"ICE-RICH" (PERIGLACIAL) & "ICY" (GLACIAL) DEPRESSIONS IN THE ARGYRE REGION, MARS.

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Introduction: Here we report, for the first time in the literature, the presence of Argyre-region (*AR*) depressions that are scalloped (sometimes), metres to decametres-deep, decametres to kilometres in scale, relatively flat-floored and polygonised. Similar depressions have been observed widely in Utopia Planitia (*UP*) [e.g. 1-3] and Malea Planum (*MP*) [e.g. 4-5]. Although there is some debate about whether the latter formed by sublimation or evaporation, it is commonly believed that the terrain incised by the depressions occur is "ice-rich" and thermokarstic in origin. Most workers assume that this "ice-richness" is derived of a bi-hemispheric, latitudinally-dependent and atmospherically-precipitated (Late Amazonian Epoch) mantle that is metres thick [e.g. 2,6].

In this abstract we have four main aims: (1) present the distribution of the *AR* depressions on a geological-unit map (**Fig. 1**), having studied all available *HiRISE* images (n=1101) of the region (290-360^{0}E, 30-70^{0}S); (2) discuss a periglacial-origin hypothesis for some of these depressions; (3) suggest that the general assemblage of depressions comprise two disparate types, i.e. periglacial (Type-1) and glacial (Type-2); and, (4) propose that if this dichotomy is valid, then the monotheistic interpretation of the depressions in *UP* and *MP* ought to be revisited.

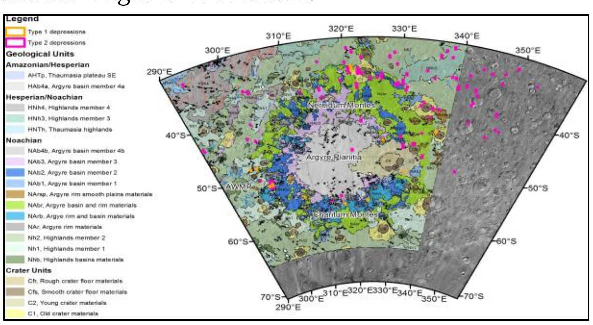


Fig. 1: Geological-unit map of the Argyre impact-crater and surrounding region of Mars (adapted from [7]). Type-1 depressions highlighted in orange; Type-2 depressions highlighted in pink.

The geological context: The Argyre basin lies in the southern hemisphere of Mars. It was formed by the impact of a large body ~3.9 Gya. Despite its age the basin, associated rim-materials and marginal highlands show geological modifications and revisions by a wide-range of processes - tectonic/volcanic, fluvial, aeolian, glacial and periglacial - possibly through to the present day [7]. In addition to the thermokarst-like depressions noted above and described below, other putatively (late-stage) periglacial-landforms have been identified in the region: a) low and high-centred polygons [8]; b) sorted polygons [9-10]; c) open-system pingos [11]; and, d) gelifluction lobes [10].

Ice-rich (Type-1) depressions in the *AR* (Fig. 2): These depressions display various plan-forms, including scallop-like, and often are clustered, possibly coalesced. Long-axis diametres range from decametres to kilometres; depths range from metres to decametre. Margins are continuous, sharp albeit rimless and well-defined; depression sides lack gravitational-slope processes or fan deposits at the floor. Generally, floors are flat or slightly concave up.

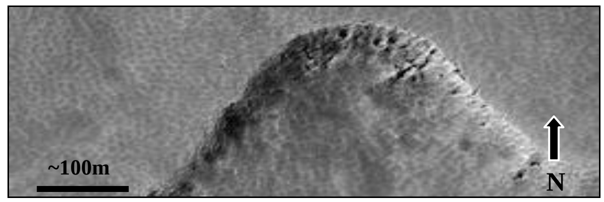


Fig. 2: "Type 1" depression in *AP* (HiRISE ESP_013890_1240; 307.523^{0}E, 55.615^{0}S). Note: polygonised depression floors, walls and surrounding terrain; also clustered pitting in adjacent polygon-junctions/margins at the northern edge of the depression.

Depression-margins, -sides, -floors and even the terrain beyond the depressions, always are incised by small-sized (~5m) and non-sorted polygons. Sometimes, polygon-junctions and/or margins within the depressions are pitted. Invariably, the depressions are embedded in (relatively youthful) terrain that is cratered sparsely and that mutes the underlying topography.

The Type-1 depressions generally are observed across several geological-units [11]: on the northern, western and southern flanks of the Argyre impact-basin (Fig. 1). However, the largest concentration of observed depressions lies within a tight longitudinal-band (~300^0-310^{0}E) on the rim materials immediately to the west of the Argyre basin.

"Ice-rich" (periglacial) depressions on Earth: "Thermokarst" describes a landscape or landforms that, by the presence of "excess ice", is/are susceptible to deformation, i.e. the loss of structural integrity by thermal destabilisation [e.g. 12]. "Excess ice," or permafrost that is "ice-rich", describes frozen ground whose pore space is filled or even exceeded by the ice within that permafrost [12]. Key and commonplace markers of "excess ice" in periglacial terrain on Earth are polygonised ice-wedge systems formed in thermal contraction cracks.

