Gravity constraints on bulk density and igneous intrusion at the Gruithuisen Domes. A. C. North[1] (allie_north1@baylor.edu), P. B. James[1](P_James@baylor.edu), N. L. Wagner[1] and D. P. Moriarty[2,3,4], [1]Department of Geosciences, Baylor University, [2]NASA GSFC, [3]University of Maryland, College Park, [4]Center for Research and Exploration in Space Sciences

Introduction: Silicic volcanism occurs rarely on the Moon, one location being the Gruithuisen Domes. The Gruithuisen Domes are a volcano complex with domes Gamma, Delta, and NW (which is too small to resolve with gravity data). These domes are significant as they are a prospective landing site for NASA's Commercial Lunar Payload Services (CLPS) initiative in 2026. It is generally accepted that this area is silicic in composition [1], although the extent of silicic materials in the subsurface is less constrained. Preliminary analysis of GRAIL data yielded an estimated bulk density of 2150 kg/m^3 for Delta [2]—which implies a highly porous and/or a highly silicic composition—and did not report a corresponding density for Gamma. In this work, we revisit the these domes with new "rank minus one" (RM1) gravity fields and clone fields that allow us to rigorously constrain density.

We consider three different scenarios of silicic volcanism for the Gruithuisen Domes. The first scenario we propose is a veneer of silicic materials formed from fractional crystallization with basaltic materials underneath (Fig. 1a); this scenario would be consistent with the "fractional crystallization" paradigm for the domes' origin [1]. The second scenario we suggest is silicic volcanism with efficient extrusion on top of a dense crust (Fig. 1b). Lastly, we propose silicic volcanism with low density magmas in the crust (Fig. 1c).

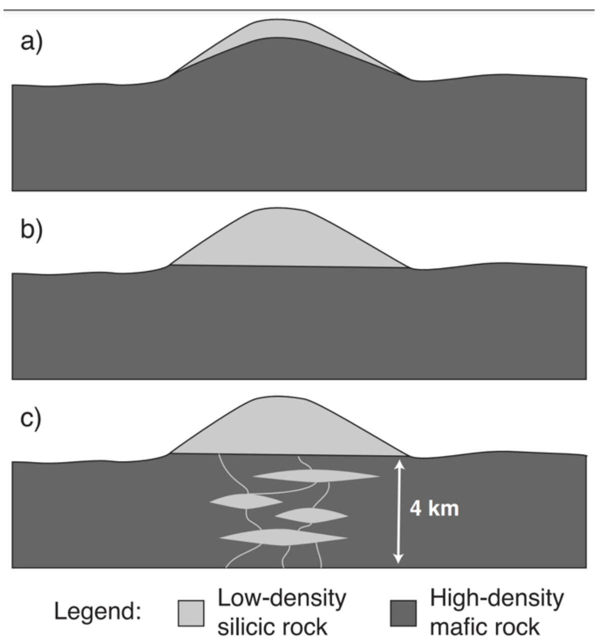

Figure 1: Possible scenarios of silicic volcanism

Methods: We performed gravity analysis in order to calculate the bulk density of the Gruithuisen Gamma dome and the Gruithuisen Delta dome. We first isolated the individual Gamma and Delta domes using masks from topographic contours. We then calculated the expected gravity-from-topography (gft) of unit density inferred from finite-amplitude LOLA data [3]. Our gravity data set is the RM1 field (λ=1) from [4], as well as the corresponding GRGM1200b, both of which came from the GRAIL mission. The use of a RM1 field is a significant advantage to us, as it allows us to maximize the resolution of the gravity analysis without introducing a downward bias in the effective density. Both of these gravity fields come with 100 clone fields (solutions that are allowed by the data covariance matrix). By performing the same density analyses on the full suite of clone fields, we can quantify the influence of the GRAIL data quality on our estimates.

For the density calculation, we applied a spherical harmonic bandpass between degrees 400 and 900. The lower end of that bandpass limits the sensitivity of our analysis to the uppermost ~4 km of the crust under the domes, and the upper end of the bandpass is the practical noise limit of the data. We also used a resolution of 0.05. Next, we referenced both the observed gravity and the predicted gft fields to the approximate radius of the top of the domes (R = 1737 km). Under the assumption of uniform density within our study area, the slope of the weighted linear regression of gravity and gft yields the bulk density. We calculated the mean and standard deviation for these values (see Table 1). We also calculated a plausible upper bound by 1.65·std+mean, which corresponds to a 95% confidence interval that the true bulk density is less than the upper bound.

