PRE- AND POST-PERIGLACIAL PERIGLACIATION IN UTOPIA PLANITIA, MARS. R.J. Soare,[1] S.J. Conway,[2] C.J. Gallagher,[3] J.M. Dohm,[4] J.P. Williams,[5] S.M. Clifford.[6] [1]Geography Department., Dawson College, Montreal, Canada H3Z 1A4 (rsoare@dawsoncollege.qc.ca), [2]CNRS UMR 6112, LPG Nantes, France, [3]UCD School of Geography, University College, Belfield, Dublin 4, Ireland, [4]The University Museum, The University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo 113-0033, Japan, [5]Department of Earth, Planetary, and Space Sciences, University of California, Los Angeles, California, 90095, [6]Lunar and Planetary Institute, Houston, Texas, 77058.

Introduction: For the first time in the scholarly literature we report the spatial and possible genetic-relationship on Mars, more specifically, at the mid-latitudes of Utopia Planitia (*UP*) (45-50^{0}N; 115-120^{0}E), of: (a) multiple ice-rich mantles that are fine-grained, youthful and separated stratigraphically; (b) small-sized, i.e. ~5-10 m, and (clastically) sorted polygons; (c) small-sized, i.e. ~5-10 m, and non-sorted polygons; and, (d) metre to decametre deep, rimless, tiered depressions **(Fig. 1)**.

We postulate that the freeze-thaw cycling of water is the developmental lynchpin of this spatially-associated assemblage and suggest that no other single process is as robust or as coherent in explaining the origin and evolution of the landform assemblage.

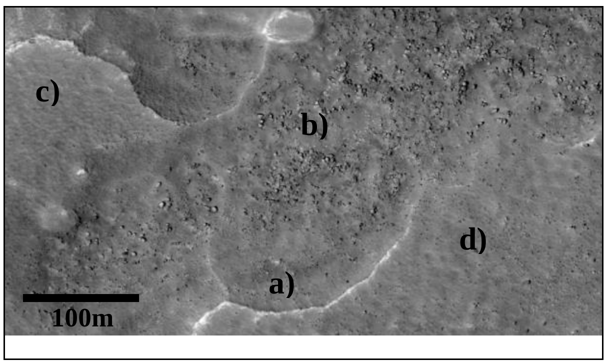

Fig. 1 - **a)** rimless depressions; **b)** sorted polygons; **c)** unsorted polygons; **d)** mantle(s) (HiRISE ESP_044977_2270, 46.633^{0}N, 117.846^{0}E, 50cm/ pixel. Image credit: NASA/ JPL/University of Arizona). North is up.

Periglacial "ice-complexes" on Earth: In cold-climate and non-glacial regions such as the Tuktoyaktuk Coastlands of northern Canada [e.g. 1-2] and theYamal Peninsula of eastern Russia [e.g. 3-4] genetically-associated landform-assemblages similar in membership to those observed in *UP* are referenced as (periglacial) "ice-complexes." The complexes comprise metre- to decametre-thick (mantle-like) sequences of fine-grained and ice-rich sediments that accumulated largely during the Late Pleistocene Epoch and were revised extensively by freeze-thaw-cycling during the Holocene Epoch. This has engendered a hydro-cryological landscape with: thermokarst lakes and emptied thermokarst-basins (i.e. alases); non-sorted, ice-wedge polygons and sorted (clastic) polygons; solifluction/gelifluction terraces; retrogressive thaw slumps and active layer-detachments; closed (hydrostatic) pingos; and, gullies **(Fig. 2)** [e.g. 1-4].

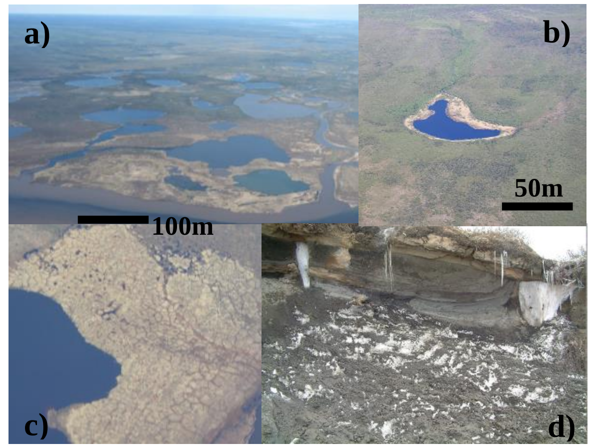

Fig. 2 - Mosaic of "ice-complex" landforms in the Tuktoyaktuk Coastlands. **a)** Thermokarst-lake landscape; **b)** alas; **c)** ice-wedge polygons (plan view); **d)** ice-wedge polygons (cross-section). Image credits: R. Soare.

