

GRAVITY CONSTRAINTS ON THE SUBSURFACE STRUCTURE OF THE MARIUS HILLS: A SHARPER VIEW OF THE MAGMATIC PLUMING SYSTEM BASED ON IMPROVED TOPOGRAPHY DATA AND NEW LUNAR DENSITY MEASUREMENTS

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Introduction The Marius Hills in central Oceanus Procellarum are the largest volcanic dome complex on the Moon. The dome field is roughly 200 by 250 km across and contains about 250 volcanic domes and cones and 20 sinuous rilles [1, 2]. The individual domes and cones are up to 25 km across and 500 meters high. Spectral observations show that both the Marius Hills and the surrounding Oceanus Procellarum plains are basaltic, with modest variations in composition [3-5]. On the entire rest of the lunar mare, only about 200 additional volcanic domes are known [6]. The next largest lunar volcanic dome complex is the Rümker Hills, which are about 80 km across and contain 30 low domes [1, 7]. The concentration of volcanos in the Marius Hills is similar to that in the Snake River Plains in Idaho and for a number of large volcanic shield fields on Venus [2]. These observations emphasize the unusual nature of the Marius Hills, which makes it a worthy target for geophysical study.

Previous studies of lunar gravity anomalies have generally emphasized large scale structures, particularly the mascons [8-10]. However, our knowledge of the Moon's gravity and topography is now sufficient to resolve structures on the scale of the Marius Hills. Previous studies have shown that gravity modeling can provide a useful probe of sub-surface volcanic structures such as dike swarms and cumulate chambers on both the Earth and Mars [11-13]. A preliminary version of this study [14] used Clementine LIDAR results for the topography model. The new results presented here make use of the much better Kaguya laser altimeter topography model [15], which permit a 50% increase in model resolution. The model interpretation presented here also benefits from new helium pycnometry measurements of the density and porosity of lunar rocks [16].

Results Figure 1 shows the free-air gravity anomaly for the Marius Hills, as derived from low altitude Doppler tracking of Lunar Prospector [17]. Results are shown up to spherical harmonic degree 110, which is the resolution limit imposed by measurement noise [17]. This corresponds to a resolving half-wavelength of 50 km, sufficient to resolve the major features of this region. The free-air gravity is strongly positive across the entire Marius Hills, with two major lobes whose outlines mirror the volcano distribution. The

northern lobe encompasses most of the dome field, and its maximum amplitude is coincident with the location of the highest concentration of volcanos [2]. The southern lobe is also contained within the boundaries of the volcanic dome field, although the concentration of volcanos in the southern part of the field is much lower than in the northern part of the field.

By assuming that the short-wavelength topography is entirely uncompensated, we can place an upper bound on the contribution of the topography to the gravity anomaly. For the northern gravity lobe, surface topography produces at most about 60% of the observed anomaly. The remainder must be due to high density subsurface material. For the southern lobe, nearly all of the 135 mGal anomaly is due to buried material.

The spatial association between the gravity anomaly and the boundary of the volcanic field suggests that this high density material is related to emplacement of the intrusive volcanic rocks in the form of a sill or batholith. For plausible density contrasts between basalt and the Moon's upper crust, the volcanic intrusives must be several km thick to explain the gravity anomaly. Deposits of such thickness should be obvious in the topography. One way to mask the topographic signature of the batholith would be if it was emplaced in a region of initially low topography. However, it is unlikely that this large volcanic field was emplaced in a topographic basin that coincidentally had the same shape as the Marius Hills. The regional mare plains in Oceanus Procellarum are on average a few hundred meters thick [18], with an upper crust of anorthosite below this. The upper portion of the anorthositic crust is highly porous due to impact brecciation [19]. Large volumes of basalt (texturally gabbro) could have later filled the pore space, producing the observed gravity anomaly.

