

Gravitational, topographic, librational, compositional & seismic data may all be used to place bounds on models of the internal density structure of the moon. We have considered a sequence of models of increasing complexity in an effort to incorporate all of the above data types. We have concluded that the crust of the moon deviates from isostatic equilibrium, even for the low degree harmonics, and that the lunar interior, below the crust, is inhomogeneous to a greater extent than can be accounted for by self compression.

The simplest model we have considered consists of two concentric spherical shells with a density ρ_0 in the outer shell, a density contrast $\Delta\rho$ across the interface at a normalized radius of $R_i/R_0 = \xi$. We first impose a weak compositional constraint in supposing that $2.7 \leq \rho_0 \leq \rho_0 + \Delta\rho \leq 5.4 \text{ gm cm}^{-3}$, where the lower bound corresponds roughly to anorthosite and the upper bound to a Fe - FeS eutectic composition at the lunar central pressure (~50 kb). (1) These bounds are shown by the dot-dash (-.-) line in figure 1. If, in addition we constrain our model to have the observed mean density $\bar{\rho} = 3.3433 \pm 0.0015$ and disallow density inversions, the envelope of acceptable density profiles is given by the dashed (--) line in Fig. 1. Recent determinations of the gravitational harmonic $C_{20} = (-202.72 \pm 1.48) \times 10^{-6}$ (2) and the librational parameters $\beta = (631.27 \pm 0.03) \times 10^{-6}$ and $\gamma = (227.39 \pm 0.42) \times 10^{-6}$ (3) enables a calculation of the spherically symmetric moment of inertia

$$\frac{I}{MR^2} = \left[\frac{3 + \beta + \gamma - \beta\gamma}{2\beta - \gamma + \beta\gamma} \right] \left[\frac{-2C_{20}}{3} \right] = (391.74 \pm 2.86) \times 10^{-3}$$

When our model is subjected to this constraint, the resulting density bounds are given by the solid line in Fig. 1. The density is thus quite well constrained in the outer 800 km of the moon.

The next step is to allow the model to depart from spherical symmetry in order to match the entire inertial tensor, three moments and three products of inertia, rather than just the average moment. To do this, we include first and second degree spherical harmonics describing the shape of the nearly spherical shells. The 8 harmonics (3 first degree, 5 second degree) of the outer layer are known from the observed topography (4) but the 8 harmonics of the crust-mantle interface must be determined by constraining the inertia tensor of the model to the observed values. The first degree harmonics are also constrained to counter-balance the center-of-figure offset of the outer layer. Such a model has 11 parameters but only 10 constraints. However, we have some a priori knowledge about each of the parameters, and this makes the system effectively over-determined, and we can perform a weighted least-squares inversion.

Two important results follow from this solution. First, the crustal configuration determined is not in isostatic equilibrium. The fact that even the second degree harmonics are non-isostatic has profound implications

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for the thermal & dynamical history of the moon. The second feature of note is that the crustal thickness determined in this way is greater by 30-50% than the mean crustal thickness, though the densities are about what would be expected from compositional studies. The mean crustal thickness, 69 km, is determined by finding the crust-mantle topography that matches the twelfth-order Bouguer gravity field and yields the correct seismic depth in Mare Cognitum (5).

The inference is that it is not possible to match the 10 constraints discussed above and the known crust-mantle boundary depth with a model that contains only the crust-mantle density contrast. A deeper density contrast is required; this conclusion cannot be reached using the mean moment of inertia and mass constraint alone. The sensitivity of the model to core parameters is being investigated.

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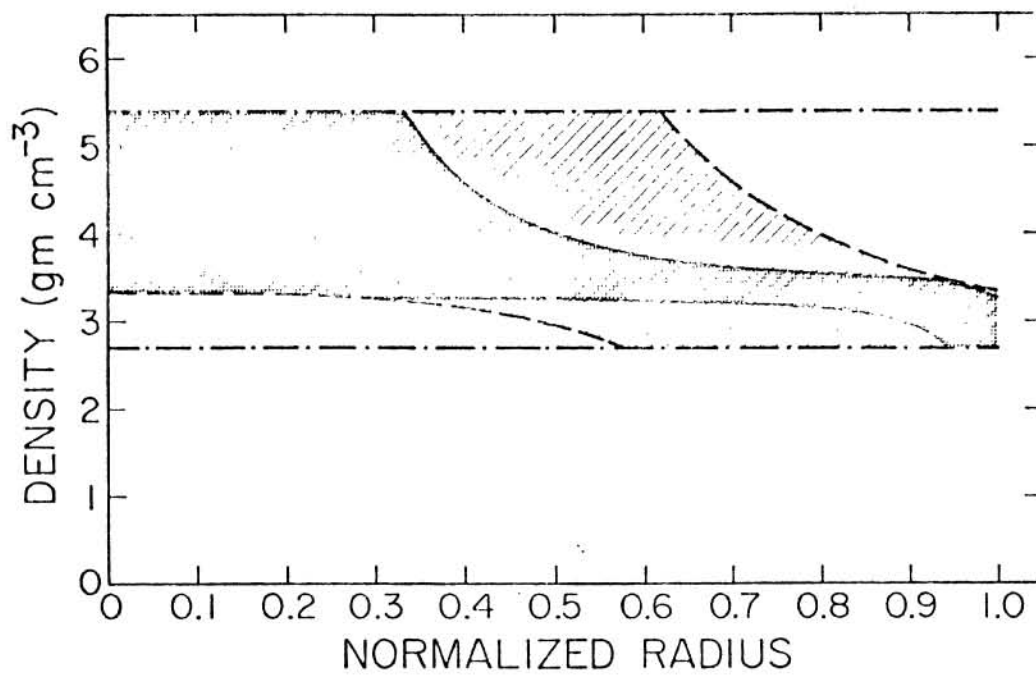


Figure 1

Envelope of Acceptable Lunar Density Profiles