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Marius Hills: Morphometry, Rheology, and Mode of Emplacement

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Introduction

Mare domes are smooth low features with gentle convex upward profiles. Isolated domes may be found in almost all maria, but significant concentrations occur in the Hortensius/Milichius/T. Mayer region, Oceanus Procellarum, and Mare Tranquillitatis [1]. The Marius Hills in Oceanus Procellarum represent the lunar region in which domes are most abundant. The surface material of the complex has been assigned to Eratosthenian age [2]. In the Marius Hills, low domes can be found as well as steep-sided features with rough surfaces, resulting from superposed flow lobes and cones, classified as class 7 domes in [3]. Often, steep domes are superimposed on low domes. They are contemporaneous or of younger age [4]. We examine a set of 30 volcanic structures, including domes with different shapes and profiles, in order to study the morphometric properties and the style of volcanism that occurred in the Marius Hills region.

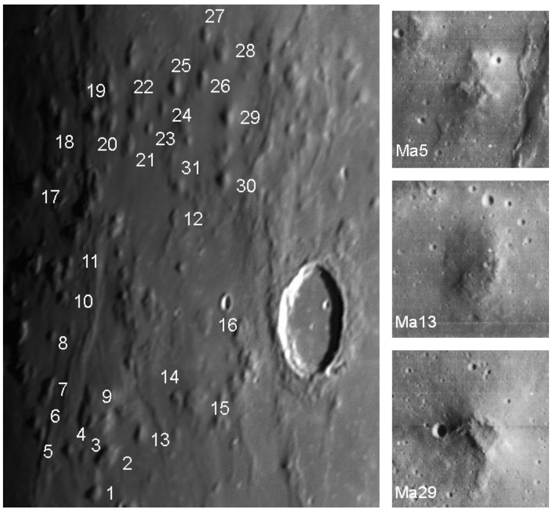

Figure 1: Left: Telescopic CCD image of the Marius Hills region, acquired under oblique illumination on April 18, 2008, at 02:08 UT. Right: Sections of Lunar Orbiter image IV-157-H2. North is to the top and west to the left.

Spectral Properties

Clementine UVVIS data reveal that the surfaces of the examined domes consist of spectrally blue mare lavas with R_{415}/R_{750} ratios, related to TiO_2 content, between 0.62 and 0.68. This broad range indicates the presence of several distinct units in the complex due to eruptions from different source regions [5]. The observed R_{950}/R_{750} ratios around 1.02 imply a weak to moderate mafic absorption and an overall high soil maturity.

Digital Elevation Maps (DEMs), Morphometric Dome Properties

Based on the low-sun telescopic CCD image shown in Fig. 1, we obtained local DEMs of the Marius Hills region based on the combined photoclinometry and shape from shading method described in [6]. It has been shown in [6] that the relative error of the height and slope values amounts to 10% while the relative accuracy of the dome volumes is about 20%. The examined domes are characterised by flank slopes ζ ranging from 2° to 9° and diameters D between 4.5 and 15 km (cf. Table 1). The edifice volumes V span a broad range between 2 and 42 km³. We extend the classification scheme in [6] and assign the non-monogenetic Marius domes to a new class H. The small domes with $D < 6$ km are assigned to subclass H_1. They are morphometrically similar to but spectrally bluer than similar domes of class E_1 situated in the Milichius/T. Mayer region [7]. Domes of subclass H_2 with $D > 6$ km and $\zeta < 5.5°$ morphometrically resemble the steep domes of class B_1 situated north of the crater Hortensius [6] and in Mare Undarum [8], but their irregular shapes also indicate a formation during several effusive episodes. Domes of subclass H_3 have diameters comparable to those of monogenetic class B_1 domes, but their flank slopes are all steeper than 5.5° and reach values of up to 9°. Such extraordinarily steep flank slopes have not been observed for monogenetic mare domes located in other dome fields [6, 7, 8].

