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Core and early crust formation on Mars

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Abstract

One of the most striking surface features on Mars is the crustal dichotomy. It is the oldest geological feature on Mars and was formed more than 4.1 Ga ago by either exogenic or endogenic processes [5,4]. In order to find an internal origin of the crustal dichotomy, located within a maximum of 400 Ma of planetary differentiation, the thermal state of the planet resulting from core formation needs to be considered.

Additionally, it was suggested that a primordial crust with up to 45 km thickness can be formed already during the Martian core formation [6]. We suggest that the sinking of iron diapirs delivered by pre-differentiated impactors induced impact- and shear heating-related temperature anomalies in the mantle that fostered the formation of early Martian crust. Thus, the crustal thickness distribution would largely be a result of planetary core formation, late impact history and the onset of mantle convection. In this study, we examine parameter sets that will likely cause hemispherical asymmetry in both core formation and onset of mantle convection. To test this hypothesis we use numerical models to simulate the formation of the Martian iron core and the resulting mantle convection pattern, while peridotite melting is enabled to track melting caused by shear and radioactive heating.

We perform 2D simulations using the spherical-Cartesian code I2ELVIS [2] for planetary accretion and the spherical code STAGYY [3] for the consequent onset of mantle convection. We apply a temperature-, stress- and melt-fraction dependent viscoplastic rheology inside a Mars-sized planet.

Radioactive and shear heating as well as consumption of latent heat by silicate melting are taken into account. The depth of neutral buoyancy of silicate melt with respect to solid silicates is determined by the difference in compressibility of the liquid and solid phase. To self-consistently simulate the silicate phase changes expected inside a Mars-sized body, we use the thermodynamical database Perple_X [1]. As initial condition for core formation (I2ELVIS), we apply randomly distributed iron diapirs with 75 km radius inside the planet, representing the cores of stochastically distributed impactors. Additionally, we explore the effect of one giant impactor core on the planetary evolution. Results indicate that the presence of a large impactor core induces hemispherically asymmetrical core formation. The amplitude of shear heating anomalies often exceeds the solidus of primitive mantle material and thus, the formation of a considerable amount of silicate melt is observed.

The resulting temperature field after core formation is then read into the mantle convection code STAYY. The hemispherical magma ocean induced by one late giant impactor favours a dichotomous crust formation during and shortly after core formation. Afterwards, the extraction of excess heat produced by the sinking of the giant impactor through the mantle leads to a localized region of massive magmatism, comparable to Tharsis, which is sustained during later evolution by a single plume forming beneath the province. The rest of the mantle is dominated by a sluggish convection pattern with limited crust formation that preserves the early formed dichotomous crustal structure until recent time.

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