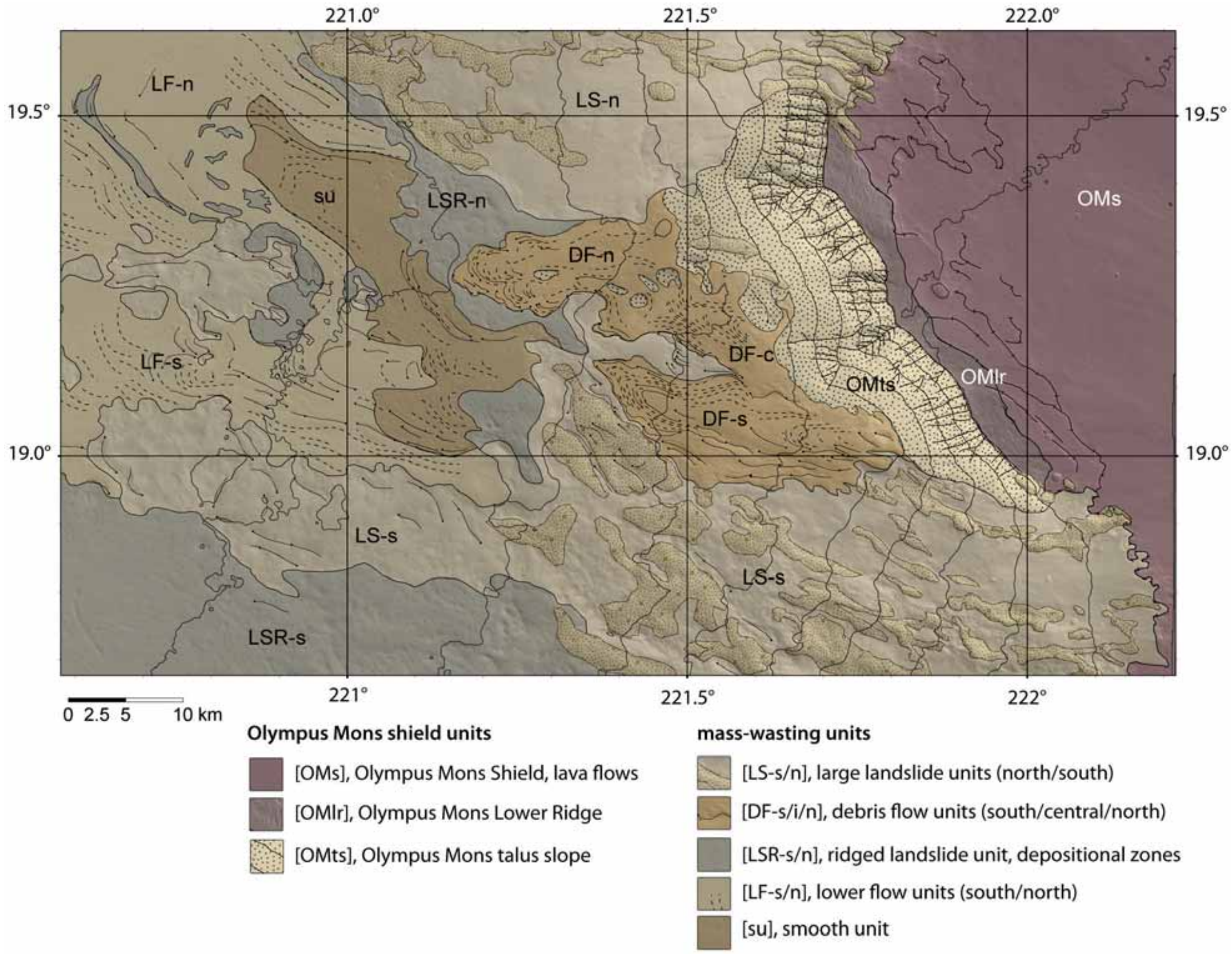
Reconstruction of the Development of Complex Mass-Wasting Landforms at the Western Scarp of Olympus Mons, Mars: Indicators for Talus-Derived Landsliding and Post-Emplacement Degradation.

