Geologically recent tectonic, volcanic and fluvial activity on the eastern flank of the Olympus Mons volcano, Mars

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1. Introduction

[2] Photogeologic analysis of High Resolution Stereo Camera (HRSC) images of the eastern flank of Olympus Mons volcano and adjacent lowland plains (orbit 1089; Figure 1), aided by HRSC-derived high-resolution digital terrain models [Gwinner et al., 2005], as well as MOC and MOLA data have provided new insight into the geological processes operating on the surface and flanks of Olympus Mons. This study continues our analysis of the western flank of the volcano [Neukum et al., 2004; Basilevsky et al., 2005]. In this study we used mostly the nadir channel images (12.5 m/px, Sun elevation 52° to 55°). An essential part of this study was the estimation of the surface ages through impact crater counts of subareas, using both HRSC and MOC images and the updated model of cratering chronology [Hartmann and Neukum, 2001].

2. Observations

[3] On the eastern flank, the surface above the steep volcano slopes (the summit plateau) shows lava flows almost everywhere, each typically with an apparent length of a few km and widths of a few hundred meters, and their surfaces inclined ~2 to 5°. Impact crater counts show that the flows are 190–200 Myr old with a signature of a 500 Myr old episode (Figure 1). At this position on the summit plateau in the western flank of Olympus, several small mesas were observed. In contrast, on the east, only one large mesa-like feature is seen. Its surface stands 200 to 650 m above the neighboring plateau areas and is covered by lava flows, whose patterns are practically identical to those in the areas outside the mesa. Contrary to what was observed in the west, almost no layers are seen here in the mesa slopes and no evidence of mesa surface collapse is observed [Basilevsky et al., 2005]. In some places on the mesa slopes, down-slope-trending dark streaks are seen suggesting the presence of a dust mantle [Sullivan et al., 2001]. The dust mantle suggested by the dark streaks is consistent with the generally low thermal inertia of this area [Mellon et al., 2000].

[4] Slopes on the western part of the Olympus Mons scarp were classified into three morphological types [Basilevsky et al., 2005]: (1) the steepest slopes with flutes and ravines; (2) less steep slopes with chaos-like depressions from which channel-like grooves trend downhill; and (3) the gentlest slopes, covered by lava flows continuing from the summit plateau to the lowland plains. Beneath type 1 and 2 slopes vast flow-like features, interpreted as possible glaciers, have been mapped. They were considered by Lucchitta [1981] and then by Milkovich et al. [2006] to be formed by glaciers. On the eastern flank of Olympus Mons, slopes of type 2 are absent. Slopes of types 1 and type 3 are abundant in the east, and in addition, a new (fourth) slope type appears when lavas flow over the rims of type 1 slopes. Beneath the slopes of the eastern flank, no vast glacier-type features have been observed.

[5] Within the study area the lowland plains typically have a smooth surface only locally complicated by readily or poorly-visible lava flows. Locally, patches of slightly brighter and darker surfaces have streak-like outlines and appear to be of eolian origin. The plains surface is inclined ~0.5° southwestward on average, but locally slopes up to a few degrees are present.

[6] In the southern part of the plains, a few networks of channels typically starting from steep-walled forking and branching troughs are seen (blue lines in Figure 1). The channels intersect, anastomose and form networks. Channels are typically 250–350 m wide, although in some places they widen up to 1.7–2.5 km. Their depth, measured from individual MOLA profiles, varies from 8 to 40 m [Pypysheva et al., 2006]. The largest network (10 km × 60 km) starts from a 1 km wide and 200 m deep arcuate trough. Some channels are single and resemble tectonic troughs and lunar rilles. They often have levees and are fringed with lava flows (Figure 2a). The morphology of a significant part of the channels, including the presence of streamlined islands and terraces (Figures 2b–2d), resembles that of martian
outflow channels [Baker, 1982; Carr, 1996]. Within the channels no evidence of significant eolian or other resurfacing is seen.

[7] Our crater counts (Figure 1) show that the surface age of the network-bearing plains varies from 30 to 145 Myr. Based on three independent crater counts made by us, the channel floors have been dated as ~25–40 Myr old. The differences between the channel age estimates and those for the lava covered plateau (the first are significantly younger) are statistically reliable at the level better than 3 sigma. The range of ages for the plains obviously reflects different episodes of lava emplacement and eolian resurfacing.

[8] Wrinkle ridges are observed (red lines in Figure 1) on the lowland plains, locally on the volcano slope and at the edge of the summit plateau. They are 100–300 m wide and up to 50–100 m high. Wrinkle ridges are commonly interpreted to be the result of compressional deformation [e.g., Mueller and Golombek, 2004]. In some places at the foot of the volcano slope, wrinkle ridges border arch-like terraces 100–200 m high. In one such place we see a channel crossing the 150–200 m high terrace (Figure 3). Here the orientation of the streamlined islands suggests that the channel-forming flow direction was toward a direction that is now uphill. We interpret this as evidence that the

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**Figure 1.** (top) Geomorphic map of the eastern flank of Olympus Mons volcano and (bottom) crater count plots. Dark red outlines – lava flows; bright red – wrinkle ridges; blue – channels; green – domes and ridges above features interpreted to be dikes; white – landslide (?) accumulations; light blue fields – mesa and adjacent hills; red numbers are crater ages.

**Figure 2.** Parts of the channel network in the lowland plains east of Olympus scarp. Arrows show the erosional terraces. (a and b) Portions of HRSC image (nadir). (c and d) MOC images M22-01909 and R16-01228. Figure 2c is the outlined area shown in Figure 2b, and Figure 2d is the outlined area shown in Figure 2c.
wrinkle-ridged terrace formed after the channel incision as the result of tectonic deformation. Thus we interpret the wrinkle ridging here to have occurred more recently than 25–40 Myr ago.

