MERCURY: DETERMINATION OF INTERNAL STRUCTURE AND EVOLUTION. Steven A. Hauck, II[1] and Sean C. Solomon[2], [1]Department of Geological Sciences, Case Western Reserve University, 10900 Euclid Avenue, Cleveland, OH, 44106-7216 (*hauck@case.edu*), [2]Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Rd., NW, Washington, DC 20015 (*scs@dtm.ciw.edu*).

Introduction: One of the most enigmatic questions with regard to the formation of terrestrial planets is the origin of Mercury's large bulk density (~5400 kg/m^3) [e.g., 1-4]. This high bulk density suggests a larger metal:silicate ratio than observed in the other terrestrial planets. However, the bulk density of the planet alone does not uniquely constrain the composition; additional information is required. We model the internal structure of Mercury, giving particular attention to the core, in order to investigate the ability of anticipated future measurements of the planet's normalized polar moment of inertia (C/MR^2) and ratio of the mantle moment of inertia to that of the planet (C_m/C) to constrain the planet's structure and composition.

Approach: Measurable quantities such as the values for a planet's mass and moments of inertia are directly related to its internal density structure. Under the assumption of a spherically-symmetric planet these quantities are related by the following equations [e.g., 5]:

$$M = 4\pi\int_0^R \rho(r) r^2 dr \quad (1)$$

$$C = \frac{8\pi}{3}\int_0^R \rho(r) r^4 dr \quad (2)$$

Excepting the Earth, the density structure, $\rho(r)$, is not typically known *a priori*, but equations (1-2) may be supplemented by appropriate equations of state [e.g., 6, 7], such as the third-order Birch-Murnaghan equation of state [e.g., 8]:

$$P = \frac{3K_0}{2}\left[\left(\frac{\rho}{\rho_0}\right)^{7/3} - \left(\frac{\rho}{\rho_0}\right)^{5/3}\right] \times \left[1 + \frac{3}{4}(K_0' - 4)\left\{\left(\frac{\rho}{\rho_0}\right)^{2/3} - 1\right\}\right] + \alpha_0 K_0 (T - 298) \quad (3)$$

which accounts for the pressure- and temperature-dependence of the density. Assuming a hydrostatic interior, pressure is given by:

$$P(r) = \int_R^r \rho(x) g(x) dx \quad (4)$$

where the gravity is given by:

$$g(r) = \frac{4\pi G}{r^2}\int_0^r \rho(x) x^2 dx \quad (5)$$

Use of equation (3) requires an assumption regarding the nature of mantle and core materials and their behavior at high temperatures and pressures. The large bulk density of Mercury suggests a large fraction of iron in the planet's core (despite the inference that FeO is a minor fraction of crustal and mantle material [9]). A pure iron core would likely be entirely solid by the present [10]. However, supplementing an iron-rich core with a light alloying element, such as is required for the Earth's core, would result in a depression of the melting point of the core. Such a melting point depression is consistent [11, 12] with limited contraction inferred from images of lobate scarps acquired by Mariner 10 [13, 14] and the detection of an internal magnetic field [15], which may require dynamo action within a (partially) molten core [16]. As for the Earth, there may be several viable candidates for a light alloying element (e.g., sulfur, carbon, oxygen, silicon), but sulfur displays highly siderophile behavior even at the low pressures of planetismal formation, and is cosmochemically abundant [e.g., 17]. Therefore, we assume that sulfur is a light alloying element in Mercury's core for reconnaissance calculations. These calculations are aided by fact that Fe-S compounds are better characterized at the relevant pressures and temperatures [17-19] than other candidate compounds.

It has been demonstrated [e.g., 20] that given knowledge of Mercury's obliquity, forced libration amplitude, and low-degree and -order gravity field coefficients $C_{2,0}$ and $C_{2,2}$, that one can determine C_m/C if the mantle is decoupled from the core by a liquid layer that does not follow the 88-day physical libration of the mantle, but does follow the 250,000 year precession of the spin-axis [20]. If the mantle is rigidly coupled to the core, then measurement of these quantities will yield no information on C_m/C. Determination of C_m/C provides the additional knowledge of the fractional moments of inertia of the mantle and the core ($C_m/C+C_c/C=1$). Thus, in addition to the potential importance of a partially liquid metallic core to explain surface tectonics and magnetic field observations we are motivated by the possibility that the combination of recent and future measurements by radar from Earth [21] and by the MESSENGER spacecraft [22] should uniquely determine C_m/C. Though C_m/C is not yet well-constrained, an empirical determination of this ratio is probable in the near future [21], and therefore it is worth investigating the implications that determination of this quantity will have for Mercury's internal structure and evolution.

Absent knowledge of the materials that make up the interior of Mercury, the quantities C/MR^2 and C_m/C do not uniquely determine the internal structure [e.g., 23]. However, adopting a composition (e.g., such as Fe-FeS for the core) can lead to bounds on structure. Although structural models have been developed before [e.g., 6], the implications of C_m/C for bounding the parameters of such models have not, to our knowledge, been systematically investigated.

