

RHEOLOGY AND MODEL AGES OF LAVA FLOWS ON ALBA PATERA, MARS S. Wiedeking¹, H. Hiesinger¹, A. Lentz¹, J. H. Pasckert¹, J. Raack¹, D. Reiss, N. Schmedemann¹, ¹Institute for Planetology, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Strasse 10, Münster 48149, Germany, stefan.wiedeking@uni-muenster.de

Introduction: We investigated 29 lava flows on the flanks of Alba Patera (20–50°N, 90–130°W) regarding their rheological properties and absolute model ages (AMAs). In difference to previous studies [e.g., 1], higher resolution images and topography data enabled us to not only study flows in greater detail, but also to include small lava flows. The calculated rheological properties have been compared to terrestrial, martian, lunar, and venusian volcanic features. We also performed a correlation analysis to investigate possible changes in the rheological properties of the lava flows with varying distances to the volcano's center and AMAs. The investigations are based on the methodology of previous publications, which have shown that the rheology of lava flows, such as the yield strength, viscosity, effusion rate and eruption duration can be derived by remotely sensed dimension measurements [e.g., 2, 3]. In these previous studies some fundamental assumptions were made: 1) lava flows behave as Bingham plastic fluids, 2) lava flows in a laminar fashion, 3) lava flows did not inflate, 4) the average density ρ of a martian lava flow is 2,500 kg/m³, 5) the Graetz number Gz has a value of 300, and 6) the thermal diffusivity κ is $3 \times 10^{-7} \text{ m}^2 \text{ s}^{-1}$.

The calculations made in this study are based on images obtained by the Context Camera (CTX), as well as data from the Mars Orbiter Laser Altimeter (MOLA). Data from the High Resolution Imaging Science Experiment (HiRISE) could not be utilized, because only a small percentage of the investigated area is covered by HiRISE images. AMAs have been derived by performing crater size-frequency distribution (CSFD) measurements on CTX images. To calculate AMAs from the CSFD, the production function of Ivanov [4] and the chronology function of Hartman and Neukum [5] were used. We performed a Poisson timing analysis as described by Michael et al. [6].

Rheological properties: The investigated lava flows are located in distances between 65 km and 346 km to the volcanic center, at about 37–46° N and 109–116° W. 11 of the lava flows were cut by graben of Alba Fossae or Tantalus Fossae. The average yield strength calculated for the 29 lava flows is $2.8 \times 10^3 \text{ Pa}$. Effusion rates are $636 \text{ m}^3 \text{ s}^{-1}$ on average. The obtained viscosities are on the order of $1.1 \times 10^7 \text{ Pa s}$ and the lavas have erupted over periods of 68 days on average. Significant correlations between the rheological properties of the lava flows and

their distances to Alba Patera's center have not been found.

Table 1: Rheological properties calculated in this study. YS is the yield strength, ER the effusion rate, VI the viscosity, and ED the eruption duration.