Assuming that the pore space is homogeneously distributed on a large scale, I model the gravity anomaly with two finite thickness spherical caps (one for each gravity lobe) using the DISKGRAV modeling program [13]. The relevant density difference is between the porous highland crust outside of the Marius Hills and the basalt-filled porosity within the Marius Hills, $\delta\rho = P\rho_{\text{Basalt}}$, where P is the porosity of the highland crust and ρ_{Basalt} is the density of the basalt in-

truded into the crustal porosity. The available measurements of the porosity of upper crustal materials (anorthosite rich rocks and impact basin ejecta breccias) suggest P in the range 15-25% is most likely [16, 19]. I assume $\rho_{\text{Basalt}} = 3100 \text{ kg m}^{-3}$ based on low titanium basalts with low porosity, similar to those found at the Apollo 12 and 15 landing sites [16]. Note that the overall uncertainty in $\delta\rho$ is dominated by the uncertainty in P . With these petrologic assumptions, the gravity observations require a batholith thickness of 4.6-7.7 km for the southern lobe. The total required mass of intruded gabbro is considerably larger than inferred by remote sensing [5]. This demonstrates the power of gravity models for constraining subsurface structure on the Moon.

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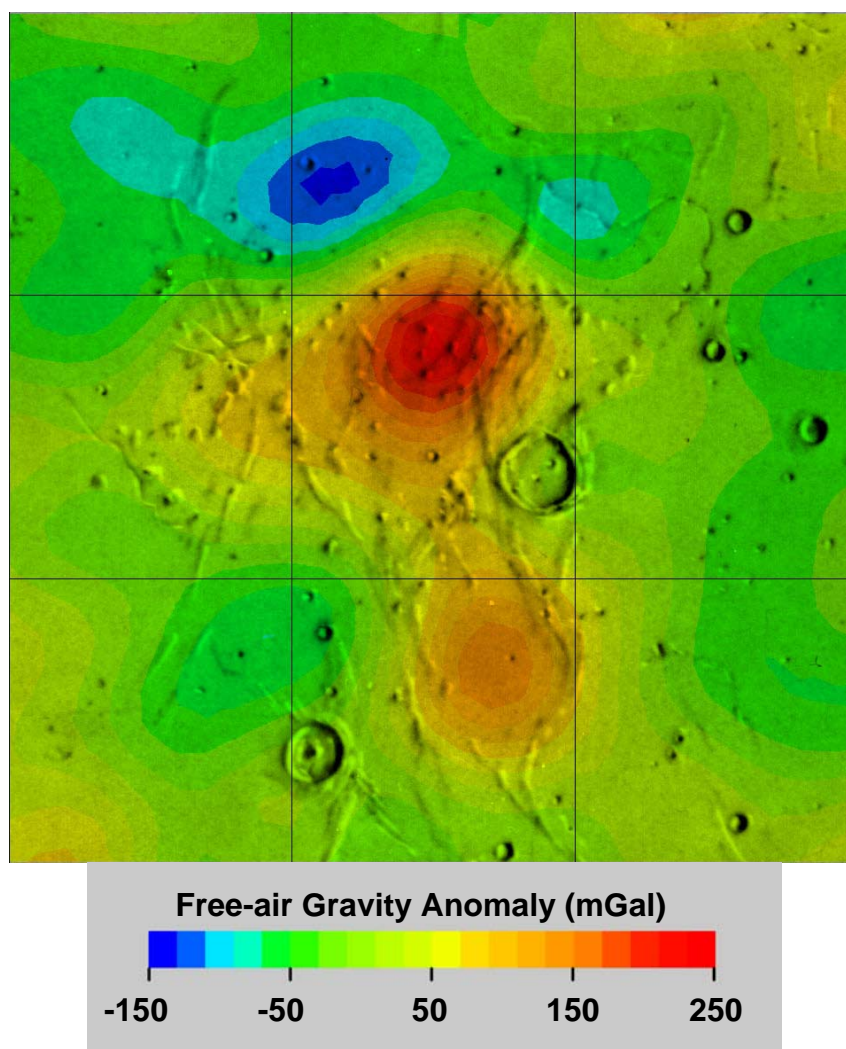


Figure 1. Free-air gravity anomalies in the Marius Hills, $5^{\circ} - 20^{\circ}$ North, $300^{\circ} - 315^{\circ}$ East, overlaid on a shaded-relief map of the region. Simple cylindrical projection. The region is 445 km across at map center (12.5° North).