EPSC Abstracts
Vol. 10, EPSC2015-775, 2015
European Planetary Science Congress 2015

Clastically-sorted polygons and pre-(ice-dust) mantle periglacialism in the Argyre region, Mars

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1. Introduction

Here, we present three new findings that point to multiple episodes of Late Amazonian Epoch periglacial revisions in the Argyre region **(Fig. 1)**:

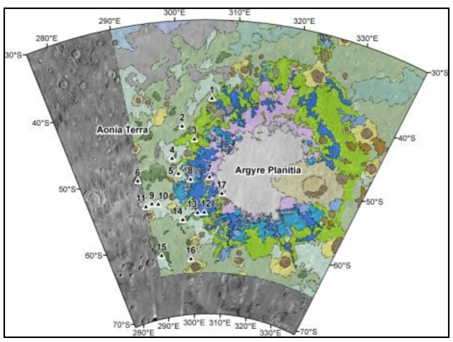

Figure 1: Sorted-polygon locations, on the basin rim and adjacent highlands. Adapted from a geological-unit map of Argyre in [1].

1) Small-sized (~15-25m in diam.) and sorted-polygons (*SPs*) **(Fig. 2)** are observed. The morphology of the *SPs* is consistent with the work of clastic sorting, cryoturbation and mobile liquid-water that has undergone freeze-thaw cycling [2-4]. Heretofore, there have been no region-wide reports of *SPs* in the southern hemisphere [5].

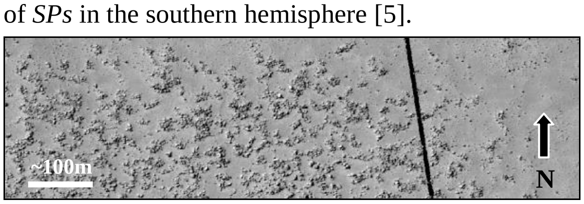

Figure 2: Sorted (partially-enclosed) polygons (*HiRISE* PSP_005597_1250; 54.797^{0}S, 291.489^{0}E; site 1 in **Figure 1**).

2) The collateral presence of gelifluction-like lobes, gullies putatively incised by the flow of water, and small-sized non-sorted polygons (perhaps formed by thermal-contraction cracking) in the general area where the *SPs* are located.

3) Stratigraphy showing that the *SPs* have been exhumed from a light-toned and possibly ice-rich mantle that, in turn, is incised by non-sorted polygons (*NSPs*). This underlines the possibility of pre- and post-(ice-dust) mantle periglaciation.

2. Sorted and non-sorted polygons

The *SPs* are observed at seventeen locations in eastern Aonia Terra (*AT*), immediately to the west and southwest of the floor of the Argyre impact-basin **(Fig. 1)** They comprise relatively-dark metre to multi-metre boulders that encircle, often incompletely, zones that are lighter of tone and without resolvable clasts **(Fig. 2)**. A few polygons show margins comprised of individual boulders; most margins, regardless of their radial symmetry or completeness, display multiple boulders. Some boulder margins are imbricated.

The distribution of the *SPs* is irregular. Sometimes, the polygons appear in the midst of dense-boulder-fields and are contiguous; elsewhere, the polygons are relatively isolated and in the midst of sparse boulders. Typically, the density of polygon distribution decreases proportionately as the boulder coverage of the terrain lessens and the surface coverage of the light-toned mantle increases **(Fig. 2)**.

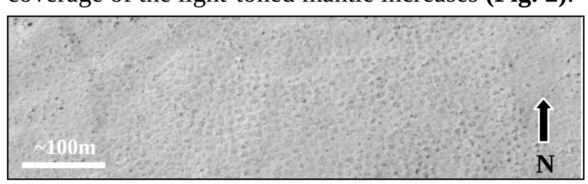

Figure 3: Non-sorted polygons (*HiRISE* PSP_005597_1250; site 1 in **Figure 1**).

Distinctly, clusters of small-sized (~5-10m in di-am.) and non-sorted polygons **(Fig. 3)** are ubiquitous in the light-toned terrain where the sorted polygons are not observed and in transitional terrain where the distribution of sorted polygons is increasingly sparse. Polygon margins measure ~25-50cm in diameter and polygon centres are slightly elevated (relative to their margins.

Immediately to the east of the *SP* sites, lobe-like features are observed on the north (equator-facing) inner-wall of an impact crater (**Fig. 4). **From a plan view, the lobes display long and short axes parallel and normal to the slope wall, respectively, with downslope segments being wider than the upslope ones. The lobes also display lateral coalescence, forming crenulated terrace-fronts. The apexes of these assemblages are synonymous with their long-axes and the side by side distribution of the two lobe assemblages gives them a saw-tooth appearance. The slope-side lobes and lobe assemblages also drape non-sorted polygons, of the type described above.

