Water Partitioning into the Martian Mantle during Accretion of Mars

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According to the latest analyses of Martian meteorites, the early Martian mantle was possibly wet with the H_2O concentration to be 780 ~ 2870 ppm (McCubbin et al., 2012). This estimate is equivalent to about 0.3~1 times the Earth ocean mass (~1.4×10^{21} kg) in the whole Martian mantle. Because of the lack of plate tectonics on Mars, water is likely to be partitioned to the interior during accretion of Mars. A planetary-scale magma ocean produced by the accretion energy and/or the blanket effect of the proto-atmosphere possibly absorbs a vast amount of water. However, it remains an open question how such a magma ocean could be formed on accreting Mars.
The precise Hf-W chronology suggests that the growth of Mars had been almost completed within the first several Myr after the formation of CAI (Dauphas and Pourmand, 2011: Tang and Dauphas, 2013), which is consistent with the theoretical estimate for the formation time of proto-planets. During such rapid accretion, a proto-Mars might gravitationally keep both degassed component and the solar nebula component as a proto-atmosphere. We call this atmosphere hybrid-type proto-atmosphere.
In this study, we analyze the thermal structure of hybrid-type proto-atmosphere by developing a 1D radiative-equilibrium model. Here we take into account the effect of the possible reduction of solar nebula pressure during accretion, taking the original nebula pressure at the Hill sphere to be 6.9×10^{-2} Pa (p_0) (Kusaka et al., 1970) and the minimum nebula pressure to be $10^{-12}\times p_0$. The accretion time is varied from 1 to 6 Myr so as to meet the chronological constraints. The building blocks of Mars is modeled by applying the two-component model (Wanke and Dreibus, 1988), which contains 35% of volatile-rich, oxidized CI chondritic material and 65% of volatile-poor, reduced E chondritic material. Impact degassing occurs for the planetesimal impacts with sufficiently high velocity as the growing Mars exceeds 0.1 times the final mass. Degassed volatile has a composition determined by the chemical equilibrium with molten silicate and metal produced by impact shock heating. Degassed component is assumed to occupy the lower atmosphere below the hydrogen-helium upper atmosphere continued to the solar nebula at the Hill radius.We solved the evolution of hybrid-type atmosphere with the growth of a proto-Mars. Independent of accretion time and nebula dissipation timescale, the proto-atmosphere is so massive and hot enough to produce the magma ocean during the last half stage of accretion. In the case without nebula dissipation, the surface pressure exceeds the solidus temperature 1500K of rock as the proto-Mars has grown larger than 0.3 times the final mass, and the surface pressure reaches ~2000bar at the end of accretion. On the other hand, in the case of lowered nebula pressure, the beginning of surface rock melting delays until the proto-Mars becomes larger than ~0.6 of its final mass due to the partial loss of degassed component to space, but the surface pressure still reaches ~ 800bar at the end of accretion. The amount of water partitioned into the magma is estimated to be ~9.6×10^{20} kg or larger. This value is equivalent to ~0.7 Earth ocean mass, which is basically consistent with the petrological evidence.

Keywords: Early Mars, Magma Ocean, Wet mantle

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