FACULAE ON CERES: POSSIBLE FORMATION MECHANISMS O. Ruesch[1], A. Nathues[2], R. Jaumann[3], L.C. Quick[4], M. T. Bland[5], T. J. Bowling[6], S. Byrne[7], J. C. Castillo-Rogez[8], H. Hiesinger[9], K. Krohn[3], L. A. McFadden[10], A. Neesemann[11], K. Otto[3], P. Schenk[12], J. Scully[8], M. V. Sykes[4], D. A. Williams[12], C. A. Raymond[8], C. T. Russell[13], [1]NASA Goddard Space Flight Center/USRA, Greenbelt, MD, USA. (ottaviano.ruesch@nasa.gov), [2]Max Planck Institute for Solar System Research, Goettingen, Germany, [3]DLR, Berlin, Germany, [4]PSI, Tucson, AZ, USA, [5]USGS, Flagstaff, AZ, USA, [6]University of Chicago, Chicago, IL, USA, [7]LPL, U. of Arizona, Tucson, AZ, USA, [8]JPL, Caltech, Pasadena, CA, USA, [9]Institut fuer Planetologie, Westfaelische Wilhelms Universitaet Muenster, Muenster, Germany, [10]NASA Goddard Space Flight Center, Greenbelt, MD, USA, [11]Institute of Geoscience, FU Berlin, Berlin, Germany, [12]LPSI, Houston, TX, USA, [12]School of Earth & Space Exploration, ASU, Tempe, AZ, USA, [13]Earth, Planetary and Space Sciences, U. of California, Los Angeles, CA, USA.

Introduction: On Ceres' low albedo surface there occur localized bright areas usually associated with impact craters [1]. The brightest and largest spots, Vinalia and Cerealia Faculae, are found within the young (~21 Ma) Occator crater [2] (Fig.1) and consist predominantly of sodium carbonate [3]. The localized, high concentration of carbonate is interpreted as the solid residue of a crystallized salt solution (i.e., brine) [1,3, 4-6]. Occator crater also hosts lobate flows suggestive of brine-based cryovolcanism [7] and/or collapsed walls [5]. Whether a relationship between the faculae and cryovolcanism exists is currently under debate.

Here we use clear-filter framing camera (FC) LAMO images (~35 m/pixel) to perform a morphological analysis of Cerealia and Vinalia Faculae (Fig. 1), and discuss possible formation mechanisms.

Observations - Vinalia Faculae: Vinalia Faculae consist of several localized bright areas adjacent to each other, found on top of a large lobate flow covering the floor of Occator crater [2,5,7]. Only the two largest bright areas are described here (Fig. 2) as the smaller spots are not spatially resolved. The facula at 20°N-242°E (site 1) is characterized by a 500 m wide circular feature (hereafter pit) and a surrounding bright halo, 5 km in width. The pit is rimless and has a relatively flat floor, distinct from a bowl-shaped crater of such a size. One of the pit sides corresponds to a darker, linear fracture [8] running several kilometers across the halo. The halo has a continuous distribution and is brighter closer to the pit, and discontinuous and patchy farther away. This pattern seems to be controlled by the underlying ropy surface of the lobate flow. This morphology can be described as a discontinuous mantling, as the halo material has no discernible relief.

Six km NE of this facula, another localized bright area of similar dimension is found (site 2, Fig. 2). This spot shares the same distal patchy distribution as the first facula, but displays a continuous, smooth material distribution in its center. Most importantly, the smooth bright material forms two ridges in a V-shaped configuration, separated by a possible topographic depression (trough-like morphology). As site 1, linear fractures [8] and depressions are found across this facula. However, the texture and relief of the bright material at the center of this facula suggests it is thicker than that at site 1.

Observations - Cerealia Facula: This bright area is located within Occator crater's central pit (Fig. 2, 20°N-240°E). It has an irregular shape and is approximately 6 km wide. In addition, it is uplifted in its center, creating a domical feature 3 km wide and 0.25 km high relative to the surroundings, and is dissected by fractures up to 300 m wide and pits. The bright material surrounding the dome has a smooth texture with darker patches and darker fractures circumferential to the dome. The contact between the bright material and the surrounding darker central pit material is characterized by patches. Small -200 m wide- bright zones are found scattered in the darker central pit material and, less frequently, small dark zones are found scattered in the bright material. The width of the contact between the different zone is sharp (<70 m). In one location, we observe the scattered bright patches to have an elongated shape radial to the central dome, similar to discontinuous impact crater rays.

Discussion: Morphologies at sites 1 and 2 indicate that surface disruption (pit, trough) as well as redistribution of adjacent bright material (i.e., mantling by fine grained material) occurred. At site 3 the above processes took place (pits on dome, radial elongated patches), as well as build-up and/or upwarping of thicker (>100 of m) bright material. We note that fractures and pits on a carbonate-rich material are also observed on the summit of the cryovolcanic dome Ahuna Mons [9,10]. Here we consider several mechanisms that could have produced the entire range of morphologies described at sites 1, 2 and 3.

Impact cratering leads to a central depression and mantling of the surrounding terrain, similar to site 1. However, the morphologic characteristics of a pit and the extensive halo at site 1 lacking a rayed pattern argue against an impact induced-origin. An impact origin is also inconsistent with our observations at site 2 and 3.

Sublimation is a process known to create depressions or pits. On Ceres, this process is known to occur at the crater Oxo, where a conspicuous ice deposit is observed [11]. There, however, the morphologies are different and no pits or mantling is observed [12].