Preliminary Results: We have developed a first-order suite of results by solving Equations (3-5) in the core using equation-of-state data for a mixture of metallic Fe and FeS and (1-2) for the entire planet subject to the boundary condition that the bulk density of a successful model match that of Mercury within 1%. These initial calculations neglect radial variation in temperature in the core, though the results are broadly similar to [6] which included this term. Rather than make additional assumptions about the mineralogy of the silicate mantle and crust, we use a single representative density for any given model, which instead may provide insight into an appropriate composition. These preliminary results employ equation-of-state data only for solid materials, but we note that liquid iron is ~ 4% less dense than solid iron at 5 GPa [e.g., 24] and that liquid Fe-S is more compressible than pure liquid Fe [25]. Using a mantle density (ρ_m) range of 2800-3600 kg/m^3, core radius (R_c) range of 1700-2300 km, ρ_{0Fe} = 7225 kg/m^3, ρ_{0FeS} = 4940 kg/m^3, K_{0Fe} = 127 GPa, K_{0FeS} = 54 GPa, K'_{0Fe} = 2.2, K'_{0FeS} = 4.0, $\alpha_{Fe} = 4.5 \times 10^{-5}$ K^{-1}, and $\alpha_{FeS} = 6.9 \times 10^{-5}$ K^{-1} [6] we calculated ~7000 successful models plotted in Figures 1-2.

In brief, we find that C_m/C may constrain R_c to within ~150 km or less (Figure 1) independent of any knowledge of C/MR^2. However, with accurate determinations of C/MR^2 and C_m/C the radius of the core can be tightly bounded within the uncertainties of both quantities and the assumed equation of state for the core (Figure 2). Further, we find that C_m/C alone is a poor constraint on the sulfur content of the core unless C_m/C >0.5 or C_m/C < 0.2, but that with C/MR^2 the composition of the core may be bounded within several wt % sulfur.

Discussion: The strong inverse relationship between C_m/C and R_c has interesting implications for the internal evolution of the planet. A large value of C_m/C suggests a relatively thick mantle that may have experienced significant convection during its early history, as has been previously modeled [e.g., 11, 12]. However, lower values of C_m/C may decrease the potential importance of mantle convection in the planet's history because a thinner mantle is less likely to have a supercritical Rayleigh number.

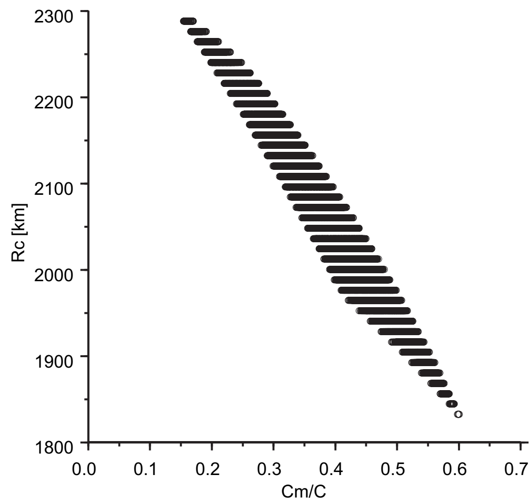

Figure 1.

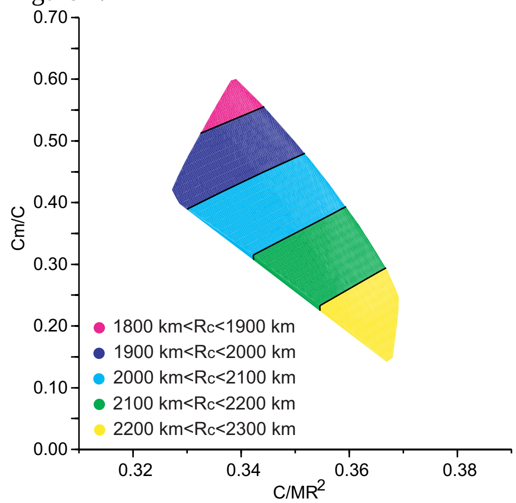

Figure 2.

References: [1] Goettel, K. A. (1988) in Mercury, 613. [2] Lewis, J. S. (1988) in Mercury, 651. [3] Wasson, J. T. (1988) in Mercury, 622. [4] Wetherill, G. W. (1988) in Mercury, 670. [5] Turcotte, D. L. and G. Schubert (1982) Geodynamics, John Wiley. [6] Harder, H. and G. Schubert (2001) *Icarus*, *151*, 118. [7] Sohl, F. and T. Spohn (1997) *JGR*, *102*, 1613. [8] Poirier, J. P. (2000) Intro. to the Physics of the Earth's Interior, Cambridge Univ. Press. [9] Robinson, M. S. and G. J. Taylor (2001) *MAPS*, *36*, 841. [10] Siegfried, R. W., II and S. C. Solomon (1974) *Icarus*, *23*, 192. [11] Schubert, G., et al. (1988) in Mercury, 429. [12] Hauck, S. A., II, et al. (2003) *EPSL*, submitted. [13] Strom, R. G., et al. (1975) *JGR*, *80*, 2478. [14] Watters, T. R., et al. (1998) *Geology*, *26*, 991. [15] Ness, N. F., et al. (1975) *JGR*, *80*, 2708. [16] Stevenson, D. J. (2003) *EPSL*, *208*, 1. [17] Hillgren, V. J., et al. (2000) in Origin of the Earth and Moon, 245. [18] Fei, Y., et al. (1997) *Science*, *275*, 1621. [19] Fei, Y., et al. (2000) *Am. Min.*, *85*, 1830. [20] Peale, S. J., et al. (2002) *MAPS*, *37*, 1269. [21] Margot, J.-L., et al. (2003) *IAU*, *25*. [22] Solomon, S. C., et al. (2001) *PSS*, *49*, 1445. [23] Spohn, T., et al. (2001) *PSS*, *49*, 1561. [24] Anderson, O. L. (2003) in Earth's Core: Dynamics, Structure, Rotation, 83. [25] Sanloup, C., et al. (2002) *JGR*, *107*, 2272.