Possible thermokarst and alas formation in Utopia Planitia, Mars

Richard J. Soare,[1] J.M. Wan Bun Tseung[1] and Claude Peloquin.[1] Dept. of Geography, Planning and Environment, Concordia University, 1455 De Maisonneuve W., Montreal, Canada, H3G 1M8. E-mail: rsoare@colba.net.

Introduction: Pits, depressions and collapse features that are consistent with the morphology of terrestrial thermokarst have been identified in five mid- to high-latitudinal areas of Mars: 1. the circum-Chryse outflow channels [1][2][3][4]; 2. Chryse Planitia itself [5][6]; 3. the volcanic fields around Olympus Mons [7] and those to the west of Elysium Mons; 4. the southern margin of the Vastitas Borealis formation [8]; and, 5. two of the great northern plains - Acidalia [9] and - Utopia Planitiae (UP) [10][11][12]. These are areas where water may have flowed in the past and near-surface ground ice could be present today.

Our research evaluates the plausibility of thermokarst formation in an area of UP where thermokarst-like features are highly concentrated: - 260^0 - 281^0 longitude and 40^0 - 50^0 latitude.

Terrestrial thermokarst: When the thermal equilibrium of ice-rich permafrost on Earth is disrupted, inducing localised or regional thawing, the formation of thermokarst may be the result. Thermal disequilibrium is the result of geomorphic, climatic or vegetational processes [13]. Some of these processes, such as road building, increases of CO_2 emissions and deforestation, are anthropogenic; others, such as slumping, the ponding of water, climate change, plant succession and fire, are non-anthropogenic [14]. Often, thermokarst formation is induced by the work of multiple processes.

There are a number of landforms associated with thermokarst processes: eroded or slumped shorelines; shallow, steeply-sided, rimless and irregularly-shaped thaw lakes; and, pits or depressions (alases) that form when thaw lakes drain or fill-in. Thaw-lakes and alases are isolated, multi-lobed or clustered, and aligned or unaligned

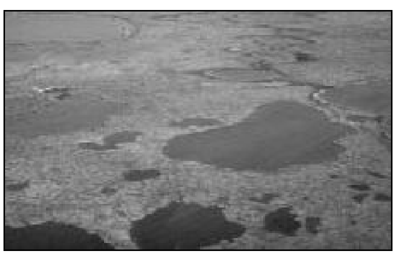

Figure 1. Ice-wedge polygons and thermokarst ponds in Hudson Bay Lowlands, Canada (sts.gsc.nrcan.gc.ca/tsdweb/lanscapes)

In the early stage of growth and development, some thermokarst lakes are centred at the junction of polygon troughs (fig.1). These troughs are underlain by ice wedges, a marker of ice-rich ground. Lake formation occurs at the polygon junctions, which are natural collection points for meltwater.

The possibility of thermokarst and alases in UP: Of the five natural variables that induce the formation of thermokarst on Earth, only slumping, the ponding of water and climate change might be relevant to Mars. Long-term climatic processes are especially important when landforms suggestive of thermokarst formation are identified on a regional scale [15], as they seem to be in UP. The possibility of these processes being induced on Mars depends upon two things: 1. the presence of ice-rich regolith; and, 2. an environment in which atmospheric pressure and average temperature are somewhat higher than they are today.

Ground ice in UP: Lobate-shaped ejecta surround many of the impact craters in the Utopia Planitia. They are visible in numerous Viking, Mars Orbiter Camera and Mars Odyssey (MO) wide- and narrow-band images. The lobate-shaped ejecta could be the products of near-surface volatiles, possibly ground-ice, that were vaporised during crater formation [16]. The hypothesised presence of near-surface ground ice in this poleward region is consistent with the data delivered by the neutron spectrometer aboard the MO [17]. It is thought that the massive discharges of the circum-Chryse channels could be the source of water *cum* ground ice in UP [18].

Collapse features in UP: We have identified two distinct types of possible thermokarst features in UP. The first type comprises dark pits and depressions that are nested solely at polygon junctions (fig. 2a). The pits and depressions tend to be aligned in a northeasterly direction. The pits and depressions are relatively small - ~ 14 - 44 m in diameter - and are largely uniform in size and shape. The uniformity of pit size and shape, as well as the occurrence of the pits solely at polygon junctions, could be indicative of a relatively short period of formation and growth, a common and abrupt end to their development and, possibly, an origin that is linked geomorphologically to the polygons.

