

Microscopic analysis of the oxygen ion irradiated Phobos analogue materials: Implications for space weathering processes on Martian moons

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Phobos and Deimos, the two moons of Mars, are both irregularly shaped, airless bodies that resemble asteroids. However, whether these moons are captured asteroids or formed in situ remains unknown. Understanding their origin is crucial in understanding the formation and evolution of the Martian system. To address this question is one of the scientific goals of the Martian Moons eXploration (MMX) mission, planned to be launched in 2026 and return Phobos samples to Earth in 2031 (Kuramoto et al., 2022). Previous studies have shown that surface materials of small bodies are altered by a mechanism called space weathering due to solar wind irradiation and micrometeoroid bombardments (e.g., Pieters and Noble, 2016). Recent observations of the plasma environment of Phobos by MAVEN revealed that, in addition to the solar wind, the surface of Phobos is bombarded by oxygen ions originating from the current Martian atmosphere (Neron et al., 2019). A previous study has investigated the effects of high-energy ($\sim$ keV) oxygen ion irradiation, reporting sputtering effects and their efficiencies (Szabo et al., 2020). However, lower-energy oxygen ions ($\sim$ eV) also compose a significant fraction of the irradiated flux (Neron et al., 2019; 2021), yet their effects on Phobos-candidate materials remain unexplored. Therefore, we developed an experimental apparatus capable of irradiating planetary analog materials with low-energy oxygen ions. We investigated the effects of oxygen ion exposure on vis/NIR/MIR reflectance spectra and Raman spectra, showing that oxygen ion space weathering is a unique alteration phenomenon characterized by the formation of Fe oxides or the depletion of organic components, processes not associated with the solar wind-induced space weathering (Tabata et al., JpGU 2024; Tabata et al., under review).

In this study, we aim to explore the fundamental processes of oxygen ion irradiation by conducting microscopic observations using Scanning Electron Microscope (SEM). Although we still do not understand the actual composition of Martian moons, understanding the fundamental mechanism of the alteration process would serve as a basic tool to interpret the observations by MMX and the analysis of the returned samples. We conducted microscopic observations and Electron Dispersive Spectroscopy (EDS) analyses on olivine, basalt, and Phobos simulant samples irradiated with oxygen ions in prior experiments. Preliminary results indicate a decrease in the Mg/(Fe+Mg) ratio in olivine, consistent with trends observed in the Raman spectroscopy analyses. However, several data points show deviated (Fe+Mg)/Si ratio from olivine, suggesting the formation of different mineral phases. Also, irradiated samples exhibited distinct morphological changes compared to unirradiated samples. The smooth surfaces typically found in the unirradiated olivine became coated with nm-sized particles, and in some observation fields, μ m-sized angular grains and pits/holes are observed. These observations provide direct evidence that oxygen ion irradiation chemically alters mineral surfaces. Furthermore, the effects of oxygen ion irradiation suggest a space weathering mechanism distinct from that induced by solar wind ions, implying that Martian moons have experienced a unique space weathering process, different from those observed on previously explored bodies such as Itokawa, Ryugu, and Bennu.

Keywords: Phobos, Mars, Space weathering, Laboratory experiment, SEM-EDS, MMX