SURVIVAL OF WATER ICE AND HYDRATED SALTS AT OCCATOR CRATER, CERES. M.E. Landis[1], T.H. Prettyman[1], S. Byrne[2], N. Yamashita[1], J.E.C. Scully[3], N. Schorghofer[1], J. Castillo-Rogez[3], H.G. Sizemore[1], C.A. Raymond[3], [1]Planetary Science Institute, Tucson, AZ, USA (mlandis@psi.edu), [2]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA, [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA.

Introduction: Occator crater's faculae are postulated to be the result of activity triggered by impact heating [e.g., 1] and/or endogenic cryovolcanism [e.g., 2]. The impact itself may also have excavated part of Ceres' extant ice table [e.g., 3]. Ceres' inferred crustal water ice content and evidence for a differentiated interior, including a global subsurface ocean, also suggest that water ice and hydrated minerals could play a key role in Ceres' near-surface evolution [3-8].

Neither water ice nor hydrated salts have been detected at Occator by the Visible and Infrared Mapping Spectrometer (VIR), sensitive to depths <100 µm [9, 10]. However, the Gamma Ray and Neutron Detector (GRaND) is sensitive to composition up to ~1 m depth and has characterized Ceres-wide buried hydrogen [3].

We describe thermophysical modeling to support the interpretation of data acquired by GRaND at low altitude in Dawn's second extended mission [11]. We model the sublimation of water ice and dehydration of Na-carbonate at Occator crater and determine whether either could survive within depths sensed by GRaND.

Thermal and Vapor Diffusion Model: We utilize the thermal and vapor diffusion model described by [12] and based in part on [13]. We vary the regolith grain diameter based on those inferred from VIR data [10]. We use regolith thermal inertia and albedo reported by [14, 15] for all cases. Occator's center is ~20° N [11].

Crater model ages for various terrains within Occator crater range from ~2 to ~20 Myr [16]. We consider a range of ages to explore the sensitivity of the resulting depth-to-ice on crater age. These ages are all many times the length of the ~25 kyr obliquity cycle [17] and obliquity has a small effect on the depth to water ice globally [e.g., 12, 18].

We neglect shadowing from crater walls. Occator is a complex crater and has a relatively flat floor compared to more bowl-shaped craters like Oxo, where crater wall slopes play a key role in ice preservation [12].

We start all ice sheets below 3 cm of desiccated regolith, much deeper than the diurnal skin depth. Burying the ice at Occator is consistent with the lack of surface water detections here by VIR [9]. We set subsurface temperature equal to the annual-average surface temperature.

Na-Carbonate Dehydration Model: Na-carbonate is pervasive within the faculae [10], and shallowly buried hydrated Na-carbonate, if present, could contribute H sensed by GRaND. We calculate the water loss from fully hydrated Na_2CO_3•$10H_2O$ (natron) based on [19]. Natron could have formed in the crust from the freezing of the ancient ocean under pressures of 10s of Mbar [8]. Once exposed on the surface, natron is not stable and cannot rehydrate without a significant source of water (e.g., on Europa [20]). We assume that once H_2O is released from the salt, it is directly lost to space.

Preliminary Results: We test three test scenarios to explore the preservation of water ice or hydrated Na-carbonate: (1) a relatively pure water ice sheet, similar to a water-ice dominated impact melt sheet within the crater [e.g., 21] (2) ice-cemented regolith with the same properties of the global ice table inferred by [3] that would be most similar to the evolution of an icy ejecta blanket, and (3) hydrated Na-carbonate in the crust or emplaced in the near surface by cryovolcanic processes.

Scenario 1: Relatively pure water ice sheet. We ran the thermal and vapor diffusion model for a water ice sheet with 90 vol % water ice beneath a 50% regolith porosity lithic layer. The results of the model are shown in Fig. 1. For the crater age range (~2-20 Myr, [16]) and for typical Occator floor grains sizes of ~110 µm [10], a water ice sheet would exist within ~0.5 m of the surface for the lifetime of Occator crater. This scenario would allow a water-ice impact melt sheet to be detectable today by GRaND.

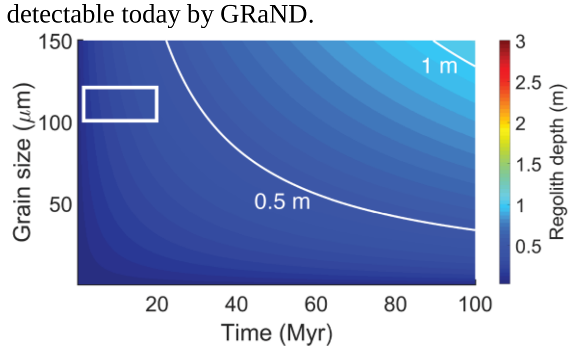

Fig. 1. Overlying regolith lag (porosity 50%) depth for a 90 vol % water ice sheet with at 20° N. The white box shows the range of ~100-120 µm, ~2-20 Myr.

