POSSIBLE (VALLEY/CHANNEL) PINGOS & "WET-BASED" PERIGLACIATION AT THE MARS DICHOTOMY.

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Introduction: Mounds that exhibit similarities of shape, scale, features, and spatially-associated landforms with terrestrial pingos (perennially ice-cored mounds) **[e.g. 1-2] (Fig. 1)** have been observed at the mid-latitudes of Utopia Planitia **[3-7]** and the Argyre region **[8]**, as well as the near-equatorial latitude of Athabasca Vallis **[9-10]**.

Pingo formation on Earth largely follows one of two pathways: **a)** the precursive pooling of surface or near-surface water, its freeze-thaw cycling and permafrost aggradation (hydrostatic/closed-system pingos [*CSPs*]); or, **b)** groundwater migration driven or facilitated by topography, geological faulting or artesian pressure (hydraulic/open-system pingo [*OSPs*]) **[1-2]**.

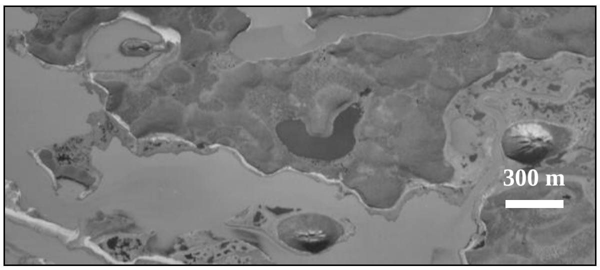

Fig. 1. *CSP*/thermokarst-lake landscape, Tuktoyaktuk Coastlands, Canada (aerial photo A27917-35-1993). Note the summit depressions/cracks on the two largest pingos, Split (centre-bottom) and Ibyuk (right). North is to the left. Image credit: National Air Photo Library, Ottawa, Canada.

Here, we discuss the possible presence of *OSPs* and a "*wet*"-based entourage of periglacial landforms within and adjacent to the Moreux impact-crater in Protonilus Mensae (42.1° N; 44.4° E) **(Fig. 2)**. This is the first time that *OSP*-like mounds in the northern hemisphere have been observed and discussed in the Mars literature.

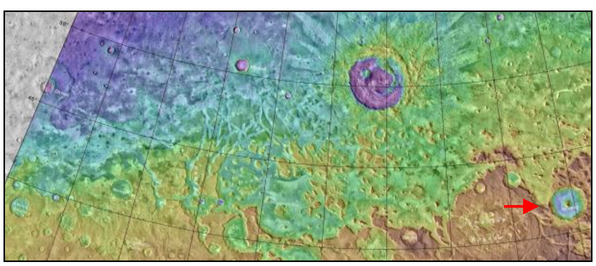

Fig. 2. *MOLA* map showing Moreux crater (red arrow, bottom right). Colours indicate elevation, lighter colour = higher elevation. Image credit: Goddard Space Flight Center, *NASA*.

Observations: In the main, the pingo-like mounds are circular/sub-circular to elongate **(Fig. 3)**. Some mounds, however, exhibit irregularities of shape, either topographically or geometrically. Mound long-axes comprise tens to hundreds of metres. Some mounds show summit depressions and/or cracks; the latter may or may not extend to the mound bases. Some mounds are polygonised, as is the surrounding terrain. Decametre-scaled, rimless, relatively flat-floored and polygonised depressions also are observed.

All of the mounds are located in or immediately adjacent to topographical lows (i.e. basins, channels or valleys). The lows are filled in, at least partially, by relatively smooth material (at *HiRISE* magnification) that blankets and mutes the underlying terrain. Some of this smooth material exhibits surface-lineation parallel to the basin, channel or valley walls. The walls themselves often show lobate landforms that link upslope alcoves to downslope splays on the basin, channel or valley floors. Arcuate and sometimes serialized ridges normal to the lobate short-axes and distal to the alcoves are present as well.

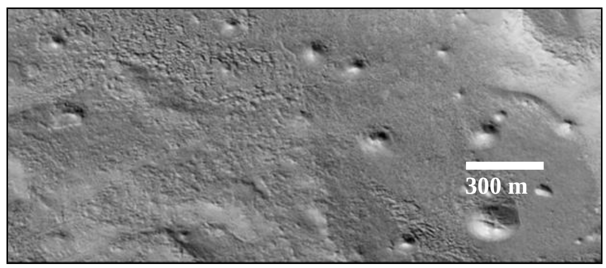

Fig. 3. Cluster of possible pingos in a topographical low, Moreux impact-crater (*HiRISE* ESP 058140_2255). Note: **a)** the similarity of shape, magnitude, and summit cracks of the largest mound (bottom right-hand corner), to Split and Ibyuk pingos (**Fig. 1)**; and of, **b)** ubiquitous small-scale pitting (top left-hand corner). North is up. Image credit: *NASA*/*JPL*/ Univ. of Arizona.

