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How to build stable geochemical reservoirs on Mars?

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To explain the complex thermo-chemical processes needed for the formation of distinct and stable geochemical reservoirs early in the thermo-chemical evolution of Mars, most geochemical studies argue that fractional crystallization of a global magma ocean may reproduce the isotopic characteristic of the SNCs [1, 2]. However, geodynamical models show that such scenario is difficult to reconcile with other observations like late volcanic activity and crustal density values as obtained from gravity and topography modelling [3, 4]. The stable density gradient, which establishes after the mantle overturn has completed, inhibits thermal convection. Albeit capable to provide stable reservoirs, this scenario suggests a conductive mantle after the overturn which on the one hand fails to sample deep regions of the mantle and on the other hand 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. Therefore, in this work an alternative scenario for the formation of early stable geochemical reservoirs is presented similar to the model of [5].

We investigate the influence of partial melting on mantle dynamics, crustal formation, and volcanic outgassing of a one-plate planet using a 2D mantle convection code. When melt is extracted to form crust, the mantle material left behind is more buoyant than its parent material and depleted in radioactive heat sources. The extracted heat-producing elements are then enriched in the crust, which also has an insulating effect due to its lower thermal conductivity compared to the mantle. In addition, partial melting can influence the mantle rheology through the dehydration (water depletion) of the mantle material by volcanic outgassing. As a consequence, the viscosity of water-depleted regions increases more than two orders of magnitude compared to water-saturated rocks resulting in slower cooling rates. The most important parameter influencing the thermo-chemical evolution is the assumed density difference between the primitive and the depleted mantle material (i.e. between peridotite and harzburgite). With small or negligible values of compositional buoyancy, crustal formation including crustal delamination is very efficient, also resulting in efficient processing and degassing of the mantle. The entire convecting mantle below the stagnant lid depletes continuously with time. In contrast, with increasing compositional buoyancy, crustal formation and mantle degassing are strongly suppressed although partial melting is substantially prolonged in the thermal evolution. The crust shows strong lateral variations in thickness, and crustal delamination is reduced and occurs only locally. Furthermore, two to four different mantle reservoirs can form depending on the initial temperature distribution [6]. Some of these reservoirs can be sustained during the entire evolution whereas others change with time - a scenario possibly valid for Mars as it may explain the isotope characteristic of the Martian meteorites.

References:
[1] Elkins-Tanton et al., 2005, EPSL; [2] Debaille et al., 2009, Nature; [3] Tosi et al., 2013, JGR; [4] Plesa et al., submitted to EPSL; [5] Ogawa and Yanagisawa 2011, JGR; [6] Plesa and Breuer, 2013, PSS.