CHARACTERISTICS, FORMATION, AND EVOLUTION OF FACULAE (BRIGHT SPOTS) ON CERES.

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Introduction: Images from the Dawn spacecraft's Framing Camera (FC) instrument show the presence of anomalously bright material dotting Ceres' surface. Analyses from Dawn's Visible and Near-Infrared spectrometer (VIR) show that these bright regions, termed "faculae," are mainly comprised of materials enriched in carbonates and other salts [1, 2]. Here we perform comprehensive global mapping of faculae to classify them by geologic setting and investigate potential mechanisms for their formation and evolution.

Characteristics of Faculae: We define faculae as areas with a bond albedo > 30% higher than that of the surrounding region in photometrically corrected clear filter FC images. The composition of the faculae measured with the VIR instrument does not match that of any known asteroid class, indicating that they formed endogenously [1]. The faculae are classified into four geologic settings (Fig. 1): 1) central pit or peak complexes or floor fractures of large craters, 2) crater rims and walls, 3) ejecta and the rims of small craters in ejecta blankets, and 4) the unique surface feature Ahuna Mons. There are at least 300 faculae in total, > 200 of which are located on crater rims or walls (Fig. 2). Faculae are distributed heterogeneously with no clear topographic correlation and occur in spectrally blue regions [3].

Relationship to Craters: Eight craters contain faculae on their floor. The brightest and most extensive occur in Occator crater [1, 4, 5]. Craters with floor faculae are notably the deepest in their region, all with d > 3 km (Fig. 3), and most contain floor fractures and pitted terrains [6, 7]. Crater size-frequency distribution (CSFD) measurements indicate that the oldest of these craters formed no more than a few hundred Ma ago [8]. More than 30 craters with diameters D > 75 km do not contain floor faculae, indicating that crater diameter is a weaker control on the presence of floor faculae than crater depth. Not all craters with d > 3 km contain floor faculae. The primary control on crater depth as a function of diameter is typically age, with gradual shallowing due to viscous relaxation and infilling by other impacts. Thus, the dearth of faculae in shallow craters with high D suggests that previously emplaced faculae may have disappeared from the surface.

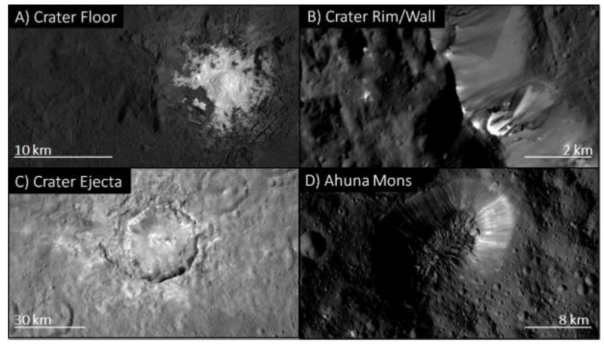

Figure 1: Examples of faculae classes. (a) Floor faculae in the central pit and dome of Occator Crater. (b) Rim/wall faculae streak down the wall of Dantu Crater. (c) Haulani crater, which also contains rim/wall and floor faculae, is surrounded by a bright ejecta blanket. (d) The unique mountain Ahuna Mons.

A small number of fresh craters are surrounded by bright ejecta blankets. Many of the most extensive bright ejecta blankets surround craters with floor faculae (e.g., Occator, Azacca [9], Dantu [10], Ikapati, and Haulani [11]), but bright ejecta also occur around other craters. These ejecta blankets have a lower average albedo than other classes of faculae, likely as a result of mixing with darker soils, and are dotted with numerous D < 1 km craters that expose higher-albedo faculae along their rims and walls.

The majority of faculae occur on crater rims or walls and typically emanate from depths within 100-200 m of the surface. Although compositionally similar to floor faculae, rim/wall faculae occur in craters of all sizes and are found preferentially in deep and wide craters. Not all fresh craters contain rim/wall faculae.

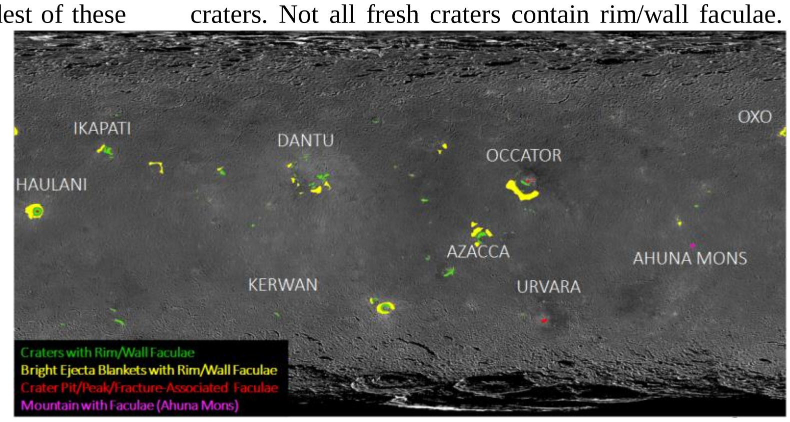

Figure 2: Map of faculae observed in FC images and their classification.

The high d/D of craters with rim/wall faculae indicates that on average they are relatively young. A negative correlation is observed between rim/wall faculae albedo and crater age; rim/wall faculae of 0-5 Ma craters such as Oxo and Haulani are on average brighter than in Occator, Dantu, and Azacca craters whose ages range from ~15-75 Ma. Hence rim/wall faculae may darken and disappear from the surface over Ma timescales.

