NEAR-FAR ASYMMETRY OF MAGMA PRODUCTION OF THE MOON: CONSTRAINTS FROM MARE VOLUMES WITHIN THE FARSIDE IMPACT BASINS.

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Introduction: To understand the thermal conditions of the lunar mantle and its lateral heterogeneity, estimates for volumes of mare basalts are essential. We have investigated the volumes of mare basalts within five farside basins and one nearside basin using topographic and multiband image data obtained by SELENE (Kaguya) [1]. Furthermore, using the high-resolution crustal thickness model [2], we investigated the crustal thickness of major impact basins and its relationship with the mare volumes. Based on these results, we discuss the relationship between the mare volumes and the crustal thickness and differences between magma productions in the farside and nearside mantles.

Estimates of Mare Basalt Volumes: We have investigated five farside basins (Apollo, Ingenii, Poincare, Freundlich-Sharonov, and Mendel-Rydberg) and one nearside basin (Crüger-Sirsalis) [1]. To estimate the volumes of mare basalts in these basins, it is necessary to estimate the thicknesses and surface areas of the mare basalts. The thickness can be estimated using premare craters partially buried by mare basalts [e.g., 3] and/or postmare craters that penetrated completely and postmare craters that failed to penetrate the mare basalts [e.g., 4]. These craters can be distinguished by determining the stratigraphic relationships between the crater interiors, rims, ejecta, and the surrounding basalts based on the mineral composition differences between the mare basalts and the neighboring highland crust.

Relationship with Crustal Thickness: According to models of magma ascent, due to the higher liquidus densities of basaltic magmas compared to that of the anorthositic crust, magmas could have been extruded to the surface preferentially in thin areas of the anorthositic crust [5–7]. Figure 1 shows the relationship between the mare volumes and the minimum crustal thicknesses (hereafter, MCTs) within the mare basins. In addition, the MCTs within the nonmare basins are indicated by arrows in this figure. The mare volumes of the nearside and other farside basins estimated by previous studies are also included in the figure [3, 8–14]. Figure 1 clearly shows that the MCTs within the basins were a dominant factor that determined whether magma erupted at the surface, that is, magma eruption could only occur in basins with small MCT. On the farside, the critical crustal thicknesses (H_c) is estimated to be ~12 km from the farside mare basin with the largest MCT (Ingenii) and the farside non-mare basin with the smallest MCT (Planck). On the nearside, the critical crustal thicknesses for magma eruption might be thicker than that of the farside. The mare basins, Nubium and Tranquillitatis, have a MCT of ~15 km, and the only nearside non-mare basin investigated here is Mutus-Vlacq, which has a MCT of ~20 km. Therefore, the critical crustal thickness of the nearside for magma eruption is H_c = 15–20 km.

Process of Magma Eruption on the Moon: Based on geological and physical observations, various models of the ascent and eruption of basaltic magma on the Moon have been proposed by previous studies [e.g. 5–7]. These models focus on how magmas ascended through the lower density anorthositic crust and erupted at the surface. According to Head and Wilson [6], magmas produced by partial melting of mantle rocks ascend through the mantle as a diaper and are trapped at the base of the crust because magmas have higher densities than the anorthositic crust, and magma-filled cracks (dikes) caused by excess pressure are propagated toward the surface.

Hereafter, we consider the simple model as follows: (1) a diapir ascending through the mantle is trapped at the base of the crust, (2) the dike formation and magma extrusion occur when the positive buoyancy of the diaper at the crust-mantle boundary becomes greater than the negative buoyancy of dike and the dike propagates toward the surface. Assuming that typical values of densities of the crust, magma, and the mantle, how far the dike propagate in the crust depends on the diaper size. Here we consider that the lunar diapers had typical sizes for the nearside and the farside, respectively. The typical size of the diapir (R_d) can be constrained using the balance of the stress intensity factor at the top of the dike (K) and the fracture toughness of the crust (K_c) at the critical crustal thickness (H_c) (Figure 2b). Assuming K_c = 100 [MPa/m^2], the typical sizes of the diapir (R_d) are estimated to be 4.4 km for the neasrside and 3.3 km for the farside.

