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The Thermal Evolution of Mercury and the Implications for Volcanism, Topography and Geoid

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ABSTRACT

The interior of Mercury is not well known and the current knowledge is based on data obtained during the Mariner 10 mission. Upcoming space missions will not deliver sufficient data before 2011, although some first measurements were performed during MESSENGER flybys. Therefore we started developing a model to allow for some anticipation of the measured data. In this work we present thermal evolution models of Mercury, obtained with a fully three dimensional spherical shell convection code. In a first attempt we want to understand the basic characteristics of the cooling behaviour of the hermean mantle. Pictures taken during the first MESSENGER flybys show features like lava flows, but they look at first sight very similar to the surrounding rocks. This rises the question after partial melt evolution in the mantle. Therefore we also investigate to what extent and how long a molten zone in the mantle could have survived, as this would be a potential source for volcanism. Furthermore we investigate, the dynamical topography and gravity field.

Introduction

The hemisphere of Mercury, which has been imaged by MARINER 10 is very similar in appearance to the surface of the Moon. Like on the Moon, craters are the dominant landform. However, Mercury is brighter (higher albedo) and does not show the contrast of dark maria versus bright highlands. Craters are shallower on Mercury. Because of the greater surface gravity, secondary craters and ejecta on Mercury are closer to the primary craters of a given size than on the Moon. Data at infrared and radio wavelengths also suggest a lack of basaltic material, which is rich in heavy elements like iron or titanium. Among the terrestrial planets Mercury is not only the smallest, but also the densest (after correction for self–compression). To explain Mercury's high density it is considered likely that the planet's mantle was removed during a giant impact event, when proto–Mercury was already differentiated into an iron core and a silicate mantle [1]. Beside the damage to the planet's mantle the vaporization would cause a significant loss of volatile elements, leaving the remaining planet molten and dominated by extremely refractory material. Since the arrival of a spacecraft at the enigmatic planet is not to be expected before 2011 (MESSENGER) or 2019 (BEPI COLOMBO) we might already prepare ourselves for the upcoming results and perform tests that allow some anticipation of the measured data. We introduce a numerical model and try to answer the following questions: How does the thermal evolution of Mercury differ from those of other terrestrial planets? To what extent and how long did molten zone in the mantle survive? What is the thermal state of Mercury's mantle today? Can we conclude from the topography and geoid onto the (past) interior dynamics?

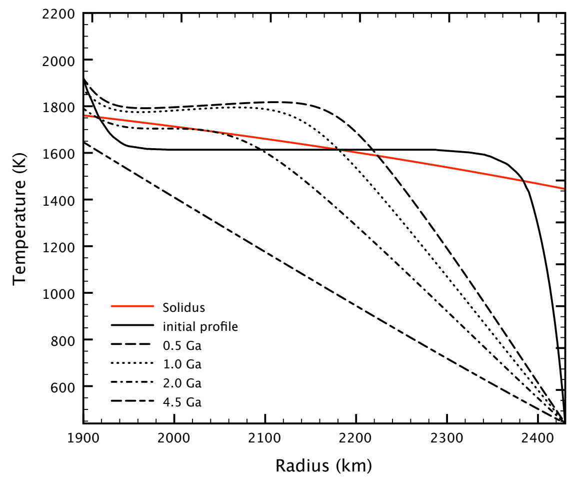

Figure 1: Evolution of the azimuthally averaged temperature.

Model

The hermean mantle is modelled as an internally and bottom heated, isochemical fluid in a spherical shell. The principle of this convection model is widely accepted and is used for various models of thermal evolution of terrestrial planets, e.g., the Earth [2], Mars [3] or the Moon [4]. We are solving the hydrodynamical equations, derived from the conservation of mass, momentum and energy. A program originally written by S. Zhang is used to solve the temperature field $T(r, \vartheta, \varphi)$ [5], which employs a combination of a spectral and a finite difference method. Beside the large core as a heat source another energy source is provided by the decay of radioactive elements. The viscosity of the mantel material dependes exponentially on the inverse temperature.