S. van Gasselt[1] (vgasselt@zedat.fu-berlin.de), E. Hauber[2], A. Dumke[1], G. Neukum[1], [1]Freie Universitaet Berlin, Berlin, Germany, [2]Institute of Planetary Research, German Aerospace Center (DLR), Berlin, Germany.

Background. Slope deposits related to the gravitational movement of debris masses and rock-slope material in high-relief terrain, such as scarps and massifs of the dichotomy boundary [e.g., 1-5], impact craters, volcanoes or tectonic grabens as well as scarps in connection with volcanic activity [6] are important estimators for the near-surface volatile budget and are relevant paleogeomorphic witnesses which help to reconstruct and understand processes involved in the formation of regional landform assemblies. Such deposits can range from deep-seated short-term slumpings to generally slow movement of volatile-rich surface layers, commonly known as solifluction and ice/water-assisted creep. Martian mass-movements of wall rock an debris are frequently discussed in connection with either ice or water as volatile constituent which either caused destabilization or which facilitated creep or flow of debris [1-3]. Some of these deposits have an Amazonian age and are restricted to confined latitudes on Mars indicating the possible presence of near-surface ice-rich material, such as the so-called viscous flow features [7-8] or creep-related landforms at mid-latitudes that are generally considered to be rock-glaciers, analoguous to their terrestrial periglacial counterparts [1-3].
Age determinations of such landforms as conducted on the basis of the impact-crater size-frequency distribution and in connection with observations of their latitudinal distribution [2-3] have added weight to the speculation that their occurrence might be attributed to climatic oscillations caused by cyclic variations of the obliquity of the Martian spin-axis as determined by theoretic modelling [e.g., 9-11]; traces of the former extent of such landforms older than 1 Gyr ago additionally support this theory [12].

Origin. This work focusses on a set of small-scaled landforms located on large-scale slope deposits and situated below the western escarpment of Olympus Mons at 221.5°E, 19°N. The tongue-shaped flow units are framed by two large avalanche deposits initiating on the shield plateau and extending a few hundred kilometers towards the western foreland plains (Figure 1). Such features are superimposed on a broad lobate deposit exhibiting arcuate ridges which was interpreted as either a landslide [1; 13-14] or a possible glacial moraine deposit [15]. Later this landform was included into the row of possible remnants of cold-based glacial landforms termed lobe- or fan-shaped deposit (FSD). The latter interpretation [16-19], however, provides backup for an Amazonian climate change controlled by obliquity variations. The small tongue-shaped landforms superimposed on that lobe and focussed on in this work have been attributed to different mechanisms ranging from a rock-glacier origin comparable to those found in the Antarctic dry valleys [e.g., 17] to possible alpine glaciation [20].

