Dehydration and Solar Wind Ion Irradiation of Sodium and Ammonium Carbonates on the Surface of Main Belt Asteroids

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Abstract. Recent observations of dwarf planet Ceres by Dawn's visible-near-infrared imaging spectrometer (VIR) detected globally occurring ammoniated phyllosilicates as well as bright spots consisting of local scale enrichment in sodium (and/or other) carbonates. These observations suggest the occurrence of aqueous alteration processes and a possible origin outside 5 A.U[1,2,3]. Beyond the Earth, sodium carbonates are unusual in the solar system, only previously detected in the plumes of Enceladus[4]. The study reported here investigates the effects of the Ceres surface environment on the stability of carbonates due to 1) solar-wind-type ion irradiation, and 2) exposure to low pressure, as a proxy for Main Belt objects.

A Fourier-transform infrared-spectrometer (FT-IR) (λ = 0.6–15 µm) was used to perform in-situ bi-directional (0°, 30°) reflectance measurement of $Na_2CO_3\cdot 10H_2O$, Na_2CO_3, $(NH_4)_2CO_3$, and $NaHCO_3$ at low temperature (~110 K). Spectra were acquired prior to and following 4 keV He^+ irradiation at varied fluence, equivalent to ~300 - 30, 000 years at 3 A.U, as well as after subsequent exposure to H_2O vapor. Changes in molecular chemistry of each salt was also investigated by complementary X-ray photoelectron spectroscopy (XPS) measurements. Here we present reflectance measurements between λ = 0.2–2.5 µm for $Na_2CO_3\cdot 10H_2O$ and $NaHCO_3$ without ion irradiation that were also performed as a function of low pressure and exposure time, to quantify the dehydration rate and spectral effects under vacuum.

Irradiation experiments with nominal $Na_2CO_3\cdot 10H_2O$ show uniform, significant spectral darkening to ~30% of original brightness in the visible region 0.6 - 1.1 µm, and brightening of ~300% (at 2.5 µm) in near-infrared range (NIR) 1.2 - 2.5 µm after 10^{18} He^+/cm^2. After irradiation, subsequent exposure to H_2O vapor reverses both the visible darkening and NIR brightening. XPS measurements show loss of C and O, with concurrent Na surface enrichment (outermost ~5 nm), with He^+ irradiation. Exposure of $Na_2CO_3\cdot 10H_2O$ to vacuum (without irradiation) results in NIR brightening coincident with loss of H_2O absorption features, while strong reddening and darkening are observed in the UV-Vis with a conduction band inflection point around 0.6 µm. Similar measurements on nitrite and ammonium carbonate are underway.

For Ceres, solar wind darkening of vacuum-dehydrated Na_2CO_3 deposits in the visible spectrum is expected to occur on a timescale of ~1-10 thousand years, significantly less than the projected age of Occator crater ~20 Ma[3]. This ion-induced visible darkening can be completely reversed by exposure to water vapor. For Ceres' bright regions of varied albedo, this suggests that brightest areas are likely to be the most recent material deposits or the most recently exposed to water, potentially indicating the sublimation of sub-surface ice[5].

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