EFFUSIVE LUNAR DOMES NEAR KEPLER AND PICCOLOMINI: MORPHOMETRY AND MODE OF EMPLACEMENT.
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Introduction: Lunar domes are smooth low features similar to low terrestrial shield volcanoes. They were formed during the terminal phases of lunar eruptions and mostly occur in the maria. A few domes have been reported in the highlands, but these are usually difficult to observe because of the brightness and ruggedness of the surrounding terrain. According to [1,2], constructional volcanic features formed during the later stages of volcanism on the Moon, characterised by a decreasing rate of lava extrusion and a comparably low eruption temperature, resulting in the formation of effusive domes. Lunar domes may also form as intrusive structures, commonly interpreted as laccoliths. In this case magma accumulates within the lunar crust, slowly increasing in pressure and causing the crustal rock above it to bow upward [2]. Recent studies about lunar domes are based on the evaluation of their spectrophotometric and morphometric properties, rheologic parameters, and their classification based on the spectra and three-dimensional shapes of the volcanic edifices [3-5]. The Consolidated Lunar Dome Catalogue [6] contains all lunar domes which have been studied in detail by the GLR group and for which accurate morphometric properties could be determined. The catalogue is continuously updated according to ongoing observing and modelling activities. In this contribution we provide an analysis of two effusive domes, located in Oceanus Procellarum to the west of the crater Kepler, and inside Rupes Altai near the crater Piccolomini, respectively.

General description: The first examined dome, named Ke1, is located to the west of Kepler at longitude 39.53° W and latitude 08.88° N, having a diameter of 13.9 km (Figs. 1 and 2). It is apparent in USGS lunar geologic map I-355 of the Kepler region of the Moon. Kepler is the centre of one of the most extended bright ray systems that covers the surrounding mare. Several ridges are aligned roughly north-south and thus radial to the Imbrium basin. An area of relatively thin lavas fails to completely cover hummocky Imbrian basin ejecta. Lunar Orbiter imagery acquired under moderate solar elevation angles does not show the dome clearly but several craterlets on its summit. The second examined dome, Pi1, is located inside Rupes Altai at longitude 28.56° E and latitude 27.46° S (Fig. 1) and has a diameter of 14 km. Pi1 is clearly apparent in the low-sun telescopic CCD images shown in Fig. 1. It is located about 85 km northwest of the crater Piccolomini inside the Nectaris basin, about 30 km closer to its centre than the Altai Scarp. The dome surface appears degraded but taking into account that this is an ancient region (3.83–3.92 Ga), lower relief structures (mare ridges and domes) or plains regions (smaller lava flows) may have been eroded by later impacts.

Spectral properties: Large parts of the mare surface surrounding the dome Ke1 are characterised by basalt lavas of moderate TiO_2 content on which ejecta of the craters Kepler and Copernicus are superimposed (Fig. 3) [7]. The geologic map [8] shows that most basalts of this region are Imbrian mare materials with some units showing characteristics of Eratosthenian mare (Em) material. For the surface around the dome Pi1, Clementine UVVIS imagery reveals a spectrally red appearance, indicating a low TiO_2 content, and a high R_{950}/R_{750} ratio, similar to the nearby highland area (Table 1, Fig. 3).

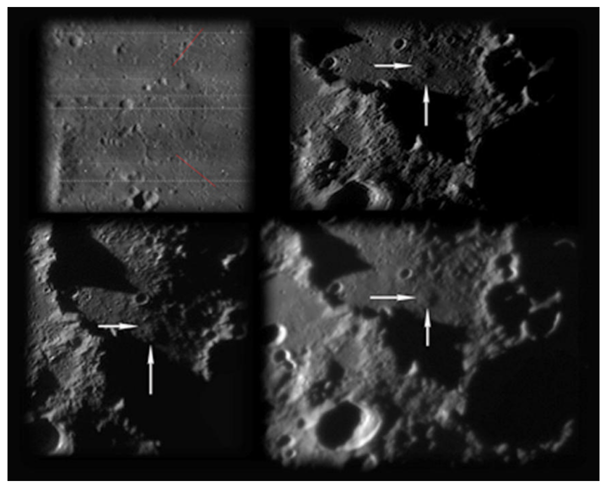

Fig. 1: Lunar Orbiter image of the dome Ke1 (top left) and telescopic CCD images of the dome Pi1 (top right and bottom row). North is to the top and west to the left.

