CLIMATE CHANGE & THE ORIGIN OF ICE-RICH PERMAFROST IN MID UTOPIA PLANITIA, MARS.

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Introduction: In our recent study of mid Utopia Planitia (UP; ~30-60^{0}N; Fig. 1) [1-3] we used all relevant HiRISE (High Resolution Imaging Science Experiment), MOC (Mars Orbiter Camera), THEMIS (Thermal Emission Imaging System) and CTX (Context Camera) to map a spatial assemblage of putatitive periglacial landforms (PPLs): flat-floored and scalloped depressions, small-sized (≤~150m) polygonal patterned-ground and polygon-junction/trough pits (Fig. 2a). On Earth, similar assemblages are diagnostic of permafrost (ground that is permanently frozen for at least two years) that is ice-rich (also referred to as ground-ice), i.e. where the presence of frozen water equals or exceeds the available pore-space in a parcel of permafrost [4-5], (Fig. 2b).

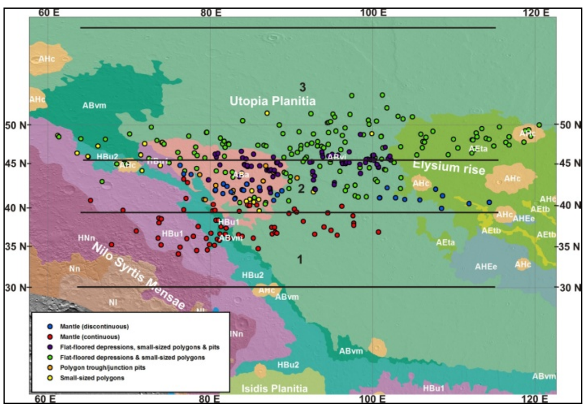

Fig. 1: PPLs in UP (areas 2 and 3). Also shown is a continuous mantle in area 1. The background map is a MOLA hillshade overlying the principal geological units [6].

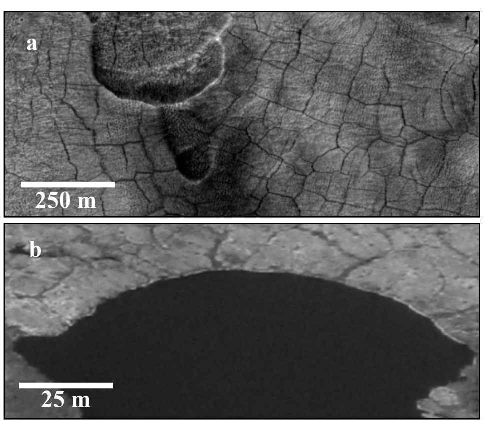

Fig. 2a: Flat-floored depressions and small-sized polygons (HiRISE PSP_007384_22 25, 42.2^{0}N; 86.3^{0}E, ~25cm/pixel. Courtesy of NASA/JPL/UofA. **Fig. 2b:** Thermokarst lake and marginal small-sized polygons, some of whose troughs are filled with water. (Tuktoyaktuk Coastlands, Canada).

Intriguingly, the distribution of PPLs stretches well beyond the longitudinal and latitudinal margins of the ABa (Fig. 1) a regionally delineated geological-unit often associated with periglacialism in UP [i.e. 6-9]. The location of the PPLs also occur in regional geological-units that vary greatly in age, i.e. HBU_1 (Early Hesperian) - AEt_a (Late Hesperian) - ABa (Late Amazonian) [4]. This indicates that the landforms are relatively youthful [1-3] although not as youthful as a metres-thick high-albedo mantle; this mantle occurs discontinuously in area 2 and continuously in area 1 (Fig. 1) [1-3].

Whether the PPLs form by means of sublimation [7-10] or thaw [2,11-13] has been a focus of controversy in the literature for some years. However, in either case the origin and evolution of the PPLs requires ground ice or ice-rich regolith. Here, we discuss the possibility that the ice-rich regolith or permafrost in mid-UP forms syngenetically as a result of freeze-thaw processes and alternating cycles of "loess-like" and "ice-dust" accumulation.

