ONE BILLION YEARS OF PERIGLACIAL/GLACIAL LANDFORMS & CYCLING NEAR THE MARS CRUSTAL DICHOTOMY: R.J. Soare[1], J-P Williams2, A.J. Hepburn[3], C. Gallagher[4], M. Koutnik[5], F.M. Butcher[6]. [1]Dept. of Geography, Dawson College, Montreal, Qc., Canada H3Z 1A4; rsoare@dawsoncollege.qc.ca, [2]Dept. of Earth, Planetary & Space Sciences, University of California, Los Angeles, CA, USA 90095, Dept. of Geography, Durham University, Durham, UK DH1 3LE, [4]UCD School of Geography, University College Dublin, Dublin 4, Ireland, [5]Earth and Space Sciences, University of Washington, Seattle, Washington, USA 98195, [6]Dept. of Geography, University of Sheffield, Sheffield, UK S10 2TN

Introduction: Using relative stratigraphy and crater-size frequency distribution [*CSFD*] we present a geochronological hierarchy of landforms, landscapes and geological units that point to the cyclical intertwining of glaciation and periglaciation across almost 1 Gyr at Protonilus Mensae [*PM*].

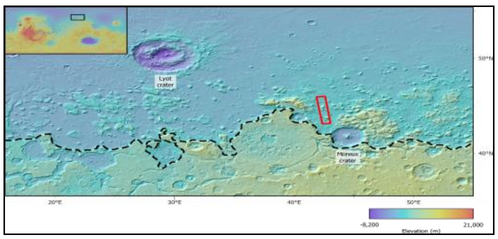

Fig. 1. Study region, highlighted by red rectangle. Background color is *MOLA* global-elevation.

PM is a mid-latitudinal region within the Ismenius Lacus quadrangle **(Fig. 1)**. It is wedged between the Lyot impact-crater to the northwest, the Moreux impact-crater to the southwest, and the Mars crustal-dichotomy to the south. The latter is a global geological-boundary that separates the ancient southern highlands from the younger northern-lowlands.

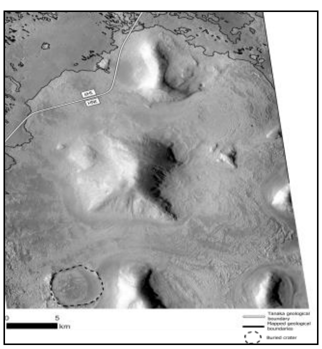

Fig. 2. Geological units *eHt* and *HNt* in the *PM* region separated by a geological contact first identified by **[1]**. The white line coincides with the geo-references in **[1]**, updated by means of *HiRISE* imagery (black line). Age estimates of highlighted crater (serrated circle) suggest that it intercepts the floor of *HNt* at depth.

Background: We focus on an area within this region that straddles the geological contact between *[eHT]*, an early Hesperian Epoch transition unit and *[HNt]*, a Noachian-Hesperian Epoch transition unit (**Fig. 2**).

Unit *eHt* comprises relatively-dark toned terrain punctuated continuously and completely by landforms whose shape, size, apparent clastic sorting and clustered distribution are akin to clastically-sorted polygons/circles [*CSPs*] on Earth (**Fig. 3**).

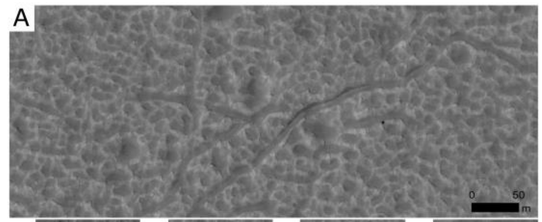

Fig. 3. Possible clastic sorting, unit *eHt*. Note: boulder-sized rocks on margins of closed structures and, deductively, finer-grained material at centres.

Clastically sorted polygons/circles [*CSPs*] (Earth) (Fig. 4): Typically, terrestrial *CSPs* are ~≤10 m in diameter. Centres are composed of relatively fine-grained and frost-susceptible clasts with poor drainage potential. Margins are elevated, relative to the centres, and are composed of larger-sized clasts (e.g. pebbles, cobbles or boulders). Distribution ranges from isolated or discontinuous to wide-ranging and continuous. Other keynote requirements/characteristics: **a)** relatively-high soil moisture; **b)** freeze-thaw cycling in permafrost active-layer; **c)** ice/soil segregation; **d)** cryoturbation; and (possibly), **e)** antecedent thermal-contraction or desiccation cracking.

Fig. 3. a) Clastically-sorted circles, Kvadehukken Svalbard. Image credit/permission obtained: I. Timling.

Unit *HNt*, as observed in a mesa-centred basin, exhibits surface coverage that is relatively light in tone, topographically irregular (possibly devolatilized and degraded) and a suite of spatially associated features that point to periglacial (including clastically non-sorted polygons/circles) **(Fig. 4)** and glacial origins (**Fig. 6**). The polygons are ~10-15 m in diameter, show slightly elevated centres but no clastic differentiation and incise thermokarst-like depressions that are metres-deep.

Clastically non-sorted polygons [*NSPs*] (Earth) (Fig. 5): Throughout the surface area of the mesa patches of relatively smooth material incised by NSPs and polygonised thermokarst-like depressions are observed. On Earth, similar spatial assemblages are diagnostic of ice-rich terrain, i.e. frozen ground whose pore space is exceeded by the presence of frozen water.