In the HRSC and MOC images of the lowland plains chains of dome-like hills are observed locally (Figures 4a and 4b). These are typically a few tens to 100–150 m across, up to a few tens of meters high and resemble in their morphology spatter and cinder cones formed along fissure eruptions of basaltic lava on Earth. Locally, these features are superposed on channels, so their emplacement occurred more recently than ~25–40 Myr ago. Similar chains of hills have been described by Head et al. [2005] in the Arsia Mons area (Figure 4c) and interpreted as spatter cones at the tops of magmatic dikes. Locally the dome-like hills are interconnected by linear ridges (black-and-white arrow in Figure 4b) and several ridges that are significantly more rectilinear than normal wrinkle ridges are observed without connection to the chains of hills (Figure 4d). Similar linear ridges have been described by Head et al. [2006] and Shean et al. [2005] in the crater Huygens and Pavonis Mons areas (Figures 4e and 4f) and interpreted as the exhumed tops of magmatic dikes.

3. Discussion

Our observations of the western and eastern flanks of Olympus Mons support the traditional interpretation of this mountain as a very large basaltic shield volcano [e.g., Carr, 1973; Greeley and Spudis, 1981; Morris and Tanaka, 1994]. On the western flank we have also found evidence of involvement of dust-and-ice airborne deposits in the accumulation of the Olympus Mons construct. These deposits are partly seen as mesas composed of prominently layered material, which when in contact with lava flows, shows evidence of collapse [Basilevsky et al., 2005].

The mesa on the eastern-flank and the adjacent hills do not show such layering. This, however, could be due to masking by the dust mantle. The observation that the eastern-flank mesa material does not show evidence of collapse when in contact with lava flows, suggests that ice, if present, is not a significant component here. The absence of vast glacier-type features in the east-flank plains also suggests a smaller (if any) involvement of ice deposition in the geological processes here.

A significant part of channels of the east-flank plains show morphologic similarity to large-scale outflow channels. The latter are traditionally considered to be the result of large-scale water erosion [Baker, 1982; Carr, 1996]. Recently, this interpretation has been challenged by the suggestion that highly fluid lavas could have cut the channels [Leverington, 2004]. In the study area we do see evidence that some “simple” channels were filled with lava and perhaps cut by lava, whose flows we see as flanking the channel (Figure 2a).

The majority of the channels of the study area, however, show well developed streamlined islands and terraced slopes (Figures 2b–2d), suggesting a leading role of water erosion. Such features are much less prominent in lava channels of the Moon and Venus (see summary by Baker et al., 1995).

Figure 3. Section of the channel network uplifted by wrinkle ridging. MOC image M03-03753. Small white arrow – streamlined islands; large white arrows – the deduced flow direction; black arrows – wrinkle ridges.

Figure 4. Chains of volcanic domes (a and b) east of Olympus Mons (white arrows) and (c) on Arsia Mons and linear (white arrows) and wrinkle (black) ridges (d) east of Olympus Mons and (e and f) NE of crater Huygens, all as surface expressions of dikes. Figures 4a and 4d are HRSC images; Figures 4b and 4c are MOC images M22-01909 and S07-01314; Figure 4e is THEMIS image I08224016; and Figure 4f is MOC image E02-01479. Figure 4b is the outlined area in Figure 4a, and Figure 4f is the outlined area in Figure 4e.
et al. [1992]). Mouginis-Mark [1990], who first described the channels east of Olympus Mons, favored the hypothesis that they were water cut. Similar considerations has been recently published for the Aatabas Vallis channels, resembling the channels studied by us [e.g., Burr et al., 2002; Plescia, 2003; Head et al., 2003]. So we believe that the majority of channels have been cut by water released due to dike emplacement, cracking of the cryosphere, and flow of deep groundwater through the crack [Head et al., 2003].

[14] Wrinkle ridges on Mars are typical for Hesperian plains [e.g., Mueller and Golombek, 2004] while in the study area they were forming toward the end of the Amazonian period. This compressional deformation could be due to the load of the Olympus Mons construct [e.g., McGovern and Solomon, 1993].

[15] Recent dike emplacement in the east-flank plains could be related to the activity of the Olympus volcano, whose latest episodes were interpreted to have been very recent [Neukum et al., 2004]. But because only part of the features interpreted to be dikes are radial to the volcano, the dike-forming magmas could also come from another close-locally-sourced area, as appears to be the case for the recent Arsia eruptions [Head et al., 2005].

[16] An important conclusion of this work is finding a very young age for several geologic processes. The key evidence for this are crater counts on the channel floor. Although the crater-count areas are relatively small, the numbers of craters counted in three independent counts on the HRSC and two MOC images were not small: 115, 130 and 180. The data points fit well the isochrons (see the plots in Figure 1). If these areas are contaminated by secondary craters, an issue now actively discussed [e.g., McEwen et al., 2005], the surface would be even younger. So we believe that in these given areas the effects of possible secondary craters are minor and thus, these geologic processes operated at the very latest part of the Amazonian period.

4. Conclusion

[17] Our observations and analysis on the eastern flank of the Olympus Mons provide evidence of a very recent suite of fluvial (channel networks), tectonic (wrinkle ridges and troughs), and volcanic (lava flows and dikes) processes. Their youth is interesting from the point of view of the origin of geologic activity in the history of Mars. The extremely long duration of the Olympus Mons volcanic activity (since 3.9 Gyr until the very recent [Hartmann and Neukum, 2001; Neukum et al., 2004]) implies correspondingly long potential hydrothermal activity, and this may provide the basis for this area to be a candidate long-duration martian life habitat.

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References


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