

UNRAVELING SOLAR WIND SPACE WEATHERING OF CARBON-RICH ASTEROIDS: LOW-FLUX VS. HIGH-FLUX ION IRRADIATION OF MURCHISON

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Introduction: Space weathering processes alter the microstructural, compositional, and optical properties of airless planetary surfaces. Solar wind space weathering forms ion-damaged rims within the outermost ~100 nm of regolith grains through atomic-displacements and implantation of energetic H⁺ and He⁺ ions [1]. Transmission electron microscope (TEM) studies of space weathered Itokawa and lunar olivine particles reveal predominantly nanocrystalline solar wind-damaged rims with only minor regions of amorphization [2-5]. This finding differs from laboratory ion irradiation experiments in which samples become amorphous at fluences 2-3 orders of magnitude lower than the independently constrained fluences for still-crystalline natural samples [6-7]. Ion flux is generally considered to have a secondary effect compared to fluence in these irradiation experiments. However, solar wind irradiation of natural samples occurs at a flux that is ~4-5 orders of magnitude lower than what is used in laboratory simulations (e.g., [6,8-9]). Constraining how the very low ion flux of solar wind influences the microstructural, chemical, and spectral alteration of silicate minerals will improve our understanding of solar wind space weathering and aid in the analysis of returned samples from the Hayabusa2 and OSIRIS-REx missions. Here we report results from low- and high-flux ion irradiation experiments on the Murchison (CM2) meteorite with comparable total fluences.

Methods: We performed low-flux and high-flux He⁺ (4 keV) and H⁺ (1 keV) irradiation experiments on separate, dry-cut Murchison slabs. Low-flux He⁺ irradiation reached a total fluence of 2.1×10^{16} ions/cm² (~400 years of exposure at Bennu) using a flux of 3.6×10^{11} ions/cm²/s; low-flux H⁺ irradiation reached a total fluence of 3.9×10^{16} ions/cm² (~30 years) using a flux of 6.6×10^{11} ions/cm²/s. High-flux He⁺ irradiation reached a total fluence of 2.0×10^{16} ions/cm² (~400 years) using a flux of 9.1×10^{12} ions/cm²/s; high-flux H⁺ irradiation reached a total fluence of 5.8×10^{16} ions/cm² (~50 years) using flux of 8.4×10^{12} ions/cm²/s. By irradiating to similar total fluences in both the low-flux and high-flux experiments, we can better isolate and evaluate the effects of ion flux. Differences between unirradiated and irradiated surfaces are determined using three analytical techniques: (1) *in situ* X-ray photoelectron spectroscopy (XPS) reveals changes in surface chemistry, (2) visible to near-infrared spectroscopy (VNIR; 0.35-2.5 μ m) highlights changes in spectral trends, such as albedo and slope, and (3) TEM and energy-dispersive X-ray spectroscopy (EDS) identifies changes in nanoscale structure and elemental composition within olivine and matrix electron-transparent thin sections prepared using focused ion beam scanning electron microscopy (FIB-SEM).

Results and Discussion: XPS analyses of the low-flux and high-flux He⁺ and H⁺-irradiated samples show a minor reduction in surface carbon content and chemical reduction of Fe³⁺ to Fe²⁺. The latter result is consistent with the higher Fe²⁺/Fe³⁺ ratios observed in phyllosilicate-rich space weathered rims of Ryugu grains [10]. VNIR analyses suggest that the low-flux H⁺-irradiated spectrum has a slightly bluer slope (over 0.65-2.5 μ m) compared to the unirradiated VNIR spectrum from [9] while the low-flux He⁺-irradiated spectral slope is comparable to the unirradiated surface. Both the high-flux He⁺ and H⁺-irradiated VNIR spectra exhibit slightly higher albedos at shorter wavelengths relative to their unirradiated counterparts, with He⁺ irradiation yielding a greater change. Thus far, the low-flux He⁺-irradiated matrix and olivine FIB sections as well as the low-flux H⁺-irradiated olivine FIB section have been examined with TEM. The surfaces of all three samples show less vesiculation than high-flux/high-fluence irradiated matrix and olivine samples from [9]. The depth of phyllosilicate amorphization in the low-flux He⁺-irradiated matrix FIB section varies laterally, with crystalline domains occurring as shallow as ~25 nm in some regions. The low-flux He⁺-irradiated olivine FIB section has a continuous, ~40-90 nm thick ion-affected layer with polycrystalline and amorphous microstructures. The low-flux H⁺-irradiated olivine sample exhibits a distinct, ~10-40 nm ion-affected layer whose uppermost ~20 nm in thicker regions is predominantly amorphous. Continuing to compare results from this work to those from [9] will provide a comprehensive understanding of how ion flux impacts the microstructural, chemical, and optical modification of various mineral phases and, in turn, help identify space weathering features from parent body alteration in Hayabusa2 and OSIRIS-REx returned samples.

References: [1] Pieters C.M. & Noble S.K. (2016) *JGR* 121(10):1865-1884 [2] Keller L.P. & McKay D.S. (1997) *GCA* 61:2331-2341 [3] Keller L.P. & Berger E.L. (2014) *EPS* 66:71 [4] Noguchi T. et al. (2014) *MaPS* 49(2):188-214 [5] Thompson M.S. et al. (2014) *EPS* 66:89 [6] Carrez P. et al. (2002) *MaPS* 37:1599-1614 [7] Keller L.P. et al. (2021) *MaPS* 56(9):1685-1707 [8] Dukes C.A. et al. (1999) *JGR* 104(E1):1865-1872. [9] Lacznia D.L. et al. (2021) *Icarus* 364:114479 [10] Noguchi T. et al. (2022) *LPSC LIII*, Abs. # 1747.