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# Rheologies and ages of lava flows on Elysium Mons, Mars

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ABSTRACT

We present results of our study of the rheologies and ages of lava flows in the Elysium Mons region of Mars. Previous studies have shown that the geometric dimensions of lava flows reflect rheological properties such as yield strength, effusion rate and viscosity. In this study the rheological properties of lava flows in the Elysium Mons region were determined and compared to the rheologies of the Ascraeus Mons lava flows. We also derived new crater size-frequency distribution measurements (CSFDs) for the Elysium lava flows to identify possible changes in the rheological properties with time. In addition, possible changes in the rheological properties with the distance from the caldera of Elysium Mons were analyzed.

In total, 35 lava flows on and around Elysium Mons were mapped, and divided into three groups, lava flows on the flanks of Elysium Mons, in the plains between the three volcanoes Elysium Mons, Hecates and Albor Tholus and lava flows south of Albor Tholus. The rheological properties of 32 of these flows could be determined. Based on our morphometric measurements of each individual lava flow, estimates for the yield strengths, effusion rates, viscosities, and eruption duration of the studied lava flows were made. The yield strengths of the investigated lava flows range from $\sim 3.8 \times 10^2$ Pa to $\sim 1.5 \times 10^4$ Pa, with an average of $\sim 3.0 \times 10^3$ Pa. These yield strengths are in good agreement with estimates for terrestrial basaltic lava flows. The effusion rates are on average $\sim 747$ m$^3$ s$^{-1}$, ranging from $\sim 99$ to 4450 m$^3$ s$^{-1}$. The viscosities are on average $\sim 4.1 \times 10^6$ Pa s, with a range of $1.2 \times 10^5$ Pa s to $3.1 \times 10^7$ Pa s. The eruption durations of the flows were calculated to be between 6 and 183 days, with an average of $\sim 51$ days. The determined rheological properties are generally very similar to those of other volcanic regions on Mars, such as on Ascraeus Mons in the Tharsis region. Calculated yield strengths and viscosities point to a basaltic/andesitic composition of the lava flows, similar to basaltic or andesitic a'a lava flows on Earth.

Absolute model ages of all 35 lava flows on Elysium Mons were derived from crater size-frequency distribution measurements (CSFD). The derived model ages show a wide variation from about 632 Ma to 3460 Ma. Crater size-frequency distribution measurements of the Elysium Mons caldera show an age of $\sim 1640$ Ma, which is consistent with the resurfacing age of Werner (2009). Significant changes of the rheologies with time could not be observed. Similarly, we did not observe systematic changes in ages with increasing distances of lava flows from the Elysium Mons caldera.



## 1. Introduction

### 1.1. Geological context

The Elysium Mons region is the second largest volcanic region on Mars and contains three volcanoes: Hecates Tholus in the north, Elysium Mons in the center and Albor Tholus in the south (Fig. 1). The Elysium Mons region is located in the northern lowlands between 15° and 35° northern latitude and 135° and 155° eastern longitude. The entire region is characterized by a broad asymmetric topography, of which Elysium Mons forms an essential part and contains one of the youngest volcanic surfaces on Mars (Plescia, 2007).

With a summit elevation of about 14 km and a volume of $20 \times 10^{13}$ m$^3$, Elysium Mons is the largest volcano of the three named above (Plescia, 2007). With elevations of 4.1 km of Albor Tholus and 4.8 km of Hecates Tholus, the other two volcanoes are much lower in elevation (Plescia, 2007).

The caldera of Elysium Mons has a diameter of about 14 km and does not show lava flows starting directly at the caldera like, for example, Ascraeus Mons. However, the western part of the caldera shows a significant scarp of about 400 m, whereas the eastern flank shows evidence of a broad flooding event caused by overflowing lavas from the caldera. These lavas cover nearly the whole eastern flank, but individual lava flows could not be recognized. This has also been observed by Plescia (2007) and is shown in Fig. 2.

The flanks of Elysium Mons show numerous lava flows changing in size and shape, some of them have been mapped during this investigation (Fig. 2). The flanks of Albor Tholus have a radial,

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hummocky morphology (Plescia, 2007). This volcano has two calderas, a small one at the northern margin and a larger one in the south. With depths of ~5.9–7.5 km for the large caldera and depths of ~6–6.5 km for the smaller caldera, both calderas are very deep in contrast to the caldera of Elysium Mons (Plescia, 2007). While Elysium Mons has only one caldera, Hecates Tholus shows a much more complex summit. It consists of four calderas varying in size and getting younger to the south (Plescia, 2007). Hecates Tholus also shows evidence of an explosive eruption on the northwestern flank that occurred ~350 Ma ago (Mouginis-Mark et al., 1982; Hauber et al., 2005).

Morphologically clearly defined lava flows were observed on Elysium Mons and in the plains between Albor and Hecates Tholus (Plescia, 2007).

Tectonic deformation seems to be very rare. Plescia (2001) identified only some concentric graben and wrinkle ridges near the caldera of Elysium Mons and morphological evidence of a thrust fault dipping toward the summit. Similarly, the other two volcanoes show concentric graben-like structures, for example, on the southern flank of Albor Tholus. This tectonic activity might be related to the rise of the whole region during volcanically active phases (Plescia, 2001). The so-formed bulge presumably is the result of a large mantle plume, located directly underneath the entire region (e.g., Kiefer and Hager, 1989). An analogue example on Earth is the hot spot below Hawaii. However, in contrast to Earth, Mars has no plate tectonics, so the hot spot does not move with respect to the surface. Another example for this kind of hot spot volcanism is the Tharsis Region, which is also thought to have formed by a similar, but even larger mantle plume (e.g., Kiefer and Hager, 1989). In addition, Pedersen et al. (2010) observed hundreds of narrow, linear ridge segments in the transition zone between the Elysium rise and the Utopia basin north-east of Hecates Tholus, which are interpreted to be dikes and dike swarms related to the volcanic activity of the Elysium Mons region.

