CHAPTER 1

Introduction and Overview

In the textbook *The Physics of Glaciers*, W. B. Paterson cites an unknown person: 'There is nothing new except what is forgotten'. Although this statement would not be necessarily signed by the author of this work, as currently many orbiters about Mars and other planets send back huge amounts of data that reveal new details, many of the aspects concerning the periglacial and even glacial environments of Mars have been discussed or anticipated in early work dating back to the days of Mariner and Viking. This work deals with many of such aspects but not without adding new observations and analyses to the discussion about the geomorphology of so-called *permafrost features* on Mars. Most of the observations in this work could only be made with the help of new camera technologies on orbiting spacecraft. Some of the observations confirm earlier assumptions and conclusions, while other observations bring up new issues. The Scope and focus of this work are summarized hereafter. The organization of this thesis and the contribution of the author to published papers and manuscripts presented in part III are summarized in section 1.2.

1.1. Scope and Focus

The Martian mean annual surface-temperature ranges suggest that Mars is a periglacial planet which should have a geomorphologic inventory that compares closely to what is observed on Earth in polar or high-altitude periglacial environments. The lack of precipitation on Mars nowadays makes an active periglacial or even glacial environment almost impossible. Things might have been different in the past as suggested by numerous observations and modelling work on the stability of the Martian spin axis.

This work focuses on observations of periglacial phenomena on Mars that are considered analogs to terrestrial landforms of circum-polar or high-altitude environments. In particular, work is focused on the distribution, morphology and development of Martian rock-glacier analogs and polygonally-shaped landforms related to thermal contraction processes. Although both landforms are completely different from each other in terms of morphology, development and mechanics of formation, they are both controlled by the periglacial environment and are valuable indicators for the past and present conditions of Mars and the Earth. The scope of this work is to obtain information about the environmental conditions during formation of these landforms and to characterize these features under consideration of knowledge obtained from terrestrial periglacial research.

Parts of this work have been published or will be submitted as stand-alone manuscripts in the near future. Therefore, each contribution has its own conclusion section. These are summarized in chapter 14. The selection of landforms analyzed in this thesis is predominantly controlled by the available image resolution of data which is provided from Mars-orbiting spacecraft. This work was initiated using Viking-based image data and topographic data from the Mars Orbiter Laser Altimeter (MOLA) operating on Mars Global Surveyor (MGS). One focus of this study was to gain more information about so-called lobate debris aprons and associated landforms on a global scale. With new experiments on and above the surface of Mars and with more data arriving daily, the original scope of the thesis was expanded by making use of very-high resolution data from the Mars Orbiter Camera (MOC) operating on MGS, high-resolution data from the Thermal Emission Imaging System (THEMIS) aboard Mars Odyssey, and data from the High-Resolution Stereo Camera (HRSC) aboard Mars Express. All these new data allowed the investigation of landforms not only at global scale and low resolution but also to obtain detailed information at meter-scale.

Although on Mars the boundary between landforms that are either periglacial or glacial in nature seems to be diffuse, the author tries to separate the environments of both systems on a theoretical basis and focuses predominantly on the periglacial environment. One reason for this is the enormous amount of terrestrial as well as extraterrestrial literature on either of these topics. The other reason is that there is only little chance to distinguish between e.g., a debris-covered glacier that belongs to the glacial systems, and a rock glacier characteristic of periglacial and permafrost environments on the basis of image data. To account for this problem, work on some of the most prominent glacial features is addressed appropriately but landscapes connected to the true glacial system, comprising all sorts of landforms formed by the action of glacial ice, are not considered in order to maintain the focus of this work and also in order to avoid speculations on issues we simply do not know. The importance of separating both glacial and periglacial environments is addressed in subsequent chapters. It is furthermore emphasized that this separation is more than addressing a simple terminological problem as both environments, glacial and periglacial, are connected to different climatic environments. It has and it will be shown that although conditions of formation within both environments are different, the observation of landforms connected to one or the other have similar implications for the evolution of such landforms on Mars. The work presented in part III covers a range of surface features that provide insights into recent periglacial processes (i.e., thermal contraction cracking), into thermokarstic degradation, and also into an earlier distribution which can now only be traced with the help of relic landforms.

1.2. Organisation of Thesis

This thesis is structured in three parts and is framed by this introduction chapter and the summary in chapter 14.

Part I *Background Theory on Terrestrial and Martian Permafrost and Periglacial Environments* is composed of four chapters. The first of these four chapters covers definitions and background information on terrestrial and Martian periglacial environments and on permafrost in general (chapter 2). Chapters 3-5 discuss selected landforms of the periglacial environment on Earth as well as on Mars.

The theoretical issues discussed in chapter 2 on *Definitions and Background of Periglacial and Permafrost Environments* cover definitions and terminological problems of the periglacial and permafrost zones. The chapter also introduces definitions and thermophysical properties of terrestrial and Martian permafrost. It discusses briefly some aspects of cryospheric systems in general and in how far glacial and periglacial aspects are considered to overlap each other. Concerning terrestrial research, this part can only tackle the most relevant aspects of these environments as an abundance of literature has been published during the last century and a complete summary addressing all relevant issues is beyond the scope of this thesis. Instead, it focuses on the general knowledge as well as on open questions regarding terrestrial environments that appear relevant for the Martian scenario as well.