Syngenesis and the formation of ground ice on Earth: In "wet" periglacial landscapes on Earth, i.e. where freeze-thaw cycling is/has been commionplace, syngenetic permafrost develops occurs when host sediments accumulate and freeze more or less concurrently in response to long- term falls of mean annual-temperatures [14-16]. The latter causes the base of the active layer to aggrade upwardly [15]. Ice-enrichment of the host sediments may occur if meltwater, derived of thawed surface snow or ice, migrates into these sediments as they freeze [14-16].

Typically, syngenetically-frozen permafrost comprise wind-blown fine-grained sediments that are silty or loess-like, show a regional distribution and extend uniformly at depths ranging from tens to hundreds of metres [5,14-16]. Where syngenetic permafrost is ubiquitous, i.e. northern Siberia [14] and central Alaska [15], periglacial "complexes" comprised of thermokarst lakes/alases and ice-wedge polygons are commonplace.

Syngenetic permafrost is well-suited to the development of these "complexes," as observed on Earth and possibly on Mars because fine-grained sediments possess small interstices; this facilitates cryosuction and the formation of segregation ice (i.e. a lenticular type of ground ice) [5].

Ground ice and periglacial-landscape evolution (Mars): If the PPLs in mid-UP are formed by periglacial processes in horizons of ice-rich regolith, then the thickness of the horizons must be equal to if not greater than the depth of the terrain (relative to the elevation datum of the surrounding plains) modified by these processes [5]. The maximum (estimated) loss of elevation associated with the depression/polygon assemblages is ~80m [3,10,12-13]. As such, this would also be the minimum depth of the ice-rich regolith in which the assemblages occur.

Ground-ice formation (Mars): Figure 1 shows that the PPLs in and around mid-UP are located in a tight latitudinal-band (42-46^{0}N). This could be the geological expression of a previously unidentified periglacial-unit (PUPU) that accumulated by aeolian transport during the very late-Amazonian period [1,3] and was enriched with ice syngenetically.

We propose that the aeolian processes responsible for the formation of the PUPU constitute two discrete but invariably-related cycles: 1. sedimentary; and, 2. meteoric. The first cycle comprises the incremental and episodic accumulation of fine-grained, desiccated sediments [17] (Fig. 3.1), i.e. sediments that are low in density, have modest shear-strength and are low in thermal conductivity [18]. The North Polar Layered Deposits are thought to comprise sediments of this type [18] and, under the influence of strongly erosive katabatic-winds, could be the source of fines in mid-UP.

Possible geological evidence of these fines has been discussed recently by Séjourné et al. [19]. They suggest that the step-like profiles observed within many of the flat-floored depressions in mid UP are the result of disparate fine-grained sediments that have been weathered and eroded differentially [19].

The second cycle alternates with the first one and could be related to quasi-episodic variations of orbital parameters [20-21]. It involves the atmospheric precipitation of ice or snow throughout mid UP (Fig. 3.2).

"Wet" or "Dry" syngenesis: If boundary conditions (mean temperatures and atmospheric pressure) consistent with thaw occur in mid UP, then ice or snow-related meltwater at or near the surface could migrate into the loess-like sediments underlying them and freeze *in-situ*, when and if mean annual-temperatures fall (Fig. 3.3). Over time, freeze-thaw cycling in association with the episodic and alternating deposition of fines and of ice or snow could generate a thick column of ground ice that is tens of metres thick (Fig. 3.4).

