Mantle Dynamics, Early Reservoir Formation and Degassing of the Martian Interior. D. Breuer, A.-C. Plesa, M. Grott, and A. Morschhauser, German Aerospace Center (DLR), Institute of Planetray Research, Rutherfordstrasse 2, 12489 berlin, Germany (doris.breuer@dlr.de).

Introduction: Volcanic outgassing of the martian interior via partial melting potentially influenced the thermo-chemical evolution and the early climate of Mars. Volatiles such as H_2O and CO_2 present in the mantle minerals are preferentially enriched in the liquid phase during melting. As a consequence, they will be extracted from the mantle during the crust formation process. Part of these volatiles will then be outgassed into the atmosphere through extrusive volcanism and part will remain in the lower crust.

The outgassing rates of water depend primarily on a factor describing the outgassing efficiency, the bulk mantle water content, and the local melt fraction in the magma source regions [1]. The outgassing rates of CO_2, instead, mainly depend on the mantle oxygen fugacity [1,2]. The latter also implies that for Mars the CO_2 content in the magma is a factor of about 10 less than for Earth and thus degassing is less efficient.

Based on simple thermo-chemical evolution models the water depletion in the martian mantle ranges between 50 and 80 % [1,3,4] with 50 % beeing the preferred model that can explain various observable on Mars such as the crustal formation history [1]. A strong water depletion is in particular possible for models showing efficient crustal delamination, i.e. when the lower basaltic crust changes into dense eclogite and sinks into the mantle. The released CO_2 content that is likely to be outgassed during the evolution of Mars amounts only to 0.6–1 bar CO_2 for an assumed mantle oxygen fugacity corresponding to one log10 unit above the iron–wustite buffer [1,2].

It is, however, important to note that these parameterized models imply that the mantle is homogeneous and thus homogeneously depleted in volatiles – inconsistent to the findings from SNC meteorites. The analysis of the ^{182}W – ^{142}Nd isotope and Re–Os systematics [5,6,7] suggest the early formation of distinct geochemical reservoirs that have been maintained separate over the entire thermo-chemical evolution of the planet.

Here we present a 2D convection model that goes beyond the parameterized evolution models as local effects of melting and volatile depletion can be accounted for and that may further explain the suggested early reservoir formation.

Reservoir formation and the distribution of volatiles: Two important effects due to partial melting are 1) the formation of a buoyant residual layer depending on the density difference between the primitive and the depleted mantle material (i.e., between peridotite and harzburgite) and 2) the increase of the mantle rheology through the dehydration (water depletion) of the mantle material: the viscosity of water-depleted regions increases more than two orders of magnitude compared to water-saturated rocks resulting in slower cooling rates. Accounting for these effects in a 2D cylindrical convection model with Mars-like parameters [8], the general findings can be summarized as follows:

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 as shown in the paramterized convection models [1,3,4]. The convecting mantle below the stagnant lid depletes continuously with time.

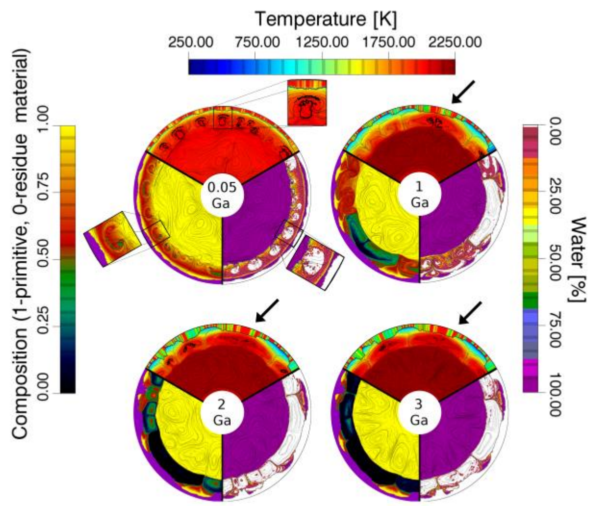

Fig. 1: Temperature, composition (mantle depletion) and water content distribution during the thermal evolution, for a scenario, where a density difference of 60 kg/m^3 between primitive and depleted (processed) mantle material was used. The arrows indicate the location of a stable upwelling in the upper depletd mantle.

Considering compositional buoyancy and dehydration stiffening, crustal delamination decreases strongly, and it further changes from global to local scale. As a consequence, the efficiency of mantle degassing and thus the formation of an atmosphere is reduced – the degassing rate decreases with increasing density difference between primordial and depleted mantle material. Furthermore, a two-layered mantle can develop with an upper buoyant mantle depleted in radioactive elements and volatiles and a lower mantle of almost primordial composition. Plumes rise from the interface between the two mantle layers, and thereby primordial material from the lower mantle is entrained into the upper mantle (see Figure 1).

The larger the assumed density difference between primitive and depleted mantle layer, the thinner remains the depleted upper mantle and the less crust is produced during the entire evolution. The stiff and buoyant upper mantle layer thermally isolates the interior, and due to the associated slow cooling of the mantle, partial melting can persist for a substantial time period in the evolution.

The upwellings in the depleted upper mantle layer are very stable and produce strong lateral variations in the crustal thickness. Crustal production is even further enhanced in regions of thickened crust due to the insulating effect of its lower thermal conductivity.

Conclusions: The results support the previous finding [1,3] that mantle degassing is likely to be insufficient for an appreciable greenhouse effect in the early evolution of Mars and the hypothesis that rather than being warm-and-wet, the martian climate was probably cold-and-wet. Furthermore, it suggests a layered mantle structure with a depleted upper mantle (depleted in crustal compounds and volatiles) and a lower primordial mantle that still contains a substantial amount of water. A third layer consisting of ecologite, i.e. delaminated basaltic material, may also exist at the bottom of the core mantle boundary. The proposed model provides a scenario for the reservoir formation as suggested by a recent analysis of the SNC meteorites [9]. It is therefore an alternative to the proposed scenario of the fractional magma ocean crystallization that predicts early formed mantle reservoirs as a consequence of a magma ocean overturn resulting in a stable mantle stratification [e.g.,10,11]. This magma ocean model, however, lacks to explain the subsequent thermal evolution of the planet [12,13].

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