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Mercury's thermo-chemical evolution constrained by MESSENGER observations

Nicola Tosi (1), Matthias Grott (2), Doris Breuer (2), and Ana-Catalina Plesa (2)

(1) Technical University Berlin, Planetary Geodesy, Berlin, Germany (nic.tosi@gmail.com), (2) German Aerospace Center (DLR), Planetary Physics, Berlin, Germany

Low-degree coefficients of Mercury's gravity field as obtained from the MESSENGER's Radio Science experiment combined with estimates of Mercury's spin state permit to compute the normalized polar moment of inertia of the planet (C/MR^2) as well as the ratio of the moment of inertia of the mantle to that of the planet (C_m/C). These two parameters provide a strong constraint on the internal mass distribution. With $C/MR^2 = 0.346$ and $C_m/C = 0.431$ [1], interior structure models predict a large core radius but also a large mantle density. The latter requirement can be met with a relatively standard composition of the silicate mantle for which a core radius of $\sim$ 2000 km is expected [2]. Alternatively, the large density of the silicate shell has been interpreted as a consequence of the presence of a solid FeS layer that could form atop the liquid core under suitable temperature conditions [3]. According to this hypothesis, the thickness of the mantle would be reduced to $\sim$ 300 km only. Additionally, the Gamma-Ray Spectrometer measured a surface abundance of U, Th and K, which hints at a bulk mantle composition comparable to other terrestrial planets [4]. Geological evidence also suggests that volcanism was a globally extensive process even after the late heavy bombardment (LHB) and that northern plains were likely emplaced in a flood lava mode by high-temperature, low-viscosity lava. Finally, the analysis of previously unrecognized compressional tectonic features as revealed by recent MESSENGER images yielded revised estimates of the global planetary contraction, which is calculated to be as high as 4–5 km [5].

We employed the above pieces of information to constrain the thermal and magmatic history of Mercury with numerical simulations. Using 1D-parameterized thermo-chemical evolution models, we ran a large set of Monte-Carlo simulations ($\sim$ 10000) in which we varied systematically the thickness of the silicate shell, intial mantle and CMB temperatures, mantle rheology, thermal conductivity of the crust, volume change upon differentiation associated with depletion and crustal enrichment factor of radiogenic elements. We considered as successful models yielding less than 5 km of global contraction after the LHB and a phase of magmatic activity extending beyond the end of the LHB along with the production of at least a 5 km thick crust. We found a small subset of admissible models ($\sim$ 1%) characterized by a dry olivine rheology, enrichment factors between 2.5 and 3.5 and a production of up to 35 km of secondary crust extending up to 3.5 Ga. In a few models convection persists until present day. Models with a 300 km thick silicate shell are generally incompatible with the contraction constraints.

From the set of successful models, we selected few representative ones that we investigated in detail with numerical simulations in 2D cylindrical and 3D spherical geometry, which confirmed the validity of the 1D approach. In addition, we found that the thin mantle produces a convection planform whose spectrum is dominated by short wavelengths. These persist throughout the planet's evolution and their gravity signature would be difficult to reveal with the present resolution of gravity data delivered by MESSENGER. Furthermore, long-wavelength convective features that have been proposed as a plausible source of compressional tectonic landforms [6] are not confirmed.

References

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