

Constraining the Volatile Depletion History of Vesta and the Moon: Insights from Evaporation Modeling

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Differentiated rocky bodies in the inner solar system are typically volatile-depleted compared to the solar system's average composition, yet the mechanisms of volatile loss remain poorly understood. Vesta, a small differentiated asteroid, can serve as an analogue for embryos and planetesimals that contributed to terrestrial planet formation. Unraveling the origin of its volatile depletion provides insights into the thermal history of the early inner solar system and the chemical compositions of the building blocks of terrestrial planets. Similarly, the Moon, formed via a giant impact, shares a genetic relationship with the proto-Earth and/or giant impactor. While more volatile-depleted than the bulk silicate Earth, the Moon displays similar extents of depletion for a number of moderately volatile elements of variable volatility. Deciphering the origin of this depletion pattern on the Moon offers critical insights into the Moon's formation history.

Elemental volatility is governed by temperature, oxygen fugacity and the thermodynamic properties and compositions of condensed phases and volatile species. By correlating elemental volatility under specific conditions with the observed depletion patterns in differentiated planetary bodies, we can constrain environmental conditions responsible for volatile loss.

In this study, we reconstruct the volatile loss processes on Vesta and the Moon by identifying plausible conditions that best match their present volatile depletion patterns. We employ a computational model simulating the evaporative loss of a series of volatile elements using a Gibbs free energy minimization approach, incorporating a comprehensive dataset of activity coefficients derived from high-temperature experiments and theoretical modeling. To validate the model, we have conducted evaporation experiments under controlled temperature and oxygen fugacity and observe a good consistency between the experimental results and model-predicted evaporative loss. Applying the evaporative loss model to Vesta shows that its mantle composition can be explained by evaporation from an oxidized magma ocean ($\sim$ DIW0) followed by volatile addition from a late volatile-rich impactor. In the case of the Moon, we find that its volatile depletion pattern can be achieved in a relatively reduced ($\sim$ DIW-2) evaporation environment.