

ANALYSIS OF MORPHOLOGICAL AND PHYSICOCHEMICAL CHANGES IN SPACE-WEATHERED HYDRATED SILICATES BY VISIBLE/IR SPECTROSCOPY AND ELECTRON TRANSMISSION MICROSCOPY

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Introduction: Airless bodies are subjected to a series of surface alteration processes known as space weathering. This includes solar wind ion and cosmic ray irradiation as well as micro-meteorite impacts [1]. These surface changes can complicate the interpretation of remote-sensing data, hindering the identification of an airless body's surface mineralogy and composition. To investigate this issue, space-weathering processes can be replicated on Earth in a laboratory. In this study, we simulated the effects of the solar-wind component of space-weathering on the surface of carbon-rich small asteroids, such as Ryugu and Bennu [2-3], by bombarding terrestrial hydrated silicates using He⁺ and Ar⁺. The ion-bombarded samples were first characterized using IR spectroscopy to probe the effects of space-weathering on spectroscopic surveys and remote-sensing data [4, 5]. The samples were then studied by electron microscopy and associated microanalysis to investigate morphological and physicochemical changes in the space weathered layer.

Materials and Methods: Our study was conducted on pellets made from crushed phyllosilicates terrestrial rocks, since hydrated silicates are the main constituents of CM- and CI- type chondrites [6], often used as analogs for Ryugu and Bennu [7, 8]. We chose three phyllosilicates, two serpentines with different Fe/(Fe+Mg) ratio and crystal lattice and an Fe-rich saponite. The pellets were subjected to ion-bombardment at the INGMAR-SIDONIE platform (IAS-IJCLab), under vacuum ($P \sim 10^{-7}$ mBar) using 40 keV He⁺ and Ar⁺ ions. The maximum reached fluences were 6.10^{16} ions/cm² for He⁺ and 2.10^{16} ions/cm² for Ar⁺. These corresponds to roughly 1000 to 10 000 years in the inner Solar System. Visible and IR spectroscopy measurements were acquired both under vacuum upon ion bombardment as the ion fluence increased, and ex-situ once the maximum fluence was reached. After spectral characterization, SEM images of the pellets surface were taken, followed by the extraction of FIB sections of the ion-bombarded layers. These FIB sections were then studied by STEM, acquiring HAADF images and EDS data, to probe both morphological and compositional changes in the ion-bombarded layers.

Results and Discussion: Spectroscopic measurements showed a variety of behaviors upon ion bombardment. Visible spectroscopy showed darkening for all He⁺ bombarded samples, coupled with reddening for both serpentines and blueing for the saponite. Visible trends for the Ar⁺ bombarded samples are less clear. IR spectroscopic measurements showed changes in the position, band area and band asymmetry of the bands at 2.7 μ m (hydration band (M)-OHs) and in the silicate spectral region ($\sim 10 \mu$ m), with one of the main changes being a position shift towards longer wavelength. STEM images and compositional data also showed a variety of behaviors, such as the presence of bubbles with varying shapes and sizes, localized in the ion-bombarded layers. EDS elemental quantification showed important chemical changes in the ion-bombarded layer, such as loss of oxygen – possibly linked to dihydroxylation affecting the silicate – as well as the emergence of a thin SiO₂-rich layer located at the surface of some samples. Magnesium depletion is also seen in multiple samples. Interestingly, no nanophase metallic iron (npFe0) has been detected in our samples.

Our analytical pipeline has highlighted spectroscopic changes as well as morphological and compositional changes upon ion-bombardment. We will discuss how these effects are related among themselves, to link nanoscale variations probed by electron microscopy to larger scale spectroscopic behaviors.

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