PERMAFROST-RELATED MORPHOLOGIES IN TEMPE TERRA, OBSERVATIONS AND MORPHOMETRY. S. van Gasselt, E. Hauber, R. Jaumann, *German Aerospace Center, Institute of Space Sensor Technology and Planetary Exploration, D–12489 Berlin, Germany, (Stephan.vanGasselt@dlr.de)*.

1 Introduction

The fretted terrain at the Martian dichotomy boundary shows various permafrost related morphologies. On the basis of Mars Global Surveyor mission data we perform morphometrical analyses of lobate debris aprons and present typical ice related morphologies from high resolution imagery. A variety of landforms indicates the possible existence of past or present ice in the near subsurface of Mars (e.g., [1, 2, 3]). Among the most spectacular ice-related features are lobate debris aprons (LDAs). They have been interpreted to be a mixture of rock particles and interstitial ice (e.g., [4]) analogous to terrestrial rock glaciers (debris transport systems comprising a creeping mixture of rock fragments and segregational or interstitial ice [5]).

Rock glaciers are sensitive indicators for the climatic environment during their formation and - if present on Mars - are thought to be possible large and easily accessible water reservoirs. The analogy between terrestrial rock glaciers and Martian lobate debris aprons is mainly based on the shape of debris aprons and their relationship to adjacent regions with permafrost-related morphology. In this study we will focus on LDA·s in Tempe Terra and investigate LDAs on the basis of high resolution imagery and topographic data. The Tempe Terra area (fig. 1) is characterized by fretted terrain [6], a type of landform often characterizing the dichotomy boundary between southern highlands and northern lowlands on Mars. In particular, we focus on an ubiquitous mantling deposit which might also indicate the past or present existence of near surface ice, but is different from the LDAs.

2 Topography and Morphology

The width of the fretted terrain in our study area varies between 60 km to 170 km. The undissected upland has an elevation of -2700 m at 66°W and about 0 m at 80°W. The lowland has its highest elevations also in the western part of the study area (-1700 m) and slopes gently ($\approx 0.1°$) towards NE, reaching minimum elevations of -3600 m at the eastern border of the study area. The elevation difference between uplands and lowlands deceases from ≈ 3000 m (at $\approx 80°$ W) to ≈ 1500 m (at $\approx 66°$ W). This elevation difference is slightly less than that reported from the dichotomy boundary in eastern Mars (2-6 km) [7].

The highlands have a generally very flat surface, sloping at an angle of less than 0.1° when measured perpendicular to the dichotomy boundary. The surfaces of very large upland segments bounded by fretted channels (Fig. 1) have larger slopes toward the lowlands (1°-2°) and might be tilted as blocks. Several fretted channels dissect the upland at the dichotomy boundary. Such channels have steep walls and flat floors [4], and their floors are often characterized by "lineated valley fill"

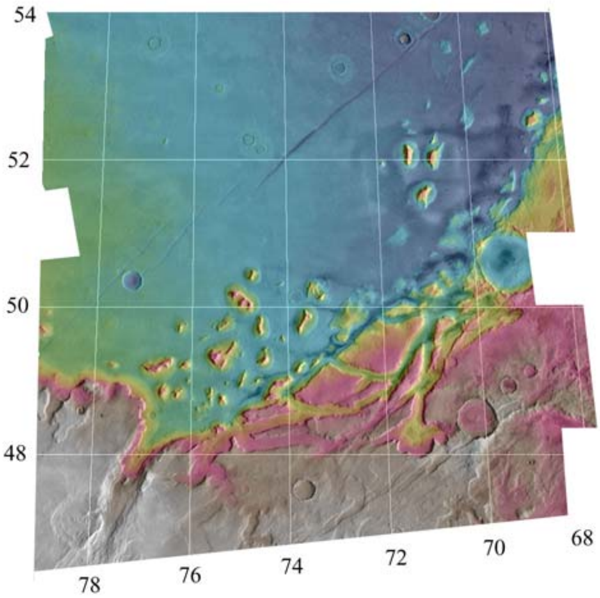

Figure 1: Viking digital image mosaic of the northern Tempe Terra region combined with MOLA topographic data.

[4] [8]. In the study area, they have uniform widths of ≈5-10 km and constant depths of few hundred meters. On the floors of some fretted channels we identify crevasse-like features.

