EVOLUTION OF OCCATOR CRATER ON (1) CERES. A. Nathues[1], T. Platz[1], G. Thangjam[1], M. Hoffmann[1], K. Mengel[2], E. A. Cloutis[3], L. Le Corre[4/1], V. Reddy[5/1], J. Kallisch[1] and D. A. Crown[4], [1]Max Planck Institute for Solar System Research, Justus-von-Liebig-Weg 3, 37077 Goettingen, Germany, (nathues@mps.mpg.de), [2]IELF, TU Clausthal, Adolph-Roemer-Straße 2A, 38678 Clausthal-Zellerfeld, Germany, [3]University of Winnipeg, Winnipeg, MB R3B 2E, Canada, [4]Planetary Science Institute, 1700 East Fort Lowell Rd, Suite 106, Tucson, AZ 85719-2395, USA. [5] Lunar and Planetary Laboratory, University of Arizona, Tucson AZ, USA (reddy@lpl.arizona.edu)

Introduction: The Dawn spacecraft to (4) Vesta and (1) Ceres [1] is equipped with two identical Framing Cameras (FC, [2]), returning > 52,000 images of Ceres in seven colors (0.44 - 0.98 µm) and one clear filter, and performing global surface color mapping at ~140 m/px resolution. For some selected sites, higher resolution color data of ~35 m/px have been obtained as well.

Occator crater (Ø ~92 km) hosts the brightest surface features on Ceres [3] named Cerealia and Vinalia Faculae. These have been commonly referred to as 'bright spots' and show an unusual diurnal light scattering behavior that is attributed to local haze [3, 4]. Spectral analysis using the Visible and Infrared Spectrometer (VIR) revealed that the bright spots are predominately carbonates mixed with some dark ammoniated minerals [5].

Occator Geology: Occator is a complex impact crater exhibiting a central pit and a remnant central peak. The central pit hosts the brightest surface feature on Ceres (Cerealia Facula) while a cluster of bright spots (Vinalia Faculae) are observed to the east of the pit (Fig. 1). The pit has a circular, plan-view diameter of ~11 km, is ~0.6 km deep, and is bounded by peripheral fractures [3]. In the center of the pit, a bright fractured, ~0.4 km × ~3 km (height × basal diameter) dome formed. Remnants of a former central peak encompass the central pit to the west and east.

Figure 1. *Color mosaic (R= 0.96, G= 0.75, B= 0.44 µm) of Occator in perspective view (vertical exaggeration 3-times) at ~140 m/px resolution.*

Occator has been modified by syn- and post-formation wall collapses that resulted amongst others in the formation of a large-scale debris avalanche deposit covering almost the entire floor. The Vinalia Faculae spots are spatially confined to the distal portion of this deposit. Bright material thickness is here rather thin as it mostly mantles the rough surface of the flow deposit. Morphology and ejecta of small impact craters at Vinalia Faculae are consistent with a bright material thickness of less than a few meters. Up to 12 small impact craters are present on the central dome of Cerealia Facula and its surroundings. These craters are entirely composed of bright material, indicating the projectiles impacted solely into this, suggesting that bright material thickness of the dome and its vicinity is higher than of the Vinalia Faculae spots (likely the entire dome is composed of bright material). In addition, bright fractures crisscross the dome in a radial pattern which is consistent with an extrusive origin. The central pit may have formed by subsidence as inferred by peripheral ring fractures. A large fracture system is located at the southwestern portion of the floor displaying a vertical offset of about 10 m between the two main fracture axes. This pattern and the offset suggest a coupled process of updoming and minor subsidence. Fractures extend towards the northeast across the large debris avalanche deposit and Vinalia Faculae.

Morphology and crater-based age dating suggest that Occator is a young crater. The formation age of the present floor material is ~6.9±0.9 Ma [6] while the crater itself formed ~34±2 Ma ago. This age difference we explain by wall collapses and subsequent floor modifications. The large debris avalanche deposit has a model age of ~9.2±2 Ma. Even younger is the bright material of the central pit (~4.0±1 Ma).

The high absolute reflectance of the dome and its sharp periphery are an indication of limited material mixing between dark floor/central peak material and bright material. Thus, the deposition of the bright material and the origin of the dome postdate central pit formation.

The morphology of Vinalia Faculae spots is consistent with a sublimation or explosive process [7].

Composition: The floor and terraces of Occator are rather dark (abs. reflect. ~0.03 @0.55 µm) and thus similar to the average cerean surface. However, Cerealia Facula is remarkably bright (in places >0.3 @0.55 µm). FC high-resolution color imagery resolves details of the dome that is spectrally rather homogeneous. Also coarser VIR IR spectra exhibit minor spectral variation. Moving radially outwards from the dome, the overall spectral shape gradually changes, finally reaching the shape of the floor. This is an indication of progressive material mixing. The bright material, likely also getting thinner, is more and more contaminated with dark material.