Flow Number	YS (Pa)	ER (m ³ s ⁻¹)	VI (Pa s)	ED (days)
1	1,29x10 ³	1,32x10 ³	1,37x10 ⁶	73
2	2,19x10 ³	1,53x10 ³	2,53x10 ⁶	97
3	1,48x10 ³	1,14x10 ³	6,45x10 ⁵	34
4	7,59x10 ²	8,19x10 ²	1,76x10 ⁶	79
5	5,86x10 ³	2,32x10 ²	3,51x10 ⁷	155
6	9,18x10 ³	2,99x10 ²	7,19x10 ⁷	223
7	1,74x10 ³	1,44x10 ²	3,28x10 ⁶	33
8	1,37x10 ³	5,12x10 ²	5,43x10 ⁶	86
9	1,69x10 ³	5,30x10 ¹	3,15x10 ⁶	21
10	5,52x10 ³	5,71x10 ¹	1,00x10 ⁸	136
11	4,01x10 ²	1,34x10 ³	2,91x10 ⁵	36
12	1,28x10 ³	3,07x10 ²	1,94x10 ⁶	55
13	9,63x10 ³	3,05x10 ²	2,14x10 ⁷	99
14	1,60x10 ³	4,58x10 ¹	2,84x10 ⁶	19
15	1,38x10 ³	1,02x10 ³	1,28x10 ⁵	15
16	9,58x10 ³	5,52x10 ²	8,13x10 ⁶	70
17	2,45x10 ³	1,16x10 ³	1,76x10 ⁶	65
18	2,90x10 ³	2,45x10 ²	1,52x10 ⁷	101
19	3,59x10 ³	9,90x10 ²	9,53x10 ⁶	160
20	2,32x10 ³	4,31x10 ²	1,97x10 ⁶	47
21	6,94x10 ²	8,40x10 ²	5,75x10 ⁵	39
22	1,54x10 ³	5,31x10 ²	5,15x10 ⁶	95
23	1,37x10 ³	1,06x10 ³	8,91x10 ⁵	46
24	1,26x10 ³	5,03x10 ²	1,30x10 ⁵	12
25	2,38x10 ³	7,32x10 ²	1,62x10 ⁶	50
26	1,33x10 ³	1,31x10 ²	3,29x10 ⁵	11
27	1,76x10 ³	2,91x10 ²	7,25x10 ⁵	19
28	1,15x10 ³	1,53x10 ³	1,91x10 ⁵	30
29	3,54x10 ³	3,37x10 ²	5,01x10 ⁶	71
Ø	2,80x10 ³	6,36x10 ²	1,05x10 ⁷	68
SD	2,62x10 ³	4,66x10 ²	2,26x10 ⁷	51

Terrestrial and extraterrestrial analogues: The rheological properties derived in this study are similar to those of other volcanic regions on Mars, especially Elysium Mons at Elysium Planitia [3]. The values are within the range of rheological properties calculated

for terrestrial lavas, although the effusion rates of Alba Patera lava flows can be larger. The derived properties vary from values proposed for lava on the Moon [e.g., 10, 11]. They are also smaller than rheologies derived for Venus [12]. It is, however, important to consider that the values derived for Venus [12] are based on festoon deposits, which are different in morphology and likely composition. Based on the derived yield strengths and viscosities, the composition of the studied martian lava flows can be identified as basaltic/basaltic-andesitic. Our findings indicate a composition that is analogue to terrestrial basaltic or andesitic a' lava flows [e.g., 13, 14].

Table 2: The rheological properties of lava on different planetary bodies. YS is the yield strength, ER the effusion rate, and VI the viscosity.

Location	YS (Pa)	ER (m ³ s ⁻¹)	VI (Pa s)
Mars ^{a-d}	10 ² –10 ⁴	23–10 ⁴	10 ⁴ –10 ⁸
Alba Patera ^a	4.01x10 ² – 2.8x10 ⁴	46–5800	1.28x10 ⁵ – 1.0x10 ⁸
Elysium Mons ^b	3.0x10 ³	99–4500	1.2x10 ⁵ – 3.1x10 ⁷
Ascræus Mons ^c	2.1x10 ⁴	23–404	1.8x10 ⁴ – 4.2x10 ⁷
Arsia Mons ^d	2.5x10 ³ – 3.9x10 ³	5.6x10 ³ – 4.3x10 ⁴	9.7x10 ⁵
Earth ^e	10 ² –10 ⁶	1–1044	10 ² –10 ¹³
Moon ^f	10 ² –10 ⁴	6–119	10 ⁸
Venus ^g	10 ⁴ –10 ⁵	100–10 ⁴	10 ⁶ –10 ⁹

* a: This study and [1]; b: [3]; c: [2]; d: [9]; e: [7], [8], [9]; f: [10], [11]; g: [12].