Scenario 2: Ice-cemented regolith. In order to model a lower limit of water ice in Ceres' regolith as well as simulate an ejecta blanket minimally affected by heating during the impact, we ran the thermal and vapor diffusion model with 20% soil porosity and pore-filling ice. The results of the model are shown in Fig. 2.

For the crater's age range (~2-20 Myr, [16]) and for typical grain sizes of ~60-80 µm found in Occator's ejecta blanket [10], the pore-filling water ice would be more deeply buried than the relatively pure water ice sheet, but still within ~0.5-1 m from the surface. If the grain size of the typical Occator ejecta was more similar to the crater floor (~100 µm), the water ice table would still be buried < ~1 m. Globally, the regolith grain size may be on the order of a few µm [3, 22], and if similar grain sizes were found at Occator, the ice would expected to be well within the upper ~1m.

Given the current interpretation of Occator's age and the ejecta grain size measurements of [10], if water ice was emplaced as part of the ejecta formation process, it could be detectable today but would not dominate the upper 1 m of the subsurface.

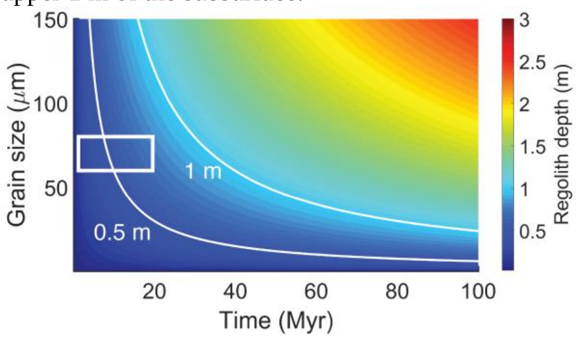

Fig. 2. Overlying regolith lag (20% porosity) depth for pore-filling water ice sheet at 20° N. The white box shows the range of ~60-80 µm, ~2-20 Myr.

Scenario 3: Hydrated Na-Carbonate. The detection of dehydrated Na_2CO_3 at Occator and partially hydrated Na_2CO_3 elsewhere on Ceres [10, 23] begs the question of whether there could be more spatially extensive hydrated Na_2CO_3 buried below Occator's surface (one of several hypotheses for how dehydrated Na_2CO_3 could have been transported or formed in near-surface).

We calculated the dehydration of natron for a variety of temperatures (Fig. 3). The 150 K line most closely matches the subsurface temperature of 20° N on Ceres with its current orbital and spin-axis configuration, and assuming the salt deposit is buried by typical Ceres regolith. Natron would dehydrate in ~20 kyr, significantly shorter than Occator's lifetime. Hydrated Na-carbonates may not form in the low pressures in the near-surface; therefore, rehydration of the deposits is neglected.

The short lifetime of hydrated Na-carbonates at Occator is consistent with their non-detection by Dawn. It also sets a latest reasonable time for the emplacement of buried natron near the surface of ~10^4 years. Otherwise, partially hydrated Na-carbonate could still be re-exposed by small impacts.

The lost water from salts may condense, freeze, and form an additional ice layer. Additionally, the faculae may locally cool the subsurface and allow for small pockets of natron to remain hydrated for longer. These two topics are left for future work.

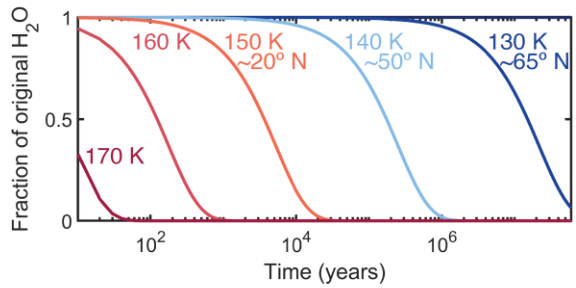

Fig. 3. Dehydration times for $Na_2CO_3 \bullet 10H_2O$. The annual average temperature at 20° N is ~150 K. Values >160 K are not expected and are only for reference.

Next Steps: The depths to materials relevant to GRaND measurements (up to ~1 m) are also depths at which ~10 m diameter small impacts would excavate [24]. Both salts and water ice have a distinct albedo from background Ceres [9, 25] and new images of the surface from Dawn's final, low-altitude orbits have resolutions up to ~5 m/pixel. We will map the locations of bright, small impact craters on Occator's floor to estimate the subsurface extent and layering of material that may contain increased water. In addition, we will refine thermophysical models to better constrain the stability of ice and hydrates at shallow depths.

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