

**DISTRIBUTION OF CARBONATES ON CERES** F.G. Carrozzo<sup>1</sup>, M.C. De Sanctis<sup>1</sup>, A. Raponi<sup>1</sup>, E. Ammannito<sup>2</sup>, J. Castillo-Rogez<sup>3</sup>, B.L. Ehlmann<sup>3,4</sup>, S. Marchi<sup>1,5</sup>, N. Stein<sup>4</sup>, M. Ciarniello<sup>1</sup>, F. Tosi<sup>1</sup>, F. Capaccioni<sup>1</sup>, M.T. Capria<sup>1</sup>, S. Fonte<sup>1</sup>, M. Formisano<sup>1</sup>, A. Frigeri<sup>1</sup>, M. Giardino<sup>1</sup>, A. Longobardo<sup>1</sup>, G. Magni<sup>1</sup>, E. Palomba<sup>1</sup>, F. Zambon<sup>1</sup>, C.A. Raymond<sup>3,4</sup>, C.T. Russell<sup>6</sup>

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**Introduction:** Different carbonates have been detected on Ceres and their abundance and spatial distribution has been mapped using VIR, the Dawn imaging spectrometer. Carbonates are abundant and ubiquitous across the surface, but variations in the strength and position of infrared spectral absorptions indicate variations in the composition and amount of these mineral [1-3]. Mg-Ca carbonates are detected in all over the surface, but localized areas show Na carbonates, such as natrite ( $\text{Na}_2\text{CO}_3$ ) and hydrated Na carbonates (e.g.  $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$ ). Their geological settings and accessory  $\text{NH}_4$ -bearing phases suggest the upwelling, excavation and exposure of salts formed from Na- $\text{CO}_3$ - $\text{NH}_4$ -Cl brine solutions at multiple locations across the planet. The presence of the hydrated carbonates indicates that their formation/exposure on Ceres' surface is geologically recent and dehydration to the anhydrous form ( $\text{Na}_2\text{CO}_3$ ) is ongoing, implying a still evolving body.

**Dataset analysis:** Dawn mission was divided into different phases on the basis of the spacecraft altitude from the target's surface: Each phase is different from the others in terms of duration, illumination conditions and altitude over the surface. The mineralogical maps presented here have been produced by using the High-Altitude Mapping Orbit dataset (HAMO), for spatial covering and spatial resolution reasons. We also use the images of the Framing Camera [4] of the Low-Altitude Mapping Orbit (LAMO) mission phase to better identify the geological units. The maps have global longitudinal coverage, latitudinal coverage from 66°S to 66°N, and a spatial resolution of ~1.86 km/pixel at the equator.

**Results:** The map shows that the carbonate band position is mostly uniform across the surface (average band center at  $3.947 \pm 0.005 \mu\text{m}$ ) indicative of Mg or Mg-Ca carbonates (e.g. magnesite,  $\text{MgCO}_3$ , or dolomite,  $\text{MgCa}(\text{CO}_3)_2$ ), with the exception of a few recognizable km-size areas displaying band centers at longer wavelengths, up to  $4.02 \mu\text{m}$ , consistent with natrite ( $\text{Na}_2\text{CO}_3$ ).

While most of the carbonate-rich areas are consistent with the presence of  $\text{Na}_2\text{CO}_3$ , some small areas in specific locations, such as in Oxo, Azacca, Kupalo and Kahukura, are different and cannot be fully fit using  $\text{Na}_2\text{CO}_3$ . The spectra of these small areas suggest the presence of hydration.

The results of the spectral modelling indicate that the species with the highest number of water molecules trialed, i.e. natron ( $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ ), cannot fit the spectra, while species with less water, give excellent fits. The best fits are obtained using thermonatrite ( $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$ ) or trona ( $\text{NaHCO}_3 \cdot \text{Na}_2\text{CO}_3 \cdot 2\text{H}_2\text{O}$ ).

Most of the areas showing enhanced band depths and centers at longer wavelengths broadly match areas showing fainter phyllosilicate band depths (5,6). Assuming that band depths are primarily indicators of the amount of the mineralogical species responsible for the absorptions, the anti-correlation between phyllosilicate and carbonate intensities suggests an inverted proportion between the two components.

**Conclusions:** The presence of Na and Mg-Ca carbonates indicates that the liquid was relatively alkaline and should have contained a large fraction of chlorides and alkali/alkaline elements, as has been predicted for fluids reacting with chondritic material at low water/rock [7].

The local and recent exposure of anhydrous and hydrated Na carbonates may indicate separate processes [7,8].

The correlation of Na carbonates with some extrusive constructs suggests that at least some Na carbonates are transported to, or near to the surface by ascending subsurface fluids in several areas of Ceres. However, the association of Na carbonate with young craters could be consistent with material mobilized or created by impact-induced heating.

The detection of hydrated Na carbonates supports an aqueous origin of Na carbonates followed by their partial decomposition (mainly dehydration) in surface environments. This implies that sites rich in hydrated carbonates have been formed/exposed recently (a few My), and dehydration of hydrated Na carbonates is still ongoing. This is in accordance with crater

counting and modeling that predict recent formation, within 10s to 100s of millions of years [9,10].

The different chemical forms of the sodium carbonate, their fresh appearance, morphological settings and the uneven distribution on Ceres indicate that the formation, exposure, dehydration and destruction processes of carbonates are recurrent and continuous in recent geological time, implying a still evolving body and modern processes involving fluid water.

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