A "complex" landscape in mid-Utopia Planitia:

a) Mantle(s) **-** Our study location exhibits surface and near-surface terrain comprised of disparate horizons (mantles) that are: relatively light of tone; smooth in texture (at the ~25cm/pix. resolution of the HiRISE imagery); have sparse superposed-craters; and, are metres to decametres thick. Where and only when the surface mantle is eroded, small-sized and clastically-sorted polygons are observed, as are clastically non-sorted boulder-fields adjacent to them. The sorted polygons also overlie decametre-deep depressions that are rimless and scalloped. Small-sized but clastically non-sorted polygons incise the surface mantle wherever it is intact or extant [5].

b) Sorted and small-sized (clastic) polygons (*SPs*) - "Sorted" describes landforms comprised of relatively dark-toned and marginal cobble to boulder-sized clasts that surround, often incompletely, clast-free material; the latter is lighter of tone and finer in grain (i.e. its grain-size lies below the best *HiRISE* resolution) than the former. Some margins comprise individual cobbles or boulders; other margins comprise multiple and sometimes mixed clasts lying side-by-side [5]. The margins also vary in their height, depending upon the thickness of the constitutive clasts or the presence/absence of clast imbrication. Polygon diameters range from ~5-10m. Interestingly, some sites exhibit *SPs* nested in *NSPs*.

c) Non-sorted and small-sized polygons (*NSPs*) - As noted above, wherever the mantle is intact or extant at our study location small-sized (~5-15m in diam.) and non-sorted polygons are observed [5]. The *NSPs* exhibit centres that are slightly elevated or domed (relative to their margins) or centres more or less at the same elevation as their margins.

d) Scalloped & rimless depressions - Sharply-incised, closed and rimless depressions are ubiquitous at our study location. These landforms are circular or sub-circular to elongate and may show inward-oriented tiers or terraces. The depressions are observed in isolation, clustered or coalesced. Depression-lengths (long axes of the depressions defined by the outermost closed-contour line) range from decametres to hundreds of metres; short axes are smaller. Depression-depths comprise decametres of material, possibly fine-grained, that predates the surface mantle and could comprise an antecedent mantle in its own right. All of the depressions are blanketed by the surface mantle and, as such, are incised by the *NSPs*. Where and when the mantle coverage of the depressions is truncated, *SPs* and non-sorted boulder outcrops are observed.

Landscape-scaled geological conciliation [adapted from 6]**:** Rather than evaluating whether individual Martian landforms or landscape features are the work of "dry" (i.e. sublimation/aeolian) or "wet" (i.e. water-based freeze-thaw cycling) processes, we postulate a geological heuristic or metric based on the spatial association, distribution and possible communal-genesis of its landscape members. This geological "conciliation" proposes that landform-origin hypotheses are plausible and avoid equifinality to the extent that: 1) the number/diversity of landforms/landform features in a Martian landscape are comparable if not synonymous with a terrestrial landscape(s); 2) the spatial association/distribution of Mars/Earth landscape members is similar; and, 3) the process-based explanation of landform origin on Mars is coherent, both synchronically and diachronically, and in keeping with the geological dictates of a terrestrial landscape [7].

Periglacial ice-complexes in mid Utopia Planitia? - Within the Mars community most members agree that the surface mantle at the latitude of our study area is the product of atmospheric precipitation and surface accumulation during the very late Amazonian Epoch, in response to obliquity-driven changes of boundary conditions and peak temperatures [e.g. 8-9].

Some members suggest that the mantle comprises dust-nucleated ice, akin to that which accumulates in the Antarctic [e.g. 10-13]. By contrast, we postulate ice having nucleated around airborne and weathered basalt; unlike dusty ice, the greater permeability and porosity of (fine-grained) basalt make it an ideal medium for periglacial processes, i.e. the formation of interstitial or segregation ice [7]. On Earth, "ice complexes" form in the presence of segregation ice and develop only where fine-grained sediments revised by freeze-thaw cycling and associated (periglacial) processes dominate the near-surface soil-horizons [14].

In particular, thermokarstic terrain on Earth, akin morphologically, as well as by its small-sized polygonisation and development in fine-grained (mantle-like) material, to the scalloped, rimless depressions discussed above, inflates or deflates as ice-rich terrain (comprised of segregation ice) aggrades or degrades [14]. Ice veins, lenses, wedges (i.e. ice-wedge polygons formed by thermal-contraction cracking) and even tabular ice are "segregation-ice" types. On Earth, a leading cause of ice aggradation/degradation is climate-change driven rises of seasonal mean-temperatures.

"Wet" or "dry" landscape evolution: In the Antarctic Dry Valleys some periglacial landscapes are affected by sublimation. For example, when buried glacial-ice is exposed to extremely cold and dry air by thermal-contraction cracks the ice begins to sublimate [15]. This deepens the cracks/troughs and gives to the polygons a high-centred or domed appearance [15]. However, no near-surface glacial ice has been observed or hypothesised at the latitude of our landscape study.

Moreover, freeze-thaw cycling and "wet" periglacial processes comprise the only geologically coherent, robust and landscape-scale set of processes by which "ice-complexes" could evolve. This is not to say that sublimation is absent from possible periglacial-revisions on Mars, i.e. the scalloped-depressions could comprise volatile loss by sublimation; however, the origin and ice-enrichment of the decametres-deep material in which the depressions occur as well as the means by which sorted and non-sorted polygons form in a shared geological-space leave "wet" periglacial processes as the most plausible formation-mechanism.

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