

THE INFLUENCE OF CORE RADIUS ON THE PLANFORM OF STAGNANT LID CONVECTION.

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Introduction: Mercury is the smallest of the terrestrial planets and while many aspects of Mercury resemble the Moon, there are significant differences between the two bodies. Reconciling the observations on Mercury (compressive lobate scarp features, apparent intrinsic magnetic field, large core, small planetary body) challenges our current understanding not only of Mercury's thermal history, but also the evolution of the other terrestrial planets. Mercury has the largest iron core of any of the terrestrial bodies, resulting in the thinnest viscous silicate shell. The dynamics of a thin viscous shell such as Mercury's mantle in the stagnant lid regime and the impact of such a thin shell on the thermal evolution of a planetary body is poorly understood.

Mercury has a present-day, dynamo-driven magnetic field [1], while the internal dynamos for the Moon and Mars have ceased. This suggests that convection within Mercury's silicate mantle ceased very early in solar system history and somewhat paradoxically, the conducting silicate mantle shell enabled the core to retain more primordial heat than in large bodies where mantle convection continues to present. Alternatively, the sluggish roll convective planform may be less efficient in transporting heat through the mantle.

Recently, King [2] has shown that the pattern of convection in a thin spherical shell geometry applicable to Mercury's mantle differs from that seen in 3D spherical models for Mars and Venus. While mantle convection on Venus, Earth and Mars takes the form of cylindrical upwellings [3], the upwellings on Mercury take the form of long, linear rolls or hemispherical sheet upwellings and cylindrical downwellings (Fig. 1). The linear upwellings in the low latitude region evolve into a nearly hexagonal pattern near the poles.

This convective planform is a direct consequence of the thin silicate shell and corresponding low Rayleigh number applicable to convection in Mercury's mantle and is observed over the range of Rayleigh numbers (10^4 - 10^7) including calculations with or without heat producing elements. In thicker silicate shells, instabilities near the base of the shell begin as linear, 2D sheets that quickly break into distinct cylindrical plumes as the instabilities rise. Sheets coalesce into plumes at the intersection of two or more linear sheets. The Mercurian mantle is too thin for the the basal boundary layer instabilities to break up into cylindrical plume structures and thus linear upwellings extend throughout the mantle.

King [2] points out that this geometry is consistent with the pattern of compressive features observed in the images from Mariner 10 suggesting that the compressive features record an ancient pattern of mantle convection as previously proposed by Watters et al. [4]. Furthermore, if convection is still present, these rolls may be observable in the gravity and topographic data that will be obtained by MESSENGER [5,6]. Finally, the pattern of mantle convection may also influence an dynamo-driven magnetic field by imposing a heat flux pattern on the core.

The calculations from King [2] assume a core radius of 1840 km, approximately 75% of the planetary radius. Uncertainty in core composition for Mercury translates into core radii ranging from 1700 to 1900 km or approximately 70-80% of the planetary radius (e.g., [7]). An improved understanding of the impact of the core to planetary radius ratio would be useful to further our general understanding planetary thermal histories. While the core to planet radius ratio is fairly well defined for the terrestrial planets and Moon, if we consider the possibility of layered convection (e.g., [8]), magma ocean scenarios [9,10], and superearths [11] there is more variability in shell geometry. The core to planet radius ratio could also be important for understanding the thermal history of icy bodies [12,13].

To investigate the impact of core radius on planform, I use the finite element code CitcomS [14, 15] to solve the equations for 3D spherical, incompressible, convection with a free-slip surface and core mantle boundary. The calculations run for 4.5 billion years model time from a hot, nearly-isothermal initial condition (e.g., $T=1880$ K). The parameters governing convection assume an olivine dominated mantle, consistent with previous Mercury mantle models [2,7,16,17]. The models use a temperature-dependent viscosity with an activation energy of 300 kJ mole^{-1} , based on diffusion creep of olivine [18]. I use the core cooling boundary condition used in Redmond and King [17] and King [2], consistent with previous Mercury thermal history models [2,7,16,17] and consider decaying internal heat sources, consistent with previous thermal history models [16].

Results: I vary the dimensionless core radius, r_c , from 0.50 to 0.80 (scaled by the planetary radius) in steps of 0.05. More than eighteen 3D calculations spanning a range of Rayleigh numbers, internal generation rates, and initial conditions with $r_c=0.75$ have been computed. All of these calculations evolved into

stable sheet-like convective planforms within 300 Myr and this planform persisted throughout the remainder of the calculation. The heat flux at the core-mantle boundary at the end of the calculations ranged from 4.8-15.8 mW/m², consistent with Mercury core dynamo [19] and thermal history models [2,7,16,17].

Calculations with $r_c = 0.5$ and 0.55 have been studied in detail [3] and are well known to result in the plume planform. Thus, the radius at which transition between the plume and roll planform occurs (r_T) lies somewhere between dimensionless core radii $0.55 < r_T < 0.75$. The systematic variation planform as a function of core radius will be discussed.

The planform of convection not impacted by using decaying heat producing elements. This is not surprising because previous calculations with uniform and zero internal heating were not impacted by the difference in internal heating.

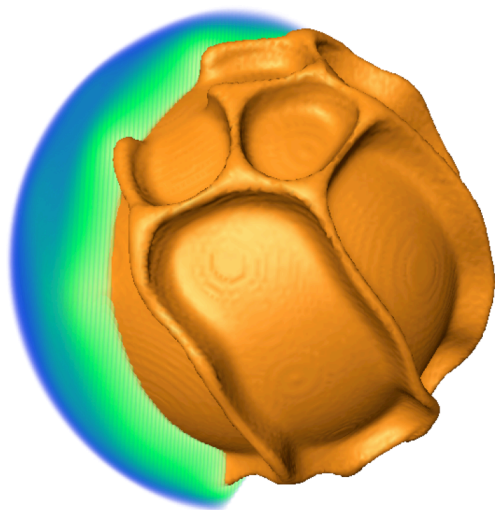


Figure 1. Roll convective planform in a thick viscous shell [2].

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