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Mercury's thermo-chemical evolution from numerical models constrained by Messenger observations

N. Tosi (1), D. Breuer (2), A.C. Plesa (2), F. Wagner (2), and M. Laneuville (3)

(1) Department of planetary geodesy, Technical University Berlin, Germany (nic.tosi@gmail.com), (2) Department of planetary physics, DLR, Berlin, Germany, (3) Department of space and planetary geophysics, IPGP, Paris

The Messenger spacecraft, in orbit around Mercury for almost one year, has been delivering a great deal of new information that is changing dramatically our understanding of the solar system's innermost planet. Tracking data of the Radio Science experiment yielded improved estimates of the first coefficients of the gravity field that permit to determine the normalized polar moment of inertia of the planet (C/MR^2) and the ratio of the moment of inertia of the mantle to that of the whole planet (C_m/C). These two parameters provide a strong constraint on the internal mass distribution and, in particular, on the core mass fraction. With $C/MR^2 = 0.353$ and $C_m/C = 0.452$ [1], interior structure models predict a core radius as large as 2000 km [2], leaving room for a silicate mantle shell with a thickness of only ~ 400 km, a value significantly smaller than that of 600 km usually assumed in parametrized [3] as well as in numerical models of Mercury's mantle dynamics and evolution [4]. Furthermore, the Gamma-Ray Spectrometer measured the surface abundance of radioactive elements, revealing, besides uranium and thorium, the presence of potassium. The latter, being moderately volatile, rules out traditional formation scenarios from highly refractory materials, favoring instead a composition not much dissimilar from a chondritic model.

Considering a 400 km thick mantle, we carry out a large series of 2D and 3D numerical simulations of the thermo-chemical evolution of Mercury's mantle. We model in a self-consistent way the formation of crust through partial melting using Lagrangian tracers to account for the partitioning of radioactive heat sources between mantle and crust and variations of thermal conductivity. Assuming the relative surface abundance of radiogenic elements observed by Messenger to be representative of the bulk mantle composition, we attempt at constraining the degree to which uranium, thorium and potassium are concentrated in the silicate mantle through a broad exploration of the parameter space. We analyze how different rheologies, buoyancy variations associated with mantle depletion and the absence or presence of a primordial crust influence the thermal history of Mercury, the duration of convection and the formation of partial melting with its associated crustal production. Additionally, we calculate the global radial contraction of the planet resulting from secular cooling, mantle differentiation and inner core growth, and compare it with the traditional estimate of 1-2 km which was recently confirmed by the analysis of Messenger's images [5].

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