

Dissertation zur Erlangung des Grades eines Doktors der Naturwissenschaften

# COLD-CLIMATE LANDFORMS ON MARS

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## ABSTRACT

This work covers the dominant aspects of landforms and processes related to the cold-climate (periglacial) and hyperarid environment of Mars and relates the knowledge obtained from terrestrial research to possible Martian analogue landforms. Among the plethora of landforms related to cold-climate environments and subsurface permafrost on Mars, those features have been investigated in detail that are related to the creep of ice and debris at the Martian dichotomy escarpment and the southern-hemispheric impact basins, especially Hellas Planitia, and which have been described controversially as either glacial or periglacial in nature. Structures related to seasonal freeze-thaw cycles on Mars which are generally known as thermal contraction polygons form a second major focus of this work. Research presented on this topic focuses on the northern hemispheric Utopia Planitia area and the south-polar cap of Mars. This work was carried out on the basis of observational and geomorphometrical analyses by utilizing imaging-sensor and topographic data in order to address questions regarding the history, development, and current state of cold-climate landforms on Mars.

This work provides new insights with respect to age, composition, source of debris and ice, and the deformational and degradational history of lobate debris aprons and similar landforms. It is shown that processes which led to creep of debris and ice at the northern hemispheric dichotomy boundary are transitional in nature and are not easily categorized using standard definitions commonly used in terrestrial research. Processes facilitating creep of debris and ice are related to thermokarstic disintegration of permafrost-rich highland terrain coupled with a more recent mantling deposit that is currently disintegrating. These processes are likely the response to cyclic climatic changes in Martian history on a global scale and are related to changes in the configuration of orbital parameters of Mars. Characteristics of recent disintegration processes are observed throughout all study areas in the northern and southern hemisphere and indicate post-emplacement modifications that might have led to rock-glacier formation under cold-climatic conditions. Transitional cryospheric morphologies covering the glacial and periglacial domain appear to exist on Mars with debris-ice transport systems containing mostly small amounts of blocky debris and large volumes of ice. Age-determinations for several key regions show that the latest activity phases were approximately 50-100 Ma ago. For one area at the Martian dichotomy boundary, much younger ages of  $<0.1$  Ma suggest even geologically recent activity.

The south polar cap as part of the Martian cryosphere, is not only seasonally active with respect to sublimation and deposition of carbon dioxide ice but also to seasonal development of thermal contraction cracks, similar to those observed in terrestrial periglacial environments. It is shown for the first time by direct observations that frost cracking does occur seasonally but that formation of ice wedges is unlikely. The configuration of water- and carbon dioxide ice seems to be comparable to terrestrial periglacial landscapes consisting of subsurface permafrost bodies and a surficial seasonally active layer.



## KURZFASSUNG

In der vorliegenden Arbeit werden wesentliche Oberflächenformen und Prozesse des Mars behandelt, die aus dem hyperariden Frostklima resultieren. Dazu werden die Beobachtungen in Zusammenhang mit Erkenntnissen aus terrestrischen Untersuchungen ähnlicher Klimaräume gebracht. Im Vordergrund stehen dabei Prozesse und Landschaftsformen, die mit dem Kriechen von Eis und Lockergestein verknüpft sind und geographisch an die Übergangszone vom südlichen Hochland zur nördlichen Tiefebene und die großen Einschlagsbecken der Südhemisphäre gebunden sind. Bis heute werden derartige Morphologien kontrovers als glaziale (glazigene) bzw. periglaziale Formen diskutiert. Darüber hinaus werden Strukturen im Bereich um Utopia Planitia und der südpolaren Umgebung untersucht, die mit saisonalen Frostzyklen und der Bildung von thermalen Spannungsrissen in Verbindung gebracht werden. Grundlage der Arbeit bilden Bilddaten aller wichtigen Orbiter Missionen sowie geomorphometrische Untersuchungen auf Basis von Topographiedaten des Mars. Die Untersuchungen liefern neue Erkenntnisse und Antworten auf Fragen zur Herkunft, Entwicklung und dem derzeitigen Zustand kalt-klimatischer Morphologien.

Bei den eisreichen Schutttransportsystemen stehen das Alter der Kriechformen, die Zusammensetzung, die Herkunft von Eis- und Gesteinsmaterial sowie das Auftreten von Degradations- und Deformationserscheinungen im Vordergrund. Der wesentliche Entstehungsprozess beinhaltet Hangprozesse in Form von Massenbewegungen sowie anschließender Thermokarstdegradation und die damit verbundene Zerlegung permafrostreichen Hochlandmaterials. Jüngere, eisreiche atmosphärische Ablagerungen überdecken alte Morphologien und unterliegen derzeit einem weiträumigen Desintegrationsprozess. Neben Hinweisen auf Permafrostdegradation werden in lokale Studien Massenbewegungen diskutiert, die einen Übergang von schuttreichen Lawinen zu blockgletscher-ähnlichen Formen dokumentieren und eine eindeutige Zuordnung zu glazialen oder periglazialen Systemen über den direkten terrestrischen Vergleich nicht zulassen. Es zeigt sich im Rahmen dieser Arbeit, dass diese Prozesse möglicherweise in enger Verbindung mit Variationen orbitaler Parameter des Mars stehen, welche eine zyklische Veränderung des Klimas und eine Umverlagerung von Volatilen verursachen.

In Bezug auf die Bildung thermaler Spannungsrisse wird im Rahmen dieser Arbeit gezeigt, dass das südpolare Umfeld des Mars nicht nur unter dem Einfluss saisonaler Sublimation und Ablagerung von Kohlendioxid steht, sondern dass durch die saisonalen Temperaturschwankungen Oberflächenstrukturen ausgebildet werden, die mit Frostspaltenbildung in periglazialen Gebieten der Erde vergleichbar sind. Erstmals können über hochauflösende Bilddaten jährliche Veränderungen und die Ausbildung von Kontraktionsrissen detailliert dokumentiert und untersucht werden. Eine Ausbildung von Eiskeilen wird derzeit ausgeschlossen. Die geschichteten Ablagerung von Wasser- und Kohlendioxid im Bereich der residualen Südpolkappe des Mars sind mit einem typischen Untergrundprofil terrestrischer Periglazialräume vergleichbar, in dem eisreicher Permafrost von einer jährlichen Auftauschicht überlagert ist.





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