Identification and characterization of polygonal networks on the Martian boreal plain

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Abstract

This paper presents results on the intensive characterization of polygonal terrains around the landing site of the NASA Phoenix probe in the northern Martian plains, based on the analysis of remotely sensed images. The results were obtained through an automated study of the small-scale polygons in the area surrounding the location of the probe, seen in the high spatial resolution images obtained by the HiRISE camera aboard the NASA Mars Reconnaissance Orbiter probe. After mapping the network, our method allowed for a geometric and topologic characterization of more than 450,000 individual polygons with an average size of about 4.6 m and a hexagonal habit, which means that there are, on average, about 6 neighbours around each polygon.

Keywords: Mars, patterned ground, thermal contraction polygons, permafrost.

Introduction

One common feature of the surface of the planet Mars is the presence of large extensions of polygonal terrains showing very diverse visual appearances (Mellon, 1997; Pina et al., 2008). They are normally viewed as being related to the existence of water-ice in the ground and to its seasonal cycles of expansion and contraction. There have been recent attempts to classify these networks into a small number of types sharing characteristics such as dimensions and visual complexity (Mangold, 2005; Mellon, 2008; Levy 2009, 2010; Dutilleul, 2009), but these studies are mainly based on qualitative observations and fall short of representing the whole spectrum of networks.

The landing site of the Phoenix Mars probe (68.2°N, 234.2°E) (see Figure 1) was, as expected, a vast plain covered by an extensive network of polygons (their aspect can be seen on the landscape view taken by the Phoenix lander, at left on Figure 2). The presence of ice at small depths in the soil was quickly demonstrated by the operations of the probe, thus adding weight to the concept of Mars as a global permafrost planet. However, the relations between this ice and the characteristics and evolution of the polygons have yet to be completely clarified. Early attempts to determine the average dimensions of the polygons in the area were limited to a small number of polygons (Mellon, 2008) due to the manual procedure employed on the analysis of HiRISE images (see right image on Figure 2).
Figure 1: Location of the landing site of Phoenix probe on Mars (68.2°N, 234.2°E) [Image credits: NASA/JPL-Caltech/University of Arizona/MSSS].

Figure 2: Martian northern plains seen from the Phoenix lander (left) and from orbit by the HiRISE camera onboard Mars Reconnaissance Orbiter (right).
In this work, we present an automated study of the small-scale polygons in the surrounding area of the location of the probe, made from images obtained by a camera (HiRISE) aboard another NASA probe currently orbiting the planet, Mars Reconnaissance Orbiter.

**Image datasets and experimental strategy**

We conducted a survey of the HiRISE images currently available, selecting those whose center falls within a region between 67.5° and 69° N in latitude and 233.5° and 235° E in longitude on Mars. Up to the moment of writing, about 40 images with centimetric spatial resolution were available; their footprints are plotted over the corresponding topographic data obtained by the Mars Orbiter Laser Altimeter (MOLA), in Figure 3.

![Figure 3](image_url)  
*Figure 3.* Footprints of HiRISE images currently available within the region between 67.5 and 69°N in latitude and 233.5 and 235°E in longitude (background image is a MOLA topographic relief at 128 pixels/degree).

The regions covered by the HiRISE images have variable surface areas, but a typical footprint is an area of about 10 x 5 km, which normally results in a digital image containing more than 2 Gpixels (for instance, 100,000 x 20,000 pixels). This huge amount of information is quite difficult to process all at once. However, given that the spatial detail provided by the images and their complete analysis can reveal important characteristics of the polygonal networks that could not be perceived by a procedure based on sampling of selected regions, we devised a strategy to extract that information. Thus, it was decided to divide the images into squared regions of 600 x 600 m² (in map-projected images with 0.25 m/pixel, this corresponds exactly to 2,400 x 2,400 pixels). When preparing these images, the polygons that intercept the border are cut and must be suppressed, as they cannot be correctly analysed. Later in the procedure, when the neighbourhood analysis is conducted, only polygons with a complete set of neighbours will be considered, so additional layers of polygons will be also filtered out. Thus, in order to get information on a maximum number of polygons we cut the images with a degree of overlapping between adjacent images. Some polygons will be counted twice, but their number is very small when compared to the global count (see scheme in Figure 4).
Identification and characterization results

We began by studying the polygonal network in a region of 2,600 x 2,600 m\(^2\) centred in the spot where Phoenix landed, contained on the HiRISE image PSP-008591-2485. Due to the already mentioned constraints on computational power available the selected region (10,400 x 10,400 pixels) was divided into 25 square scenes, each covering 600 x 600 m\(^2\) (2,400 x 2,400 pixels) with an overlap (E-W and N-S) between adjacent images of 100 m. We created this overlap in order to count the maximum number of polygons, since the procedure employed for neighbourhood analysis (Bandeira et al., 2008, 2010) only uses complete polygons, i.e., the polygons cut by the edges of the images and their neighbours are not counted to avoid bias on the measurements.

