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Mercury's Thermal Evolution: Implications for Volcanism, Topography and Geoid

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Abstract

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 and 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, as these are observables which can be measured with laser altimetry from an orbiter around the planet.

1 Introduction

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.

2 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 'from below' the decay of radioactive isotopes provides internal heating of the hermean mantle. The viscosity of the mantel material dependes exponentially on the inverse temperature.

3 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. 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 convection 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 formed 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 1, left). 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 and less pronounced but not less numerous.

In our calculations, a region of partial melt in the

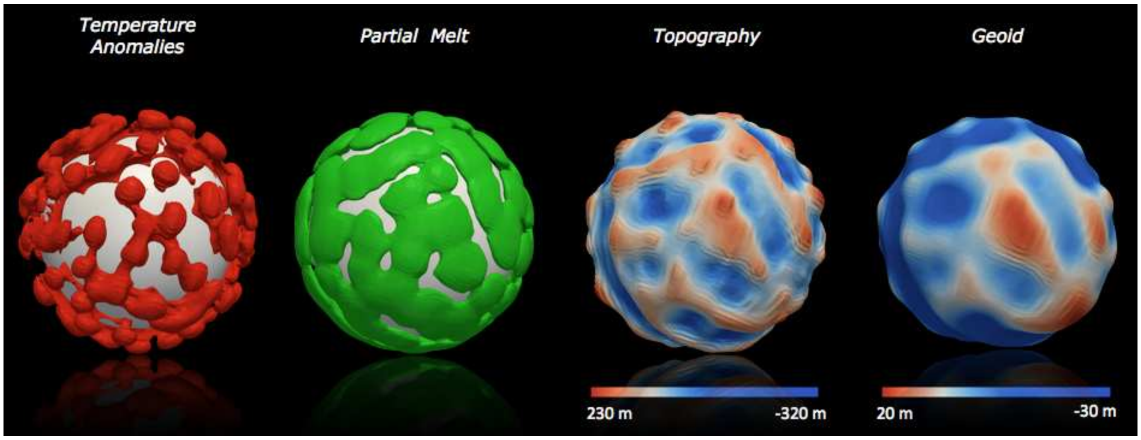

Figure 1: Temperature Anomaly: Isosurfaces (red) of 20k above azimuthally averaged temperature, Partial Melt: Isosurfaces (red) of 5k above solidus temperature, Topography and Geoid: vertical scale is for better visualization and not to scale, colors resemble actual values.

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 (see Figure 1, second to left). 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.

The hot upwellings cause a surface deformation (dynamical topography) which itself causes a gravity anomaly. In Figure 1 the two right panels show the dynamical topography and geoid caused by the plumes in the right panel.

4 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. Eventually observables like topography can be measured with spacecrafts in orbit (e.g. BEPI COLOMBO) and then allow conclusions on the interior dynamics of Mercury.

References

[1] W. Benz, A. Anic, J. Horner, and J.A. Whitby. The origin of mercury. *Space Science Reviews*, 132, 2007. DOI10.1007/s11214-007-9284-1.

[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.*, 94:241–267, 1996.

[3] H. Harder. Mantle convection and the dynamic geoid of Mars. *Geophys. Res. Lett.*, 27:301–+, 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*, 149:54–65, January 2001. 10.1006/icar.2000.6514.

[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.*, 114:531–547, 1993.

[6] D. Breuer, S. A. Hauck, M. Buske, M. Pauer, and T. Spohn. Interior evolution of mercury. *Space Science Reviews*, 132, 2007. DOI10.1007/s11214-007-9228-9.