# Constraints on atmospheric pressure on early Mars inferred from nitrogen and argon isotopes

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Geomorphological evidence such as valley networks and deltas on Mars requires repeated episodes of liquid water runoff in the Noachian period. A dense atmosphere possibly caused water-ice being transported to the highlands. Fluvial terrains can be created by episodic melting events of ice under such conditions [1]. The dense atmosphere was lost from Mars, but the mechanism and timing are poorly constrained.

We constructed a one-box atmosphere-hydrosphere model with multiple species ($CO_2$, $N_2$, $H_2O$, and noble gases). We calculated the evolution of the volume and isotopic composition of the Martian atmosphere taking into consideration several processes, including impacts of asteroids and comets, atmospheric escape induced by solar radiation and wind, volcanic degassing, and a gas emission from interplanetary dust particles. A threshold for the atmospheric collapse (0.3 bar) was assumed following recent 3D global-circulation-model simulations [e.g., 2]. Comparing our results with nitrogen and argon isotopic compositions at 4.1 Ga recorded in Allan Hills (ALH) 84001 provided a lower limit of the atmospheric pressure on early Mars.

Since impacts mainly contribute to the evolution of atmosphere during the late accretion at 3.5-4.5 Gyr ago, the atmospheric pressure evolved stochastically for the first ~1 billion years. The atmospheric evolution depends on the volatile abundances in the impactors. In cases where relatively volatile-poor impactors were assumed, the impact erosion prevailed over the injection of volatiles and the atmospheric collapse occurs during this period.

Whereas the nitrogen ($^{15}N/^{14}N$) and argon ($^{38}Ar/^{36}Ar$) isotopic ratios kept unfractionated values before the collapse, they increased stochastically after the collapse. Impacts of asteroids and comets in a thinner atmosphere increased abundances of nitrogen and argon. It resulted in higher escape rates of these species and subsequently increased their isotope ratios. The cases of a moderately dense atmosphere (> 0.3 bar) at 4.1 Ga are consistent with unfractionated nitrogen and argon isotope ratios recorded in ALH 84001 [3]. This lower limit of the atmospheric pressure is valid regardless of the presence/absence of the Martian magnetic dynamo at 4.1 Ga because the atmospheric nitrogen was removed by photochemical escape driven by solar radiation.

The reported data on the trapped-nitrogen-isotope composition of ALH 84001 are highly scattered (~7 per mil to >200 per mil) in the literature. Identification of the actual nitrogen isotope ratio at 4.1 Ga would help to constrain the evolution of the Martian atmosphere.

Our results provided a lower limit of the atmospheric pressure at 4.1 Ga. If we combine our results with other constraints on the atmospheric pressure on early Mars [4], a moderately dense atmosphere (~0.1-1 bar) was suggested. We suggest that the moderately dense atmosphere was lost after 4.1 Ga by the impact erosion and the escape induced by solar radiation and wind.

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