

Formation and evolution of the periglacial landscape under major climate change: Application to Mars (Utopia Planitia) and Earth

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1. Introduction

In the last few years, evidences of Mars showing large quantities of ice in the permafrost have become increasingly abundant. The fate of this ground-ice reservoir is tied to dramatic global climate change during the recent history of Mars (<10 Myr). The planet is thought to have undergone periodic variations of its orbital parameters deeply modifying the climate like Milankovitch's cycles on Earth.

The western Utopia Planitia (UP) in the northern mid-latitudes of Mars contains relatively young landforms (<10 Myr): scalloped depressions [1-5], spatially-associated polygons [2-4, 6], polygon-junction pits [2-3, 6-7]. There is an agreement within the community that they are periglacial in origin and, derivatively, indicate the presence of an ice-rich permafrost. However, these landforms were studied individually and, many questions remain about their formation-evolution and climatic significance.

In contrast, we conducted a geomorphological study of all landforms in UP to : (i) propose model of their formation and evolution; (ii) show that are part of a complex landforms assemblage and; (iii) discuss the climatic modifications of the ice-rich permafrost in UP. Our work combines a study of Martian landforms using HiRISE images, HiRISE DEM, MOLA and a comparison with analogous periglacial landforms in Canada and Siberia.

2. The periglacial landforms of UP

The scalloped depressions are circular to elliptical with diameters of ~100-1,000 m for a depth <70 m (Fig. 1) [1-5, 8]. They are flat-floored with an equator-facing slope that is gentler (1.2°) than the pole-facing slope (6°) [8]. The depressions are thought to be the result of sublimation or melting of ground-ice and subsidence of the ground [1-5]. Their NS asymmetric profile is thought to be due to an asymmetric insolation of their slopes [2-3].

Two types of polygons are observed in UP (Fig. 1) [2-4, 6]. Large polygons of 100 m in diameter occur

on the plain between the depressions (inter-depression polygons). Smaller polygons of 6 m in diameter are observed inside the depressions (intra-depression polygons) [2, 8]. They show a morphological change from a concave shape to a convex shape [8]. Both types of polygons are thought to be formed by thermal-cracking of a permafrost [6, 8].

Elongated pits are observed at the junction of some inter-depression polygons (Fig. 1) [2-3, 6-7]. They are ~10-100 m in diameter for a depth of 5-36 m [2, 7]. They are observed exclusively along the N-S polygonal troughs [7, 9]. The polygon-junction pits are thought to be due to sublimation or melting of ground-ice [2-3, 6-7].

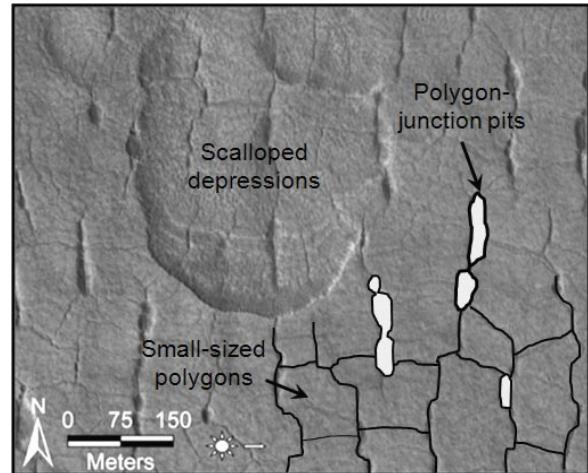


Figure 1: Periglacial landforms of Utopia Planitia (HiRISE image PSP_002202_2250).

3. The periglacial landscapes of Canada and Siberia

Abrupt climate-changes in the periglacial environments on Earth such as Northern Canada and Central Yakutia (Siberia) deeply modified the landscape [10-11]. These regions are underlined by a continuous and ice-rich permafrost of 40-80% of ice by volume.

A unique assemblage of landforms possibly analogous to the Martian counterpart is observed: thermokarst lakes, ice-wedge polygons and polygon-junction ponds (Fig. 2) [10-11]. The thermokarst lakes are the result of the subsidence of the ground following the localized thawing of excess-ice. Most of thermokarst lakes were formed during the Holocene climatic optimum where higher temperatures induced the extensive thawing of the permafrost [10-11]. The ice-wedge polygons are formed by freeze-thaw cycles of an ice-cemented ground. The polygons could evolve from concave to convex through the melting of the ice-wedge network [10]. The localized melting of the ice-wedges induces the formation of small ponds localized at the junction of the polygons [11].

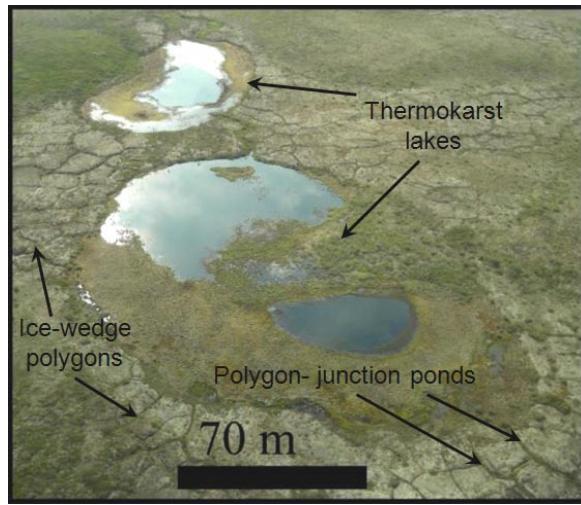


Figure 2: Periglacial landscape of Canada (aerial photo July 2009).

4. Degradation of an ice-rich permafrost under obliquity change

The landforms in UP share traits of form, scale, general appearance and spatial proximity with the periglacial landforms of Canada or Siberia. We suggest that they are integrated in a complex landform assemblage indicating the presence of an ice-rich permafrost in UP [12].

From our study, we show that the ice-rich permafrost of UP were subject to important degradation. The scalloped depressions are the result of extensive sublimation of ground-ice and subsidence of the ground [8]. The morphological evolution from concave to convex of the intra-depression polygons is due to sublimation of ground-ice [8]. The polygon-junction pits are the result of the sublimation of the

N-S polygonal troughs and subsidence of the ground [9].

We suggest that the ice-rich permafrost of UP were degraded during high-obliquity periods of Mars. The scalloped depressions show an equatorward development due to enhanced insolation-driven sublimation of their pole-facing slope [8]. The expansion occurred during high-obliquity periods of Mars since only with such orbital configuration the pole-facing slopes receive more solar radiation in summer than the equator-facing slopes [13].

In accordance to our study, Global Climate Model predicted the deposition of an eolian icy-deposit in UP during periods of medium obliquity (35°), and then the sublimation of the ice of this deposit when Mars moved back to higher obliquity periods (45°) [14].

6. Conclusion

Our results show that the assemblage of landforms in UP indicates the presence of an ice-rich permafrost like on Earth. This permafrost was degraded during a relatively recent high-obliquity period inducing a major climate change. The region of Utopia Planitia is probably a marker of the last major climate change that occurred on Mars.

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