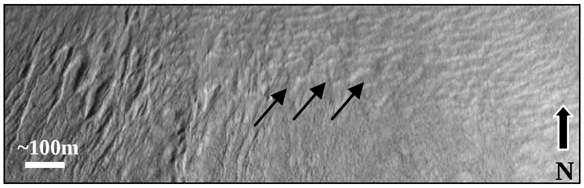

Figure 4: Possible gelifluction lobes. (*HiRise* ESP_028857_1255; 295.217^{0}E, 54.245^{0}S; site 6 in **Figure 1**).

There are multiple locations in our study region where gullies are observed within impact craters; typically, they are ~4km in length and originate from rocky out-crops ~50m below the crater rim. They occur on north/northeast-facing slopes and incise a polygonally-patterned mantle that covers the rest of the crater wall. The alcoves are up to 1km wide, narrowing downslope, and are bounded laterally by steep incisions. The channel portion of these gullies often is braided and/or leveed. The depositional fans show multiple superpositions and often are incised by channels or channel segments.

The lighter-toned material encircled by the *SPs* also forms a wide-ranging, relatively uniform and ~metre-thick mantle that blankets the terrain [6-7] wherever the sorted polygons and associated boulder-fields are not observed (Fig. 2). When mantle patches and the *SPs* are contiguous, the former show a slightly higher elevation than the latter.

3. Discussion

Absent of boots on the ground and the ability to dig a soil pit or trench, validating a periglacial hypothesis that assumes the vertical and highly localized displacement of clasts to metres of depth must be indirect. Towards this end, we have identified a three-feature landform assemblage in *AT* that is spatially collateral with the sorted polygons. Collectively, the assemblage points to periglacialism, freeze-thaw cycling and the availability of mobile liquid-water.

(1) The key morphological characteristics of the crater-wall lobes are consistent with slope-side gelifluction on Earth (Fig. 5). Gelifluction is a type of mass-wasting induced by three key variables: (a) the availability of liquid water at or near the surface; (b) the presence of a near-surface permafrost-table that prevents the downward movement of moisture and promotes soil saturation; (c) soil composed of fine-grained and silty material that can remain wet longer than coarse-grained material and facilitate the downhill creep of slope masses [12].

(2) A number of key traits point to the possibility of the gullies in our study region having been formed by "water-rich" debris flows, e.g. levees, discontinuous channel segments and cutoffs, channel sinuousity, steep incisions and multiple small fan-shaped deposits. Moreover, the equatorial orientation of the observed gullies and crater-wall lobes could be a marker of insolation-driven mobilisation of near-surface water-ice in *AT*.

(3) The light tone of the mantle in *AT*, the uniformity of its distribution and its mid-latitudinal location, are characteristics shared with the widely reported and possibly "ice-rich" latitude-dependent mantle; the latter is thought to have formed by means of atmospheric precipitation and surface accumulation in response to a period of high obliquity in the very recent past [e.g. 13-14]. Thermal-contraction polygons do not require an ice-rich medium to form. However, mantle incision by these *NSPs* does point to the possibility of cryotic processes having been at work in their formation subsequent to the emplacement of the mantle.

The slightly higher elevation of the mantle than the *SPs*, along with the similarity of tone be-tween the mantled terrain and the polygon centres (possible mantle-remnant material), suggests that clastic polygon-formation could have predated the mantle.

4. Conclusion

We have identified a multi-feature-landscape assemblage that possibly benchmarks the relatively-recent presence of mobile liquid-water (gelifluction lobes and gullies) and of ice-rich terrain (mantle and thermal-contraction polygons). Against this backdrop we infer that the *SPs* in *AT* are the work of periglacial processes. We also report that the newly identified *SPs* and *NSPs* are separated, stratigraphically and geochronologically, by the mantle. This suggests, contrary to the dominant paradigm in the discipline, that Late Amazonian Epoch periglaciation on Mars is not synonymous with the accumulation or subsequent ablation of mantle material.

5. References

[1] Dohm, J.M. et al. *Icarus* 253, 66-98, 2015. [2] Taber, S., *The mechanics of frost heaving…*, 1930. [3] Washburn, A.L. *Periglacial processes & environments*, 1973. [4] French, H.M., *The periglacial environment*, 2007. [5] Banks, M. et al.,*JGR*, 113, E12015, 2008. [6] Mustard, J.F. et al. (2001). *Nature* 412, 411-414, 2001. [7] Milliken, R.E. et al. *JGR* 108, E6, 505, 2003.