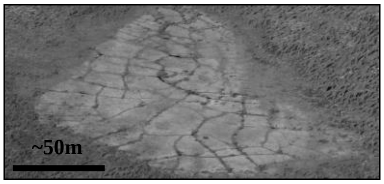


Fig. 3: Drained thermokarst-lake basin (alas), Tuktoyaktuk Coastlands, northern Canada. Note: polygonised basin floor; some water-filled polygon-junctions/margins. Image credit: R. Soare.

"Thermokarst" also refers to a process, i.e. the slump, fall or subsidence of "ice-rich" permafrost as it deflates or settles out in response to the thaw-engendered [or sublimation-based] loss of "excess ice" in its pore space [12].

The scale of this process varies widely, mirroring the spatial distribution of "excess ice" and the depth of thermal instability; consequently, the thermokarst process engenders depressions that vary substantially in size, i.e. metres to kilometres in diameter and metres to decametres in depth. Rises of mean temperature, either locally or regionally, are a leading cause of the thaw-engendered [or possibly sublimation] loss of excess ice [12] and the subsequent formation of alases (**Fig. 3**).

Typically, terrestrial alases are rimless, relatively flat-floored, polygonised and show a range of shape, scale and depth comparable to the depressions in the *AR* **(Fig. 3)**. Based on these similarities we ascribe a similar origin to the latter, i.e. rooted in "ice-rich" terrain that has undergone temperature excursions near, at and perhaps above 0^0C [13].

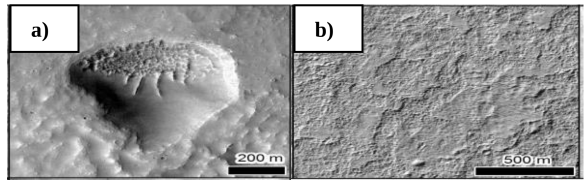
"Icy" (Type-2) depressions in the *AR* (Figs. 4a-b): Type-2 depressions comprise three sub-groups (a, b & c); each of them reside in sparsely-cratered terrain that, like the Type-1 depressions, mutes the underlying topography; however, unlike the Type-1 depressions the Type-2s are observed throughout the *AR* (**Fig. 1**).

Type-2(a): decametre to kilometre-scale (comparable to the Type-1s); rimless, shaped similarly to the Type-1s; neither polygonised nor clustered (**Fig. 4a**).

Type-2(b): multi-metre to decametre-scale pits or hollows, clustered densely (often overlying the Type 2(a) depressions), rimmed, unpolygonised and shaped irregularly (**Fig. 4a**). Occasionally, Type-2(a/b) assemblages overlie Type 1 depressions [13].

Type-2(c): scaled like Type 2(b), raised rims and irregular shape, dense distribution on inter-crater plains (**Fig. 4b**); most widespread of the Type-2 depressions.

"Icy" (glacial) depressions on Earth (Fig. 5a-b): Thermokarst (alpine) lakes occur in debris-covered "dead-ice," decoupled from an originating glacier (**Fig. 5a**). Here, crevasses formed by glacial advance/ retreat fill up with meltwater; this generates small rimless-lakes (decametres in diametre/metres deep) [e.g. 14]. Continuous, unpolygonised permafrost surrounds the lakes; and "excess ice" is absent.



Figs. 4a-b: a) Sharply-rimmed Type 2(b)s nested in rimless Type 2(a) depression; b) Landscape-wide Type 2(c) depression.

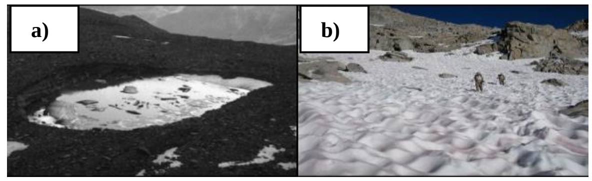


Fig. 5a-b: a) Dead-ice lake [14, copyright, the Regents, Univ. of Colorado]; **b)** Snow-field suncups, Mather Pass, California [15].

Typically, high-alpine "suncups" (**Fig. 5b**) are bowl-shaped, evenly though densely-spaced, and roughly-hexagonal shaped with sharp and narrow ridges; the suncups form by differentiated albeit highly localised ablation of dirty vs clean snow [14].

Morphologically, the Type-2 depressions are similar to dead-ice depressions and suncups in high-alpine terrain on Earth; here, glaciation is commonplace and sublimation often engenders mass loss. Were there a relict (water-ice) mantle where the Type-2 depressions occur on Mars, sublimation could account for the apparent loss of mass required by depression formation.

Discussion: Elsewhere [16], we present morphological and non-morphological grounds for dichotomising the *AR* depressions into two types. Here, we use the morphology of the depressions to infer an "ice-rich" periglacial origin for the Type-1s, to propose an "icy" glacial origin for the Type-2s. and, analogically, to ask whether a similar dichotomy exists in *UP* and *MP*.

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