Chapters 3-5 deal with terrestrial as well as Martian landforms indicative of cold climates and permafrost environments. There, the state of knowledge regarding formation and development of such landforms as well as problems and open issues connected to their formation will be addressed. That chapter will also introduce the working fields of the author that will be discussed in more detail in part III of this thesis. Those chapters are organized with respect to landforms rather than with respect to the planetary environment although terrestrial features are clearly separated from possible Martian analogs. Thus, chapter 3 discusses *Landforms Indicative of Creep of Debris and Ice* and combines terrestrial as well as Martian analogs. Chapter 4 covers aspects of *Thermal Contraction Polygons and Formation of Polygonal Surface Patterns* on the Earth and on Mars. Finally, chapter 5 on *Pingo Landforms and Frost Mounds*, compares terrestrial and Martian frost-mounds and theories on pingo-formation. This organization accounts for the different morphologies and genetic implications connected to thermal-contraction polygons as well as rock glaciers. Terrestrial research is summarized with a focus on formation conditions, morphologies as well as degradation, rather than summarizing aspects considered secondary with respect to the Martian environment. The length of these chapters is justified by the large number of papers published on these topics. It therefore presents a summary of knowledge gathered since the late 1980s on especially Martian landforms.

Part II covers technical aspects concerning *Methods and Approaches in Data Analysis*. In chapter 6 aspects of *Instrument Data and Data Processing* are addressed covering briefly instrument descriptions as well as fundamental data processing work that has been performed. Additionally, various instrument datasets obtained from Mars-orbiting spacecraft are related to each other. Chapter 7 on *Data Analysis and Methods for Data Interpretation* covers general methods that have been applied in the course of this thesis. The most relevant methods are addressed there, however, special data treatment is summarized in the appropriate sections on methodologies in part III and chapters therein.

Part III *Investigations of Key Areas* contains published work, work currently in review or close to submission. In this part, five chapters deal with the geomorphology of the Martian periglacial environment and the relation to observations of terrestrial analogs. Despite the fact that polygonal thermal contraction patterns are covered only in chapter 8 on *Seasonal Variations of Polygonal Thermal Contraction Crack Patterns in a South Polar Trough, Mars*, the large amount of data processing and data analyses of the South Polar cap with respect to these landforms is being continued and is also briefly summarized in a supplement section following chapter 8. Parts of the author's work on these landforms have been presented at numerous conferences and are also included in section 4. The manuscript was published in *Journal of Geophysical Research* (2005) by *S. van Gasselt, D. Reiß, A. K. Thorpe, G. Neukum*. The concept, data extraction, data processing, data fusion, and analysis as well as writing of the manuscript and preparation of figures were carried out by the first author. The other authors supported this work with respect to (a) pre-selection of polygonal features in MOC image data, (b) discussions on the implications of observations, and (c) improving the readability of the manuscript.

Chapters 9 to 12 cover aspects of Martian rock-glacier analogues. Chapter 9 on *Cold-Climate Modification of Martian Landscapes: A Case Study of a Spatulate Debris Landform in the Hellas Montes Region, Mars* by *S. van Gasselt, E. Hauber, G. Neukum* has been published in *Journal of Geophysical Research* (2007). The concept, data extraction, data fusion, data analysis, figure preparation, and writing of the manuscript was carried out by the first author. The results were discussed with the co-authors of the manuscript.

Chapter III.10 on *Current State and Disintegration of Rock-Glacier Landforms in Tempe Terra, Mars* is in preparation for submission to *Journal of Geophysical Research* and was written by *S. van Gasselt, E. Hauber, G. Neukum*. The idea, data extraction, data analysis and writing as well as figure preparation were conducted by the first author. Support from the first co-author was gained with respect to morphological observations on the mantling deposit in the fretted terrain of the highland plateaus.

Chapter III.11 on *Lineated Valley Fill at the Martian Dichotomy Boundary: Nature and Degradation* presents work that has not been submitted yet. That work was initiated as joint work between the author of this thesis, *E. Hauber, J. W. Head, D. R. Marchant*, and *G. Neukum*. One aim of this study is to find a common denominator with respect to the glacial hypothesis as supported by the groups at Brown and Boston University and the non-glacial hypothesis as supported by the groups in Berlin at FUB and DLR. However, the chapter presents first results obtained by the group in Berlin only, and does not necessarily represent opinions of the groups at Brown and Boston University.

Chapter 12 on *Geomorphic Evidence for former Lobate Debris Aprons at Low Latitudes on Mars: Indicators of the Martian Paleoclimate* was submitted to *Journal of Geophysical Research* and has been accepted for publication. The manuscript was prepared by *E. Hauber, S. van Gasselt, M. G. Chapman, G. Neukum*. The Implications of observations were discussed by all authors. Age determinations, extraction of topographic profiles, global mapping of lobate debris aprons as well as preparation of figures 12.6, 12.8, 12.10 and some minor text writing were performed by the author of this thesis.

Chapter 13 on *Deposition and Degradation of a Volatile-Rich Layer in Utopia Planitia, and Implications for Climate History on Mars* presents work that has been published in *Journal of Geoophysical Research* (2007) and which was written by *A. Morgenstern, E. Hauber, D. Reiß, S. van Gasselt, G. Grosse, and L. Schirrmeister*. Due to the relevance of degradational processes in periglacial landscapes as indicator for climatic changes, this work has been included. This joint-project was initiated between colleagues at the Alfred Wegener Institute, Potsdam (A. Morgenstern, G. Grosse, L. Schirrmeister) who are experienced in the field of terrestrial periglacial processes and colleagues at DLR. Except for summarizing work concerning thermal contraction patterns on Mars and providing the database for sublimation landforms and polygonal thermal contraction patterns in Utopia Planitia, the author's involvement was limited to organizational issues and co-writing the research proposal.

Individual conclusions on each topic are provided at the end of each chapter of part III. A short general summary, conclusions and the connection to work that has been performed by other authors are provided in chapter 14. □