THE ORIGIN AND FORMATION OF SCALLOPED TERRAIN IN UTOPIA PLANITIA: INSIGHT FROM A GENERAL CIRCULATION MODEL.

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Introduction: Depressions that are scalloped, flat-floored, rimless and inwardly-terraced are ubiquitous in the middle latitudes of Mars, principally around 270°W and from 40°N to 50°N. They are between 100 m to 3 km long and 5 m to 80 m in depth. Some depressions are isolated, others appear to have coalesced, giving them a scalloped appearance. The depressions often are nested in small-sized polygonal patterned ground. It has been suggested that the features are the product of thermokarst processes, which are commonplace in wet periglacial environments on Earth. [1-4]. The thermokarst hypothesis, however, has been problematic: so far, climate change models have been incapable of producing boundary conditions sufficiently wet and warm to emplace, maintain and then thaw or sublimate deep, near-surface ground ice in the middle latitudes.

Here, we report the impact of obliquity variation and atmospheric dust opacity to explain the origin and formaton of the scalloped terrain in Utopia Planitia. Assuming a dusty atmosphere, the new climate model favors the precipitation and emplacement of water-ice in this region during periods of high obliquity [14]. This ice-rich aeolian deposit is consistent with thermokarst processes and degradation and also can be invoked to explain the formation of inner terraces within the scalloped depressions.

Thermokarst processes and landforms on Earth: In terrestrial environments, scalloped and rimless depressions commonly are found in periglacial areas where ground ice and small-sized polygonal patterned ground are widespread. When ground ice thaws, flat-floored and steeply -sided depressions called “alases” form [5]. For example, in central Yakoutia (Siberia), alluvial thermokarst occurs and is essentially concentrated in the Pleistocene terraces composed of silty and sandy materials that is covered by loesslike silt mantles [6]. Such materials favor a relatively high concentrations of ice, up to 80% by mass and highly developed thermokarst landforms.

A stratified ice-rich deposit : In northern Utopia Planitia, some of the pits have inner terraces or exposed strata corresponding to a stratified aeolian deposit [1, 7]. The morphology of these pits is consistent with the thawing or sublimation and the subsequent collapse of a stratified ice-rich sediments.

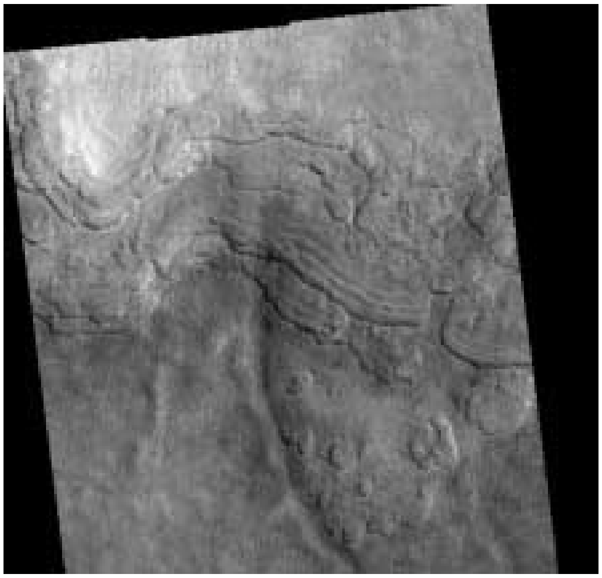

Figure 1: Scalloped terrains. HIRISE image (PSP_002070_2250). Credit: NASA/JPL/Univ. of Arizona.

Different hypotheses have been proposed to understand the origin of these stratified deposits within the scalloped terrains. Ponding may have occurred due to the fluvial discharges mentioned by [8]. It is possible that this region was affected by both fluvial and lacustrine phases of discharges mainly from the circum-Elysium outflow channels [1]. Another hypothesis supposes that the area was covered by a layer of a ice-dust mixture, mostly formed as airfall deposition of a few tens of meters thick [9,10].