Another mechanism is *fragmentation by decompression of gas-rich ice*. The ascent of gas-rich ice to the surface and exposure to the vacuum of space might lead to an explosive event [e.g., 13]. The rate of ascent of solid ice from few kilometers depth and through a <500 m wide conduit will depend on the ice's initial temperature and cooling by the surrounding rock. Once extruded, particulate, fragmented material might be ejected and subsequently distributed around the uprising ice. The continued extrusion of ice could potentially form a debris/scoria cone (site 2).

Finally, an explosive event (and pit formation) could be triggered by the *violent evaporation of liquid water in vacuum*. Water vapor produced by a boiling brine exposed to an airless surface can reach sonic speed [e.g., 14] and entrain solid particles. These particles can be preexisting material in the brine, or grains formed during evaporation. Depending on the particle size and density, the entrained solids will fall on the surface near their ejection point, possibly creating a halo [e.g., 15]. Eventually, freezing of a cap above the extrusive briny flow would stop the boiling phase [e.g., 16]. Continuous extrusion and freezing would lead to build-up of topographic relief. The composition of such a cap would include anhydrous salts as well as water ice. For the latter two scenarios, the ice will rapidly sublimate and only be preserved below a dusty lag deposit [17-19]. Sublimation of covered or spatially-unresolved ice might still be ongoing as suggested by the detection of haze above the faculae [20].

Conclusions: Both *decompression of gas-rich ice* and *evaporation and freezing of liquid water in vacuum* should be considered as plausible mechanisms to explain the faculae morphologies. The different features between the sites can be understood as different stages or intensities of a single formation mechanism. The intensity (e.g., rate of extrusion) or duration of the processes appear to have increased in a sequence from site 1, to site 2 and site 3. It is unclear whether an age correlation exists in the sequence. Overall, these observations further highlight the importance of Occator faculae for our understanding of Ceres recent and possibly fluid-based activity.

References: [1] Nathues et al. (2015) *Nature*, 528, doi :10.1038/nature15754. [2] Neesemann et al. (2017) in prep., *Icarus*. [3] De Sanctis et al. (2016) *Nature* 536, 54-57. [4] Nathues et al. (2016) *PSS*, doi :10.1016/ j.pss.2016.10.017. [5] Nathues et al. (2017) *LPSC 48th*. [6] Neveu and Desch, (2015) *GRL*, doi:10.1002/ 2015GL066375. [7] Krohn et al. (2016) *GRL*, doi: 10.1002/ 2016GL070370. [8] Buczkowski et al. (2017) *LPSC 48th*. [9] Ruesch et al. (2016) *Science,* 353, 6306, aaf4285. [10] Zambon et al. (2016) *GRL*, doi :10.1002/ 2016GL071303. [11] Combe et al. (2016) *Science* 353,6303, aaf3010. [12] Sizemore et al (2017) *LPSC 48th.* [13] Kieffer et al. (2006) *Science* 314, 1764-1766. [14] Porco et al. (2006) *Science*, 311, 1393-1401. [15] Wilson and Head (2017) *Icarus* 283, 146-175. [16] Quick et al. (2016) *Icarus* 284, 477-488. [17] Titus (2015) *GRL*, doi :10.1002/2015GL063240. [18] Formisano et al. (2016) *MNRAS,* doi:10.1093/mnras/stv2344. [19] Schorghofer (2016) *Icarus*, doi :10.1016/ j.icarus.2016.04.037. [20] Thangjam et al. (2016) *ApJ*, 833 :L25.

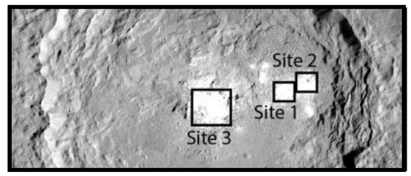

***Figure 1**. Section of the 92-km large Occator crater on Ceres (20°N-240ºE) with location of sites shown in Fig. 2.*

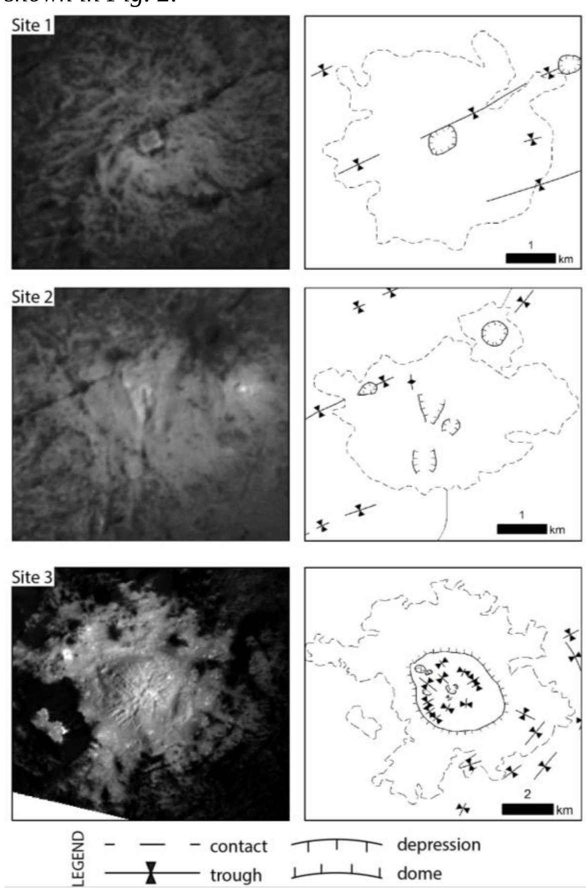

***Figure 2**. FC LAMO images of bright spots (left) with associated structural and morphological sketches (right) found within Occator crater. Site 1 and site 2 form the Vinalia facualae. Site 3 is Cerealia facula.*