EPSC Abstracts,
Vol. 4, EPSC2009-71, 2009
European Planetary Science Congress,

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

G.J. Golabek (1), T. Keller (1), T.V. Gerya (1) and J. Connolly (2)

(1) ETH Zürich, Institute of Geophysics, Zürich, Switzerland (gregor.golabek@erdw.ethz.ch), (2) ETH Zürich, Institute for Mineralogy and Petrology, Zürich, Switzerland

Abstract

One of the most striking surface features on Mars is the crustal dichotomy, a large difference in elevation and crustal thickness between the southern highlands and the northern lowlands. The dichotomy is among the oldest geological features on Mars and 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; Marinova et al., 2008] or endogenic processes [e.g. Harder and Christensen, 1996; Zhong and Zuber, 2001; Roberts and Zhong, 2006; Keller and Tackley, 2009]. 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.

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]. Therefore we suggest that the sinking of iron diapirs delivered by pre-differentiated impactors 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 hemispherically 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. Peridotite melting is enabled to track melting and crust formation caused by heat released from core formation and radioactive heating.

We perform 2D spherical simulations using the code I2ELVIS applying the recently developed "spherical-Cartesian" methodology [Gerya and Yuen, 2007]. It combines finite differences on a fully staggered rectangular Eulerian grid with Lagrangian marker-in-cell technique to solve momentum, continuity and temperature equations as well as the Poisson equation for gravity potential in a self-gravitating planetary body. In our model setup, 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 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 employ the thermodynamical Perple_X database [Connolly, 2005]. As initial condition, we employ randomly distributed iron diapirs with 75 km radius inside the planet, representing the cores of stochastically distributed impactors characteristic for the late accretion stage of terrestrial planets [e.g. Chambers, 2004; Rubie et al., 2007]. 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. Furthermore, the amplitude of shear heating anomalies generally well exceeds the solidus of primitive mantle material. The formation of a considerable amount of silicate melt is observed. Some of the generated melt segregates to the surface to form primordial crust, whereas negatively buoyant melt from deeper sources sinks to the CMB. The hemispherical asymmetry in temperature induced by a giant impactor works in favour of an onset of low-degree mantle convection after core formation. Such a hemispherical convection geometry might

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subsequently be sustained by phase-dependent viscosity [Keller and Tackley, 2009], and thus harbour an early development of a dichotomous crustal thickness distribution.

Figure 1: Europlanet logo