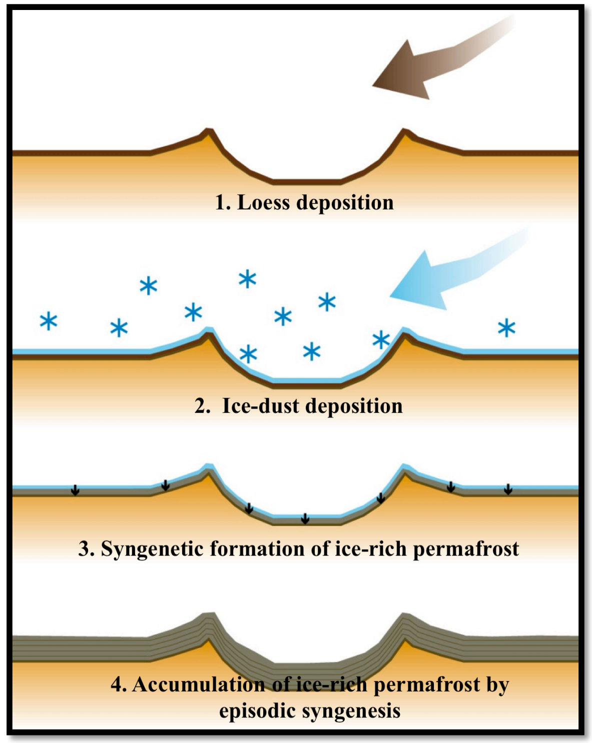

Fig. 3: The formation of ground ice in mid UP by syngenesis and the alternating deposition/accumulation of loess-like sediments and ice or snow.

Syngenetically formed ground-ice also occurs in the McMurdo Dry Valleys of the Antarctic [22-23]. The ground ice is shallow and extends no further than a metre from the surface [22-23]. Moreover, it formed when air/soil temperatures were below 0^{0}C; thus, the ice enrichment of these otherwise "dry" sediments would have taken place by means of diffusive exchanges with the atmosphere and phase changes driven by seasonal temperature-variations [22-23]. No periglacial complexes such as those found in northern Siberia or central Alaska have been observed in the McMurdo Dry Valleys.

Further work is required to evaluate whether thick columns of syngenetic and ice-rich permafrost, the essential building block of periglacial complexes on Earth, can be formed by vapour diffusion either on Earth or on Mars.

References: [1] Soare, R.J. and Osinski, G.R. (2009). *Icarus* 202 (1) doi:10.1016/j.icarus.2009.02.009. [2] Soare, R.J. et al. (2011). *GSA*, *Special Issue* 483, doi:10.1130/2011.248 (13). [3] Soare, R.J. et al. (2012). *PSS*, doi:10.1016/j.pss.2011.07.007. [4] Mackay, J.R. (1998). *Géographie physique et quaternaire* 52 (3) 1-53. [5] French, H.M. (1996). *The periglacial environment*, Longman, Harrow, 341 p. [6] Tanaka, K.L. et al. (2005). *USGS*, Map 2888. [7] Morgenstern, A. et al. (2007). *JGR* 12 (EO6010) doi:10.1029/2006

JE0 02869. [8] Lefort, A. et al. (2009). 114 (EO4005) doi: 10.1029/2008JE003264. [9] Zanetti, M. et al. (2010). *Icarus* 206 (2) doi:10.1016/j.icarus. 2009.09. 010. [10] Séjourné, A. et al. (2011). *PSS*, 59 (5-6) doi:10.1016/j.pss.2011.01.007. [11] Costard, F. and Kargel, J.S. (1995). *Icarus* 114 (1) 93-122. [12] Soare, R.J. et al. (2007). *Icarus* 191 (1) doi:10.1016/j.icarus. 2007.04.018. [13] Soare, R.J. et al. (2008). *EPSL* 272 (1-2) doi:10.1016/j.epsl.2008.05.010. [14] Schirrmeister, L. et al. (2002). *Int. J. of Earth Sciences* 91, doi:10. 1007/s005310100205. [15] Bjella, K.L. et al. (2008). *Guidebook, CRREL Permafrost Tunnel, Fox, Alaska*, 9th Int'l Permaf. Conf., Fairbanks, Alaska. [16] Harris, S.A. et al. (1988). Glossary of permafrost and related ground ice terms, *Tech. Memo.* # 142, NRC, Canada. [17] Skinner, J.A. and Tanaka, K.L. (2001). *LPS XXXII*, # 2154. [18] Johnson, J.B. and Lorenz, R.B. (2000). *GRL* 27 (17) 2769-2772. [19] Séjourné, A. et al. (2012). *PSS* 60, 248-254, doi:10.1016/pss. 2011.09. 004. [20] Madeleine, J.B. et al. (2009). *Icarus* 203 (2) doi:10.1016/j.icarus.04.037. [21] Head, J.W., et al. (2012). Mars Recent Climate Change Workshop, Moffett Field, California. [22] Lacelle, D. et al. (2011). *5th Mars Polar Science Conference*, Fairbanks, Alaska, # 6083. [23] Marinova, M.M. et al. (2011). *5th Mars Polar Science Conference*, Fairbanks, Alaska, # 6051.