# IMPLICATIONS OF MESSENGER OBSERVATIONS FOR MANTLE CONVECTION ON MERCURY.

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**Introduction:** Orbital observations by the MESSENGER spacecraft are providing new information on Mercury's surface geology, composition, internal structure, and magnetic field [e.g., 1-6]. These recent results from MESSENGER provide important constraints on the thermal state and history of Mercury.

Specifically, observations of Mercury's spin state [7] and determination of the planet's gravity field have allowed the estimation of the planet's normalized polar moment of inertia and the ratio of the polar moment of inertia of the solid outer portion of the planet to that of the entire planet [8]. These data indicate that Mercury has a large core and a relatively thin shell of mantle plus crust [5]. Convective vigor is strongly dependent on the thickness of the convecting layer. A thin mantle may be subcritical, potentially restricting convective flow in the mantle.

Models of Mercury's interior [5, 8] consistent with the observed moment of inertia parameters suggest that the interior may host a multiple-layer structure consisting of a solid inner core, a liquid outer core, a solid FeS layer at the top of the core, and mantle and crustal layers. A solid FeS layer would imply that temperatures at the base of the mantle do not currently exceed FeS solidus temperatures of 1600-1700 K. This unexpected solid layer at the top of the core also implies that a no-slip boundary condition at the base of the mantle may be more appropriate than the usual free-slip condition.

Moreover, Mercury experienced the emplacement of extensive volcanic smooth plains near the end of the late heavy bombardment [3], as well as a substantial decline in volcanism since that time, consistent with a marked decay in heat production as inferred from MESSENGER Gamma-Ray Spectrometer (GRS) measurements of U, Th, and K abundances at Mercury's surface [2]. Each of these observations places key constraints on the thermal evolution of the mantle.

Here, we investigate the implications of MESSENGER observations for the evolution of Mercury's interior by modeling convection in a mantle constrained to be relatively thin, possibly have a solid iron sulfide layer at its base at present, and capable of producing widespread volcanism to and somewhat after the end of the late heavy bombardment.

**Numerical Simulations:** We use the axisymmetric, spherical-shell, finite-element code CITCOM [9, 10] to model mantle convection. The models employ an extended Boussinesq formulation [11] with a temperature- and depth-dependent viscosity [12], and an internal heat production that declines at a rate consistent with GRS measurements of Mercury's surface material [2]. As the distribution of heat-producing elements between the crust and mantle is poorly constrained, we consider a broad range of absolute heat production for the mantle. In our models the temperature at the core-mantle boundary varies with time, taking into account the contribution of heat due to the secular cooling of the core. Consistent with internal structure models for Mercury [5, 8], we take into account a range of core radii from ~1800 to 2100 km. We also investigate both free-slip and no-slip boundary conditions at the bottom of the mantle to understand the potential importance of a basal solid layer for mantle convection. The main parameters for the simulations are listed in Table 1.

| **Parameters** | **Value** |
|---|---|
| **Planet radius (km)** | 2440 |
| **Surface temperature (K)** | 401 |
| **Conductivity (W $m^{-1}K^{-1}$)** | 3.0 |
| **Diffusivity (m $s^{-2}$)** | $7.07 \times 10^{-7}$ |
| **Heat capacity (J $kg^{-1}$ $K^{-1}$)** | 1212 |
| **Mantle density (kg $m^{-3}$)** | 3500 |

**Table 1**. Main parameters for numerical simulations.

**Results:** In order to understand the overall thermal history of Mercury, we consider a wide range of parameters including core size, initial viscosity, heat production, initial thermal state, and velocity boundary conditions. Initial results indicate that mantle convection is possible even for relatively thin mantle layers, for a wide range of heat production values (from 25% of the GRS inferred surface heat production) and possible mantle flow laws (e.g., olivine- versus pyroxene-dominated).

