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Sorted (clastic) polygons in the Argyre region, Mars, and possible evidence of pre- and post-glacial periglaciation in the Late Amazonian Epoch

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ABSTRACT

The Argyre basin and associated rim-materials in the southern highlands of Mars are ancient, having been formed by the impact of a large body ~3.9 Gya. Despite its age, the regional landscape exhibits a wide range of geological/geomorphological modifications and/or features, e.g. fluvial, lacustrine, aeolian, glacial and periglacial. Collectively, this bears witness to the dynamic evolution of the Argyre region from the deep past through to, perhaps, the present day.

Here, we present three principal findings that point to at least two distinct episodes of periglaciation, separated by a possible glacial-interval, during the very Late Amazonian Epoch in eastern Aonia Terra (*AT*), i.e. on the western flank of the Argyre basin. These findings are the product of our circum-Argyre study of all HiRISE images (~35–65°S and ~290–350°E).

(1) (a) The first periglacial episode involves the development of small-sized (~15–25 m in diam.) and clastically-"sorted polygons" (*SPs*). The *SPs* are observed at eighteen locations within eastern *AT*. Hitherto, the presence of *SPs* in this region has been reported at one location alone. No other observations of *SPs* in the southern hemisphere of Mars have been documented. Morphologically similar landforms develop in cold-climate (permafrost) landscapes on Earth by means of periglacial processes, i.e. freeze–thaw cycling, segregated-ice formation, cryoturbation and frost heave.
(b) We ascribe a periglacial origin to the *SPs* in eastern *AT* on the basis of this similarity of form and, no less importantly, on the close spatial-association of the *SPs* with blockfields (whose weathered "clastic" products are the building blocks of periglacial sorting on Earth), gelifluction-like lobes and possible "wet" gullies. Where similar assemblages occur in terrestrial permafrost-landscapes, the presence of liquid water and of boundary conditions tolerant of freeze–thaw cycling, are observed or inferred.
(c) Fifteen of the eighteen *SP* locations are clustered longitudinally (44.4–57.5°S; 289.9–302.4°E). This is inconsistent with the latitudinal- and (obliquity-driven) dependency of freeze–thaw cycling in the Late Amazonian Epoch hypothesised by many workers in the discipline.

(2) The second periglacial episode is highlighted by the development of small-sized and clastically non-sorted polygons (*NSPs*). These polygons could have formed by means of a "dry" cryotic process, i.e. thermal-contraction cracking.

(3) The *NSPs* incise (and thus postdate) a light-toned mantle, thought by numerous workers to comprise an "ice-dust" admixture. At some of the locations where the putatively icy-mantle has undergone apparent ablation, underlying *SPs* are observed. This suggests that the *SPs* predate the mantle and, derivatively, the *NSPs* as well.

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The proposed geochronology of "wet-based *SP* – icy mantle – dry-based *NSP*" (periods and interval) is entirely new to the community. Moreover, it underlines the possibility that periglacial and glacial boundary-conditions, at least in our study area, may have oscillated much more substantially in the very Late Amazonian Epoch than many workers have thought possible.

1. Introduction

The Argyre basin (~1200 km in diam. and ~4 km deep) and associated rim-materials lie in the southern hemisphere of Mars. They were formed by the impact of a large body ~3.9 Gya (Robbins and Hynek, 2012; Robbins et al., 2013). Despite its age, the regional landscape exhibits a wide range of geological/geomorphological modifications and/or revisions that have punctuated its evolution, perhaps through to the present day (Dohm et al., 2015), e.g. fluvial (Dickson et al., 2007; Conway et al., 2011; Raack et al., 2012); lacustrine (Parker, 1989; Dohm et al., 2015); aeolian (Hayward et al., 2007; Silvestro et al., 2010); glacial (Kargel and Strom, 1992; Baker, 2001; Banks et al., 2008, 2009; El-Maarry et al., 2013); and, periglacial (Seibert and Kargel, 2001; Banks et al., 2008; Levy et al., 2009; Soare et al., 2014a,b).

Here, we present three new findings that constrain the possible occurrence of at least two distinct episodes of periglaciation, separated by a glacial interval, in a region that encompasses the western flank of the Argyre impact-basin in eastern Aonia Terra (*AT*). These findings are the product of a circum-Argyre study of all HiRISE images (~35–65°S and ~290–350°E).