The polygonal network is visually homogeneous and occupies the whole area visible in each scene. Although the small-scale polygons are not equally discernible in every region of the image, in most of the cases the edges are clearly detected; even taking into account the cases in which the identification of polygons is uncertain, the global segmentation performance is very good. The sequence used to detect the polygons is original and developed by the authors of the current paper. It is based on the analysis of the watershed transform (Beucher and Lantuéjoul, 1979), namely, on the selection of the edges that present the higher contrast (or dynamics) with the adjacent regions (or basins) of the image. The edges with the highest dynamics correspond normally to the contours of the polygons on the terrain. Details of this methodology can be consulted in a previous paper (Pina et al., 2006). This approach permitted us to identify some 450,000 polygons in the 25 square scenes, with about 17,500 polygons per each 600 x 600 m\(^2\) region. An example of this detection is presented in Figure 5.
We computed some geometric and topological parameters of the polygons, whose ranges of variation are indicated in Table I. To obtain the dimension of a polygon ($L_{\text{mean}}$), we averaged the lengths of the two axes measured in each case: the major axis and its perpendicular bisector. The average size of the polygons in this region is slightly above 4.50 m, which is in complete agreement with a previous study (Mellon, 2008) but is now supported by much stronger statistics. Size distributions are presented in Figure 6: the red thick curve is the average for the whole area (2,600 x 2,600 m$^2$), while each black thin curve represents the distribution within each of the 25 images (600 x 600 m$^2$). The distributions are very much identical, confirming the great homogeneity of polygon dimension in the area.

In what concerns topological features, we have computed the number of neighbours of each polygon in the network. This permitted us to again verify (Pina et al., 2008; Saraiva et al., 2009) the applicability of some classic topological laws that describe the correlation between the area or perimeter of a polygon and its number of neighbours (respectively, Lewis (1928, 1931) and Desch (1919) laws), and between the number of neighbours of a polygon and the average number of neighbours of its neighbours (Aboav-Weaire law (Aboav, 1970, 1980; Weaire, 1974; Weaire and Rivier 1984)). The number of neighbours of a polygon varies between 3 and 14, and approximately respects the hexagonal habit, with a strong consistency between images (average values range between 5.97 and 5.99), as presented in the "histogram" of Figure 7 (a continuous curve was drawn instead of a bar chart, so that the very high similarity between the individual regions and the average results could be better noticed). The three mentioned laws are also experimentally verified (the quality of the fitting, measured by $R^2$, is above 0.92 for the Lewis law, above 0.94 for the Desch law and above 0.99 for the Aboav-Weaire law), and the respective parameters (one per law) fall within the intervals of variation previously obtained for Martian polygonal networks (Saraiva et al., 2009): the Lewis parameter varies within the interval 0.34-0.39, the Desch parameter is about half of that, 0.19-0.22, while the Aboav-Weaire parameter lies in the interval 0.91-1.08.

Both segmentation and characterization tasks were performed with original software code developed on purpose in Matlab.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
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<tr>
<td>Area of the network (km$^2$)</td>
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<td>Number of polygons</td>
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<td>Average axis (m)</td>
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<td>Variance of number of neighbours</td>
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<td>Density (number of polygons / km$^2$)</td>
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<td>Lewis law constant</td>
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<td>1.0000</td>
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</table>

Table I.- Range of variation for the measurements performed within each 600x600 m$^2$ region.

Figure 6.- Size distribution of the mean axis of the small-scale polygons for each 600 x 600 m$^2$ scene (black thin lines) and for the whole 2,600 x 2,600m$^2$ region (thick red line).
Conclusions and on-going work

The preliminary results of this study of the polygonal terrains around the Phoenix landing site clearly demonstrate the advantages of using automated approaches for this type of analysis, since they allow for the elaboration of detailed cartography of the networks, even with large numbers of small-scale polygons occupying extensive areas; furthermore, this is a procedure that, taken together with other types of data that may be acquired by different instruments (altimeters, spectrometers) about the surface of Mars, can be of great help when considering the models currently most widely accepted for their origin, namely the thermal contraction and expansion of ice in the ground.

We are in the course of applying this strategy to all available HiRISE images of the plains around the Phoenix landing site. The images are being analysed in detail, with the goal of achieving the automatic identification of the polygons and the full geometric and topological characterization of the networks. The quantified information that is currently being collected will be mapped, so that the behaviour of parameters can be analysed in detail to look for differences at the local and regional scales.

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References