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The volcanic history of Olympus Mons from paleo-topography and flexural modeling

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A B S T R A C T

Paleotopography and flexural modeling are here used to constrain the formation history and eruption rates of Olympus Mons, the tallest shield volcano on Mars. The timing of the initiation of significant edifice construction is constrained using lava flows whose paths deviate significantly from the down-slope direction of the present-day flexural trough, and thus are classified as topographically discordant. Flexural models are used to place limits on the fraction of Olympus Mons that could have been present at the time of emplacement of one strongly discordant flow. Comparison of the predicted flexural response with the paleotopography indicates that no more than 29–51% of the volume of Olympus Mons could have been present at the time the discordant flow was emplaced. The end of the primary edifice construction stage is constrained by the formation of the aureole deposits, which are inferred to post-date the bulk of the volcano. The ages of $3.67^{+0.05}_{-0.10}$ Ga for the discordant flow and $2.54^{+0.55}_{-0.69}$ Ga for the aureole deposit span the period during which the majority of Olympus Mons formed, a period of approximately $1.13^{+0.74}_{-0.65}$ Gyr. The resulting eruption rate of 0.003–0.015 km^3/yr is similar to that observed in terrestrial hot-spot volcanism, supporting a similar geodynamic mechanism driving shield-forming volcanism on Earth and Mars. After this period, the rate of volcanic resurfacing dropped off considerably, but low levels of volcanic activity have been maintained through the last several hundred million years.

1. Introduction

Olympus Mons is the largest known shield volcano in the Solar System, standing an average of 21 km above the Martian datum and up to 24 km above the surrounding plains. Olympus Mons is located to the northwest of the Tharsis rise and the somewhat smaller Tharsis Montes shields. As the largest single volcano on Mars, the volcanic history of Olympus Mons has important implications for the geodynamic history of Tharsis and Mars as a whole. Previous studies have shown that the age for the majority of the volcanic surface is ~200 Ma (Basilevsky et al., 2006; Neukum et al., 2004; Robbins et al., 2011; Werner, 2009). However, the ages of isolated exposures of the surface date back to the Noachian and late Hesperian (Neukum et al., 2004). Although this suggests a long history of active volcanism, the specific volcanic history of Olympus Mons is difficult to work out. The fundamental problem is that crater retention ages date only the surface of the edifice, which is dominated by the youngest flows and may have little bearing on the age of the bulk of Olympus Mons.

In this study, a combination of paleo-topography, flexural modeling and crater retention ages are used to investigate the volcanic history of Olympus Mons. To constrain the onset of volcanic loading, we focus on the prominent flexural trough surrounding the edifice, resulting from the deformation of the lithosphere by the volcanic load (Fig. 1). In Section 2, we identify lava flows on the outer margins of the flexural trough that deviate from the modern down-slope direction and thus pre-date the flexural trough. Because these topographically discordant flows formed prior to the topography of the flexural trough they must predate the bulk of the edifice volume. In Section 3, thin-shell spherical harmonic flexural models are used to evaluate what fraction of the edifice volume would have been needed to redirect one strongly discordant flow.

To constrain the end of the main edifice-construction phase, we use the aureole deposits that are thought to have formed when Olympus was similar to its present-day size (McGovern et al., 2004a). The ages of the topographically discordant lava flow and the aureole deposits thus bracket the primary construction period of Olympus Mons. Section 4 uses crater size-frequency distributions to estimate the ages of these features. Using these constraints it is possible to constrain the eruption rate during the time in which the majority of the Olympus edifice formed and compare this with terrestrial volcanoes.

