THERMAL-CRACK POLYGONS ON MARS: LINK BETWEEN THEIR DENSITY/TYPE AND THE GEOLOGY OF THE SUBSTRATE.
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Introduction: On Earth, sharp drops below 0°C in surface temperature can lead to the thermal contraction of ice-rich terrains, forming ground cracks. Over time, the cracks deepen, widen and join up to form polygonally-patterned ground. At that point, polygons show no difference in elevation between their margins and center, and are defined here as flat-centered polygons (FCPs). The cracks can be infilled iteratively during summer with sand [1], water [2] or both [3], which then freeze to form sand- or ice-wedges. These wedges grow seasonally, progressively uplifting the sedimentary polygon margins over the elevation of their center, forming low-centered polygons (LCPs). When these wedges degrade by way of increased mean temperatures, the elevation of the polygon margins decreases below the elevation of the centers, forming high-centered polygons (HCPs).

On Mars, morphologically similar polygonally-patterned ground is observed mid- to high-latitudes in both hemispheres, and are thought to form by similar means (e.g. [4]). Debate is ongoing, however, as to whether the polygon margins are underlain by ice or sand. Based on the increasing presence of LCPs with poleward latitude in Utopia Planitia, and the fact that presence of sand wedge should not vary with latitude, recent work concluded that LCPs in the study area were ice-wedge polygons [5]. In this area, polygons are thought be formed within a subsurface ice-rich mantling layer.

Here we report and discuss variations in the spatial distribution of polygonally-patterned ground and in the relative proportions of LCPs and HCPs in relation to their host substrate. Polygons seem to concentrate on a sinuous unit that appears bright on the Thermal Emission Imaging System (THEMIS) day-infrared (IR) imagery - the "sinuous unit". On the contrary, polygons are absent in a nearby unit, in contact with the sinuous unit, which is covered in boulders up to tens of meters in size, appearing dark in THEMIS day-IR imagery - the "boulder unit" (Figure 1). We focus here on how the nature of the various substrates favored or inhibited the formation and/or preservation of subsurface water ice, and if the morphology of thermal-contraction crack polygons could give further insight into the properties of these substrates.

Method: Compared to [5], we restricted the latitudinal range and extended the longitudinal range, in order to fully cover the sinuous unit (Figure 1). The polygons of the study zone are typically 5 to 25 m in diameter, and we mapped them on 104 images (55 from [5], and 49 new ones) from the High-Resolution Science Imaging Experiment (HiRISE, 25-50 cm/pixel) over the study zone. We gridded the images in 500x500 m squares, and noted in each square the presence or absence of polygons of each type (LCPs and HCPs) when at least five were present [6]. When neither LCPs nor HCPs were present but at least five FCPs were, we also noted their presence. We mapped the extents of the sinuous and boulder units using data from THEMIS, the Context Camera (CTX), and HiRISE when possible. We also mapped the extent of craters (rims and floor). We produced a geomorphic description of these units. We made a topographic cross-section spanning the contact between the sinuous and boulder units (Figure 1) with data from the Mars Orbital Laser Altimeter (MOLA).

For each of the units we calculated three parameters: the percentage of squares containing polygons, the percentage of polygonised squares containing solely FCPs, and the ratio LCP/HCP (number of squares containing LCPs / number of squares containing HCPs).

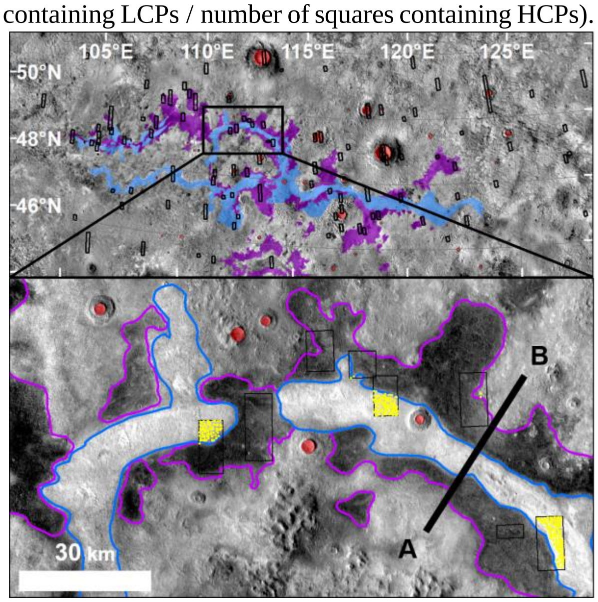

Figure 1: the study zone (top panel) with the sinuous unit in blue, the boulder unit in purple, craters in red, and the HiRISE footprints as black rectangles. On the bottom panel, note how the polygons (yellow points) are concentrated on the sinuous unit and absent from the boulder unit. Background: THEMIS global day-IR mosaic (THEMIS team/Arizona State University).