Their specific geometry resembles that of terrestrial chevron crevasses, which form by a combination of shear stress exerted by the valley walls and -to a minor degree- by longitudinal tensile stress (i.e., extending flow) resulting from glacier bed steepening [9]. We do not know, however, which processes are responsible for the deformation of the mantling deposit. One possibility would be creeping of the mantling deposit, as suggested by [10]. Their orientation seems to be structurally controlled in two ways: One preferred trend is parallel to the Mareotis Fossae (N50°-60°E), a system of long and narrow grabens. The other is concentric about the center of a possible impact crater in the northern lowlands (center at 79°W, 56°N). Although there is evidence for fluvial sapping on the uplands near the dichotomy boundary, we find no evidence for a fluvial origin and later enlargement of fretted channels.

Very high-resolution images (1.5 - 12 m/pixel) taken with the Mars Orbiter Camera (MOC) onboard the Mars Global Surveyor (MGS) spacecraft show that the surface at the dichotomy boundary in Tempe Terra is covered by a smooth mantling deposit. It is often degraded by erosion, resulting in surfaces whose texture is highly variable, ranging from smooth over stippled, pitted, or knobby to heavily etched. In some places it is completely removed. The disintegration process is controlled by slope aspect (i.e., sun irradiation),

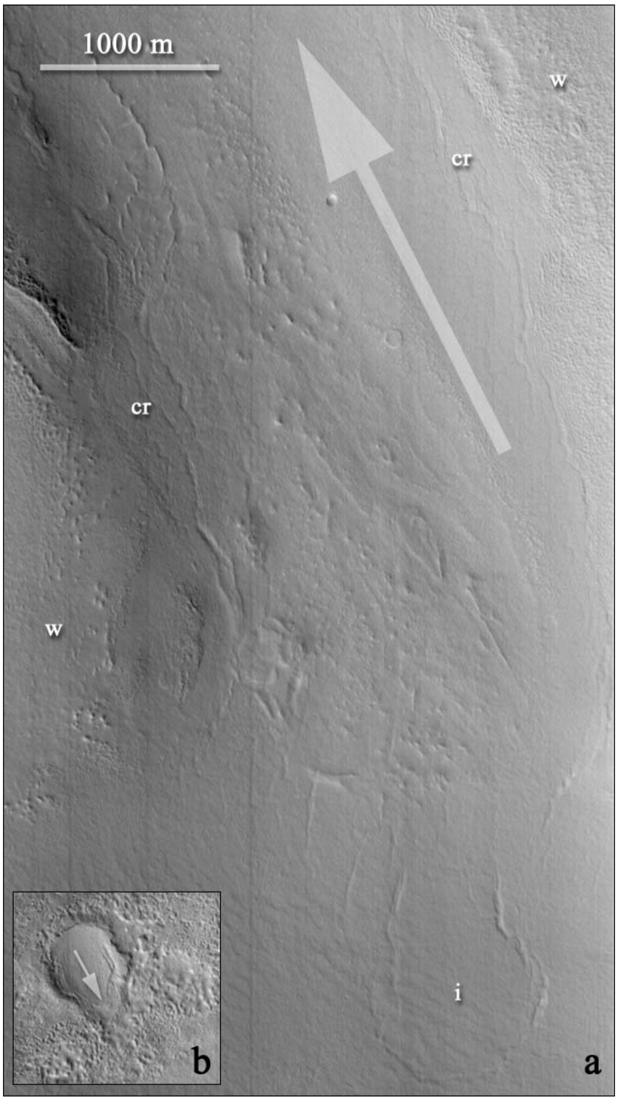

Figure 2: The floor of a fretted channel (a) is covered by a mantling deposit. Crevasses (cr) are situated near the channel walls (w). They also outline an impact crater completely buried by the mantle (i). Small image at the bottom left (b) shows a crater filled by the mantling deposit. The mantle seems to have flown out of the crater. Detail of MOC image M03/06586 (6.23 m/pixel).

the southern (sun-lit) slopes being more affected than northern slopes. This indicates the sublimation of a volatile constituent, as previously proposed [11] [12]. The global presence of this mantle at latitudes higher than ≈30-50° in both hemispheres has been inferred from global-scale roughness maps [13] and directly observed in MOC images [11, 14]. It was interpreted to be a mixture of ice and soil which was atmospherically deposited during a recent period of high orbital obliquity less than 100,000 yrs ago [12]. Our investigation of MOC images confirms other observations of this deposit [11, 12]. Several features related to the mantle resemble terrestrial glacial features, and some of them may be attributed to flow or creep processes. An observation in Tempe Terra might support this notion: A little crater (≈ 500 m) is filled with the mantling deposit. Where the crater rim is breached, the mantle seems to have flown out of the crater (Fig. 3). A second possibility is that the underlying material (i.e. the lineated valley fill [4, 8, 15] might have flown, and that the overlying mantle only mirrors that deformation.