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Dome	*Long.*	*Lat.*	*ζ* [°]	*D* [km]	*h* [m]	*V* [km³]	*Cl.*
Ma1	-55.53	9.88	5.7	7.8	390	10.7	H_2
Ma2	-55.26	10.32	5.5	12.1	580	36.6	H_2
Ma3	-55.81	10.32	2.1	6.4	120	1.9	H_2
Ma4	-56.15	10.72	3.9	6.1	210	3.7	H_2
Ma5	-55.96	10.72	3.5	5.9	180	3.4	H_1
Ma6	-56.83	10.58	3.4	6.1	180	3.7	H_2
Ma7	-56.67	11.10	2.9	9.2	230	7.6	H_2
Ma8	-56.61	11.74	3.8	6.4	210	3.0	H_2
Ma9	-55.68	11.04	2.8	8.1	200	7.6	H_2
Ma10	-56.37	12.19	4.3	7.5	280	4.0	H_2
Ma11	-56.60	12.49	4.1	10.9	390	14.8	H_2
Ma12	-53.88	13.13	3.9	6.4	220	4.2	H_2
Ma13	-54.54	10.58	5.3	7.8	360	7.0	H_2
Ma14	-53.73	11.02	2.7	7.5	180	3.8	H_2
Ma15	-53.35	10.99	3.9	14.2	480	42.2	H_2
Ma16	-53.14	11.90	2.2	11.2	220	15.6	H_2
Ma17	-57.44	13.45	3.9	10.4	350	17.0	H_2
Ma18	-56.90	14.22	5.8	7.9	400	10.1	H_3
Ma19	-56.09	14.28	5.6	8.5	420	11.3	H_3
Ma20	-55.70	14.25	3.0	9.7	250	7.6	H_2
Ma21	-55.19	13.04	3.2	8.9	250	9.0	H_2
Ma22	-55.11	14.34	4.2	7.3	270	6.3	H_2
Ma23	-54.73	14.14	5.3	4.5	210	1.9	H_1
Ma24	-54.44	14.39	3.7	5.8	190	3.2	H_1
Ma25	-54.20	14.65	5.8	7.5	380	9.0	H_3
Ma26	-53.60	14.75	8.5	7.1	530	10.4	H_3
Ma27	-53.65	15.26	6.1	6.5	350	7.3	H_3
Ma28	-53.25	15.09	4.2	11.5	420	21.8	H_2
Ma29	-52.97	14.28	9.0	7.2	570	13.1	H_3
Ma30	-52.94	13.53	8.3	7.4	540	13.5	H_3

Table 1: Morphometric dome properties.

Rheologic Properties

The rheologic model developed in [9] and used in [6] to estimate the rheologic properties of monogenetic mare domes cannot be directly applied to the Marius domes as they presumably consist of several superimposed volcanic constructs. For the three example domes Ma5 (subclass H_1), Ma13 (H_2), and Ma29 (H_3) (cf. Fig. 1), we estimated the lava viscosity η, the effusion rate E, and the duration T of the effusion process under the assumption that the volcanic edifice is composed of two layers of maximum thickness $h/2$ (cf. Table 2, with D_u as the diameter of the assumed upper layer inferred from the DEM). The modelled lava viscosities are of the order 10^5, 10^6, and 10^7 Pa s for Ma5, Ma13, and Ma29, respectively, while the effusion rates are of similar magnitude with values between 10 and 50 $m^3 s^{-1}$. Lava effusion occurred over increasingly long periods of time for the domes representing subclasses H_1, H_2, and H_3. The rheologic properties of Ma5, Ma13, and Ma29 are comparable to those of monogenetic domes of the classes B_2 (with flank slopes $\zeta < 2.0°$), B_1–E_1 ($2.0° < \zeta < 4.0°$), and the steepest B_1 domes ($\zeta > 4.0°$), respectively (cf. [7]).

Dome	D_u [km]	η [10^6 Pa s]	E [$m^3 s^{-1}$]	T [years]
Ma5	4.5	0.12 / 0.23	49 / 29	1.4 / 1.4
Ma13	4.2	1.7 / 7.7	51 / 15	3.4 / 3.4
Ma29	5.9	19 / 31	26 / 17	9.7 / 9.6

Table 2: Rheologic properties inferred for the assumed lower and upper layers of the domes Ma5, Ma13, and Ma29.

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