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Thermo-chemical evolution of a one-plate planet: application to Mars

A.-C. Plesa (1,2) and D. Breuer (1)

(1) German Aerospace Center (DLR), Institute of Planetary Research, Berlin, Germany (ana.plesa@dlr.de), (2) Westfälische Wilhelms-Universität Münster, Institute of Planetology, Münster, Germany

Little attention has been devoted so far to find a modelling framework able to explain the geophysical implications of the Martian meteorites, the so-called SNC meteorites. Geochemical analysis of the SNC meteorites implies the rapid formation, i.e. before $\sim$4.5 Ga, of three to four isotopically distinct reservoirs that did not remix since then [3]. In [4] the authors argue that a fast overturn of an early fractionated magma ocean may have given origin to a stably stratified mantle with a large density gradient capable to keep the mantle heterogeneous and to prevent mixing due to thermal convection. This model, albeit capable to provide a plausible explanation to the SNC meteorites, suggests a conductive mantle after the overturn which is clearly at odds with the volcanic history of Mars. This is best explained by assuming a convective mantle and partial melting as the principal agents responsible for the generation and evolution of Martian volcanism.

In this work, we present an alternative scenario assuming a homogeneous mantle and accounting for compositional changes and melting temperature variations due to mantle depletion, dehydration stiffening of the mantle material due to water partitioning from the minerals into the melt, redistribution of radioactive heat sources between mantle and crust and thermal conductivity decrease in crustal regions. We use the 2D cylindrical - 3D spherical convection code Gaia [1, 2] and to model the above mentioned effects of partial melting we use a Lagrangian, particle based method. Simulation results show that chemical reservoirs, which can be formed due to partial melting when accounting for compositional changes and dehydration stiffening, remain stable over the entire thermal evolution of Mars. However, an initially depleted (i.e. buoyant harzburgite) layer of about 200 km is needed. This depleted layer in an otherwise homogeneous mantle may be the consequence of equilibrium fractionation of a freezing magma ocean where only the residual melt rises to the surface. If the heat released by accretion never allowed for a magma ocean to build, a large amount of partial melting of about 20% in the earliest stage is required to form such a buoyant layer. These models show an active convective interior and long lived partial melt production, which agrees with the volcanic history of Mars [5].

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