GEOLOGIC MAP OF THE INTERIOR OF OCCATOR CRATER, CERES, AND ITS BRIGHT FACULAE, BASED ON 2D AND 3D PERSPECTIVE VIEWS OF HIGHEST RESOLUTION (METER-SCALE) DAWN DATA.

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Introduction: Dawn explored dwarf planet Ceres from 2015-2018 [1], using its Framing Camera (FC) [2] and additional instruments [3-5]. Occator is a 92 km diameter complex crater, and is one of the most well-known features on the surface because of its enigmatic interior bright deposits [6-8]: (i) Cerealia Facula is in the central pit, which also contains a central dome (Cerealia Tholus), (ii) Pasola Facula is on a ledge above the central pit, and (iii) Vinalia Faculae are in the eastern crater floor. The faculae are ≦6 times brighter than Ceres' average visual normal albedo [9] and are mostly composed of sodium carbonate and ammonium chloride, which are the solid residues of brines that were exposed on the surface [10-11].

Motivation: Using data from Dawn's prime and first extended missions (≥385 km in altitude, ≥35 m/pixel FC images), a variety of studies, including geologic mapping, sought to uncover the sources behind Occator's faculae [12-14]. However, key questions remained about faculae emplacement. During Dawn's second extended mission (XM2), low elliptical orbits provided FC images of Occator with a ground sampling distance of ~3.3 m/pixel from ~35 km altitude. Here we address these key questions by analyzing the geology of Occator via the creation of a new, XM2-based geologic map, which provides a methodically-derived and self-consistent interpretation of the data that cannot be achieved by visual inspection alone.

Methods:

Data. Our basemap is the ~3 m/pixel XM2 clear filter FC mosaic produced by DLR [15]. It is orthorectified onto the Low Altitude Mapping Orbit digital terrain model (LAMO DTM) [16], which we also used to create 3D perspective views. For small areas not covered by the basemap, we used a XM2 clear filter FC mosaic (~10 m/pixel) produced by D.P. O'Brien (PSI) and the DLR LAMO clear filter FC mosaic (~35 m/pixel) [16].

Mapping procedure. We mapped the crater interior at 1:50,000 and the areas of particular interest (i.e. faculae) at 1:10,000. We used a combination of 2D mapping in *ESRI ArcMap* and 3D mapping in *ESRI ArcScene*, which facilitated greater insights into the placement of contacts, stratigraphic relations etc. than 2D mapping alone. We first mapped on the *ArcScene* 3D perspective view, before transferring the mapping into the *ArcMap* 2D view for refinement. Our mapping approach was informed by USGS practices.

Results:

Geologic units: crater floor. The XM2 data reveals that the crater floor and terraces are mantled to varying extents by a veneer of lobate material, which is a slurry that flowed around the crater interior prior to its solidification. The massif material is adjacent to the central pit and was not coated by lobate material because it is high-standing. It may be the remnants of an early, transient, liquid-water-dominated central peak [17].

Geologic units: lobate material. The lobate material forms a large, thick sheet in the southern and eastern crater interior, as well as isolated pond-like deposits. We divide the lobate material into three sub-units based on surface texture: smooth, interspersed and hummocky. The smooth and hummocky lobate materials were mapped previously [14,18], while the interspersed lobate material is a new sub-unit: it is smooth lobate material interspersed with knobs (mapped as domes or mounds) and striations. The lobate material was emplaced as a slurry of impact-melted water, salts in solution and blocks of unmelted silicates/salts flowed around the crater interior shortly after crater formation [12]. Striations form when the lobate material flowed shortly before solidifying. The domes and mounds are protruding pinnacles, blocks of unmelted silicates and/or formed by frost-heave-like processes derived from the lobate materials' solidification/expansion [19].

Geologic units: bright material. We divide the bright material into two sub-units based on texture: continuous and discontinuous. The continuous bright material often forms roughly circular deposits, surrounded by the discontinuous bright material, which in turn is often surrounded by the faint mottled bright material (a surface feature made of dispersed bright material points). Our observations are consistent with the faculae being residual deposits of brines that lost their liquid water when exposed on the surface [e.g. 6,10,12].

The lack of flow fronts in the bright material is caused by multiple overlapping flows, the buildup of ballistic deposits and/or the presence of fine-scale, unresolved flow fronts. Based on the lack of compressional features, a lack of evidence that Pasola Facula and Cerealia Facula were originally connected, and a regular correlation between Cerealia Facula and topography, we interpret that the majority of Cerealia Facula was emplaced prior to the formation of the central pit. The faculae originated from numerous sources of brine in a hydrothermal system, based on analogs with the Earth and Mars, the association of the faculae with the crater center and fractures, and impact modeling [20].

Geologic units: dark material. Patches of dark material occur within the bright material, and the dark and bright materials superpose each other. We interpret the dark material as (i) ejecta that was excavated from underneath the bright material, (ii) deposits that mass wasted on top of the bright material and (iii) as areas that were not coated by the faculae-forming brines. Pit chains coated in dark material occur throughout the crater, and are often associated with the faculae. Pit chains cross-cut Vinalia Faculae, but may still be the conduits that allowed the faculae-forming brines to reach the surface, because of the relative ease of fracture formation and reactivation on Ceres [21].

Geologic units: talus/spurs. The talus material and spur material are located on steeply sloping regions, e.g. the rim of the crater. We interpret the talus material as dry mass wasting material and the spurs, which occur upslope of the talus, as the source outcrops of the talus.

Thickness estimates. We estimate localized thicknesses throughout the faculae by using (i) superposing impact craters (and an excavation depth of >0.08 [22]), (ii) the depth of fractures that only expose bright material and (iii) the thicknesses of outcrops of bright material. The Vinalia Faculae are consistently ~2-3 m thick, while Cerealia Facula ranges from <3 m, ~5.5 m or ~31 m thick to ≥50-100 m thick on Cerealia Tholus.

Conclusions: We interpret that the faculae are hydrothermal deposits emplaced under the control of a complex hydrologic plumbing system formed by fracture networks and hydrologic gradients. The presence of regions of dark material not covered in bright material, and the variation in faculae thicknesses, indicate that the availability of the faculae-forming brines varied from location to location on relatively short spatial scales. Model ages derived from crater size frequency distributions and thermal evolution modeling show that the source of the faculae-forming activity is long-lived (i.e. at least millions of years after crater formation [23-25]), indicating that Ceres is a world on which impact-induced activity can be protracted, and/or on which geologically recent endogenic activity occurred.

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