EVOLUTION OF THE MARTIAN SURFACE PRESSUE: IMPLICATIONS FOR THE PLANETARTY SURFACE ENVIRONMENT

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ABSTRACT

The evolution of the Martian surface pressure is important in respect to long-time stability of liquid water during the planets history. Further, due to a denser humid CO_2 atmosphere, photochemical processes may produce a protecting O_3 layer for organic matter and UV based reactions on Martian minerals. The time variation of the surface pressure is influenced by atmospheric loss processes of heavy neutral and ionized particles like molecular CO and CO_2 or other atomic constituents caused by the solar wind interaction with atmospheric constituents above the Martian ionopause, as well as photochemical processes and chemical weathering with the surface. We present preliminary results, which focus on atmospheric erosion processes for determining the time-evolution of equivalent partial pressures of O, CO, and CO_2 and the total Martian surface pressure. Further we discuss also the implications for the planetary surface environment and exobiology.

1. MASS LOADING

To evaluate the time evolution of the efficiency of ionized CO_2 and CO molecules from the Martian atmosphere into the solar wind plasma flow around the planetary obstacle (ionopause) we present a simple idealized model, neglecting finite ion gyroradii and nonspherical ionopause geometry. Mass loss of the molecules can be visualized by assuming that the planetary ions with mass density ρ_i above the ionopause produced by photoionisation, electron impact ionisation and charge exchange are incorporated into the solar wind flow constraint by a mass loading limit [1]. The rate of change of atmospheric mass M_a can be expressed as:

$$\frac{dM_a}{dt} = \frac{d\rho_n}{dt} V , \qquad (1)$$

where V represents the interaction volume consisting of a hemispherical shell whose inner radius is the ionopause radius R_{ip}, while its outer radius lies one atmospheric scale height above ($R_{ip}+H$). The change of neutral gas into ions proceeds with an ionization frequency J so that $d\rho_n/dt=-J\rho_n$ and the steady state condition requires that $J\rho_n=div(\rho_i v_i)\approx \rho_i v_i/H$ where v_i is the ion velocity, which is << v_{sw} Momentum balance considerations between the solar wind and the ionized constituents lead to

$$\frac{d\rho_n}{dt} \approx -\rho_{sw} \frac{(v_{sw} - v_i)}{H} . \qquad (2)$$

Thus, the ion mass loss rate can be written as

$$\frac{dM_a}{dt} = -\frac{K(\rho v)_{sw} V}{H} \approx -2\pi K(\rho v)_{sw} R_{ip}^2 , \qquad (3)$$

where K represents the so called mass loading limit defined by Michel in the order of about 1/3 [1]. By considering a steady-state situation, we modeled the plasma velocities in the Martian magnetosheath as a non-dissipative fluid which obeys the standard ideal MHD equation extended for mass loading processes [2].

2. OTHER NON-THERMAL LOSS PROCESSES

Atmospheric erosion on Mars due to the occurrence of magnetohydrodynamic (MHD) plasma instabilities at the ionopause and ionospheric particle acceleration to velocities > v_{esc} due to momentum transfer (MT) below the ionopause can remove mainly O^+ ions, which may have its origin mainly from dissociation of H_2O vapour but not from atmospheric CO or CO_2. Particle sputtering, however can also remove CO and CO_2

molecules, so that this process will contribute to the pressure loss of the atmosphere during the Martian history [3]. Because ion pick up and sputtering depend on the solar wind mass flux which was higher in the Martian past we use for the solar wind parameters an observation-based reconstruction from solar-like stars with various ages from [4] for obtaining the evolution of the pressure loss over the planets history.

3. EVOLUTION OF THE SURFACE PRESSURE

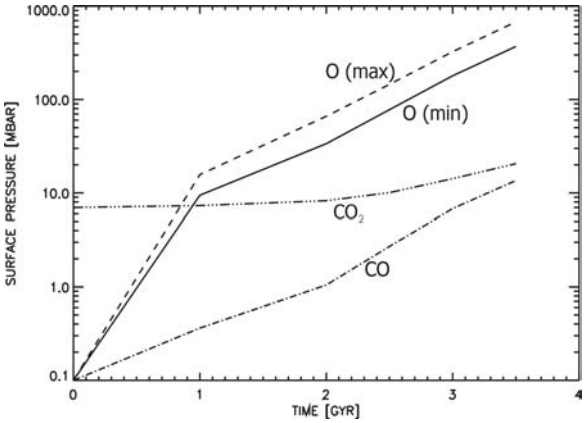

Fig. 1. Equivalent partial pressures of O, CO, and CO_2. max: escape rates due to MT are included; min: escape rates due to MT are not considered.

The solid and dashed lines in Fig. 1 are related to O, which may be equivalent to H_2O lost from Mars. One should note that the equivalent pressure value for O in Fig.1 was never in such an amount in the atmosphere but an estimation of the sublimation rate of the H_2O vapour averaged over the Martian surface from the subsurface and H_2O-ice reservoirs indicate that it should be no problem that an amount of an equivalent pressure up to 700 mbar as estimated as max in our study could have been lost from the atmosphere to space between the time period of about 2 – 3.5 Gyr ago. The low CO_2 surface pressure obtained from CO_2 loss rates as shown in Fig. 1 indicates that the Martian atmosphere was transparent to dangerous solar UV radiation during much of its history, and impact erosion as well as CO_2 weathering into the Martian surface may have been the main atmospheric loss process before 3.5 Gyr ago, since ion pick up and sputtering may have removed CO_2 and CO from the Martian atmosphere only to an amount of about 30 to 40 mbar compared to the present surface pressure level of about 7 mbar during the past 3.5 Gyr. However, at least a 114 mbar CO_2 atmosphere is needed 4 Gyr ago for the explanation of the Martian $^{15}N/^{14}N$ isotope ratios [e.g. 5]. However, even a 114 mbar CO_2 atmosphere would not produce photochemically a significant protective O_3 layer 4 Gyr ago as it may be the case in a 1 bar humid CO_2 atmosphere [6]. Further, recent Mars Odyssey data revealed that only ≈ 0.36 mbar CO_2 may be stored in the ice of the polar caps, which could have contributed to the surface pressure due to out gassing during warmer periods. Since Mars was protected by solar wind erosion by an intrinsic magnetic field before 3.5 Gyr and one does not reach a surface pressure of at least 114 mbar 4 Gyr ago impact erosion may also have played an important role between 3.5 - 4 Gyr but with its major efficiency before 4 Gyr ago.

4. CONCLUSION

Our study suggests that Mars may have lost its dense CO_2 (≥1bar) atmosphere and more Earth-like "habitability" before 4 Gyr ago. Thus, our results indicate a very short time period (≤ 500 Myr) for stable H_2O, UV surface protection and the possible evolution of microbial life forms. We suggest that future studies should focus in more detail on processes, which can remove CO_2 from the atmosphere into the surface.

ACKNOWLEDGEMENTS

H. L., G. K., H. K. B., and N. E. acknowledge the support by the Austrian Academy of Sciences, "Verwaltungsstelle für Auslandsbeziehungen", and by the Hungarian and Russian Academy of Sciences.

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