Observations. The Olympus Mons escarpment rim is situated on an elevation of approximately 7200 m in the northern study area and 8300 m in the southern area. The elevation level of the footslope increases from north to south from 2500 m to 3200 m and is covered by several basal debris units masking the exact basal boundary. The western foreland area adjacent to the Olympus Mons scarp and talus can be divided into three main units: [1] a unit composed of three tongue shaped landforms in the central study area which are framed by two chaotic and dissected outer units in the north and south extending from the shield towards the foreland zone, and a smooth and flat deposit characterized by arcuate ridges in the west. The three flow units discussed in this text and termed southern flow unit (DF-s), central flow unit (DF-c) and northern flow unit (DF-n) are located at the footslope of the southwestern Olympus Mons volcano scarp and originate at different elevation levels starting at 1100 m in the north, 2450 m for the central unit and and 3500 m for the southern unit. Their lengths vary between 20 km, over 16 km and 27 km for DF-s. All units descend over more than 1-2 km towards the northern lowland and are characterized by distal accumulations of boulder material derived from either older and buried units or from desintegrating terminal areas.
The main Olympus Mons escarpment slopes at an angle of approximately 17-20°. For this work a detailed geomorphologic study has been conducted by merging all higher-resolution image datasets (MOC, THEMIS-VIS, CTX, HRSC) available thus far and by deriving detailed topographic information using MOLA-based topographic profiles and terrain-model data using HRSC stereo imagery.
Results of that analysis show that despite the striking morphological similarities to certain terrestrial rock-glacier landforms the probable formation mechanism of the tongue-shaped flow units is related to a volatile release from footslope talus at the western Olympus Mons escarpment. The release of volatiles and mixture with talus debris ultimately led to formation of two coalescing tongue-shaped lobes which are draped over the underlying topography and which are characterized by well-pronounced marginal and terminal ridges and levees as well as characteristic streamlined intra-flow morphologies around obstacles and contortion patterns at locations defined by coalescing flow. These geomorphic patterns suggest flow conditions comparable to volatile-rich materials and are common to ice as well as to rock glaciers and also to landslides. Topographic analyses, however, show a well-defined concave profile suggesting not only considerable flow energy allowing for uphill runout but also post-emplacement degradation in connection with



thermokarstic degradation of volatile-rich debris.
Investigation of the exact source areas of these tongue-shaped units have led to the conclusion that talus destabilization occurred at several locations at the western escarpment. While the southernmost tongue is derived from the upper shield area and shares a common source with the large chaotic southern avalanche deposit (LS-s), the northern tongue-shaped unit originates underneath and within small alcoves of the footslope talus deposit.

Implications. Observations of the complex flow units superimposed on the western basal fan-shaped units at Olympus Mons point towards a formation by a single and sudden release of volatiles from either ice-rich talus and/or from ice-ich avalanche deposits. While the exact mechanism for the release of intra-talus volatiles remains uncertain but is considered to be triggered by erosional effects at the footslope/foreland boundary, the release of volatiles and debris from the southern avalanche unit is most probably related to interaction of young shield lava flows and ice rich talus units. In the latter case, the absolute age of small tongue-shaped flow units would therefore constrain the age of the most recent volcanic activity at the Western Olympus Mons shield. However, only few pit-like features in the range of a few tens of meters can be observed on the flow surfaces and it cannot be ruled out that such structures are related to disintegration processes of debris units. These pits would additionally point towards post-emplacement degradation by thermokarst as suggested from the general topographic profile. Most of the pitted features, however, are elliptical in shape which could speak for residual movement after main debris tongue emplacement. This process would suggest transitional effects similar to what is observed in the eastern Hellas Montes region [20].

As an alternative, it is conceivable also that formation of the tongue-shaped flow units have been triggered in the course of degradation and removal of a much larger fan-shaped unit causing finally hillslope destabilization and oversteepening of lower, i.e., basal, units. Such processes are well known and documented from scarp areas where a former body of ice and debris was removed and are commonly summarized under paraglacial mass-wasting processes [e.g., 21,22].

[1] Carr and Schaber, 1977; [2] Squyres, 1978; [3] Lucchitta, 1984; [4] Head et al., 2006; [5] Levy et al., 2007; [6] Lucchitta, 1979; [7] Milliken et al., 2003; [8] Arfstrom and Hartmann, 2005; [9] Murray et al., 1973; [10] Laskar and Robutel, 1993; [11] Laskar et al., 2004; [12] Hauber et al., 2007; [13] Zimbelman & Edgett, 1991, [14] Zimbelman & Edgett,1992; [15] Lucchitta, 1981; [16] Head and Marchant, 2003; [17] Head et al., 2005; [18] Milkovich et al., 2006; [19] Shean et al., 2007; Basilevsky et al., 2005; [20] van Gasselt et al., 2007, [21] Church & Ryder, 1989; [22] Ballantyne, 2002.