Some images reveal a few more or less well-developed parallel, thin (15-20 m wide) ridges running at ± constant elevations along upper channel walls [26]. Although they resemble lateral moraines or washboard moraines, we do not observe any evidence for transport along this valley floor (in agreement with [11] and [16]). These ridges might be related to the degradation of the mantling, and might represent zones of higher resistance of the mantle against erosion.

3 Lobate Debris Aprons

Lobate debris aprons have been observed primarily along steep escarpments near the dichotomy boundary [e.g., 17, 19, 11, 20] and the large impact basin of Hellas [e.g., 21]. The morphology of the lobate debris aprons in Tempe Terra is very similar to terrestrial protalus lobes [22,23] which are derived from talus slopes of mountainous permafrost environments. In this study we have observed and analyzed mesas as relics of the ancient highlands and their associated slope aprons in the northern Tempe Terra region on the basis of their morphometry.

We derived geographic coordinates, topographic elevations, lengths, areas and volumes [27]. Assumptions were made with respect to the (a) base of the debris apron, which was assumed to be horizontal and flat [5], and (b) to the volume of that part of the mesa which has been buried by the apron. The volume can be approximated using the apron height (assuming vertical walls) and the mesa area. Thickness estimations, and consequently, volume approximations, are based on DEMs and orthoimagery.

3.1 Topography

The morphologic boundary between highland and lowland areas is characterized by two and sometimes three distinct components, (a) a steep upper slope (the wall-rock), (b) sometimes an intermediate shallow-sloped unit with downslope facing striae, and (c) the highly textured apron [11]. The intermediate unit mentioned by [11] is not observed very often at the

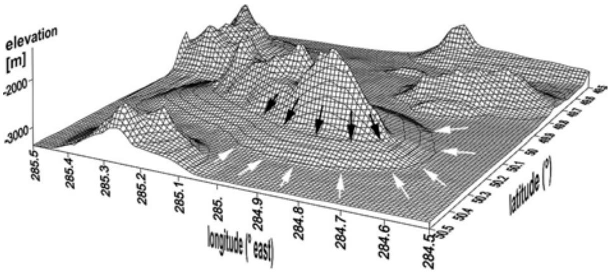

Figure 3: Characteristic morphology of lobate debris aprons at remnants of the ancient highlands. Debris aprons are characterized by a highly convex profile. White arrows are pointing to the footprint, black arrows to the boundary of wall rock to apron.

isolated remnants. At a few sample locations we measured the angles of intermediate units ($\approx 6^\circ - 8^\circ$) and angles of debris aprons ($\approx 2^\circ - 4^\circ$). The results are in agreement with values presented by [11].

In plan view, the mesas north of the dichotomy boundary have a more or less irregular polygonal shape and a rugged top, in contrast to the more flat-topped mesas of the type locations in Elysium or Arabia Terra. Outwards from the wall rock zone large aprons evolve in radial direction and form an elliptical to circular-shaped footprint. The cross-section shapes of the aprons are convex upward, steepening towards the terminus of the apron (fig. 3). The length of the debris aprons varies between 1.4 km to 6.3 km with an average of ≈4.0 km in the northern direction and ≈3.5 km in the southern direction which indicates a dependency on the amount of sun irradiation. The average length of the aprons is less than that given by [20] for Deuteronilus and Protonilus Mensae with 10.8 to 33 km, and also less than that given by [11] and [17] (15 km). No correlation between apron or mesa length and the geographic latitude or the distance to the dichotomy boundary could be found.

The thickness of the (upper) mesas ranges from ≈20 meters to ≈1100 meters. The thickness of the aprons varies between ≈70 and ≈600 meters assuming a flat base. We observed that the relative thickness of aprons and mesas do not correlate. Furthermore, we cannot observe a correlation between the geographic latitude (or distance from the dichotomy boundary) to the thicknesses of apron or remnant. Minimum thickness values are lower than those given by [20] (276 m), the maximum values are about the same.

If the size of lobate debris aprons were a direct function of the amount of erosion which has taken place, we would expect a correlation between their sizes and their geographic coordinates. Therefore, it seems appropriate to consider mechanisms which are supported by climatic factors and which are independent of the size and the geographic distribution of remnants.

