Ice-Enriched Loess and the Formation of Periglacial Terrain in Mid-Utopia Planitia, Mars

Conference or Workshop Item

ICE-ENRICHED LOESS AND THE FORMATION OF PERIGLACIAL TERRAIN IN MID-UTOPIA PLANITIA, MARS. R.J. Soare,[1] S.J. Conway,[2] G.D. Pearce[1] and F. Costard.[3] [1]Department of Geography, Dawson College, 3040 Sherbrooke St. W., Montreal, Quebec, Canada H3Z 1A4 (rsoare@dawsoncollege.qc.ca); [2]LPGN, CNRS/Université Nantes 44322, Nantes, France; [3]UMR 8148, Université Paris-Sud 11, bat. 509, 91404 Orsay, Cedex, France.

Introduction: In recent work [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) images in mid Utopia Planitia (UP; ~30-60^0N; Fig. 1) to map flat-floored and scalloped depressions, small-sized (≤~150m) polygonal patterned-ground and polygon-junction/trough pits (Fig. 2a). On Earth, similar landscape-assemblages are periglacial in origin and indicative of ice-rich permafrost (ground that is permanently frozen for at least two years) [4-5] (Fig. 2b).

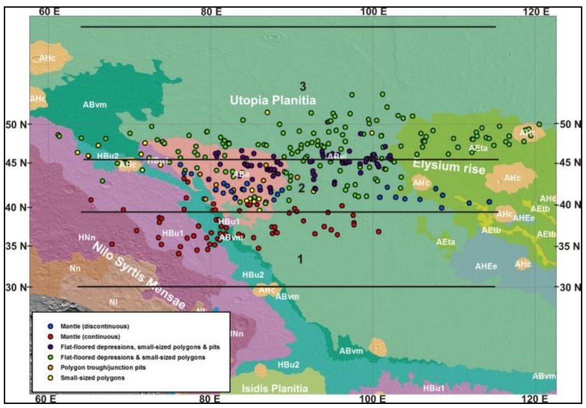
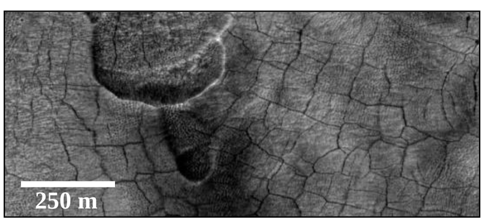


Fig. 1: Location in UP of putative periglacial-landforms (areas 2 and 3) and adjacent mantle in red and light blue (areas 1 and 2). The background map is a MOLA hillshade overlying the principal geological units [6].



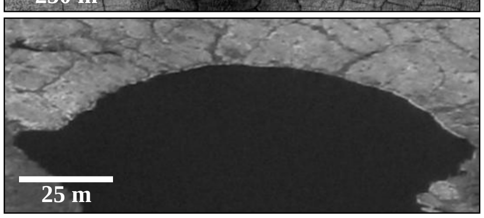


Fig. 2a: Spatially-associated assemblage of putative periglacial-landforms in mid-UP, Mars (HiRISE PSP_007384_2225, 42.2^{0}N; 86.3^{0}E, ~25cm/pixel. Courtesy of NASA/JPL /UofA. **Fig. 2b:** Thermokarst lake and marginal small-sized polygons, some of whose troughs are filled with water. (Tuktoyaktuk Coastlands, northern Canada, July 2009).

Intriguingly, the distribution of the putative periglacial-landforms (PPLs) stretches well beyond the longitudinal and latitudinal margins of the ABa (Fig. 1); this is the geological unit most often associated with periglacialism in UP [i.e. 6-9]. The distribution of PPLs also cross cuts 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 an overlying 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 in mid-UP forms syngenetically in loess-like sediments eroded from the North Polar Layered Deposits (NPLDs) and transported episodically by wind to the middle latitudes of UP.

Ground ice and periglacial-landscape evolution (Earth): In periglacial landscapes on Earth syngenetic permafrost forms when host sediments accumulate and freeze quasi-simultaneously during extended periods of cold climate-change [14-16]. The latter causes the base of the active layer to aggrade upwardly [15].

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

Syngenetic permafrost is well-suited to the development of periglacial complexes because the former possesses small interstices; this facilitates cryosuction and the formation of segregation ice: a lenticular type of excess ice [5]. Excess ice, where the presence of frozen water equals or exceeds the space available to it in a column of soil, is a volumetric term and a subcategory of ice-rich permafrost or ground ice [5,16]

Ground ice and periglacial-landscape evolution (Mars): If the PPLs in mid-UP are formed by periglacial processes in regolith that is ice-rich, i.e. dominated by excess ice, then the thickness of the ice-rich regolith 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 [6]. The maximum (calculated) 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): Fig. 1 shows that the PPLs in and around mid-UP are located in a tight latitudinal-band (40-55^{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. meteorological. The first cycle entails the episodic (but not obliquity-driven) and region-wide accumulation of desiccated and fine-grained sediments [17], i.e. sediments that are low in density, have modest shear strength and are low in thermal conductivity [18]. The NPLDs 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 evidence of these fines has been discussed recently by Séjourné et al. [19]. They suggest that the regionally ubiquitous flat-floored depressions comprise fine-grained sediments that vary in ice content and in their susceptibility to sublimation. Accordingly, the step-like profiles observed within many of the depressions are layered markers of differential sublimation [19].

The second cycle also is regional in breadth, involves the episodic precipitation of atmospheric volatiles and is possibly linked to very late-Amazonian excursions of obliquity [20]. We propose that the accumulation of “dry” fines and of “wet” volatiles is intertwined inextricably and linked syngenetically by means of thaw-freeze cycling.

“Wet” or “Dry” syngenesis: On Earth, periglacial complexes of the type putatively identified in mid-UP have been observed in periglacial regions with three principal characteristics: (a) ice-rich permafrost tens to hundreds of metres thick; (b) the ice-rich permafrost comprises fine-grained sediments often transported and deposited by the work of wind; and, (c) these fines were wetted *in situ*, i.e. by the seasonal thaw of surface snow or ice, and subsequently became frozen *in situ* as annual mean- temperatures fell [5,14-15].

Syngenetic ice-rich permafrost also occurs in the McMurdo Dry Valleys of the Antarctic [21-22]. The ice-rich permafrost is shallow and extends no further than a metre from the surface [21-22]. Moreover, as it formed when air/soil temperatures were below 0^{0}C, the ice enrichment of these otherwise “dry” sediments would have taken place by means of diffusive exchanges with the atmosphere and phases changes driven by seasonal temperature-variations [21-22]. 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 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] Lacelle, D. et al. (2011). *5th Mars Polar Science Conference*, Fairbanks, Alaska, # 6083. [22] Marinova, M.M. et al. (2011). *5th Mars Polar Science Conference*, Fairbanks, Alaska, # 6051.