dome	long.	lat.	R_{750}	R_{415}/R_{750}	R_{950}/R_{750}
Ke1	-39.53°	08.88°	0.1399	0.6119	0.9833
Pi1	28.56°	-27.46°	0.1912	0.5920	1.0866

Table 1: Albedo at 750 nm and spectral ratios R_{415}/R_{750} and R_{950}/R_{750} of the examined lunar domes.

Morphometric dome properties: Based on our telescopic CCD images we obtained DEMs of the examined domes by applying the combined photoclinometry and shape from shading method described in [3] (Fig. 4). The flank slope ζ, diameter D, height h, and edifice volume V of the domes were extracted from the DEMs (Table 2). According to [3], Ke1 belongs to class C and is assigned to subclass C_2 due to its spectrally blue appearance. The steeper dome Pi1 belongs to class B_1. It is shown in [3] that the relative error of the height and slope values amounts to 10% while the relative accuracy of the dome volumes is about 20%.

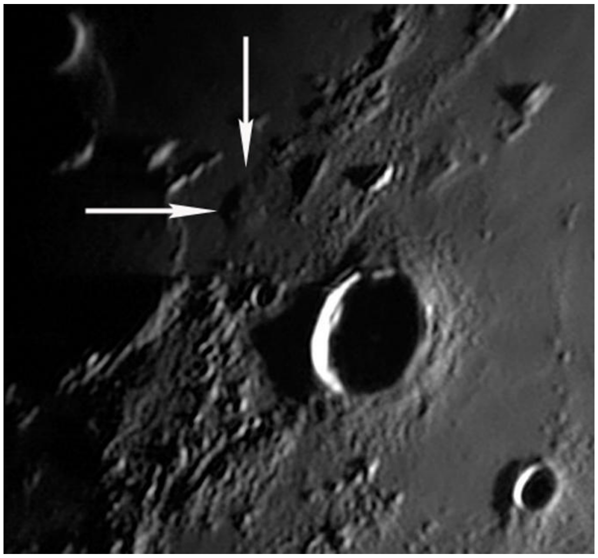

Fig. 2: Telescopic CCD image of the dome Ke1. North is to the top and west to the left.

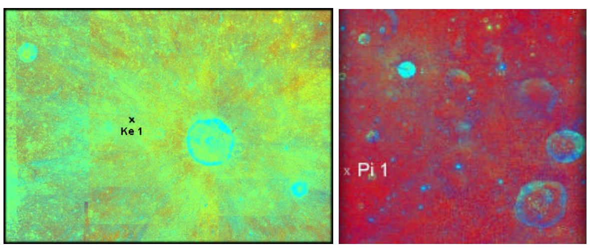

Fig. 3: Clementine colour ratio images of the dome Ke1 (left) and the dome Pi1 (right).

dome	flank slope	D [km]	h [m]	V [km^3]	class	rheol. group
Ke1	1.4°	13.9	170	12.5	C_2	R_1
Pi1	2.9°	14.0	350	17.9	B_1	R_3

Table 2: Morphometric properties of the examined domes.

dome	η [10^6 Pa s]	E [m^3 s^{-1}]	T [years]	U [10^{-6} m s^{-1}]	W [m]	L [km]
Ke1	0.33	299	1.3	44	39	173
Pi1	10	208	2.7	7.9	163	159

Table 3: Rheologic properties and dike geometries inferred for the examined domes.

