Investigation of thermokarst depression asymmetry in Siberian ice-rich permafrost in comparison to asymmetric scalloped depressions on Mars

M. Ulrich, A. Morgenstern, F. Günther & L. Schirrmeister
Department of Periglacial Research, Alfred Wegener Institute, Potsdam, Germany

D. Reiss
Institut für Planetologie, Westfälische Wilhelms – Universität, Münster, Germany

E. Hauber
Institute for Planetary Research, German Aerospace Center (DLR), Berlin, Germany

1 INTRODUCTION AND BACKGROUND

Thermokarst landscapes are widely distributed on Northeast Siberian Ice Complex deposits. Large thermokarst depressions (0.5 – 3 km wide, 10 – 30 m deep) with steep slopes and flat bottoms have been formed by massive surface subsidence during Late Glacial to Early Holocene global warming. Particularly, the high ground ice content of Ice Complex deposits (up to 90 vol%) is a crucial factor for deep thermokarst formation. Lateral growth of thermokarst basins occurred due to thermoerosion and gravimetric mass wasting along the slopes. Preliminary studies indicate a specific asymmetric depression morphometry suggesting spatially directed thermokarst processes of still unclear reasons.

Comparable depressions can be observed in Mars' mid-latitude regions in close relation to a several meters thick water-ice-rich mantle layer, which was deposited during variations in orbital Mars parameters. These small (80 m – 2 km wide, 5 – 25 m deep), rimless, scallop-shaped depressions show a N-S asymmetry, which is opposed on both hemispheres with the steeper slopes pointing polewards. Formation hypotheses for these depressions include an asymmetric sublimation of ground ice with respect to the aspect (i.e. N-S) due to solar insolation and therefore a poleward migration.

We investigate a large thermokarst depression in Ice Complex deposits in the Siberian Arctic as terrestrial analogue for scalloped depressions in Martian ice-rich mantle deposits focusing on the influence of solar insolation on thermokarst morphology.

2 DATA AND METHODS

A Digital Elevation Model (DEM) of 3 m/pixel derived from geodetic measurements of thermokarst depression morphology was used for solar radiation modeling within ArcGIS^{TM}. Morphometric parameters (slope angle, aspect, elevation, curvature) were extracted for quantitative terrain analysis. Landsat-7 ETM+ thermal data were used for analyzing spatial patterns of thermal emittance within the thermokarst depression.

Comparative analyses of Martian scalloped depressions were conducted using data in high resolution (HiRISE, CTX) from the Mars Reconnaissance Orbiter (MRO). Topographic information was derived from a DEM of 1 m/pixel based on a HiRISE stereo pair. Brightness temperatures for a selected region were derived from Thermal Emission Imaging System (THEMIS) infrared data.

3 RESULTS AND DISCUSSION

Several asymmetries within the terrestrial thermokarst depression become obvious in the DEM showing steeper slope angles of the south-facing slopes. GIS based morphometric analyses confirm a spatially directed thermokarst development in ice-rich deposits. Based on the general basin form, slope asymmetry, lake location, and the lake terrace arrangement, we suppose a lateral thermokarst development in NNW direction. The results suggest solar insolation and surface temperatures as crucial factors controlling thermokarst slope instability and steepness. The highest amounts of solar insolation and temperatures on south-facing slopes are forcing lake migration and, therefore, lateral thermokarst development.

On Earth, the steeper south-facing thermokarst depression slopes are geomorphologically more active and therefore younger. By direct analogy, this would imply scallop development on Mars primarily forced on the steep pole-facing slopes in an equatorward direction, probably during high obliquity (>45°) periods with higher summer temperatures on the pole-facing slopes rather than current poleward migration. The morphometric characteristics of the equator-facing slopes imply the absence of strong erosional processes and current surface stabilization. Further, current thermal properties and albedo data show always lower temperatures and higher albedo of the scalloped terrain comparable to the adjacent non-degraded uplands within the investigated area. This would be in disagreement with areal heating and enhanced sublimation on the equator-facing slopes in the present stage.