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Numerical modelling of accretion, sintering and differentiation of asteroid 4 Vesta

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Abstract

The Dawn mission provided more precise values of e.g. the mass, the bulk density and the dimensions of the asteroid 4 Vesta. The ground-based observations prior to the mission indicated a dry, basaltic surface composition meaning that the body is differentiated and has been resurfaced by basaltic lava flows. The latter distinguishes Vesta from primordial planetesimals like 21 Lutetia which retained its native surface material (and may still be partially differentiated[1]). The differentiated interior is confirmed by the mass concentration towards the centre of Vesta measured by Dawn. In fact, the core is expected to have 214-226 km in diameter[2]. In the present study numerical calculations of the thermo-chemical evolution of the asteroid 4 Vesta have been performed adopting the new data obtained by the Dawn mission. We have used the thermal evolution model by [3], which includes accretion (based on the accretion model by [4]), sintering of the accreting porous material due to hot pressing[5], associated changes of the material properties (such as density and thermal conductivity), melting, convective heat transport and differentiation by porous flow of chondritic planetesimals. The heat transport by melt segregation is modeled assuming melt flow in porous media and by supplementing the energy balance equation with additional advection terms. The advection terms for iron and silicate melts are calculated using the Darcy flow equation. This approach is valid for melt fractions large enough such that the melt forms an interconnected network but lower than the rheological critical melt fraction (≈50%). In particular we compare the evolution scenarios arising from the instantaneous (Fig. 1) accretion of Vesta at different formation times t_0 (relative to the formation of the calcium-aluminum rich inclusions) with those arising from various non-instantaneous accretion rates. This is important due to the competition between heating in the interior and heat loss through the surface. The latter is minimized

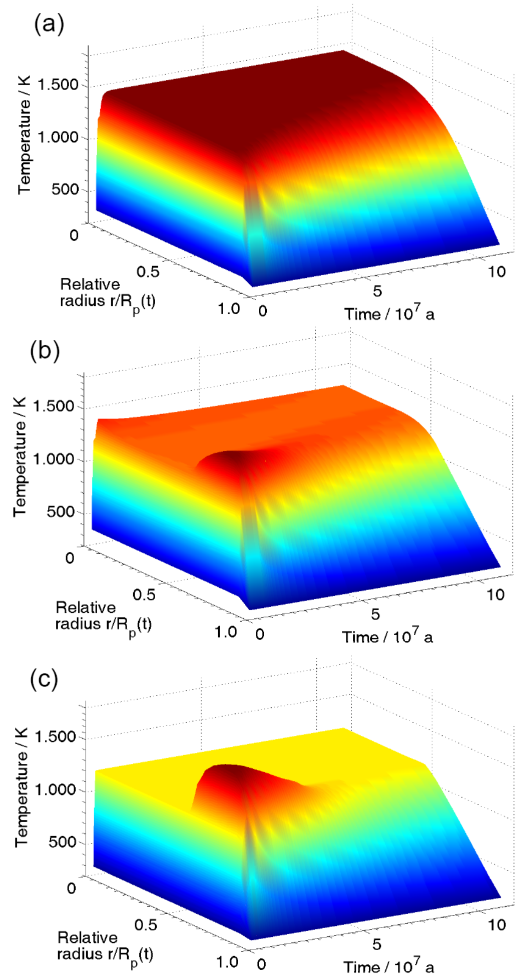

Figure 1: Temperature as a function of radius and time of a 260 km sized planetesimal which accreted instantaneously at t_0=1 Ma after the CAIs. Thereby the grain size b determines the permeability of the solid matrix in a partially molten system and is crucial for the differentiation. Shown are the cases (a) b=0.01 mm, no core formation, (b) b=0.5 mm, slow core formation and small core, and (c) b=3 mm, fast core formation.

in an instantaneous accretion model where the growth rate is infinite. With decreasing growth rate the heating decreases in effectiveness with consequences for key parameters such as the peak temperature and the extent and lifetime of completely or partially molten regions in the interior. While a fast accreting body may melt and differentiate, a slow accreting body of equal final size and age may stay completely solid and undifferentiated. Evolution scenarios arising from those assumptions have been examined. Implications for the compaction, (partial) differentiation, crust formation and resulting internal structure of Vesta have been derived. The final structures arising from our models will be presented.

References

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