Absolute model ages: AMAs could be derived for 14 of the 29 lava flows, because 15 of the lava flows have either reached equilibrium, or have too few superposed impact craters, making a reliable age determination impossible. Secondary craters have been excluded from the CSFD as well as areas disturbed by graben, because they would falsify the result. The AMAs range from 130±40 Ma (N(1) = 6.13 x 10⁻⁵ km⁻²) for Flow 26 to 810±60 Ma (N(1) = 3.96 x 10⁻⁴ km⁻²) for Flow 15. The results indicate a late volcanic activity. Although the surface age of Alba Patera is thought to be of a late Hesperian to early Amazonian age [15], recent volcanic activity on Mars is not uncommon. Studies on lava flows at Elysium Planitia, for example, have shown AMAs ranging from 2 to 250 Ma [16]. There are, however, two other factors that might as well contribute to the young model ages derived in this study. One of them are resurfacing events, for which we found visual indicators in the form of alterations on

the margins of various lava flows. An origin for the resurfacing, however, has not been found yet. The margins have also been excluded from the counting area, not only due to the alterations, but also, because the retention of craters is very low on steep surfaces. In the CSFD plots, only one of the lava flows (Flow 18) shows evidence for a resurfacing event, resulting in two possible model ages (330 Ma and 770 Ma). The second factor is the available small counting area. Due to the small size of some of the investigated lava flows, the area available for the CSFD ranged from ~8.2 km² to ~170 km². Hence, the AMAs could also represent the limits of the CSFD measurement technique, although we counteracted this effect by excluding lava flows with less than 10 impact craters with a diameter larger than 100 m. Correlations between the rheological properties or the distance to the volcano's center and the AMAs were not observed.

Conclusion: The calculated rheological properties are consistent with previous studies. Our results contribute to a better understanding of Alba Patera and of the composition of the material erupted by the volcano, which was found to be most likely basaltic/basaltic-andesitic. The AMAs for individual lava flows are much younger than the AMAs proposed for the volcano's surface in past studies [e.g., 15]. They indicate a late volcanic activity of Alba Patera, which is consistent with investigations of lava flows in other volcanic regions on Mars [e.g. 16]. The correlation analysis of the lava flows did not show significant correlations between their rheological properties, AMAs and distances to the volcanic center. While this appears to be reasonable, it must be noted that the analysis might be affected by effects that occur when only small number statistics are available. Hence, the results of the correlation analysis might change, when extending the number of lava flows taken into account.

References: [1] P. Cattermole (1987) *J. Geophys. Res.*, 92, E553-E560 [2] H. Hiesinger et al. (2007) *J. Geophys. Res.*, 112, E05011. [3] J.H. Pasckert et al. (2012) *Icarus*, 219, 443-457. [4] B.A. Ivanov (2001) *Chronol. Evol. Mars*, 96, 87-104. [5] W.K. Hartman and G. Neukum (2001), *Space Sci. Rev.*, 96, 165-194. [6] G. Michael et al. (2016) *Icarus*, 277, 279-285. [7] H.J. Moore (1987) *Volcanism in Hawaii*, 2, 1569-1588. [8] S.K. Rowland and G.P.L. Walker (1990) *Bull. Volcanol.*, 52, 615-628. [9] N.H. Warner and T.K.P. Gregg (2003) *J. Geophys. Res.*, 108 (E10), 5112. [10] H.J. Moore et al. (1978) *Proc. Lunar Planet. Sci. Conf.*, 9th, 3351-3378. [11] L. Wilson and J.W. Head (2003) *J. Geophys. Res.*, 108 (E2), 5012. [12] S.M. McCollay and J.W. Head (2004) *Proc. Lunar Planet Sci. Conf.*, 35th, 1376. [13] H. Pinkerton and L. Wilson (1994) *Bull. Volcanol.*, 56, 108-120. [14] C.R.J. Kilburn (2000) *Encyclopedia of Volcanoes*, 291-305. [15] D.H. Scott and K.L. Tanaka (1986) *USGS Misc. Invest. Series*, Map I-1802-A. [16] J. Vaucher et al. (2009) *Icarus*, 204, 418-442.