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Influence of rheology and giant impactors on the terrestrial core formation

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Abstract

Knowledge about the terrestrial core formation mechanism is still very limited. The fracturing mechanism was proposed for cold planetary interiors surrounded by an iron layer [Stevenson, 1981], which develops from an overlying magma ocean. In this case the cold central region is displaced by a degree one mode from the centre of the accreting planet and fractured due to the large stresses. In contrast, the consideration of short-lived radioactive heating may result in warmer central regions and the preference of higher mode iron diapirism as core formation mechanism [e.g. Rubie et al., 2007; Ziethe and Spohn, 2007]. Current thinking additionally indicates the importance of giant impacts [e.g. Tonks and Melosh, 1993; Rubie et al., 2003] on core formation. We perform 2D cylindrical simulations using the code I2ELVIS applying the newly developed "spherical-Cartesian" methodology [Gerya and Yuen, 2007]. It combines finite differences on a fully staggered rectangular Eulerian grid and Lagrangian marker-in-cell technique for solving momentum, continuity and temperature equations as well as the Poisson equation for gravity potential in a self-gravitating planetary body. In the model, the planetary body is surrounded by a low viscosity massless fluid ("sticky air") to simulate a free surface [Schmeling et al., 2008]. We apply a temperature- and stress-dependent viscoplastic rheology inside Mars- to Earth-sized bodies and include heat release due to radioactive decay, shear and adiabatic heating. As initial condition we use randomly distributed iron diapirs with random sizes in the range of 20 to 100 km radius inside the accreting planet, representing the iron delivered by predifferentiated impactors. Additionally, we add a giant impactor core into several models. For simplicity, we neglect the heating of the planetary body by the impact itself. Additionally, we assume the impactor to be at rest at the beginning of the simulation. A systematic investigation of the influence of silicate rheology and of giant impactors with varying radius on different-sized protoplanets is being performed.

Depending on the silicate rheology, which is strongly dependent on the water content of olivine [Katayama and Karato, 2008] and the initial temperature profile, we observe different regimes of core formation: For weak planetary interiors, we observe iron diapir sinking, which is similar to already published core formation models [e.g. Ziethe and Spohn, 2007]. For highly viscous planets, depending on the activation volume either an asymmetric iron layer forms, which surrounds the central part of the planet or a mixture of diapirism and fracturing mechanism develops. We find that the diapir sinking in this case may differ significantly from previous assumptions as we observe the formation of large temperature asymmetries and widespread rigid body rotation phenomena on a short timescale.

Results including a giant impactor core indicate that for Mars-sized bodies it can induce a runaway differentiation process limited to one hemisphere only. This may have implications for the formation of the Martian crustal dichotomy as the release of potential energy limited to one hemisphere will cause a thermal asymmetry and would lead to more crust formation on one hemisphere. Our observations show that the presence of giant impactors on Earth-sized bodies trigger a fast global differentiation as suggested by Ricard et al. [2009]. Even under the above mentioned restrictions, the results indicate that core formation on accreting terrestrial protoplanets is dominated by the largest impactors. It is a very fast process on a timescale shorter than 0.1 Ma.