Results: The boulder unit has a very low percentage of polygonisation (~ 0.5 %), and exhibits no LCPs or HCPs. The sinuous and crater units both show a high percentage of polygonisation (> 80 %) compared to the unclassified terrains (40 %; Figure 2). Craters also have fewer FCPs (so more LCPs and HCPs) than the sinuous unit and unclassified terrains (50 % vs > 70 %), and have a higher LCP/HCP ratio (0.40 vs ~ 0.23 and ~ 0.26; Figure 2). The cross-section (Figure 3) and the regional-scale elevation data show that the sinuous unit is higher in elevation than the neighboring boulder unit, which is lower in elevation than the surrounding unclassified terrains.

Discussion:

Polygons & substrates. The sinuous and crater units have a similar percentage of polygonised squares (Figure 2), and no difference in polygon dimensions is measurable between these units. We infer that these units must have cracked in a similar way. Thus, they have similar surficial rheological properties [7] favoring the development of a polygonal network, e.g., a high porosity and high ice content (e.g. [8], [9]) which could be produced in sedimentary material that underwent ice deposition events. In contrast, we interpret the unclassified terrains, which exhibit discontinuous polygon fields, to have heterogeneous surficial rheological properties that inhibited the development of such a network (e.g., low porosity/ice content because of a massive material such as bedrock; Figure 2). We interpret that the boulder unit, with very few polygons, could be constituted of a homogeneous massive material with low porosity that totally hinders ice-enrichment and polygon formation. The lower percentage of squares containing solely FCPs and higher LCP/HCP ratio in the crater unit compared to the other units could be explained by a cold trap effect [5, 10].

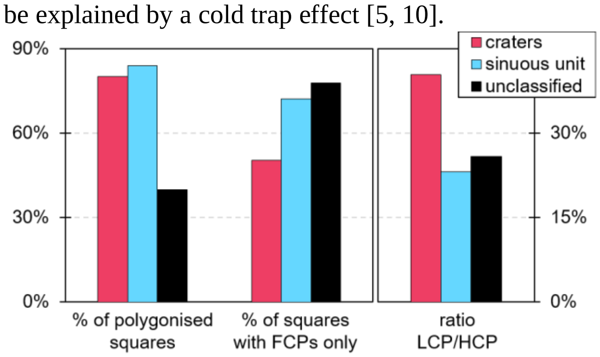

Figure 2: percentage of polygonised squares, percentage of squares with FCPs only and LCP/HCP ratio for all units.

Unit emplacement. The boulder unit is located at relatively low elevations (Figure 1 & 3), seems to be constituted of massive material, exhibiting boulders sometimes angular that could result from *in situ* breakdown. Observations of puzzle-rocks support this hypothesis. The sinuous unit probably has a high ground ice content, exhibits a sinuous and elongated shape, and is spatially associated with the boulder unit, but always at a higher elevation (Figure 3) and seemingly overlapping it in some places (Figure 1). Our study zone is located at the terminus of Hrad Vallis, a Late-Amazonian channel originating from Elysium Mons, thought to have conveyed both lava and water-rich flows [11]. We thus suggest that the boulder unit could be an ancient low-viscosity lava flow [12] that followed a pre-existing channel and ponded in low-elevation areas. The sinuous unit could be a later, more viscous flow, formed from sedimentary material deposited in Hrad Vallis and mobilized by a fluid (e.g., a lahar). It would have followed the same low-elevation path as the lava flow, depositing over it and forming this sinuous positive relief feature. This origin for the sinuous unit would imply that polygons of our study zone did not form exclusively in an ice-rich mantling unit as previously thought, but also in other ice-rich units.

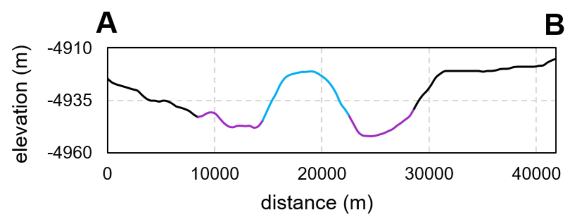

Figure 3: the cross-section shown in Figure 1 (vertical exaggeration = 200). The sinuous unit and the boulder unit are displayed in blue and purple, respectively.

Conclusion: We showed that the morphology of polygons can be used as a tool to gain insights into the geology of a substrate. Here it allowed us to infer different origins for the boulder (lava flow) and sinuous units (aqueous flow), that match the geological context of the area.

Future work: We will apply this technique to terrains in Arcadia Planitia, where evidence of glacial features are observed, to further investigate this relationship.

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