The dome and immediate vicinity exhibit distinct absorption bands at ~3.4 µm and ~3.9 µm which have been attributed to carbonates [5]. These absorption bands are also present in Vinalia Faculae materials but are ambiguous in floor spectra that are rather similar to Ceres' average spectrum.

Discussion: Occator exhibits evidence of present and past endogenic activity, millions of years after crater formation. While the central dome is likely an outcome of past extrusive events triggered from depth, the former central peak is a result of a surface rebound after impact. The central pit, which is known from other solar system bodies [8], formed probably by subsurface removal of melt material [9]. The impact obviously delivered sufficient energy to trigger processes that led to the present occurrence of the bright spots. Whether the impact energy triggered a long-lasting process in the sub-surface or whether the instant mass removal was already sufficient for the ascent of deep-seated reservoir material, is unknown. Probably periodic or episodic ascending bright material from a subsurface reservoir formed the dome. It expelled from fractures and extruded onto the surface. Isolated patches of bright material within the pit could also point to a sedimentation process and subsequent collapses. However, such a process would require an enormous amount of replenished sub-surface brine to fill most of the pit, whereby the liquid water evaporated quickly leaving behind carbonates.

According to several evolution models [10, 11] Ceres contains large amounts of H_2O in the form of an icy mantle and a large liquid reservoir ('ocean') at depth. The icy mantle probably contains fine-grained carbonaceous chondritic (CC) material captured during slow freezing of a convecting liquid shell. Upon heat loss to space and decay of radio-nuclides [11], an ice-rich outer shell developed and the amount of residual liquid decreased while solute concentrations increased, finally resulting in a high-salinity brine layer or isolated lenses [6]. Fines, carbonates like $CaCO_3$, and patches of brine got trapped in the growing shell. Due to accumulation of exogenic material and loss of water by sublimation, a dark surface lag formed, protecting the ice from instantaneous sublimation. Inclusions of brine may have also been lost during this process, leading to the precipitation of dissolved solids in the mechanically disturbed subsurface ice layer. Besides water, methane and carbon dioxide are probably the most abundant gas species dissolved in the pressure regime between Ceres'core and icy mantle. Regardless of the mechanism that produces ascending high-salinity brines, the fact that salt minerals are observed at Occator's bright areas require the precipitation of solutes upon sublimation of water. The pressure release caused by an upward movement of the brine produces significant H_2O losses, thereby oversaturating the liquid in carbonate and chloride minerals. Before the onset of sublimation, methane and carbon dioxide would exsolve from the solution, form vent systems and escape through those along with relatively large portions of water vapor.

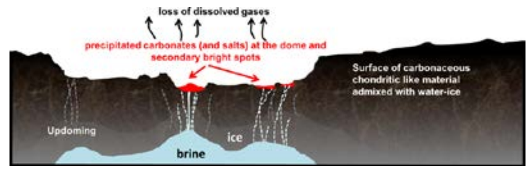

Figure 3. *Ceres' upper crust in accordance with [6]. The upper crust is made of dark material rich in phyllosilicates (brown) intercalated with ice (light brown). Activity was triggered by impact energy that lowered substantially the viscosity of subsurface ice (light gray). Underlying brine (light blue) ascended through vents which formed by exsolution of gas phases. Brines finally reached the surface at the central pit, thereby losing the solvent (H_2O) and precipitating the dissolved solutes (carbonates, and possibly other salt minerals; red areas). Small volumes of brine also migrated upwards along cracks reaching the surface and precipitating salts.*

Conclusions: Age determination of lithological units along with their morphologies and compositions led us to conclude that the floor region of Occator was subject to a long-lasting activity. The central dome and bright material in its vicinity formed due to a periodic or episodic ascent of bright material from a subsurface reservoir expelled through fractures. Originally triggered by the Occator impact event, possibly methane and carbon dioxide originally dissolved from a region deep within Ceres, exsolved from brines and forced materials rich in carbonates to ascend.

References: [1] Russell, C. T. and Raymond, C. A. 2012 (New York, Springer), [2] Sierks, H. et al. 2012 (Springer), [3] Nathues, A. et al. 2015, Nature 528, 237, [4] Thangjam, G., ApJL 2016, 833, [5] De Sanctis et al. 2016. Nature 536, 54, [6] Nathues et al. P&SS, in press, [7] Ruesch et al. LPSC 2017, [8] Wood C.A. et al. 1978, 9th LPSC, 3691-3709, [9] Bray, V. et al. 2012, Icar 217, 115, [10] Castillo-Rogez, J. C. 2011, Icar 215, 599, [11] Travis, B.J. et al. 2015, 46th LPSC, 2360