Darkening and Disappearance of Faculae: Potential mechanisms for the disappearance of faculae include gradual alteration, darkening due to space weathering, or burial via impact-induced lateral mixing. Fresh craters on Ceres are spectrally blue and exhibit distinct optical properties compared to morphologically similar older areas on the surface, indicating some process of space weathering or regolith gardening homogenizes the surface [3]. The extent and timescale of impact-induced lateral mixing was estimated using a simple computational model with a crater population sourced from the Ceres crater production function [12]. Under the assumption that all crater ejecta fall within one crater diameter with no loss of material to space, model results indicate that direct impacts or the material thrown by impacts will cover or disseminate faculae over timescales of ~150-600 Ma.

Modeled Formation of Rim/Wall Faculae and Bright Ejecta: A similar computational model was used to evaluate whether the number of observed rim/wall faculae is consistent with their formation via the impact excavation of previously emplaced faculae. In this model, a grid with the surface area of Ceres is populated in 1 Ma time steps with craters with D sourced from the Ceres crater production function [12]. During each time step new craters either 1) produce floor faculae that are carried to subsequent iterations if D > 75 km (approximately the pit crater size cutoff on Ceres [13]), 2) completely overlay and disseminate previously emplaced floor faculae as bright ejecta, or 3) intersect previously emplaced floor faculae to produce rim/wall faculae that are carried to subsequent time steps of the simulation. Any rim/wall faculae not disseminated by subsequent impacts after a certain time period are removed from the surface to simulate the combined effects of space weathering and lateral mixing. The modeled number of craters with rim/wall faculae ranges between ~50-250 for imposed faculae disappearance times of 0.25-1 Ga (Fig. 4) and varies modestly depending on the size of the buried faculae, here assumed to be D < 10 km. Model values are consistent with the ~200 observed craters with rim/wall faculae.

Conclusions: The presence of faculae in most deep craters is consistent with initial material formation via impact-induced heating and upwelling of volatile-rich materials [1,14], endogenously distributed subsurface processes [1], or a combination of both [15]. Rim/wall and ejecta faculae prevalence is consistent with their formation via the excavation of previously emplaced bright material. Data collectively point to a relatively modern formation/exposure of faculae and their removal by a combination of impact mixing and space weathering over geologically relevant timescales (< 1 Ga). Hence it appears that Ceres' surface properties are not restricted to ancient times, but remain dynamic at present day.

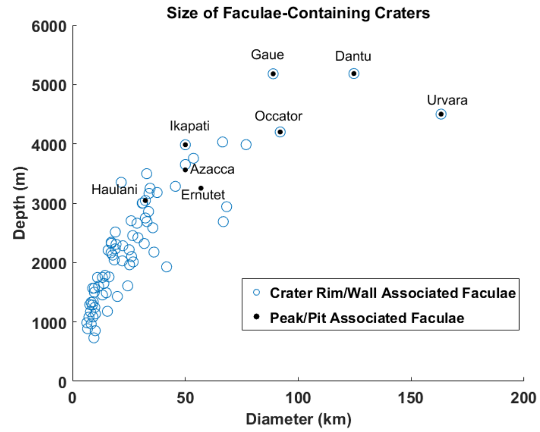

Figure 3: Depth and diameter of craters containing floor faculae (black spots) and rim/wall faculae (blue circles).

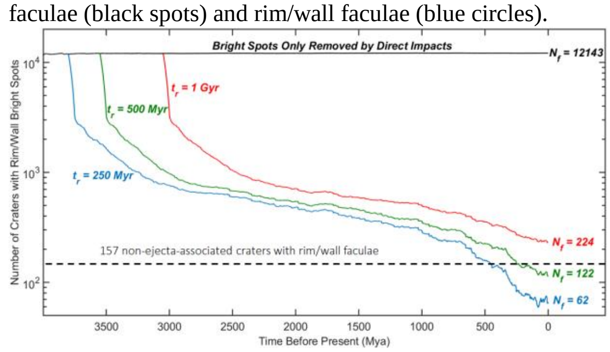

Figure 4: Modeled number of craters containing rim/wall faculae as a function of time before present. The black line depicts the modeled number of craters with rim/wall faculae if no timescale is imposed for faculae removal. The blue, green, and red lines depict the modeled number of craters with rim/wall faculae if faculae are removed from the simulation after 250 Ma, 500 Ma, and 1 Ga, respectively.

References: [1] De Sanctis et al. (2016). *Nature.* [2] Palomba et al. (2017). *LPSC 48.* [3] Pieters, C. M. et al. (2016) *LPSC 47.* 1383. [4] Nathues et al. (2015). *Science.* [5] Jaumann et al. (2017). *LPSC 48.* [6] Buczkowski et al. (2016). *LPSC 47.* 1262. [7] Sizemore, H. G. et al. (2017). *LPSC 48.* [8] Schmedemann, pers. comm. [9] Longobardo et al. (2017). *LPSC 48.* [10] Stephan et al. (2017) *LPSC 48.* [11] Tosi et al. (2017) *LPSC 48.* [12] Hiesinger et al. (2016) *Science.* [13] Schenk, P. et al. (2016). *LPSC 47.* 2697. [14] Bowling, T. et al. (2016) *LPSC 47.* 2268. [15] Nathues et al. (2017). *LPSC 48.* 1385.