LUNAR COMPOSITION AND STRUCTURE: III. MANTLE DENSITY MODELS AND IMPLICATIONS FOR THE EXISTENCE OF A METALLIC CORE;

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The accepted value of the lunar moment of inertia factor is 0.3905 ± 0.0023 [1] implying some form of density increase with depth in the interior. Given reasonable bounds on crustal mean density and thickness, additional density increases must occur either in the mantle with a maximum amplitude of approximately 10% or in the form of a small metallic core, or both [e.g. ref. 2]. Thus application of the moment of inertia constraint to infer the existence of a dense metallic core requires additional information on the density structure of the mantle.

As described in an accompanying paper [3], modal mineralogies have been constructed as a function of depth in the lunar mantle for a series of four possible bulk compositions, three thermal models, and four simplified models of lunar differentiation and internal evolution. In this paper, we calculate mantle density profiles corresponding to each of these modal mineralogy profiles and evaluate the resulting implications for the existence of a metallic core.

Method. We use available laboratory data on compressibility and thermal expansion of individual minerals as functions of temperature, pressure, and composition [4]. These compilations are not complete to all relevant temperatures and pressures; however, application to the lunar interior requires relatively modest extrapolations of existing data. For a given mineral assemblage with known STP density, density is calculated at a specified temperature and pressure by numerically solving the Murnaghan-Birch equation of state [e.g. 5]. Pressure is determined by integrating the hydrostatic equation downward from the base of the crust. Allowed values of crustal mean density ranged from 2.8 to 3.05 g cm^{-3} while crustal mean thickness was allowed to range from 61 to 86 km. We adopt the constraint that the observed lunar center-of-figure to center-of-mass offset is a consequence of a nearside/farside crustal thickness asymmetry. This allows bounds on crustal mean thickness to be calculated for any assumed mean crustal density [6]. However, our conclusions are not strongly sensitive to this assumption. Final density models were tested against the constraints of mean density (3.344 ± 0.003) and moment of inertia. Metallic cores with an assumed Fe composition were added when necessary to match the mean density and moment of inertia constraints.

Results. A representative sample of density models calculated according to the methods outlined above are presented in Fig. 1a, b, c. Each figure includes models calculated using each of the four assumed bulk composition models and each of the four assumed evolutionary models [3]. Fig. 1a is for thermal model (a) [ref. 7]; Fig. 1b is for thermal model (b) [ref. 8]; and Fig. 1c is for thermal model (c) [ref. 9]. Density increases occur primarily at the plagioclase/spinel and spinel/garnet transitions (200 and 500 km depth, respectively) as well as at the crust/mantle and mantle/core boundaries. Gradual density decreases are calculated in the upper mantle (especially for thermal models (b) and (c)) because of large temperature gradients which result in a slight dominance of thermal expansion over hydrostatic compression. In the case of thermal model (c) a local density minimum occurs near 400 km depth where the temperature profile sharply changes slope.

In all models which staisfied the mean density and moment-of-inertia constraints, metallic iron cores with radii $\geq$~300 km were needed. This is basically because the mantle density increases that were calculated were all substantially less than the (~10%) increase needed to satisfy the moment of inertia constraint without a dense core. We emphasize that our choice of an Fe composition is arbitrary; FeS cores would be larger and FeNi cores would be smaller. In the case of thermal model (b) which has a higher central temperature (1700°C) and therefore produces lower mantle densities, successful models were only obtained for relatively dense crusts and rather large core radii of > 410 km. The smallest minimum core radii were calculated using thermal model (a) and ranged from 280 to 390 km depending on the assumed bulk composition and evolutionary model.

We provisionally conclude that present bulk composition models and reasonable (but simplified) evolutionary models require dense metallic cores with radii ≥~300 km to match the mean density and moment-of-inertia constraints. A constraint that we have not directly applied in these calculations is the requirement that model seismic velocities be in exact agreement with observational extimates. In an accompanying abstract [10], we have shown that most models possess characteristics that are in qualitative agreement with the most recent mantle velocity estimates of Nakamura [11]. However, confirmation and refinement of the latter estimates would allow better discrimination between possible bulk composition and evolutionary models. Such discrimination would obviously have implications for lunar density models and, hence, for the existence of a metallic core.

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REFERENCES. (1) Ferrari A.J. et al. (1980) *J. Geophys. Res.* **85**, 3939. (2) Hood L. (1986) In *The Origin of the Moon*, W.K. Hartmann et al., eds., LPI, Houston. (3) J. Jones and L. Hood (1986), this volume. (4) Simmons G. and Wang. H. (1971) *Single Crystal Elastic Constants and Calculated Aggregate Properties: A Handbook*, 2nd ed. M.I.T. Press, Cambridge, 370 pp.; Skinner B.J. (1966) In *Handbook of Physical Constants* (S.P. Clark, ed.), p. 75-96, *Geol. Soc. Amer. Mem.* **97**; O.L. Anderson and Y. Sumino (1982) In *CRC Handbook of Physical Properties of Rocks* Vol. III, (R. Carmichael, ed.) CRC Press, Boca Raton, FL, 340 pp. (5) Buck W.R. and Toksoz M.N. (1980) *Proc. Lunar Planet. Sci. Conf. 11th*, 2043. (6) Basaltic Volcanism Study Project (1981) *Basaltic Volcanism on the Terrestrial Planets*, Pergamon Press, Inc., New York, 1286 pp. (7) Toksoz et al. (1978) *Moon and Planets* **18**, 281. (8) Binder A. and M. Lange (1980) *J. Geophys. Res.* **85**, 3194. (9) Schubert G., R. Young, and P. Cassen (1977) *Phil. Trans. R. Soc. Lond. Ser. A.* **285**, 523. (10) Hood L.L. and Jones J.H. (1986), this volume. (11) Nakamura Y. (1983) *J. Geophys. Res.* **88**, 667.

Figure 1
Density Models of the Lunar Interior Consistent with Mean Density and Moment of Inertia