First, we report and discuss the presence of small-sized (~15–25 m in diam.) and clastically-sorted polygons (*SPs*) at eighteen locations in *AT*. Heretofore, morphologically-similar polygons have been identified in two other regions of Mars: (a) at the high latitudes of the northern hemisphere (Gallagher and Balme, 2011; Gallagher et al., 2011) and (b) within the near-equatorial and putative floodplains of Elysium Planitia (4.5°N, 156.0°E) (Balme and Gallagher, 2009). *SPs* located in our study area were reported by Banks et al. (2008) but only at one location.

Sorted polygons are commonplace features of periglacial landscapes on Earth. "Periglacial" refers to the processes and features associated with "freeze–thaw" cycling; liquid water may but need not be involved with these processes and features (Washburn, 1973; French, 2007). "Sorting" comprises the vertical and horizontal separation of clasts from finer-grained material and is the result of segregation-ice formation, cryoturbation and frost heaving (e.g. Taber, 1930; Washburn, 1973; French, 2007). "Sorting" occurs <u>if</u> and <u>only</u> <u>if</u> three basic conditions are met. First, the terrain must comprise an admixture of cobbles or boulders and fine-grained sediments (invariably located in high latitude or alpine blockfields); second, soil moisture must be relatively high (at least 20%); and third, freeze–thaw cycling must be commonplace (e.g. Taber, 1930; also, Washburn, 1973; French, 2007).

Absent of a soil pit or trench whose horizons or relative stratigraphy could be used to validate or invalidate a formation hypothesis for the *SPs* based on periglacial processes, we ascribe a periglacial origin to the *SPs* on the basis of: (a) their morphological similarity to *SPs* in terrestrial permafrost-landscapes and (b) their close spatial-association with blockfields (whose weathered "clastic" products are the required building-blocks of periglacial sorting on Earth), gelifluction-like lobes and possible "wet" gullies. Where similar assemblages are observed in arctic or alpine landscapes, the presence of liquid water and of boundary conditions consistent with freeze-thaw cycling are observed or inferred.

Second, we report and discuss the presence of small-sized and clastically non-sorted polygons (*NSPs*). The *NSPs* could be the work of thermal-contraction cracking but, in and of themselves, do not require liquid water to form or to propagate.

Third, we note that the *NSPs* incise (and thus postdate) a light-toned mantle putatively comprised of ice-dust. At some of the locations where this icy-mantle seemingly has undergone ablation or dissection, *SPs* have become visible. This points to the antecedent formation of the *SPs* and their subsequential blanketing by the mantle.

Here, we will describe and discuss the various polygon types associated with this proposed periglacial–glacial–periglacial stratigraphy in the Argyre region, highlighting a range of regional "wet" and "dry" boundary conditions that, hitherto, has not been identified in the literature.

2. The geology of the Argyre region (Fig. 1)

The Argyre impact-event resulted in the modification of ancient (southern-hemispheric) crustal-materials comprised of igneous, sedimentary, and metamorphic rocks (Dohm et al., 2015); this includes materials tapped from great depths, perhaps even associated with the upper mantle (Buczkowski et al., 2008a,b, 2010). Basin, rim and impact-ejecta deposits are ubiquitous in the region and they have been mixed/modified by post-formation impact-cratering as well as by the work of wind, water (in all three phase states), tectonism and gravity-driven processes (Dohm et al., 2015).

No less important is the impact-related formation of tectonic structures and structurally-controlled basins in the region. This would have (and perhaps still does) facilitate(d) the local and regional migration of surface, near-surface or deeply-seated water and heat, from early on in the geological history of the impact basin through to the relatively recent past (Dohm et al., 2015; also, see Soare et al., 2014a).

2.1. Structure and sorting in the Argyre region

In our survey of all circum-Argyre *HiRISE* (High Resolution Imaging Science Experiment) images ($n = 805$) we have identified (Fig. 1) and catalogued (Table 1) eighteen locations with sorted clastic-landforms (Fig. 2) in eastern *AT* (40.6–63.0°S; 289.9–305.8°E). The eighteen locations are distributed amongst eight geological-units of varying age; each of these units exhibit prominent and numerous structural-characteristics, complex geological-histories and countless (putative) markers of hydrogeological activity (Dohm et al., 2015). Fifteen of the locations (#2–16) are clustered (showing a distinct latitudinal and longitudinal bias: (44.4–57.5°S; 289.9–302.4°E); they also exhibit a close spatial-association with kilometre-scale blockfields (Table 1 and Fig. 3).

2.1.1. NAb1, Argyre-basin member 1 (locations 8a–d; 9a–b) (Dohm et al., 2015)

Locations 8(a–d) and 9(a–b) are in the highly-degraded Argyre impact-crater rim; moreover, the locations lie in the midst of a