Climate modelling : In the past few years, Mars water cycle has been implemented in the LMD/GCM (Laboratoire de Météorologie Dynamique General Circulation Model) and has shown an encouraging agreement with TES observations [11]. Recently, the model has been used to explore Late Amazonian water cycle, and has predicted the formation of glaciers on the western flanks of Tharsis Montes, Olympus Mons, and in eastern Hellas [12]. Geological evidence for northern mid-latitude glaciation [13] has also been analyzed in the light of the GCM, and a first climatic scenario of formation has been proposed [14].

Interpreting the depressions of northern Utopia Planitia as being of thermokarstic origin implies that 1) climate changes have favored the periodic accumulation of thick water-ice and dust deposits to form the observed layers; 2) buried ice became unstable and sublimated away, resulting in collapsed pits and scalloped morphology ; 3) near-surface ice has undergone cyclic sublimation to create polygons.

To investigate where such conditions could have been achieved on Mars, we performed high-resolution simulations of past water cycle and explored different scenarios by combination of different orbital parameters, dust content of the atmosphere and surface water-ice sources. We found that the model predicts accumulation of at least 10 mm of water-ice per year at the location of the scalloped terrains (cf Fig. 2) for an obliquity of 35°, an equatorial source of water (based on geological observations of tropical mountain glaciers, cf [12]) and a dust optical depth higher than 1. High dust content of the atmosphere is a necessary condition of this accumulation, and GCM thus suggests both ice and dust-rich layers in agreement with stratified aeolian deposits of Utopia Planitia.

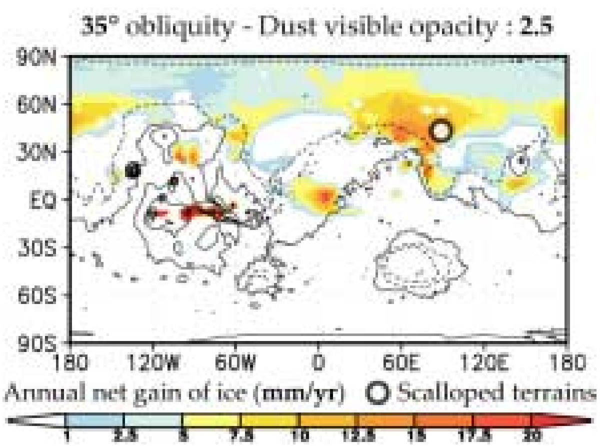

Figure 2: Predicted water-ice deposits under 35° obliquity (dust visible optical depth of 2.5). Solar longitude of perihelion has been set to 270°. Note the accumulation of ice in the northern mid-latitudes.

Origin of the thermokarst episode : In Siberia, alases are very sensitive to the global warming. In the Lena basin, the increase of the annual mean temperature increases since 1930 accelerates the extension of thermokarstic depressions by a deepening of the active layer [15]. Applied to Mars, the detection of thermokarst morphology can be a usefull marker of past climate variations.

The formation of scalloped thermokarst-driven terrains could have been produced by the sublimation of buried ice at high obliquity. Indeed, preservation of the deposits, which depends on a balance between winter precipitation and summer sublimation, is only achieved for an obliquity around 35°. Under higher obliquity conditions, summer maximum temperatures are too high to allow preservation of the deposits, and thermokarstic degradation and formation of alases could occur throughout the higher obliquity period.

In the northern lowland plains, such as those found in Utopia Planitia, the analysis of typical high volumes of the ejecta and the perched craters suggest that the northern lowlands have experienced one or more episodes of resurfacing involving removal of material, most likely caused by the sublimation of ice in the materials [16]. Though this sounds plausible, there are other possibilities: for example, the aeolian deflation of dusty debris also could be invoked.

Conclusion. This study supports some previous work, but also gives some new interpretations about the regional concentration of scalloped terrains in Western Utopia Planitia. Here, we report on the formation of scalloped terrains by the sublimation of a water-ice rich dusty deposit. We point out three main characteristics : a stratified deposit, a strong morphological analogy with Siberian alases, and a correlation with major accumulation of water-ice deposits predicted by a climate model. At high obliquity (e.g. 35°), the LMD/GCM predicts the formation of deposits of ice in Western Utopia exactly where most scalloped terrains are observed. This accumulation is only possible under high dust conditions, in agreement with the supposed stratified ice-rich aeolian deposits previously described in the scalloped terrains by Costard and Kargel [1].

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