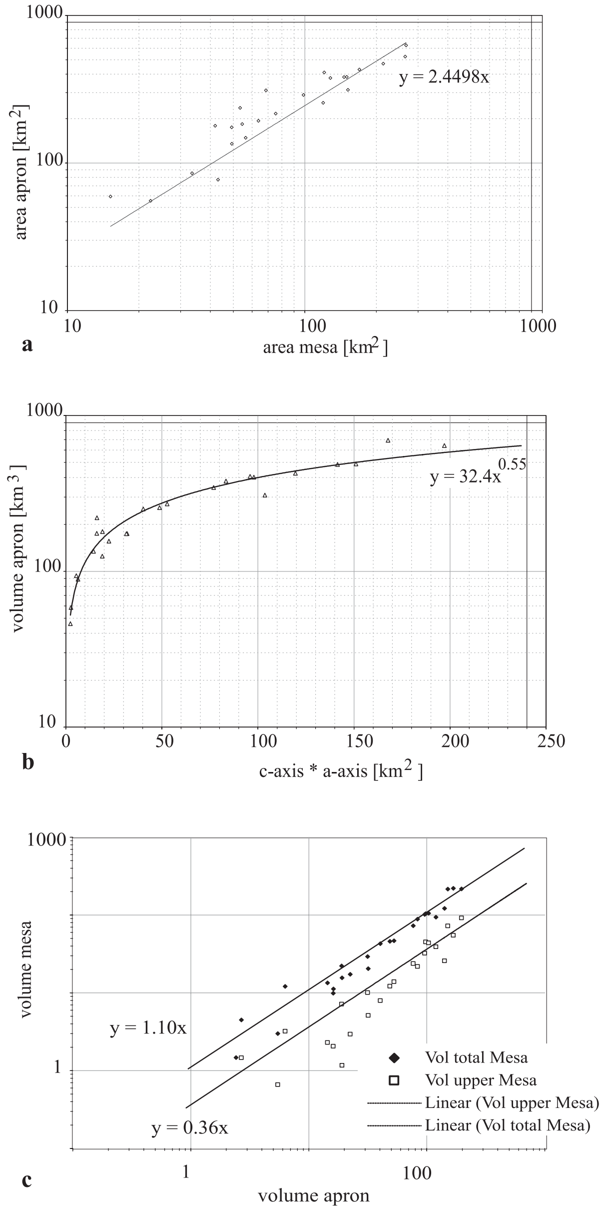

Figure 4: (a) plot of mesa areas against the area of their aprons. Aprons are about 2.5 times larger than the mesa. (b) plot showing the dependency of apron volumes to apron lengths. Accordingly, Tempe Terra apron volumes can be estimated using the lengths of the apron axes, derived from measurements in orthoimagery. (c) A function of apron volumes against mesa volumes (visible and buried part).

3.2 Quantitative Volumes and Areas

The mean volume of debris aprons at Tempe Terra (fig. 4b and 4c) ranges from $\approx$2 km^3 to $\approx$197 km^3 with a mean surface area of $\approx$282 km^2, ranging from $\approx$56 km^2 to $\approx$627 km^2 (fig. 4a). The remnant areas have a mean value of $\approx$115 km^2 (15 to 417 km^2, fig. 4a) and a mean volume of $\approx$21 km^3 (0.04 to 92 km^3, fig. 4c). As [5] points out, there is a close relationship between the source area of debris production and the surface area of a rock glacier. The ratio is controlled by bedrock resistance, relief and climate. Other authors proposed values between 1:1.36 to 1:4.4 [24, 25, 26]. Since the source area of debris aprons can be related to isolated steep-walled remnants (i.e., the area of the remnant), we can compare the results for Martian debris aprons. From the regression plot for 27 observations at Tempe Terra (fig. 4a) we obtain a value of $2.45 \times AS = AR$ [km^2], with source area (AS) and rock glacier area (AR). The factor ranges from 1.8 to 4.5, which corresponds well with the ratios given in [24, 25, 26]. It must be kept in mind that the method is only valid if the remnant top is not flat but steep, i.e. the entire mesa can be a source for rock glacier debris input. The volumes of the debris apron therefore correlates very well with the remnant volumes (fig. 4c). The volume ratio between wall rock and debris apron represents a key value for remnant degradation. The volume of the visible part of the mesa (the upper part) is about one-third of the volume of the apron (0.36). The calculated total remnant volume and the apron volume show a ratio of $\approx$1:1.1.

We observed that ratios between areas and geographic coordinates (latitude, topographic elevation, and distance from the dichotomy boundary) do not correlate at all. A constant rate of retreat of the dichotomy boundary would result in a gradual distribution concerning sizes, volumes and areas of remnants and aprons.

4 Conclusions

In the northern Tempe Terra region of Mars we find a variety of landforms (e.g., degraded mantling deposits, crater-fill, moraine-like features, and lobate debris aprons), which provide abundant evidence for ice-rock or ice-dust interactions. The current environmental conditions on Mars and the morphology and topography demonstrate that there can be active processes near the subsurface. Although we find a general consistency of morphometric ratios at lobate debris aprons, which indicate inactivity, there are strong indicators of active processes in the present (degrading mantling deposit). The area, size and volume distributions of lobate debris aprons in Tempe Terra show that present climatic factors have to be considered for their formation.

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