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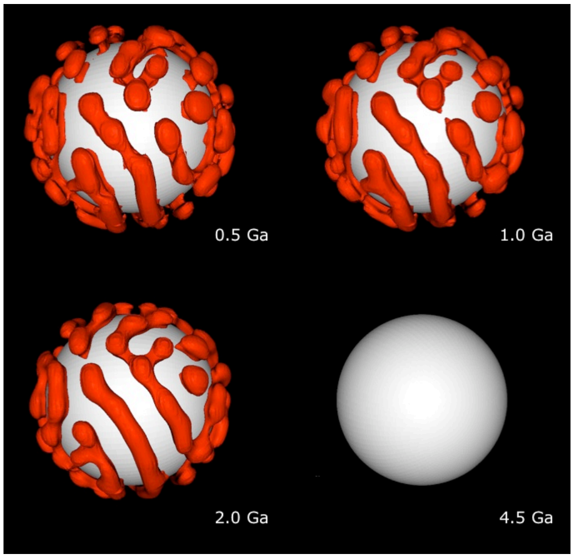

Figure 2: Isosurfaces (red) of the temperature anomaly. In the reddish areas the temperature is about ten degrees K higher than the azimuthally averaged temperature. The grey ball in the centre is the core.

Results

The model shows the typical behaviour of a one–plate–planet, meaning the surface is not broken into several tectonic plates but the outside is a single rigid shell. The thermal evolution is generally charaterized by the growth of a massive lithosphere on top of the convecting mantle. The lower mantle and core cool comparatively little and stay at temperatures between 1900 K and 2000 K until about 2.0 Ga after the simulation was started (see figure 1). The stagnant lid comprises roughly half the mantle after only 0.5 Ga. Since the rigid lithosphere does not take part in the convection anymore, the heat coming from the interior (due to the cooling of the large core) can only be transported through the lithosphere by thermal conduction. This is a significantly less effective mechanism of heat transport than convenction and hence the lithosphere forms an insulating layer. As a result, the interior is kept relatively warm. Because the mantle is relatively shallow compared to the planet's radius, and additionally the thick stagnant lid is formes relatively rapid, the convection is confined to a layer of only about 200 km to 300 km. Convection structures are therefore relatively small structured (see Figure 2). The flow patterns in the early evolution show that mantle convection is characterized by numerous upwelling plumes, which are fed by the heat flow from the cooling core. These upwellings are relatively stable regarding their spatial position. As the core cools down the temperature anomalies become colder but not less numerous.

In our calculations, a region of partial melt in the mantle forms immediately after the start of the model at a depths of roughly 220 km. While in the entire lower mantle the temperature exceeds the solidus, the highest melt degrees can be found in the upwelling plumes. The partial molten region persists a significant time (up to 2.5 Ga). How long the partial molten zone actually survives depends strongly on the initial conditions of the model. For instance, an outer layer with a reduced thermal conductivity would keep the lower mantle significantly warmer and a molten layer survives longer.

Discussion and Conclusion

Due to the weak constraints of important parameters (e.g. sulfur content of the core, mantle rheology, amount and distribution of radiogenic heat sources, planetary contraction, thermal conductivity, etc) numerous models are required to understand the importance and influence of the mentioned variables. The models variety is huge and more investigations of the results on initial parameters are yet to be performed. Although rather preliminary our results are in general consistent with [6]. The special interior structure of Mercury compared to the other terrestrial planets makes his thermal history very unique. Future work will cope with the thorough investigation of several parameters and their influence on the model outcome.

References

[1] W. Benz, A. Anic, J. Horner, and J.A. Whitby, "The origin of mercury," *Space Science Reviews*, vol. 132, 2007.

[2] S. Zhang and D.A. Yuen, "Various influences on plumes and dynamics in time dependent compressible mantle convections in 3–D spherical shells," *Phys. Earth Planet. Int.*, vol. 94, pp. 241–267, 1996.

[3] H. Harder, "Mantle convection and the dynamic geoid of Mars," *Geophys. Res. Lett.*, vol. 27, pp. 301–+, 2000.

[4] T. Spohn, W. Konrad, D. Breuer, and R. Ziethe, "The Longevity of Lunar Volcanism: Implications of Thermal Evolution Calculations with 2D and 3D Mantle Convection Models," *Icarus*, vol. 149, pp. 54–65, Jan. 2001.

[5] S. Zhang and U. Christensen, "Some effects of lateral viscosity on geoid and surface velocities induced by density anomalies in the mantle," *Geophys. J. Int.*, vol. 114, pp. 531–547, 1993.

[6] D. Breuer, S. A. Hauck, M. Buske, M. Pauer, and T. Spohn, "Interior evolution of mercury," *Space Science Reviews*, vol. 132, 2007.