

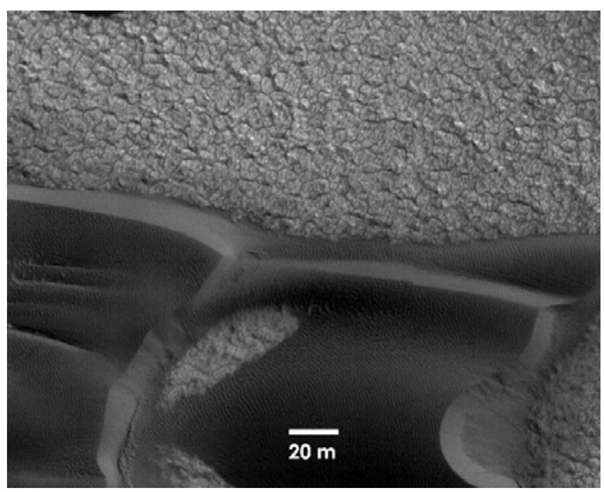

Figure 6. Polar dunes on a polygonal patterned basal surface. The dunes themselves do not exhibit polygons. HiRISE Image PSP_001341_2650.

Size distribution. The observed size distribution as a function of latitude is consistent with predictions of peak seasonal tensile stress (Mellon, 1997). Higher stresses occur at higher latitudes because lower temperatures retard viscous relaxation of stress. Higher tensile stress results in subdivision of larger polygons into smaller forms to relieve the stress.

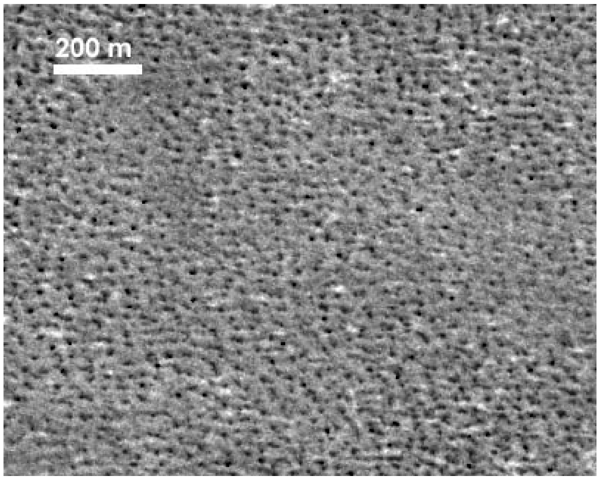

Figure 7a. MOC image R22-00099 showing basketball terrain in the high northern latitudes.

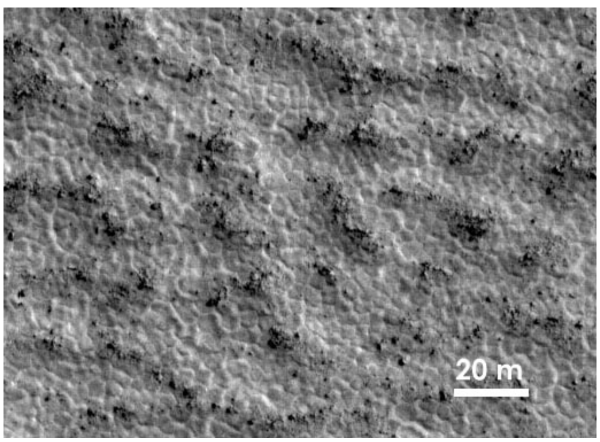

Figure 7b. Subset of HiRISE image PSP_001404_2490 showing rock and rubble piles with interspersed polygons on the underlying terrain. This image is in the same location as Fig 7a.

Basketball terrains. Basketball terrain (surface that exhibits a bumpy texture in MOC images similar to the surface of a basketball) has been reported at high latitudes on Mars (e.g., Kreslavkey and Head 2002; Head et al., 2003). One theory is that this terrain is the result of deep polygonal tough erosion by ice sublimation (Head et al., 2003). HiRISE images in the high northern latitudes show this texture is actually the result of regularly spaced rubble piles, independent of the underlying polygonal patterns (see Fig 7). These piles may be the result of polygon development and rock redistribution during an earlier epoch where the polygons that formed them are no longer visible, or may have formed independently of permafrost-polygonal processes.

Polygons at Phoenix landing sites. Polygons are ubiquitous at latitudes in which the Mars Scout Phoenix will be landing in 2008. The presence of polygonal patterned ground indicates that ground ice either is present or has been present in the geologically recent past. Other lines of evidence indicate the ice is currently present at these latitudes (e.g., Boynton et al 2002). Therefore, the presence of ubiquitous polygonal ground indicates that the ice-rich permafrost is also ubiquitous.

References:

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