The second landform type includes pits, depressions and collapse features that are rimless, flat-floored, steeply sided, shallow and irregular in shape. Some of the features are isolated, others are clustered, some of the features are multi-lobed, others appear to have coalsesced. The pits, depressions and collapse features are present within crater basins (fig. 2b) on ejecta blankets (fig. 2c) and in the surrounding landscape (fig. 2d). On average, the features are larger than the polygon junction pits and vary substantially in size - ~ 220 - 1600 m in diameter - form and spatial distribution. This could be indicative of a longer period of formation and growth than the polygon junction pits and of an origin unrelated to polygon genesis, although in some instances, the features are arrayed in fields of polygonal patterned ground. Interestingly, some landscapes include both landform types (fig.2d).

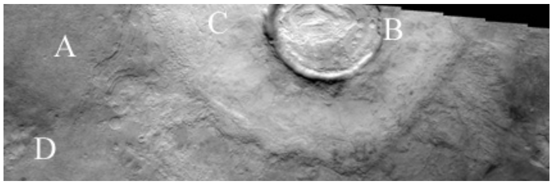

Figure 2. a. pits at polygon junctions; b. collapse features in crater basin; c. collapse features in ejecta; d. collapse features in pit fields. MO image V05265017. Image is ~ 19.5 km across.

Climate change and thermokarst formation in UP: On Mars, climate change seems to be the only process that might induce regional thermal disequilibirum in ice-rich regolith. We argue that both types of thermokarst-like features in UP could be geomorphological relicts of near-surface ground ice that melted, evaporated or sublimated at high obliquity.

However, in a uniformly, ice-rich landscape whose thermal equilibrium is being disturbed solely by climate change, one would expect ground-ice melting and collapse features to be overwhelmingly present in the landscape. The features of UP, by contrast, are irregular if not random in their distribution.

Differences in albedo or topography could exercise a modest influence on the local formation of thermokarst. We argue that the the main mechanism responsible for triggering local thermokarst formation on Mars is eolian deflation or erosion: the random removal of surficial regolith and the subsequent exposure of near-surface ground ice to the higher temperatures and atmospheric pressure of high obliquity. This induces the localised melting, evaporation or sublimation of ground ice which, in turn, leads to the formation of collapse features (possible alases) in the areas of aeolian deflation.

Alternative hypotheses:

A. Polygon junction pits: Aligned collapse pits have been identified in areas of volcanic or tectonic activity such as Alba Patera, Tractus Catena and Tharsis. Some of the pits are similar in size to the polygon junction pits of UP; others are larger. However, the formation of these pits is associated with ground subsidence following lava tube drainage, magma chamber evacuation or graben formation [19].

The polygon junction pits of UP, by contrast, occur in an area not usually associated with volcanic or tectonic activity. Second, the occurrence of the pits at polygon junctions is a characteristic that is not shared with the pits in the other areas. In addition, the polygon junction presence is highly reminiscent of thaw lakes that form at polygon junctions in periglacial environments on Earth. Third, the polygon junction pits are regional in distribution. By contrast, the hypothesised volcanic and tectonic pits are concentrated around fault lines and grabens. Fourth, the alignment of the polygon junction pits is consistent with the dominant patterns of wind circulation in the area. Likewise, the alignment of terrestrial thermokarst lakes, in places like the Tutoyaktuk peninsula of northern Canada, is associated with the work of wind [20].

B. Larger collapse features: Wind-eroded features roughly similar in appearance and in size to some of the larger collapse features discussed above are not uncommon in UP. However, when wind erosion takes place in the absence of near-surface ground ice, layers of sedimentary beds may be exposed. By contrast, the features that we associate with thermokarst formation in UP occur largely unaccompanied by sedimentary exposure. In addition, the morphology, size and random spatial organisation of the thermokarst-like landforms are consistent with terrestrial thermokarst.

Discussion: We suggest that the polygon junction pits and larger collapse features in UP are a product of thermokarst formation. The features could have been formed during the last episode of high obliquity. We argue that the irregular presence of thermokarst in the landscape is a function of aeolian deflation, which randomly removes surficial regolith and exposes underlying ground ice to changed boundary conditions. However, the presence of two distinct types of thermokarst-like features in the landscape is intriguing. A continuum of evolutionary form exists in terrestrial thermokarst landscapes that does not exist in UP. Explaining this divergence is a matter of ongoing inquiry.

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