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Towards self-consistent modelling of the Martian dichotomy: Coupled models of simultaneous core and crust formation

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One of the most striking surface features on Mars is the crustal dichotomy. The crustal dichotomy, a large difference in elevation and crustal thickness between the southern highlands and the northern lowlands, is the oldest geological feature on Mars. It was formed more than 4.1 Ga ago [Solomon et al., 2005; Nimmo and Tanaka, 2005; Frey, 2006] owing to either exogenic [e.g. Nimmo et al., 2008; Andrews-Hanna et al., 2008] or endogenic processes [e.g. Zhong and Zuber, 2001; Roberts and Zhong, 2006; Keller and Tackley, 2009].

Based on the geochemical analysis of SNC meteorites it was suggested that a primordial crust with up to 45 km thickness can be formed already during the Martian core formation [Norman, 1999]. The final accretion stage of terrestrial planets is based on stochastically distributed impacts [e.g. Chambers, 2004; Rubie et al., 2007]. Therefore we suggest that the sinking of iron diapirs, delivered by late pre-differentiated impactors, might have induced shear heating-related temperature anomalies in the mantle, which fostered the formation of early Martian crust. In this study, we examine parameter sets that will likely cause an onset of hemispherical low-degree mantle convection directly after, and coupled to, an already asymmetrical core formation.

To test this hypothesis we use a numerical model, where we self-consistently couple the formation of the Martian iron core to the onset of mantle convection and crust formation. We perform 2D spherical 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 Poisson equation for gravity potential in a self-gravitating planetary body. In this model, the planet is surrounded by a low viscosity, massless fluid ("sticky air") to simulate a free surface [Schmeling et al., 2008]. Previous studies showed that the convection patterns in the Martian mantle are highly dependent on its effective viscosity structure [e.g. Harder and Christensen, 1996; Keller and Tackley, 2009]. Therefore we apply a temperature, stress- and phase-dependent viscoplastic rheology inside a Mars-sized planet and include radioactive-, shear- and adiabatic heating. As initial condition we employ randomly distributed diapirs with 75 km radius inside the accreting planet, which represent the iron delivered by predifferentiated impactors. Additionally, we explore the effect of a giant impactor core on the planetary evolution. To self-consistently simulate the mineralogical phase changes expected inside a Mars-sized body, we employ the thermodynamical Perple_X database [Connolly, 2005].

First results indicate that both the presence of one large impactor core and viscosity layering due to phase-dependent rheology might induce low-degree convection already during core formation. Furthermore, the amplitude of shear heating anomalies generally well exceeds the solidus of primitive mantle material. Therefore the formation of a considerable amount of melt is to be expected. Since preliminary studies indicate that most heat is released at mid-mantle depth, some of the generated melt will segregate to the surface to form basaltic crust, whereas negatively buoyant melt from deeper sources will sink to the CMB. The depth of neutral buoyancy will be determined by the difference in compressibility of melt relative to solid silicates. Both the hemispherical asymmetry induced by a giant impactor as well as the low-degree pattern of convection caused by phase-dependent viscosity may therefore contribute to an early evolution of a dichotomous crustal thickness distribution.