Geophysical Research Abstracts,
Vol. 11, EGU2009-2390-3, 2009
EGU General Assembly 2009

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 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]. 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 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 planet 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- and Earth-sized planets 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 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 Peierls 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.
Depending on the maximum Peierls stress, which is strongly dependent on the water content of olivine [Katayama and Karato, 2008], we observe different regimes of core formation: A weak planet develops for low Peierls stress, where we observe diapir sinking, which is very similar to already published core formation models [e.g. Ziethe and Spohn, 2007]. However for high Peierls stress a strong planetary interior forms. 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. They are controlled by spontaneously forming circular shear zones lubricated by shear heating. These phenomena favor a faster segregation of the iron and may have significant influence on geochemical signatures on dry accreted planetary bodies. They would allow for high temperature and pressure equilibration of the silicates with the metals without the need of a very deep global magma ocean.