

HYDROUS SALTS ON PLANETARY SURFACES: LABORATORY MEASUREMENTS UNDER CONDITIONS RELEVANT TO CERES. C. Bu¹, G. Rodriguez Lopez¹, C.A. Dukes¹, L.A. McFadden², J-Y. Li³, and O. Ruesch² ¹University of Virginia (Laboratory for Astrophysics and Surface Physics, Materials Science and Engineering, Charlottesville, VA 22904; cb8nw@virginia.edu; gr3dw@virginia.edu; car8r@eservices.virginia.edu); ²NASA Goddard (NASA/GSFC, Mail Code: 693, Greenbelt, MD 20771; lucyann.a.mcfadden@nasa.gov; ottaviano.ruesch@esa.int); ³Planetary Science Institute (1700 E. Ft. Lowell Rd., Tucson, AZ 85719; [jyli@psi.edu](mailto: jyli@psi.edu)).

Introduction: Cerealia Facula within Occator crater (19.4°N, 239.0°E), the largest and brightest region on Ceres, has a geometric albedo of ~5x brighter than the average Ceres geometric albedo in the visible wavelengths [1–3]. With increasing distance from the central dome, the reflectivity gradually decreases, and the spectral slope (within 0.45–0.98 μm) changes from positive (red) to almost zero, based on Dawn’s Framing Camera (FC) measurements [1,4]. Dawn’s Visible Near-Infrared Mapping Spectrometer (VIR) measurements, particularly within Cerealia Facula, confirm the presence of anhydrous sodium carbonate (Na₂CO₃, natrite), evidencing aqueous alteration at Ceres [3]. Hydrated salts are expected to form from the sub-surface aqueous alteration, subsequently deposited on the dwarf-planet surface by either brine fountaining or as precipitates with sublimating water [5]. However, VIR detects no water signature.

In this work[6], we determine the inherent stability and correlated spectral effects of emplaced hydrous sodium carbonates, as well as anhydrous carbonates, exposed to Ceres’ surface environment. Laboratory characterization of the spectral modifications resulting from exposure to the cryogenic, airless conditions existent on Ceres is particularly important for spectral matching and mineralogical identification.

Experiment: Na₂CO₃·10H₂O (natron) powder samples (45–83 μm grains) were prepared in a cold room (T = 277 K), transported in a cooler with dry-ice (T = 195 K), and stored in a refrigerator at 266 K. Subsequent X-ray powder diffraction (XRD) analysis and spectral measurements confirmed that sample preparation resulted in no significant modification to the composition and crystallographic structure. Reflectance measurements were acquired using a Perkin Elmer Lambda-1050 spectrometer, coupled with a Harrick Praying Mantis (PM) diffuse reflectance accessory. The sample powders were loaded into a temperature-controlled sample cup within a low-temperature reaction chamber (LT-RC). Then the LT-RC was evacuated to ~10⁻³–10⁻⁵ Torr (≈10⁻⁶–10⁻⁸ Earth atmosphere), and *in-situ* time-sequenced spectra (wavelength λ = 0.22–2.50 μm; resolution Δλ = 4 nm) were taken every 5 minutes. Spectral measurements were performed at 240, 200 and 122 K, approximating Ceres’ maximum, and typical equatorial daytime and nighttime surface temperatures, respectively [7,8]. Samples were ‘flash-

frozen’ prior to the chamber evacuation to retain hydration [9]. The spectrometer, PM, and LT-RC were all purged with dry-N₂ during target cooling to eliminate condensation of ambient water vapor onto the optics or samples. Relative reflectance spectra were normalized and corrected for instrumental error using the ratio of the data to the spectrum for a PTFE powder standard.

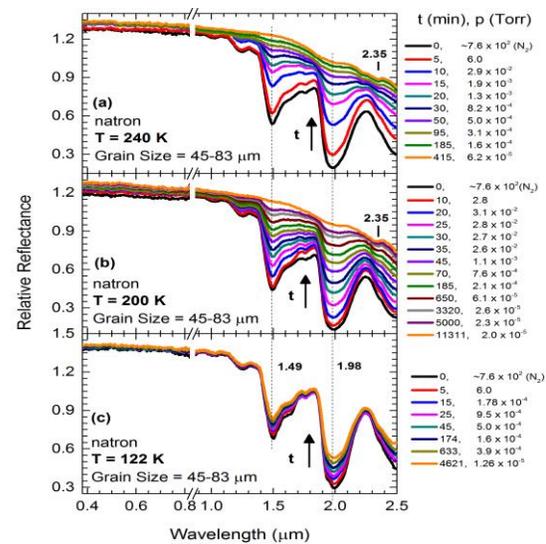


Figure 1. Dehydration of natron (Na₂CO₃·10H₂O) due to low pressure at (a) 240 K, (b) 200 K, and (c) 122 K, alternating the spectral signatures by attenuation of the water bands at ~1.49 and 1.98 μm and enhancement of the carbonate signature at ~2.35 μm.