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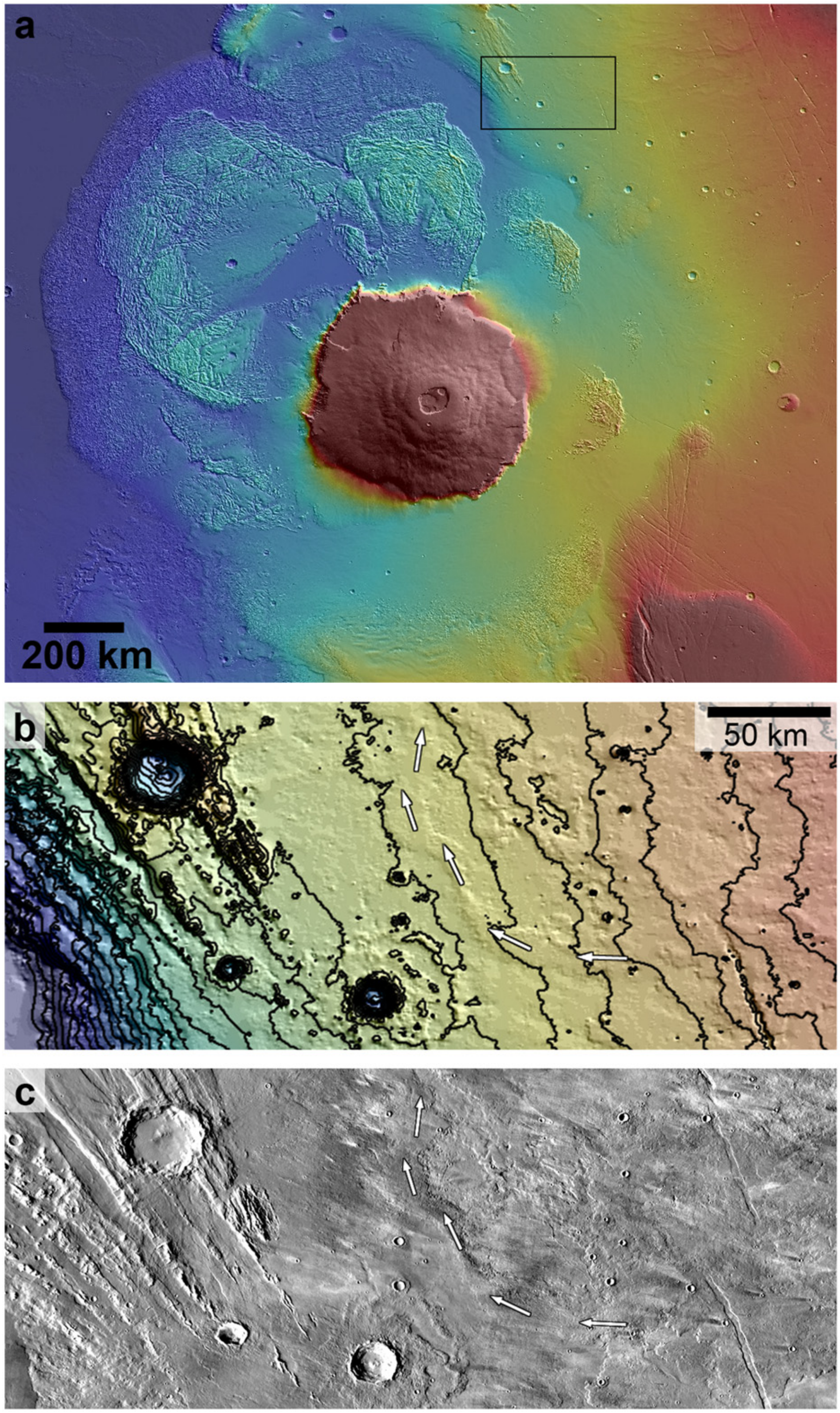

Fig. 1. (a) MOLA topography (Smith et al., 2001) context map of Olympus Mons and the surrounding flexural trough. (b) MOLA topography and contour map showing the topographically discordant lava flow (arrows). (c) THEMIS daytime infrared image mosaic (Christensen et al., 2001) over the region shown in (b).

2. Paleo-topography analyses from lava flows on the flexural trough

The concept of paleo-topography has been used in terrestrial geodynamics to reconstruct the vertical motions of the lithosphere (e.g., Liu and Gurnis, 2010), but has seen less use in planetary applications (Phillips et al., 2001). Our paleotopography reconstructions are predicated on the fact that fluids (e.g., lava) flow along the path of the steepest descent. Thus, the down-flow direction of a lava flow should match the down-slope direction at the time of its formation. Olympus Mons is surrounded by a large flexural trough that has been partially infilled by concurrent volcanic eruptions (Fig. 1a). We surveyed the inward-facing flanks of the flexural trough in Mars Orbiter Laser Altimeter (MOLA) topography (Smith et al., 2001) to identify topographically discordant flows whose paths deviate significantly from the down-slope direction. An analysis of six