CARBON PRESERVATION WITHIN CERES REGOLITH MINERALS: A NEED FOR ANALOG WORK TO AID IN SUCCESSFUL SAMPLE RETURN.
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Introduction: Ceres is a differentiated dwarf planet and is the most water-rich object (~25 wt.%) in the inner solar system. NASA's Dawn spacecraft also revealed many similarities between Ceres and ocean worlds, in particular in terms of composition [1]. Ceres shows localized areas of hydrated carbonates and phyllosilicates due to pervasive aqueous alteration [2–4].

Ceres exhibits compositional links to carbonaceous chondrite-like asteroids. Carbonaceous chondrite parent bodies contain precursors of amino acids, and so likely possess conditions ideal for the formation of complex organics, in addition to the presence of mineral catalytic surfaces and an aqueous environment [5]. In fact, the large veins in the boulders of Cb-type asteroid Bennu require an amount of fluid at least 10^5 the volume of the veins, flowing through its interior [6]. Likewise, Ceres is expected to have hosted liquid throughout its history, first in the form of a global ocean. Later on, aqueous microenvironments, i.e., fluid pools with organic matter and other reactants, could be created through impacts into Ceres' icy surface. Furthermore, local surface deposits of organic matter and high concentrations of carbon possibly aliphatic compounds have been revealed by the Dawn mission [7–8]. Thus, Ceres' environment contains the three prerequisites for life: water, carbon, and a source of energy. For these reasons, Ceres is the focus of a Planetary Mission Concept Study [9] under assessment by the ongoing Planetary Science and Astrobiology Decadal Survey. That study recommends that a sample return from Ceres should be pursued in the next decade. The objective of this study is to get a better understanding of Ceres' surface material, in particular evaporites and organics, in order to inform the design of a future in situ and/or sample return mission at Ceres.

Evaporites on Ceres: Dawn found a pervasive display of salts across Ceres' surface. The vast salt deposits detected in Occator crater (e.g., Cerealia and Vinalia Faculae) likely formed by the extrusion of brine water through fractures created by the impact from depths of >35 km [4]. The bright spots are produced following the effusion of salty liquid transported to the surface by ascending subsurface fluids [10]. Vinalia Faculae contains high concentrations of minerals in a relatively thin, diffuse deposit (~2-3 m thick), most likely sourced from the deep brine reservoir [11-12]. That material is intimately mixed with dark floor material that is likely rich in organic matter. Thus, that region represents the best possible location to sample both bright material and dark material at Vinalia Faculae.

Spectral analysis shows that Cerealia Facula contains an abundance of carbonates and ammonium salts, as well as hydrated halite toward the center and the presence of liquid water is required for the formation of these minerals [4]. Impact heating melts ice abundant in ions, such as Na^+, Cl^-, CO_3^{2-}, NH_4^+, and HCO_3^+, and a deeper brine component enriched in chlorine also contribute to the faculae. The freezing/sublimation leads to the precipitation of such minerals [13]. Similar compounds have been found at Enceladus [14] and are suspected at Titan [15]. Hence, the investigation of Ceres' salt deposits is expected to provide insights into the compositional evolution of ocean world environments.

Sampling Strategies: Several concepts for the future exploration of Ceres' evaporites sample directly the Vinalia with the goal to return both evaporitic and darker rocky floor material. Because of these missions' interest is in the nature of Ceres' organics, contamination control is a serious concern. Fortunately, a future mission can leverage extensive contamination control strategies developed for previous missions, in particular OSIRIS-REx [16]. To minimize exposure to terrestrial contaminants, collectors could be configured for direct, robotic insertion into analytical instruments. One mission, labeled Calathus, proposes the use of a system to first clean the upper layer of Cerean soil in order to obtain pristine samples [17].

As the sampling of evaporites would be a first, sampling strategies need to be carefully assessed. The main risk in sample collection is sample degradation. We surmise that sodium carbonate and other precipitating salts could have undergone multiple cycles of dissolution, and recrystallization, and could accumulate organic 'fossils' within the salt crystals forming out of the brine solutions. Salts observed on Ceres' surface are highly soluble in water and if the mechanism heats up the sample to the melting point of water, then there is a risk that the salt sample can be altered or destroyed. Therefore, the sample collection mechanisms need to be cooled to below -20°C in order to preserve any organics within the samples [17]. Furthermore, organics are fractionated based on their nature and their relative densities and viscosities [18]. This needs to be considered given organics may be present in trace amounts in the evaporites, which cannot be currently detected by *in situ* techniques. Technological advancements in sample capture and drilling have allowed for the possibility of exploration of the surfaces of small bodies Bennu and Ryugu. These advancements are highly relevant and applicable to the surface of Ceres. Thus, returning with sufficient material (with a mass of ~100 g from the top 10 cm of the surface) and at ~-20 ºC would be sufficient for a complete understanding of the prevalence of organics in the evaporites, and the mechanism of their formation whether in the interior of Ceres or on the surface.

Laboratory Support to a Future Sample Return Mission: Laboratory work on Ceres analog minerals needs to be undertaken for a safe, viable sample collection from the Cerean surface. This includes physical and mechanical properties of evaporites and carbon incorporation within them. For example, the material in Vinalia Faculae that has been recently emplaced [19] is suggested to have been sprayed or ejected from a vent [20]. Material exposed that way is expected to be in the form of loose grains, which is consistent with the grain size estimated by Raponi et al. [11]. Whether the carbon in the salt crystals and low temperatures result in changing the sticking properties of the sample need to be assessed. The NASA Concept study [9] calls for using a drill bit, derived from the DragonFly mission, to break up surface material as a backup in case the material is stronger than expected. We will discuss potential laboratory measurements that could be done to assess how the presence of carbon changes the optical properties of salts and whether small amounts of carbon-rich material can be traced in salts.

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