Rheologic properties: The rheologic model developed in [9], which relies on the morphometric dome properties, yields estimates of the lava viscosity η, the effusion rate E, and the duration T of the effusion process for a monogenetic lava dome (cf. also [3,4]). Using the morphometric values listed in Table 2, we obtained rheologic properties for Ke1 (Table 3) which are comparable to those of the class C_2 domes in the Cauchy region in Mare Tranquillitatis, such as Cauchy τ and ω [3]. The dome Pi1 is characterised by a high lava viscosity of 10^7 Pa s. Its rheologic properties are similar to those of the comparably steep domes north of Hortensius in Mare Insularum, especially the dome H3 [3]. According to the model developed in [10], we estimated the magma rise speed U and the dike geometry (width W and length L) for Ke1 and Pi1 (Table 3). For both domes we found low magma rise speeds of the order 10^{-5} m s^{-1} and dike lengths of more than 150 km. The inferred dike widths amount to 39 m and 163 m for Ke1 and Pi1, respectively. Assuming that the vertical extensions of the dikes are similar to their lengths [11], the magma reservoirs feeding the dome-forming eruptions were located in the upper lunar mantle, well below the crust. With its rheologic properties and dike dimensions, Ke1 is a typical representative of the rheologic group R_1 introduced in [4], while Pi1 belongs to group R_3 due to its high lava viscosity.

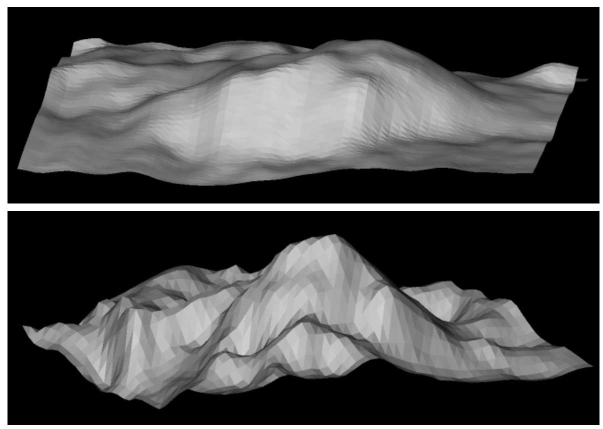

Fig. 4: DEMs of the dome Ke1 (top, view from western direction) and Pi1 (bottom, view from southwestern direction). The vertical axis is 15 times exaggerated.

Conclusion: The domes Ke1 near Kepler and Pi1 near Piccolomini are typical mare domes. Ke1 is morphometrically similar to the class C_2 domes in the Cauchy region and Pi1 to the class B_1 domes north of Hortensius. The spectral and morphometric analysis of Pi1 indicates that it is a mare dome later covered by highland material ejecta. The rheologic modelling results and inferred dike geometries indicate that the domes Ke1 and Pi1 were produced by magmas of comparably high viscosity ascending at low speed from magma reservoirs located at great depth below the lunar crust.

References: [1] Wilhelms (1987) *USGS Prof. Paper 1348*; [2] Head and Gifford (1980), *Moon and Planets 22*; [3] Wöhler et al (2006), *Icarus 183*; [4] Wöhler et al. (2007), *Icarus 189*; [5] Lena et al. (2007), *PSS 55*; [6] Lena and Wöhler (2008), *http://digilander.libero.it/glrgroup/consolidatedlunardomecatalogue.htm*; [7] Hiesinger et al. (2003), *J. Geophys. Res. 108 (E7)*; [8] Wilhelms and McCauley (1971), *USGS, Flagstaff, Arizona*; [9] Wilson and Head (2003), *J. Geophys. Res. 108 (E2)*; [10] Rubin (1993), *Earth Planet. Sci. Lett. 199*; [11] Jackson et al. (1997), *Lunar Planet. Sci. XXVIII*.