Earth analogues:

a) Typically, *CSPs* are observed in areas of continuous, deep and "*ice-rich*" permafrost where the landscapes are dotted with thermokarst lakes and alases, i.e. thermokarst-lake basins absent of water **[1]**. "*Ice rich*" = permafrost dominated by segregation ice **[11].** The mounds originate with the loss of lake water, by evaporation or drainage, and the exposure of the lake basin to freezing temperatures. As the freezing front propagates downwards through the floor and sideways from the margins towards the basin centre, trapped near-surface pore-water (hydrostatically) uplifts the sedimentary overburden (i.e. the newly-exposed lake floor) and a mound begins to form. Radial-dilation cracks may propagate from the summit as the mound grows, an ice core forms, and tensile stresses within the overburden increase. Sometimes, these cracks grade into the surrounding terrain polygonised by thermal-contraction cracking **[1]**.

Pingo heights range from metres to decametres and long-axis diameters may comprise hundreds of metres. Pingo shapes encompass a broad spectrum from circular/sub-circular to elongate or irregular.

b) Typically, *OSPs* form in areas of marked relief, i.e. on the floors, foregrounds or outwash plains of glaciated valleys **(Figs. 4a-c)**. *OSP* shape, scale, summit fracturing and the presence of summit depressions broadly mirrors that of the *CSPs* described above **[12-13]**.

The mound-forming liquid water may originate upslope or up-valley (its hydraulic potential). It migrates to the mound site by means of near-surface intra-permafrost taliks. Emergence occurs where the permafrost, not required to be ice-rich or incised by thermal-contraction polygons, is particularly thin or discontinuous **[2]**.

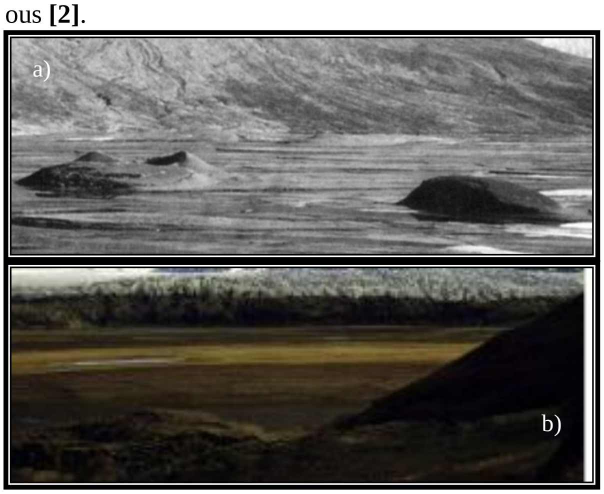

Fig. 4. a) Collapsed open-system pingo (left) and pingo remnant (right) on outwash plain, Central West-Greenland **[13]**. **b)** View of Müller ice-cap terminus from summit of unnamed open-system pingo, Axel Heiberg Island, Canada. Image credit: R. Soare.

Alternatively, the hydraulic potential may be the work of sub-permafrost and deeply-seated (artesian) groundwater. The groundwater upwells through local geological faults and is sufficient in pressure to uplift or break through continuous permafrost. Here too, the surface permafrost may or may not be polygonised and need not be ice-rich **[e.g. 12-13]**.

A third hypothesis suggests that near-surface faults deliver meltwater from the temperate basal-zones of glaciers through to the foregrounds or outwash plain sites where the *OSPs* develop **[12] (Figs. 4a-b)**.

Although not required by any of the *OSP* formation-pathways or hypotheses, where ice-rich and/or polygonised terrain are observed in *OSP* landscapes they comprise additional markers of cold-climate hydrology and liquid water on a local/regional scale.

Discussion: The Moreux impact-crater is thought to be mid-Amazonian Epoch in age and straddles the Mars dichotomy at the mid-latitudes of the northern hemisphere. Although the basement here and in adjacent areas is ancient, relatively pristine (impact-free) surface textures and materials point to landscape-scale revisions that are more youthful than this **[14]**.

Amongst these revisions are spatially-associated assemblages of landforms that, by comparison with terran landscapes, suggest the work of periglaciation and glaciation. With regard to the former, polygonised terrain and thermokarst-like depressions could be artefacts of water-ice loss near the surface. Concerning the latter, lineated valley-fill, glacier-like (lobate) landforms, possible moraines and small-scale pitting (highlighting the sublimated-loss of ice) play a comparable role.

The connexion between icy precipitation and surface accumulation of this precipitate at Moreux-like latitudes during the Late Amazonian Epoch is well-documented in the literature **[15-16]**. No less so is the periglacial revision of terrain covered by ice **[17-19]**.

We propose that the landscapes populated by *CSPs* or *OSPs* on Earth and those in the Moreux impact-crater region are sufficiently similar to ascribe a pingo-like origin to the Moreux mounds reported by us.

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