Results: Incorporated-water-molecule loss occurs instantaneously with low-pressure exposure, altering natron’s spectral signature by attenuation of the water bands (~1.49 and 1.98 μm), enhancement of carbonate features (~2.35 μm), and brightening > ~1.4 μm (Fig. 1). The water absorption features of natron reduce below VIR’s detection limit (< 2%, area of the 1.98-μm water band with respect to natron prior to vacuum-exposure) within a time scale of <6 days at 200 and 240 K. At 122 K, natron retains water longer, depleting the water band to < 2% within ~300 years, derived from an Avrami dehydration model.

Concurrent with the dehydration at 240 and 200 K, a temperature-dependent systematic shift of the 1.98-μm water-band center (position of the minimum) toward shorter wavelengths was observed; no shift was noted

for the duration of experiment at 122 K, due to the attenuated dehydration rate (Fig. 2a). Dehydration of natron also results in a reduction of the blue slope over 1152–2200 nm, but no significant spectral changes in the visible range (452–752 nm) (Fig. 2b).

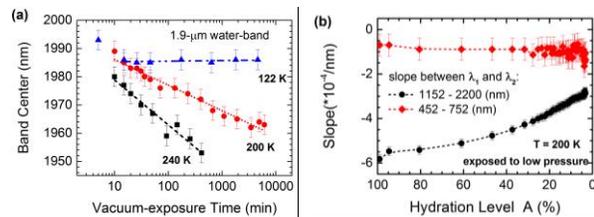


Figure 2. (a) A temperature-dependent systematic shift of the 1.98- μm water-band center toward shorter wavelengths for natron under vacuum exposure. (b) Vacuum-induced dehydration of natron results in reduction of the near-infrared blue slope but no significant change in the visible range.

Extended vacuum-exposure of natron *after dehydration*, or of anhydrous Na_2CO_3 , results in no further spectral changes in the NIR or visible range, but enhanced UV absorption, with the absorption edge shifting toward longer wavelengths (from ~ 0.22 to $0.34 \mu\text{m}$ over ~ 13 days), and gradual formation of two new features at ~ 235 and 275 nm are observed.

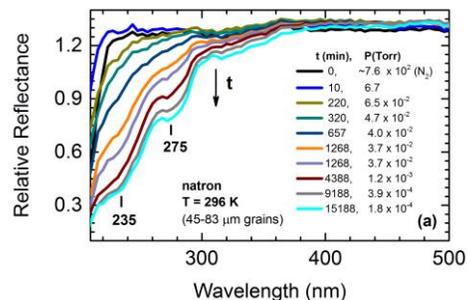


Figure 3. Extended vacuum-exposure of natron results in enhanced UV absorption, with the absorption edge shifting toward longer wavelength and the formation of new absorptions at ~ 235 and 275 nm .

Discussion: The rapidity of dehydration for natron at 200 and 240 K explains the detection of only anhydrous Na_2CO_3 and non-detection of water/ice by VIR within Ceres' mid-latitude region. Indeed, definitive observation of hydrated salts should be a strong indicator for the presence of surficial water or very-recently deposited material emplaced by a fast-transport mechanism from the sub-surface such as cryo-volcanism. In the unlikely case that hydrous sodium-carbonate is detected, the position of the 1.9- μm water-absorption can be used to determine the hydration state and estimate the age of the deposits. In Ceres' high latitudes / polar regions ($\leq 120 \text{ K}$), the age of the hydrated sodium-carbonate deposits, if observed, can be approximated using the experimental dehydration rate derived

from an Avrami model [6,9], given a similar surface temperature and regolith grain size.

Our spectral measurements at $0.4\text{--}2.5 \mu\text{m}$ show that sodium carbonates alone cannot account for the red slope observed by Dawn's FC at Cerealia facula, nor can dehydration of salts due to low pressure explain the progressive change in slope or albedo between dome center and crater background [1,4]. Other mechanisms, e.g., mixture of with Ceres' global mineralogy [1,3] or space weathering [10,11], must be invoked.

For $0.22\text{--}0.40 \mu\text{m}$, the extended vacuum-processing of sodium carbonates results in enhanced UV absorption and shift of the absorption edge toward longer wavelengths, better matching—but not identical—to Ceres' UV-visible spectral slope [2,12]. We hypothesize that these spectral modifications are due to the vacuum-induced production of short-range local defects (e.g., pore formation, dislocations, etc.). We correlate the new absorption features at 275 and 235 nm to electronic transitions within the CO_3^{2-} group. The 275-nm absorption may be a factor in the 280-nm feature observed in HST spectra of Ceres [2].

Conclusion: Exposure of hydrous sodium-carbonates to the cryogenic, airless conditions of space have spectral effects over two regimes: the first is concurrent with dehydration; the second occurs after dehydration with continued exposure to vacuum and cannot be correlated with dehydration explicitly. Carbonate spectra are not static, and quality laboratory characterization is particularly important for spectral matching and mineralogical identification. While this study focuses on the environment relevant to Ceres, these findings also have implications for the interpretation of observations from other planetary objects under similar conditions.

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