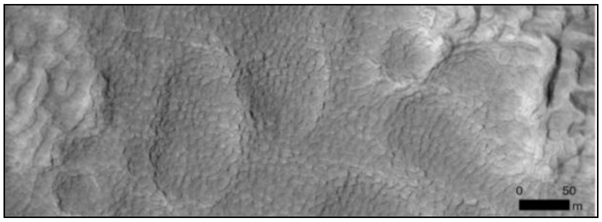

Fig. 4. Surface coverage of unit *HNt* by polygonised terrain comprised of *NSPs* and thermokarst-like depressions..

Fig. 5. Oblique view of polygonised drained thermokarst basin (Husky Lakes, NWT, Canada).

Degraded (glacial?) terrain (Mars) (Fig. 6): A suite of spatially-associated landforms within unit *HNt* in the mesa-centred basin could be glacial remnants.

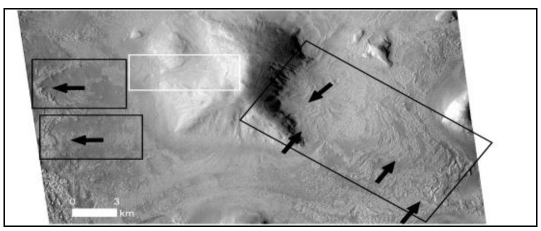

Fig. 6. Serialised moraine-like ridges [*MLRs*] (black arrows) frame *viscous flow features [VFFs]* radiating from slope-side scars (possibly cirques) and mesa valleys (white rectangle). Lobate debris aprons [*LDAs*] constrain the reach/breadth of the *VFFs*.

Degraded glacial terrain (Earth) (Fig. 7):

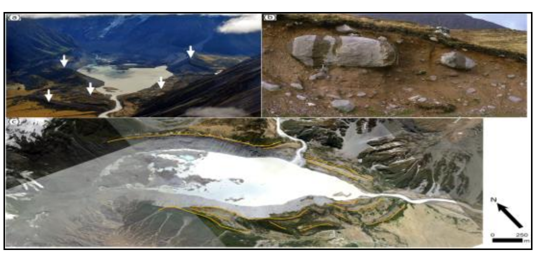

Fig. 7. a) Mueller Glacier, New Zealand. White arrows show crests of large latero-frontal moraine and smaller terminal moraine. **b)** Basal till; note the angular and poorly-sorted mixture of boulders and cobbles. Photo credit: M.J. Hambrey; reproduced with permission of Glaciers Online (https://www.swisseduc.ch/glaciers/). **c)** Recessional-moraine assemblage at glacier terminus; moraines indicated by white arrows in **a)** identified by orange lines. Image in **c):** *LINZ* database (https://data.linz.govt.nz/).

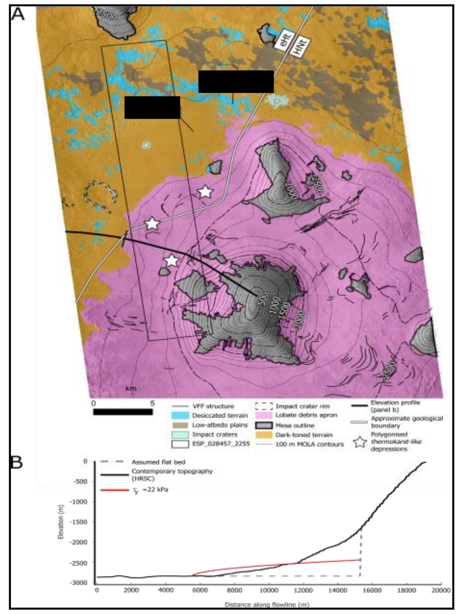

Fig. 8. a) Location of units *eHt* and *HNt* amidst topographical profile of the massifs-centred basin. **b)** Modelled **c**ross-sectional profile of unobserved *VFF* (flow #1) on the floor of unit *HNt* that underlies observed *VFF* (flow #2), *GLFs* and *LDAs* at the surface.

Proposed relative-stratigraphy and associated geochronology: Unit *HNt* predates unit *eHt* **[1]**. Flow #1 on floor of *HNt* extends beyond the geological contact of *eHt* to the west and underlies the latter (**Fig. 8b**). Crater-size frequency estimates suggest a minimum age of ~≥100 Ma - ~≤1 Ga for unit *eHt* and the *CSPs* that incise it **[2].** Deductively, flow #1 must be older than this. Crater-size frequency estimates suggest a minimum age of ~≥10 Ma - ~≤100 Ma for the degraded (possibly relict glacial) surface of *HNt* **[2]**. Depending upon whether the *NSP*/thermokarst-like assemblages are exhumed or not, they pre- or post-date the formation of the degraded glacial terrain. If the latter, then this places their age well within the mean and youthful estimates of age for similar terrain at the mid- to high latitudes of the northern plains **[e.g. 3-5]**. Overall, the temporal span comprised by the intertwined periglacial and glacial cycles possibly identified here are one to two orders of magnitude greater than the spans currently reported in the literature.

References: [1] Tanaka, K.L. et al. (2014). USGS Scientific Investigations, *Map 3292.* **[2]** Soare, R.J. et al. (2022). Book chapter in "*Ices in the Solar System: a volatile journey from Mercury and the moon to the Kuyper Belt and beyond.* Elsevier Science, in press. **[3]** Mustard, J.F. et al. (2001). *Nature* 412, https://doi.10.1038/35086515. **[4]** Levy, J. et al. (2009b). *J. Geophys. Res.* 114 (E01007), https://doi:10.1029/2008JE003273. **[5]** Gallagher et al. 2011. *Icarus* 211, doi:10.1016/j.icarus.2010.09.010.