### 1.2. Motivation

The rheological properties of the lava flows of Elysium Mons are not well known. Although there have been several studies on lava flows in Elysium Planitia and around the Elysium Montes (e.g., Mouginis-Mark et al., 1984; Mouginis-Mark and Yoshioka, 1998; Plescia, 1990; Glaze et al., 2003; Glaze and Baloga, 1998, 2007; Vaucher et al., 2009; Hurwitz et al., 2010), there are no studies of lava flows directly located on the flanks of Elysium Mons and in the plains between the three volcanoes. In the past such studies have been hindered by the lack of high resolution images of this region, because the lava flows on the flanks of Elysium Mons are much smaller than the extensive flows in Elysium Planitia. Most of the previous studies were based on Mariner and Viking images with spatial resolutions of several tens of meters. With HRSC and CTX images that cover large areas of Mars, we now are able to map and measure such lava flows in great detail at 5–25 m/pixel spatial resolution.

These high resolution images also allow us to perform crater size-frequency distribution (CSFD) measurements of the lava flows in the Elysium Mons region to determine their surface model ages. Our CSFD measurements complement previous age determinations of lava flows in Elysium Planitia by Hartmann and Berman (2000). To our knowledge there are no published ages for individual lava flows on the flanks of Elysium Mons.

The combination of the surface ages with the rheologies and location of the lava flows on Elysium Mons allows us to investigate changes in the rheologies over space and time, which has not been studied before.

With our study we address the following questions: (1) What are the rheological properties of the lava flows on Elysium Mons? (2) Is there a difference in the rheologies to other volcanic regions on Mars and elsewhere in the Solar System? (3) Is there a change of the rheological properties over time and distance to the caldera of

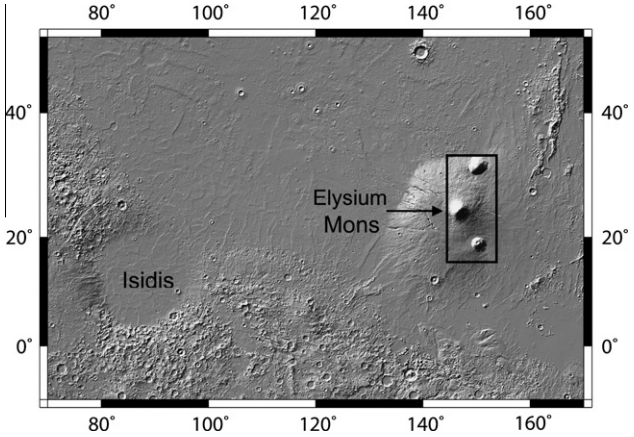


**Fig. 1.** Context map of the Elysium Mons region. The black box outlines the study area.

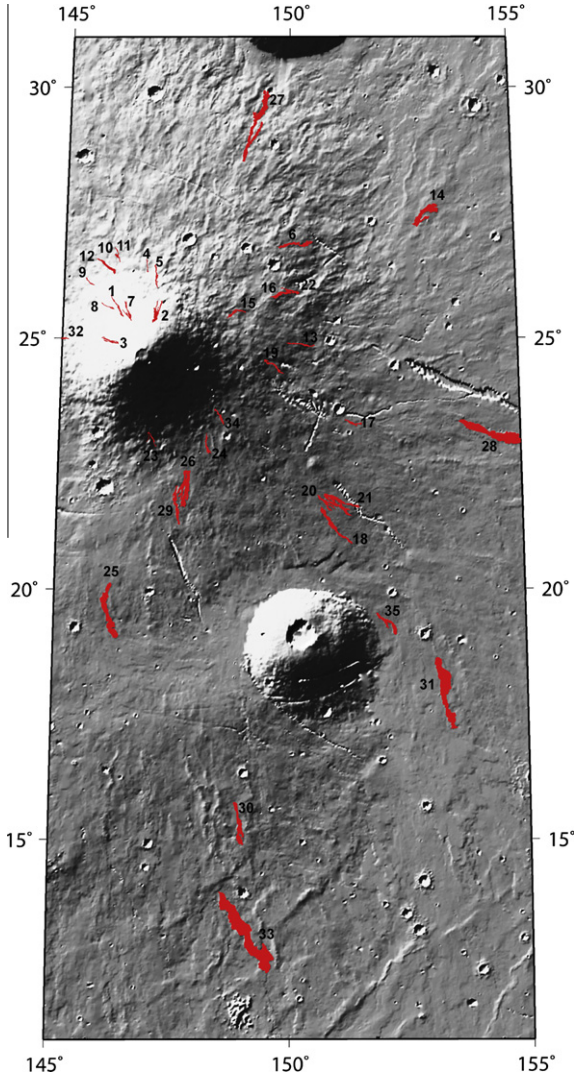


**Fig. 2.** MOLA shaded relief map of the studied lava flows (red) in the Elysium Mons region.