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INVESTIGATION OF POSSIBLE COASTAL AND PERIGLACIAL LANDFORMS IN GALE CRATER, MARS.

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Introduction: The Martian surface water reservoir appears to have been affected by a major change at the Late Noachian/Early Hesperian Epoch [e.g., 1]. Since then, surface water appears to have been limited with decreasing pluvial and fluvial activity [2] and a corresponding retreat of groundwater to greater depths [3]. Constraining the evolution of water reservoirs during this transition is hence crucial to understand the geological and climatic history of Mars. Here, we focus on the 150 km diameter Gale Crater (-5.4°N, 137.9°E), which is currently investigated in situ by the Mars Science Laboratory (MSL) rover, Curiosity, since August 2012. Gale crater was formed during Late Noachian/Early Hesperian, ~3.6 Ga ago [4, 5] and is filled by sedimentary deposits including a crescent-shaped mound of layered deposits, Aeolis Mons (informally also named Mount Sharp), up to 5 km high and 6000 km^2 in area [6]. In order to reconstruct the paleoenvironments and the associated hydrological systems that existed within Gale, and their evolution through time, we provide a geomorphological study of possible coastal and periglacial landforms using CTX and HiRISE images, and a HRSC DEM.

Possible coastal landforms: A front-scarp fan is situated at the outlet of a deeply incised channel cutting through the western crater wall (***Fig. 1a***). The fan has a steep front and is morphologically similar to Gilbert-type fan deltas on Earth, which is a strong hint to the existence of a paleolake in Gale. Subhorizontal terraces first observed by [7] are situated along the western flank of Aeolis Mons at -4450, -4000, and -3700 m in elevation (***Fig. 2b***). They may result from wave actions at different lake levels. An intriguing scarp cuts the eastern base of the mound at -4300 m in elevation over more than 30 km in length (***Fig. 1c***). Above the scarp, the flanks of the mound are incised by canyons or re-entrants, which are oriented parallel to the direction of the steepest slope. Below the scarp, no canyons are visible and the slopes are gentler than those above the scarp. These morphologies may be explained by the existence of a paleolake where the scarp would correspond to a past shoreline. Moreover, the canyons have an appearance (steep sides, abrupt head scar, low aspect ratio in plan view) that resembles some experimentally-formed sapping valleys [e.g., 8]. If they indeed formed by sapping, this could have happened during the slow decrease of the lake level, when liquid water (e.g., from snowmelt [9]) would drain towards the lowering base level and induce sapping.

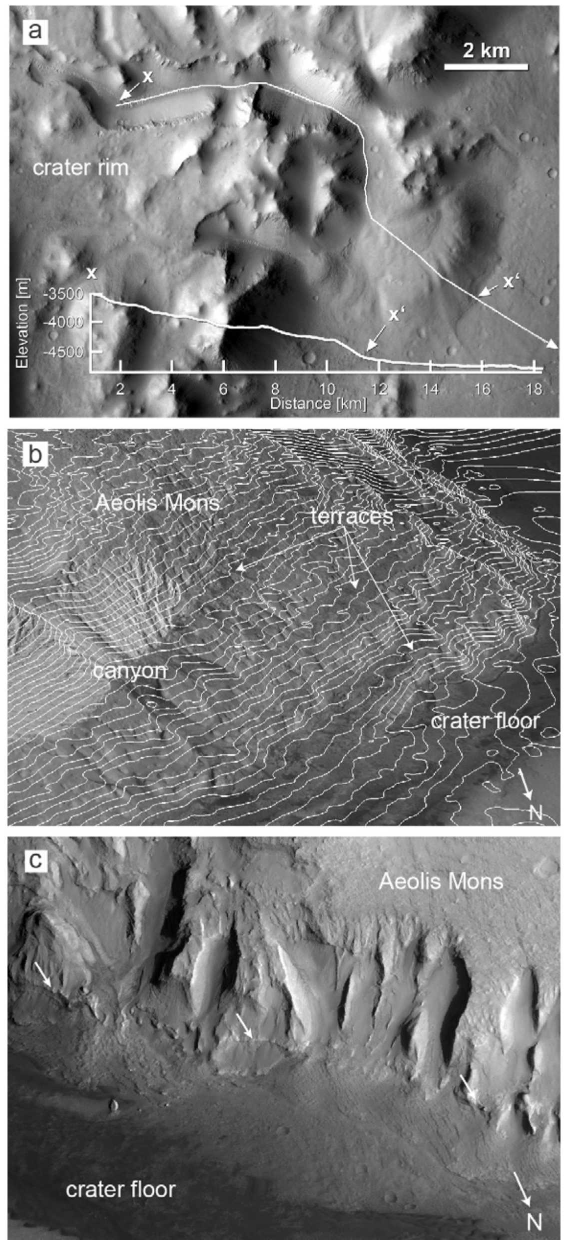

***Fig. 1**: Possible coastal landforms. (a) Scarp-fronted fan morphologically similar to Gilbert-type fan deltas on Earth (CTX image, centered at 5°S/136.7°E). (b) 3D view of sub-horizontal terraces carved into the base of Aeolis Mons (CTX mosaic over a HRSC DEM, centered at 4.9°S/137.3°E, elevation contours: 50m, vertical exaggeration: x2). The canyon is ~1 km wide. (c)3D view of a possible shoreline (arrows). Note the difference in morphology above and below the scarp (CTX mosaic over a HRSC DEM, centered at 4.87°S/138.3°E, vertical exaggeration: x2). The scarp shown is ~15 km long.*

