Stability of atmospheric redox states of early Mars inferred from time response of the regulation of H and O losses

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Atmospheric losses including escapes to space and depositions to the surface play an essential role in the evolution of the Martian surface environment. Especially, a ratio of total losses of hydrogen and oxygen from the atmosphere is crucial to determine its atmospheric redox state. In the condition that H and O losses originate from H_2O, an atmospheric redox state remains the same if the ratio is 2:1, otherwise it is driven into oxidizing or reducing. It was shown by McElroy. (1972) that Jeans escape flux of H and H_2 and nonthermal escape flux of O were regulated to be in the ratio of 2:1 in a converged model of present-day Mars, which is called "self-regulation". Whether or not the self-regulation works in real atmospheres depends on its timescales, but time responses of the self-regulation are not well understood in different atmospheric conditions.
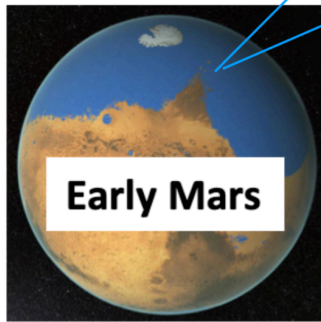
Here we study time responses of the self-regulation in different atmospheric conditions and discuss the stability of atmospheric redox states. We use a 1D time-dependent photochemical model for various atmospheric conditions and parameters, such as atmospheric CO_2 pressure, surface temperature and O escape rate.

We find that the self-regulation timescale is essentially controlled by the net redox balance (pO_x [mbar] = $2pO_2 - pCO - pH_2$) in a converged state. The timescale gets longer as $|pO_x|$ increases, which suggests that redox-neutral atmospheres have the shortest timescale. We also find that the self-regulation can be classified into two regimes. First regime is the same as the one explained by Liu and Donahue. (1976), which tends to work in oxidizing atmospheres ($pO_x > 0$) including present-day Mars in a way that H escape changes to reach the regulated state following a change in H_2 transportation from the lower to upper atmosphere. Second one is likely to work in thicker and reducing atmospheres ($pO_x < 0$) over a relatively long timescale. The regulation occurs dominantly by changes in CO abundance in the lower atmosphere. These results imply that thicker atmospheres in early Mars are less redox-stable than present-day Mars. Our model calculations also indicate that CO-dominated atmosphere of about 100 mbar might be possible around 3 Ga. We finally discuss the redox stability of H_2-rich CO_2 atmosphere of early Mars.

Keywords: Mars, Photochemistry model, Atmospheric escape, Habitability, Water loss process

- MIS07-04 -

How did H_2O on early Mars go away?

H : O = 2 : 1 ?

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Early Mars

Credits: NASA/GSFC

Current Mars

Credits: NASA