We have also identified a more limited set of models for which present core-mantle boundary (CMB) temperatures are within the 1600-1700 K range, consistent with the possible presence of a solid iron sulfide layer. Figure 1 illustrates the temperature field for a case with a no-slip boundary condition at the CMB that corresponds to a solid layer at the top of the core, and a core radius of 2074 km. In this simulation, mantle convection persists for 3.7 Gy, and slightly longer in the free-slip boundary condition case (4 Gy). Present CMB temperatures, ~1680 K, are near the FeS solidus temperature, which is 1630 K for a CMB pressure of 4.2 GPa. We also find in this case that widespread partial melt is generated during the first 2.7 Gy (Fig. 2) at an average depth of 200 km. Due to solution trade-offs, somewhat lower initial temperatures can lead to present CMB temperatures below the FeS solidus, though generally with a shorter interval of large-scale magma production. We consistently observe early mantle convection and mantle melt production. Recent work indicates that circum-Caloris volcanism may have been at least in part the result of dissipation of basin-forming impact heat in a contemporaneously convecting mantle [13]. Our models, constrained by MESSENGER observations, are consistent with the contemporaneous convection required by this idea.

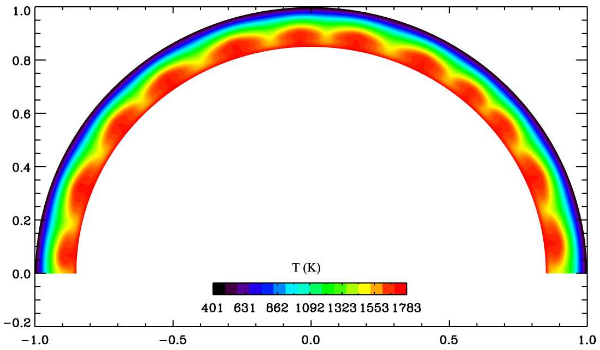

**Figure 1**. Axisymmetric temperature field at 2.4 Gy, where the equator is at the center. In this simulation, the core radius is equal to 2074 km and there is a no-slip bottom boundary condition. The convection is still active in the modern mantle, with multiple convective cells.

**Conclusion**: Despite Mercury's thin mantle, internal heat generation and secular cooling sustain mantle convection over a broad array of initial and boundary conditions. We also find several simulations in which the base of the mantle cools to temperatures below the FeS solidus temperature, thus allowing the presence of a solid iron sulfide layer at the top of the core. Such a layer may result in a no-slip boundary condition at the base of the silicate mantle, which depending on how long a solid core layer is present, decreases the duration of convection only slightly. Finally, in a broad range of simulations, we find that mantle convection and melt production persist over a substantial fraction of Mercury's history, consistent with Mercury's observed, widespread volcanism [3].

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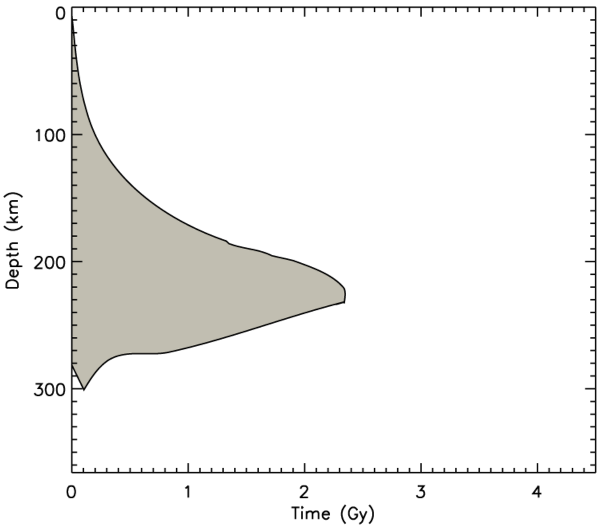

**Figure 2**. Evolution of the extent of a global layer of partial melt as a function of time for the simulation depicted in Figure 1. The shaded region indicates the depths over which pervasive melting occurs. In this model, melt production lasts for 2.4 Gy.