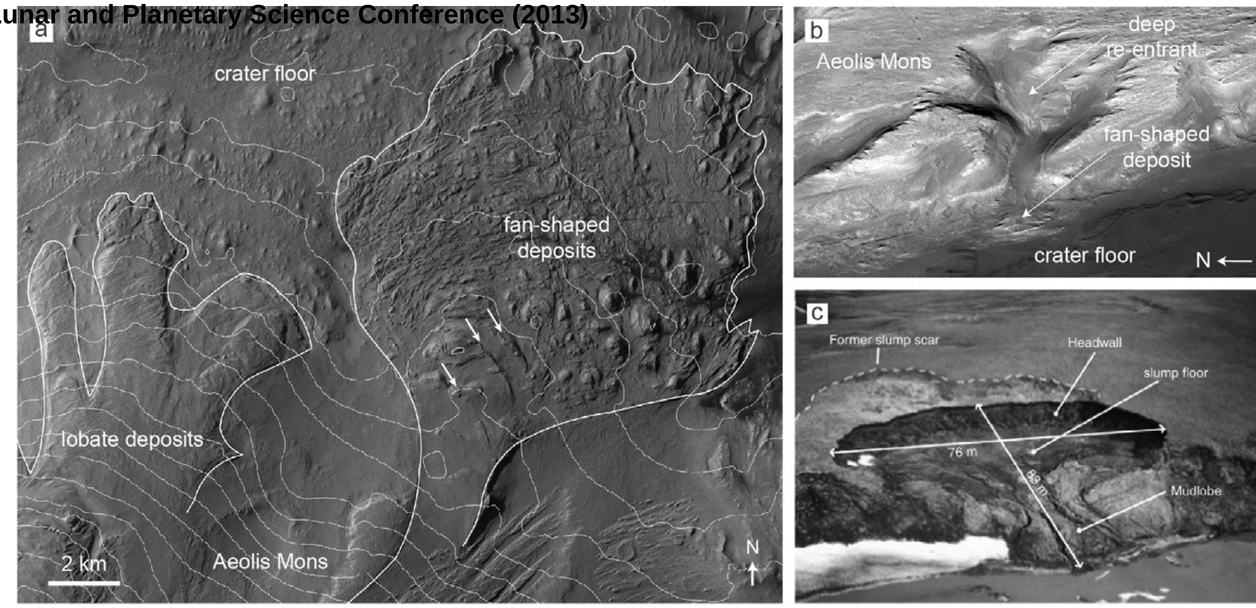

Fig. 2 (above): *Possible periglacial landforms. (a) Lobate and fan-shaped deposits lying along the northern flank of Aeolis Mons possibly corresponding to rockglaciers (CTX mosaic, elevation contours: 200 m, centered at 4.6°S/137.9°E). (b) 3D view of a fan-shaped deposit at the mouth of a deep re-entrant on the western flank of Aeolis Mons (CTX image over a HRSC DEM, centered at 5.28°S/137.17°E. The valley directly above the fan is ~1.5 km wide. (c) Retrogressive thaw slump in Thetis Bay, Herschel Island at the arctic coast of Canada (published by [12]). Note the morphologic similarity to panel b.*

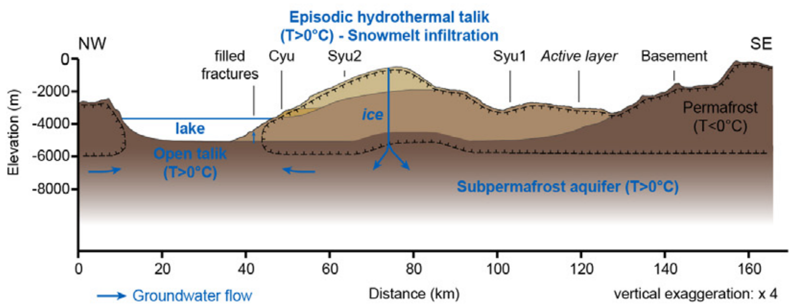

Fig. 3: *Representation of the proposed periglacial environment of Gale crater and its hydrological system at high obliquity during the Hesperian Epoch. The units Syu1, Syu2, and Cyu are described in [4, 5].*

Possible periglacial landforms: Lobate deposits form tongues that are each 1 to 1.5 km wide and up to ~100 m thick, lying along the flank of Aeolis Mons on slopes ranging between 12° and 18° (***Fig. 2a***). The maximum extent of the lobate deposits is the base of the flank, which suggests that they correspond to viscous flow lobes resulting from a slow movement such as creeping (e.g., as for rockglaciers, as previously suggested by [10]). Some fan-shaped deposits, 11 km in diameter and up to 200 m thick, display a very rugged surface texture and are located at the outlet of a valley, which probably corresponds to the main pathway of the transported material. Some oblique cracks are visible on the fan-shaped deposits that have probably been formed during the mass movement (***Fig. 2a***, arrows). The fan-shaped deposits share morphologic similarities with spatulate rockglaciers, which are talus-derived rockglaciers formed beneath scree slopes and composed of frozen-cemented debris displaying a broad lower part [11]. Other fan-shaped deposits are located at the mouth of deep re-entrants with steep headwalls on the western and southern slopes of Aeolis Mons (***Fig. 2b***). These fan-shaped deposits reach a thickness of up to 200 to 500 m. They share morphologic similarities with retrogressive thaw slumps on Earth, which result from the thaw of ice-rich permafrost [12, 13] (***Fig. 2c***).

A periglacial environment: These landforms are consistent with the former presence of ice-rich permafrost in Aeolis Mons during the Hesperian Epoch (***Fig. 3***). This model requires orbital and high obliquity configurations allowing the stability of ice at the surface at these latitudes. Episodic infiltration of snowmelt [9] and groundwater flows from east of Isidis basin [14] may have recharged a subpermafrost aquifer and a lake. Episodic thaw of an active layer may have led to the formation of thaw slumps (also possibly triggered by coastal erosion of the base of the mound).

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