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Evolution of Volatile Composition on the Accreting Earth: Effects of Impact-induced Atmospheric Erosion and Element Partitioning

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Unveiling the sources of Earth's volatile elements is crucial to understanding the origins of atmosphere, oceans, and life. The volatiles in rocky planets are thought to have been delivered by chondritic materials. However, the elemental composition of the bulk silicate Earth (BSE) shows the depletion of carbon (C) and nitrogen (N) relative to hydrogen (H), a high C/N ratio, and a low C/H ratio compared to chondrites.
We study the effects of the elemental partitioning, impact-induced atmospheric erosion, and core segregation during and after the magma ocean stage on the volatile abundances of BSE. We modeled both the main accretion stage and the late accretion stage. The former considered the elemental partitioning between the atmosphere, magma ocean, and metal which segregates into the core. The latter considered the partitioning between the atmosphere, oceans, and carbonate (the crust). By calculating the evolution for the range of partitioning coefficient, solubilities, and impactor properties, we evaluated how the resulting volatile composition of BSE depends on these input parameters.
As a result, we succeeded to reproduce the elemental composition of major volatile elements in current BSE when we chose the appropriate parameter values. While the elemental fractionation during the main accretion ended up with the excess of N/C, the preferential loss of N from the atmosphere during the late accretion reproduced BSE's volatile pattern. The resulting BSE's composition depends on the impactor's size distribution: an impactor's size distribution with steeper slope leads to more effective atmospheric erosion than a shallower slope. The differences in solubilities and partitioning coefficients between elements also influence the results. We show these parameter dependences and discuss plausible accretion scenarios for Earth formation.