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Chemical heterogeneities in the interior of terrestrial bodies

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Mantle chemical heterogeneities that can strongly influence the interior dynamics have been inferred for all terrestrial bodies of the Solar System and range from local to global scale. Seismic data for the Earth, differences in surface mineral compositions observed in data sets from space missions, and isotopic variations identified in laboratory analyses of meteorites or samples indicate chemically heterogeneous systems. One way to generate large scale geochemical heterogeneities is through the fractional crystallization of a liquid magma ocean. The large amount of energy available in the early stages of planetary evolution can cause melting of a significant part or perhaps even the entire mantle of a terrestrial body resulting in a liquid magma ocean. Assuming fractional crystallization, magma ocean solidification proceeds from the core-mantle boundary to the surface where dense cumulates tend to form due to iron enrichment in the evolving liquid. This process leads to a gravitationally unstable mantle, which is prone to overturn. Following cumulate overturn, a stable stratification may be reached that prevents efficient material transport. As a consequence, mantle reservoirs may be kept separate, possibly for the entire thermo-chemical evolution of a terrestrial body. Scenarios assuming fractional crystallization of a liquid magma ocean have been suggested to explain lavas with distinct composition on Mercury's surface [1], the generation of the Moon's mare basalts by sampling a reservoir consisting of overturned ilmenite-bearing cumulates [2], and the preservation of Mars' geochemical reservoirs as inferred by isotopic analysis of the SNC meteorites [3]. However, recent studies have shown that the style of the overturn as well as the subsequent density stratification are of extreme importance for the subsequent thermo-chemical evolution of a planetary body and may have a major impact on the later surface tectonics and volcanic history. The rapid formation of a stagnant lid that traps the uppermost dense cumulates close to the surface and prevents them from sinking into the mantle or the difficulty to initiate thermal convection because of the stable compositional gradient established after the overturn are difficult to reconcile with observations [4, 5].
More recent results show that the crystallization achieved upon solidification of a liquid magma ocean is considerably more complex than previously assumed. In fact, the onset of solid-state convection prior to complete crystallization of the mantle can efficiently reduce mantle chemical heterogeneities [5]. We thus conclude that mantle mixing may partly or even completely erase the effects of fractional crystallization well before complete solidification. Nevertheless, the subsequent differentiation caused by partial melting, may introduce additional heterogeneities between residual and primitive mantle that could explain compositional differences observed over the surface of terrestrial bodies [6].

References:
[1] Charlier et al., 2013, EPSL; [2] Elkins-Tanton et al., 2011, EPSL; [3] Elkins-Tanton et al., 2005, JGR; [4] Tosi et al., 2013, JGR; [5] Plesa et al., 2014, EPSL; [5] Maurice et al, 2015, EGU; [6] Plesa & Breuer, 2014, PSS.