When the same-sized diaper ascends in an area with thinner crust ($H < H_c$), the diapir reduces in size and magma extrusion occurs (Figure 2a). Considering the balance of K and K_c at the crustal thickness of $H < H_c$, we estimated volume of single eruption as a function of crustal thickness. The observed total volumes in each basin can explained by multiple eruptions of 200–2000 times for the nearside basins and 10–100 times for the farside basins using the estimated volume of single eruption (Figure 1). Using these estimates, the total volumes of magma produced under the eruptible areas with $H < H_c$ are calculated to be 5.0 x 10^6 km^3 for the nearside and 3.3 x 10^4 km^3 for the farside.

Near–Far Dichotomy in Magma Production: The eruptible areas are estimated to be ~1.2 x 10^6 km^2 for the nearside and ~1.4 x 10^5 km^2 for the farside, corresponding to 6.3% and 0.7% of the areas of each hemisphere, respectively. Assuming that the magma productions per surface area in areas of $H > H_c$ were same as those in the eruptible areas, the total volumes of magma production are estimated to be 8.3 x 10^7 km^3 for the nearside mantle and 4.5 x 10^6 km^3 for the farside mantle, corresponding to the near/far ratio of ~18 times.

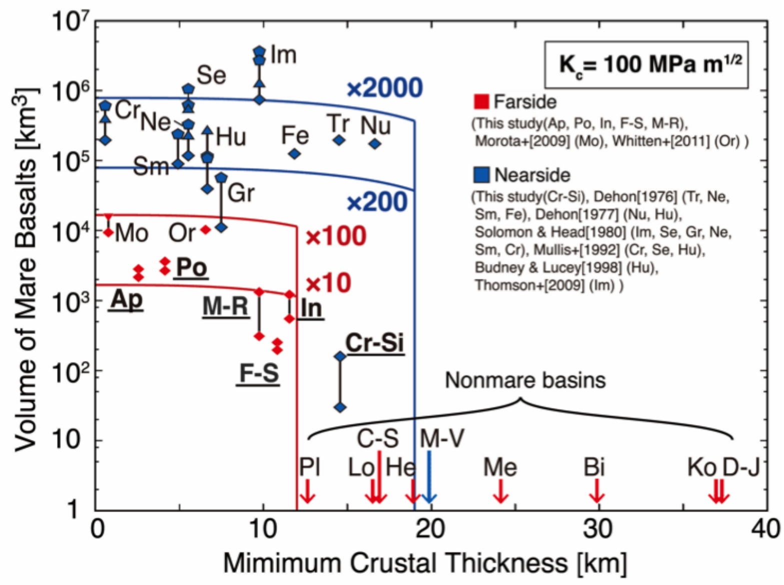

Figure 1. Mare volumes within the basin estimated by this study and previous studies, as a function of the minimum crustal thickness within the basin main-ring (modified from Taguchi et al. [1]). Six basins investigated in this study are underlined. The arrows indicate the minimum crustal thicknesses within the non-mare basins. Techniques used to estimate the thicknesses of mare basalts are indicated by symbol shapes, diamonds: pre-mare/post-mare craters [3, 4], pentagons: crustal thickness and tectonics [8], upper triangle: gravity anomaly [9], and lower triangle: crater density [13].

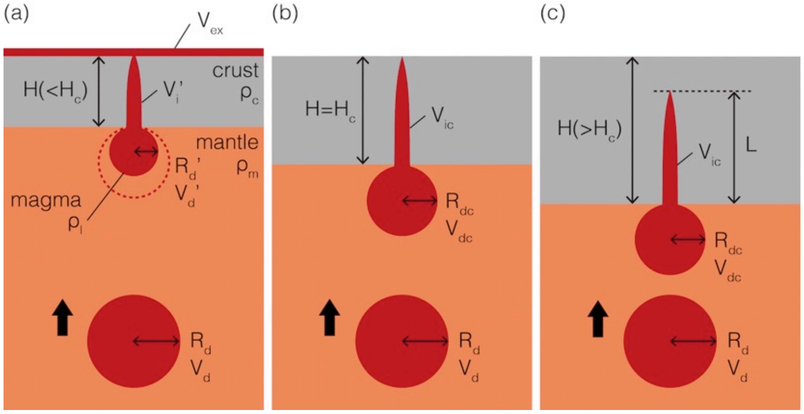

Figure 2. Schematic image of magma ascent and eruption for (a) $H < H_c$, (b) $H = H_c$, (c) $H > H_c$.

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