INVESTIGATION OF THERMOKARST FEATURES IN NE SIBERIA AS POSSIBLE TERRESTRIAL ANALOGUES OF MARTIAN SCALLOPED DEPRESSIONS.

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Introduction and background: High Resolution Imaging Science Experiment (HiRISE) images with resolutions of ~25-32 cm/pixel [1] enable to analyze putative periglacial landforms on Mars (e.g., polygons, scalloped depressions) in very high spatial resolution. However, the investigation of terrestrial analogues is necessary to improve the understanding of possible ground ice degradation processes on Mars.

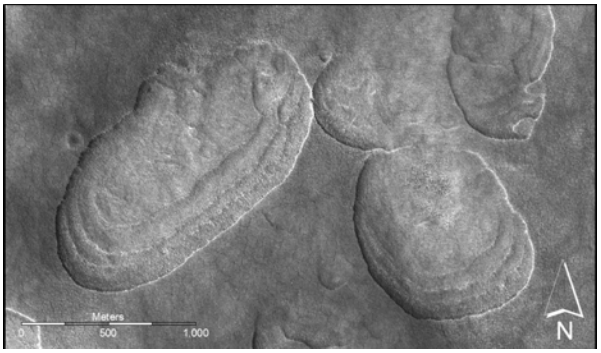


Fig. 1. Scalloped asymmetric depressions in Utopia Planitia (HiRISE, PSP_001938_2265, 46.0N/92.1E)

Such degradation features are present in Mars` mid-latitude regions (40°-60°) in close relation to volatile-rich mantle deposits [2]. These “scallops” or “scalloped depressions” (Fig. 1) were first interpreted as thermokarst by *Sharp* [3]. Accordingly, further authors mentioned the visual similarities of the scallops and terrestrial thermokarst (e.g. [4-6]). It has to be noted that the term “thermokarst”, if used for terrestrial phenomena, implies thawing of ground ice which is unlikely under current Martian atmospheric conditions [7]. Various authors studied the surface morphology of scalloped depressions on Mars and suggested formation processes by solar insolation driven ground ice sublimation (e.g. [5], [8,9]). Other authors suggested an origin of the scallops by ponding water comparable to terrestrial drained thermokarst lake depressions [6]. However, the prolonged existence of ponding water, which is needed to disturb the thermal equilibrium of massive ground ice bodies, is not possible under the current Martian atmosphere, and there is no evidence for standing or flowing waters within the scalloped depressions [8]. Rather, the latitude dependent distribution and the north-south asymmetrical shape of the scalloped depressions, which is opposed on both hemispheres with the steeper slopes pointing polewards (Fig. 1), suggest solar insolation as primary controlling factor for their formation. The depth of scallops is up to 80m and probably corresponds to the thickness of the mantle deposits [5]. They often coalesced and the floors of greater depressions show ridges which are subparallel to the pole-facing scarp interpreted as different stages of scarp retreat [8], while scallop development is forced by enhanced sublimation on the equator-facing gentle slope.

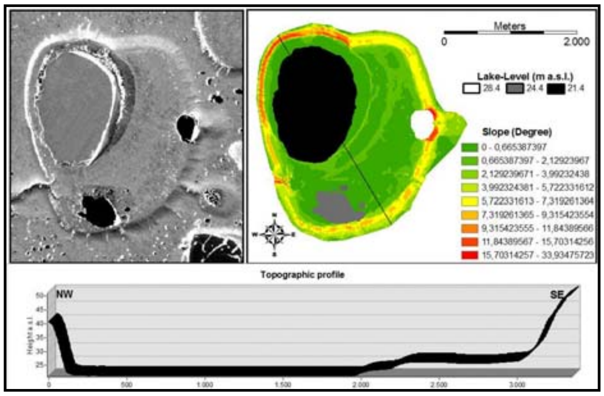


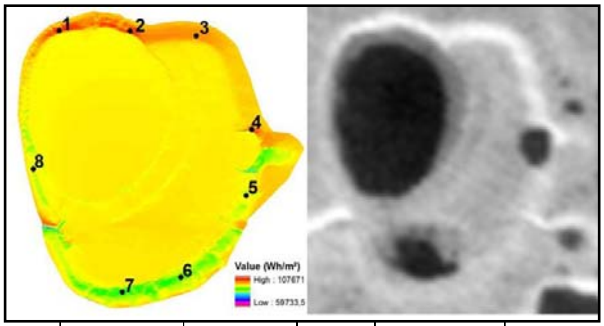
Fig. 2. Left: Investigated thermokarst depression in the Lena Delta (72.327N/126.198E), ALOS PRISM subset. Right: Slope map of the thermokarst depression derived from a DEM (Digital Elevation Model). Below: Topographic profile through the depression, marked by the black line in the slope map.

