UNCOMPENSATED MARE BASALTS AS A MODEL FOR LUNAR MASCONS

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Lunar mascons are regions of positive gravity anomalies over topographic basins. First discovered by Doppler tracking of Lunar Orbiter 5 [1], mascons are among the most prominent features in the lunar gravity field. Mascons are found at many of the near-side, circular mare basins, including Crisium, Humorum, Imbrium, Nectaris, Orientale, and Serenitatis. Acquisition of new, high resolution gravity and topography data sets by the Clementine spacecraft [2] allows a new look at the mass distributions that produce these gravity anomalies. We show that a model with uncompensated mare basalt fill and Airy compensated basement (sub-basalt fill) topography can explain the observed mascon gravity anomalies.

Because mascons are gravity highs in regions of topographic lows, they require the existence of excess mass somewhere in the structure of these impact basins. Two fundamentally different models have been proposed. In one, an uncompensated load is located close to the lunar surface [3], for example from the basalt fill found in all mascon basins. In the second, the excess mass occurs as super-isostatic relief at the crust-mantle boundary (or moho) [4]. Subsequent modeling has generally invoked some combination of these two processes [e.g., 5-7].

If super-isostatic uplift of the lunar moho occurs under mascon basins, the most likely cause of this uplift is the basin-forming impact. The physics of large impacts is poorly understood, and such uplift would be an important constraint on impact models. The survival of such uplifts for nearly 4 billion years also imposes stringent mechanical and thermal constraints on lunar models. It is likely that the basin-forming impact raises the temperature of the lithosphere and uppermost mantle beneath the basin by a few hundred Kelvin and that elevated temperatures remain for 10 million years or more after the impact [8]. Because viscosity is an exponential function of temperature, raising the lithosphere's temperature by this amount favors rapid viscous relaxation of moho topography towards isostasy, thus destroying any super-isostatic topography created by the impact. Avoiding this dilemma probably requires either that the Moon's interior was very cold at the time these impact basins formed or that impact energy (or at least the portion that is partitioned into heat) is much less than predicted by existing models.

In contrast, the uncompensated surface load model is mechanically much simpler. There was generally a substantial time-lag between basin formation and basalt emplacement, allowing the lithosphere to cool and thicken prior to basalt emplacement. Based on the locations of graben and wrinkle ridges in the vicinity of mare loads, the elastic lithosphere thickness at the time of basalt emplacement has been estimated to be from 40 to in excess of 75 km for the various mascon basins [9,10]. For the predominant wavelengths of basalt loading, these lithospheric thicknesses are large enough that the load will be largely uncompensated. With a sufficient basalt thickness, this can produce a positive gravity anomaly within a topographic low. Given the relative simplicity of the surface loading model, we think that it is desirable to quantitatively test its potential before invoking the difficult circumstances required to make the moho uplift model work.

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Gravity and topography data sets obtained during the Clementine mission [2] can be used to test mascon models. Topography data were obtained from the Clementine lidar and are available on a 1 by 1 degree grid. The free-air gravity model is based on Doppler tracking of Clementine as well as Apollo and Lunar Orbiter spacecraft. It is expressed as a spherical harmonic degree 70 field, corresponding to a resolution of 5.1 degrees (156 km).

To test the hypothesis that mascons are produced by uncompensated mare basalts, we have performed a series of numerical simulations. We assume that the basement (sub-basalt fill) topography is Airy compensated and that the basalt fill is uncompensated, for the reasons outlined above. Collectively, the basement topography plus the basalt fill sum to the observed topography. The free-air gravity anomaly produced by this mass distribution is determined by integrating over the volume of density anomalies and then filtering to the resolution of observed gravity field.

A variety of methods have been used to constrain the magnitude of the basalt fill in mare basins. Near the margins of the maria, where the basalt is thin, the depths of partially filled craters indicate that the basalt layer is between 0.5 and 1 km thick [11,12]. This method breaks down when the basalt thickness is more than about 1.5 km and is therefore not applicable to the centers of mascon basins. Instead, artificial flooding models of relatively unflooded basins (such as Orientale) have been compared with the basalt distribution in other basins to estimate the basalt thicknesses in these other basins [13]. Based on this technique, detailed basalt thickness models have been proposed [10], with thicknesses of 8.5 to 9 km suggested at the centers of Imbrium and Serenitatis. In contrast, comparison of the depths of flooded and unflooded basins in Clementine topography data suggest maximum basalt thicknesses of only 3 to 4 km at the centers of flooded basins [14].

Results obtained to date indicate that the observed gravity amplitudes at mascon basins can typically be produced by 3 to 4 kilometers of uncompensated basalt fill at the basin center. The required amount of basalt fill is consistent with available constraints on the actual basalt thickness, indicating that this model is a plausible explanation for mascon gravity anomalies and that super-isostatic uplift of the lunar moho may not be required by the gravity observations. This contrasts with another recent study [15,16], in which an estimate of the gravitational effects of the basalt load was removed from the gravity, with the residual gravity downward continued to the base of the crust to estimate the required moho topography. A numerical filter was used to control the amplification of noise in the downward continuation. The conclusion of that study was that substantial super-isostatic moho uplift is required to explain the observed gravity, although recent improvements in that modeling [17] significantly reduces the required amount of super-isostatic uplift.

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