Rheological controls on the terrestrial core formation mechanism

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Knowledge about the terrestrial core formation mechanism is still very limited. The fracturing mechanism was proposed by [1] for cold central protocores surrounded by an iron layer, which develops from the overlying magma ocean. In this case the cold protocore is displaced from the centre of the accreting planet and fractured due to the large stresses, whereas the consideration of short-lived radioactive radioactive heating may result in warmer central regions and the preference of iron diapirism as core formation mechanism [2,3]. Until now most numerical models of core formation via diapirism were limited to the simulation of the sinking of a single diapir. We perform 2D spherical simulations using the code I2ELVIS applying the newly developed "spherical-Cartesian" methodology combining 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 [4]. In the model the planet is surrounded by a low viscosity (η = 10^{19} Pa s), massless fluid ("sticky air") to simulate a free surface [5]. We applied a temperature and stress dependent viscoplastic rheology inside Mars- and Earth-sized planets and included heat release due to radioactive decay. As initial condition we use randomly distributed diapirs with random sizes in the range 50 to 100 km radius inside the accreting planet, which represent the iron delivered by predifferentiated impactors. A systematic investigation of the diapir behaviour for different activation volumes and yield stresses is being performed, and results are being compared to the isotopic time scale of core formation on terrestrial planets. We show that the rheology controls which formation mechanism becomes dominant. We observe 3 major regimes of core formation: First a weak viscous protocore for low activation volumes and low yield stress, which is very similar to the already modelled diapirism. Second a plastic protocore for high activation volumes and low yield stress, which shows a mixture of diapirism and the fracturing mechanism even in warm planetary conditions. We find that the diapir sinking in this case may differ significantly from previous assumptions as we observe large asymmetries induced by a collective Rayleigh-Taylor like behaviour of neighbouring diapirs as suggested by [6], which leads to the formation of "convective channels". The final regime is the strong protocore, which develops an asymmetric iron layer surrounding the central part of the planet as described by [1]. It requires heating by radioactive decay and/or displacement of the central region towards the surface due to gravitational instability of the iron layer to allow for iron core formation [see also 7].

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