Approach: We investigate permafrost degradation in ice-rich, fine-grained deposits in NE Siberia focusing on the influence of solar insolation on thermokarst morphology, and present first results of field studies, solar insolation modeling and remote sensing analysis.

Permafrost is related to stable cold and dry climate conditions. Connected with non-glaciated and continental cold-climate environments over long periods is the Late Pleistocene polygenetic formation of fine-grained deposits. These Ice Complex sediments are distributed in northeastern Siberian lowlands and characterized by very high ground-ice contents up to 80 vol-% [10]. About 50% of the Ice-Complex regions are influenced by permafrost degradation [11]. Climate warming during the Late Pleistocene - Early Holocene transition caused the formation of innumerable thermokarst depressions. They show characteristic bowl-shaped morphologies with steep, often asymmetrically-shaped slopes. Terraces therein point to different stages of surface subsidence (Fig. 2) and polygonal patterns in varying occurrence suggest ice wedge growth after permafrost aggradation. A general basin asymmetry in N-S direction was identified by remote sensing analyses (Fig. 2) caused by spatially directed thermokarst processes [12] in possible analogy to directed development of the Martian scalloped depressions. Following [5], we suggest the Siberian Ice-Complex landscapes as terrestrial analogues for Martian degraded volatile-rich mantle deposits.

Data and Methods: During a field campaign in summer 2008, detailed data were acquired in the Lena Delta, NE-Siberia, for investigation of thermokarst morphometry, surface characteristics and their controlling factors besides paleoenvironmental reconstruction and ground truthing for remote sensing data analyses [12]. Geodetic measurements were conducted for detailed investigations of thermokarst depression morphometry. Incident and reflected hemispherical solar radiation was measured on exposed slopes and surfaces to estimate differences of radiation balances caused by topography. The Digital Elevation Model (DEM) derived from geodetic measurements was used for solar radiation modeling within ArcGIS^{TM}. Calculated parameters were adjusted according to atmospherically conditions in the high-arctic Lena Delta region and an estimated snow-free time span between June and September. Additionally, Landsat 7 ETM+ thermal data were used for analyzing spatial patterns of thermal emittance within the thermokarst depression.

Preliminary results and discussion: Several asymmetries become obvious in the DEM showing steeper slope angles in the NNW and NE part of the thermokarst depressions (Fig. 2). The south facing steepest slopes in the NW of the largest lake and in the N of the eastern lake show the strongest modeled influence of solar insolation confirmed in the Landsat thermal data (Fig. 3). First results of the *in-situ* solar radiation measurements show also the differences between the differently exposed slopes. On the S-facing slope N of the eastern small lake we observed an area (several square meters) of disturbed vegetation cover and slope movement, obviously not caused by lake propagation (point 4 in Fig. 3). Such phenomena similar to retrogressive thaw slumps could be observed only on steeper S-facing slopes in adjacent thermokarst depressions. Therefore, slope instability and steepness are probably influenced by solar insolation. However, the NW part of the depression and the area north of the eastern lake seems to be interrupted by the lakes, disturbing former elliptical depression shape and indicating lake propagation into the thermokarst basin slopes (Fig. 2). Thus, the influence of ponding water on thermokarst development must be considered. But the results indicate solar insolation as crucial factor of thermokarst slope instability and therefore on lake migration (see the table in Fig. 3).



Point	Insolation (Wh/m²)	Slope (Degree)	Point	Insolation (Wh/m²)	Slope (Degree)
1	101177	13	5	91348	7
2	101333	14	6	87652	7
3	97587	7	7	85828	8
4	105480	21	8	91109	8

Fig. 3. Left: Solar radiation modeled with ArcGIS^{TM} in relation to the topography of the thermokarst depression. Right: Subset of a Landsat thermal image (ground resolution 60x60m). Brighter areas point to higher thermal surface emittance. Below: The table show exemplary insolation and inclination for different points within the depression.

Conclusion: Thermokarst formation on Earth is strong influenced and driven by standing water bodies. Direct comparison to Martian scallops is problematic. However, investigating the influence of solar insolation on terrestrial thermokarst morphology can improve our understanding of insolation-driven scallop development on Mars. The development and shape of the Martian scallops, especially the morphology and the suspected migration of the steep pole facing scarp, can not be explained sufficiently by solar insolation.

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