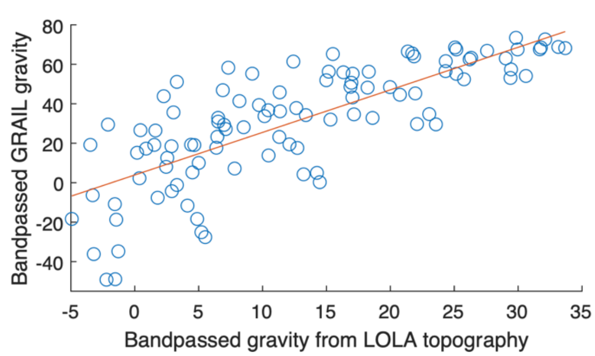

Figure 2: Example scatterplot for bulk density calculation. Scatterplot of RM1 field for Gamma (λ=1).

Results and Discussion: The mean, standard deviation, and plausible upper bounds for bulk density from the clone fields are displayed in Table 1. Density estimates for the GRGM1200B vary considerably due to our choice of a maximum spherical harmonic degree well above the degree strength of the field. By comparison, the RM1 fields have modest standard deviations and allow us to quantify an upper bound on the plausible bulk density of the domes.

Gravity clone fields	**Mean**	**Standard Deviation**	**Upper Bound ($p<0.05$)**
Gamma (GRGM1200B)	1845	746	3076
Delta (GRGM1200B)	1282	918	2796
Gamma (RM1)	**1682**	307	2295
Delta (RM1)	**1738**	359	2330

Table 1: Best-fit densities (units of kg/m^3)

Our results indicate a low bulk density for both Gamma and Delta. With a statistical certainty of $p<0.05$, these domes have densities less than 2295 and 2330 kg/m^3, respectively, which would indicate extremely high silica content and/or extremely high porosity. Our analysis implicitly assumed that silicic materials are confined to the local topographic edifices (e.g., Fig. 1b). However, the low bulk density results suggest that the presence of low-density intruded materials in the upper crust is more likely (e.g., Fig. 1c). Our Bouguer map indicates the gravitational contribution of intrusive bodies.

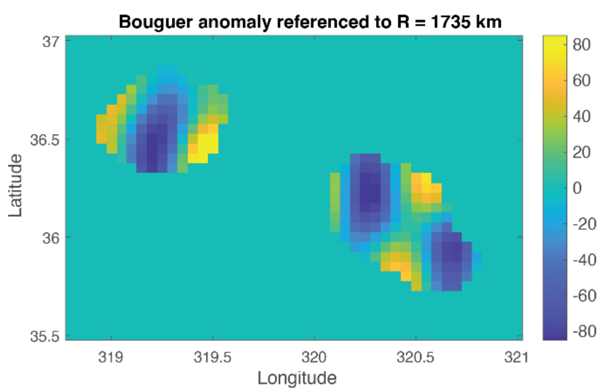

Figure 3: Bouguer Anomaly (mGals) for Gamma and Delta domes.

Bouguer anomaly: After the bulk density estimation, we calculated a Bouguer anomaly. We used a reference radius approximately three kilometers below the Gruithuisen peaks (R = 1735 km) and an assumed density of 2560, based on a dacite composition with a porosity of 6% [5] similar to the Apollo basalt samples.

The resulting Bouguer anomaly (from the band-passed RM1 λ=1 field, masked to the domes) is plotted in Fig. 3. This reveals negative Bouguer anomalies as large as –80 mGal. If these are interpreted as low-density intrusive bodies, the total volumes of these intrusions are equal to 57 km^3 and 244 km^3 for Gamma and Delta, respectively. For comparison, the total extruded volumes of these domes are 290 km^3 and 470 km^3, respectively [6]. Our estimates of intrusive volume may be considered plausible lower bounds for two reasons: (1) our gravity analysis has a shallow sensitivity, and intrusions deeper than ~4 km do not strongly influence the gravity anomaly; (2) we have estimated these volumes under the assumption of silicic intrusions. A larger volume of denser intrusive rock would be needed to reproduce the observed Bouguer anomaly.

Conclusions: The GRAIL data confidently rule out a silicic veneer paradigm (Fig. 1a) at the Gruithuisen domes. The efficient extrusion paradigm (Fig. 1b) would require bulk densities to be $\lesssim$2300 kg/m^3 for both domes, which would imply high silica content and/or high porosity. The preferred model incorporates igneous intrusion (Fig. 1c). The intrusive/extrusive ratios for Gamma and Delta are at least 0.20 and 0.52, respectively, and the total volume of silicic volcanic material associated with these domes is at least 1,081 km^3.

Future Work: We plan to apply this analysis to other instances of silicic volcanism on the lunar surface. We also plan to apply remote sensing characterization to our calculations. We hope the research will serve as insight to future research done on silicic volcanism and aide the scientific work in NASA's CLPS mission.

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References:

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