# EVOLUTION OF OCCATOR CRATER ON (1) CERES

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## Introduction

The Dawn spacecraft is equipped with two Framing Cameras (FC) which obtained images in seven colors and one clear filter, performing global mapping of the cerean surface. One of the prime imaging targets is the crater Occator hosting the brightest surface features on Ceres (Nathues et al. 2015) which contain significant amounts of carbonates while the dark background surface is dominated by ammoniated phyllosilicates (De Sanctis et al. 2015, 2016). Here we report our results on the evolution of Occator crater. Further details are reported in Nathues et al. (2017).

## Geology of Occator

Occator (Ø ~92 km) is a complex impact crater exhibiting a bright central pit (Cerealia Facula) and a remnant central peak (Fig. 1A/B). Further bright regions (Vinalia Faculae) populate the north-east of the crater floor (Fig. 1A/C). The pit has a Ø of ~11 km, is ~0.6 km deep, and is bounded by peripheral fractures (Nathues et al. 2015, 2017). In its center a bright fractured, ~0.4 km × ~3 km (height × basal diameter) dome formed (Fig. 1B). Occator has been modified by syn- and post-formation wall collapses resulting in the formation of small-to-large-scale debris avalanche deposits (unit *l* in Fig. 2). The largest flow deposit covers almost the entire floor and is crosscut by an extended fracture system. The Vinalia Faculae are located on the largest flow deposit. Here the bright material thickness is rather thin, mostly mantling the rough flow surface, and the appearance of small craters let us conclude that bright material thickness reaches only a few meters or less. Small craters on the central dome and its surrounding bright material suggest that material thickness of the dome and its vicinity is significantly higher than for the Vinalia Faculae. Fractures of different lengths crisscross the dome in a radial pattern. The central pit shows peripheral ring fractures.

## Composition

Most regions of Occator are, as Ceres globally is, rather dark (abs. reflectance ~0.03 at 0.55 µm). However, some floor areas are remarkably bright (>~0.3 at 0.55 µm). FC high-resolution color data resolves details of the dome (Fig. 1B), which is spectrally rather homogeneous (Fig. 3); a finding that is also supported by VIR data (Fig. 4). Moving outwards from the dome, the overall color and IR spectral shape gradually changes, finally reaching the shape of the dark floor material. This is an indication of dark and bright material mixing. The dome and its bright vicinity exhibit distinct absorption bands at ~3.4 µm and ~3.9 µm (Fig. 4) which are attributed to carbonates (De Sanctis et al. 2016). Floor and bright areas show different absorption bands and thus are of different composition. Color spectra of (flow) floor (south) material (#8, Fig. 3) are nearly similar to dark background material (#9) that is according to De Sanctis et al. (2015) dominated by magnesium-rich and ammoniated phyllosilicates. VIR spectra of the dome's center clearly differ from other bright and dark sites (Fig. 4). It seems that those sites showing lower reflectance values than the dome consist indeed of mixtures of bright dome and dark floor materials. For instance, the dark sites' absorption band minima of the 2.7 µm feature due to $OH^-$ bonding in phyllosilicates is at a slightly shorter wavelength than for the bright dome; other bright sites are intermediate. The absorption at ~3.1 µm due to ammoniated-clays (De Sanctis et al. 2015) is weak for floor material and absent in dome spectra; other bright sites seem to be intermediate. The ~3.4 and ~3.9 µm absorption features of the bright regions are similarly intermediate: the bright dome center has the deepest absorption bands of all areas; the dark sites do not uniquely exhibit those two absorption bands.

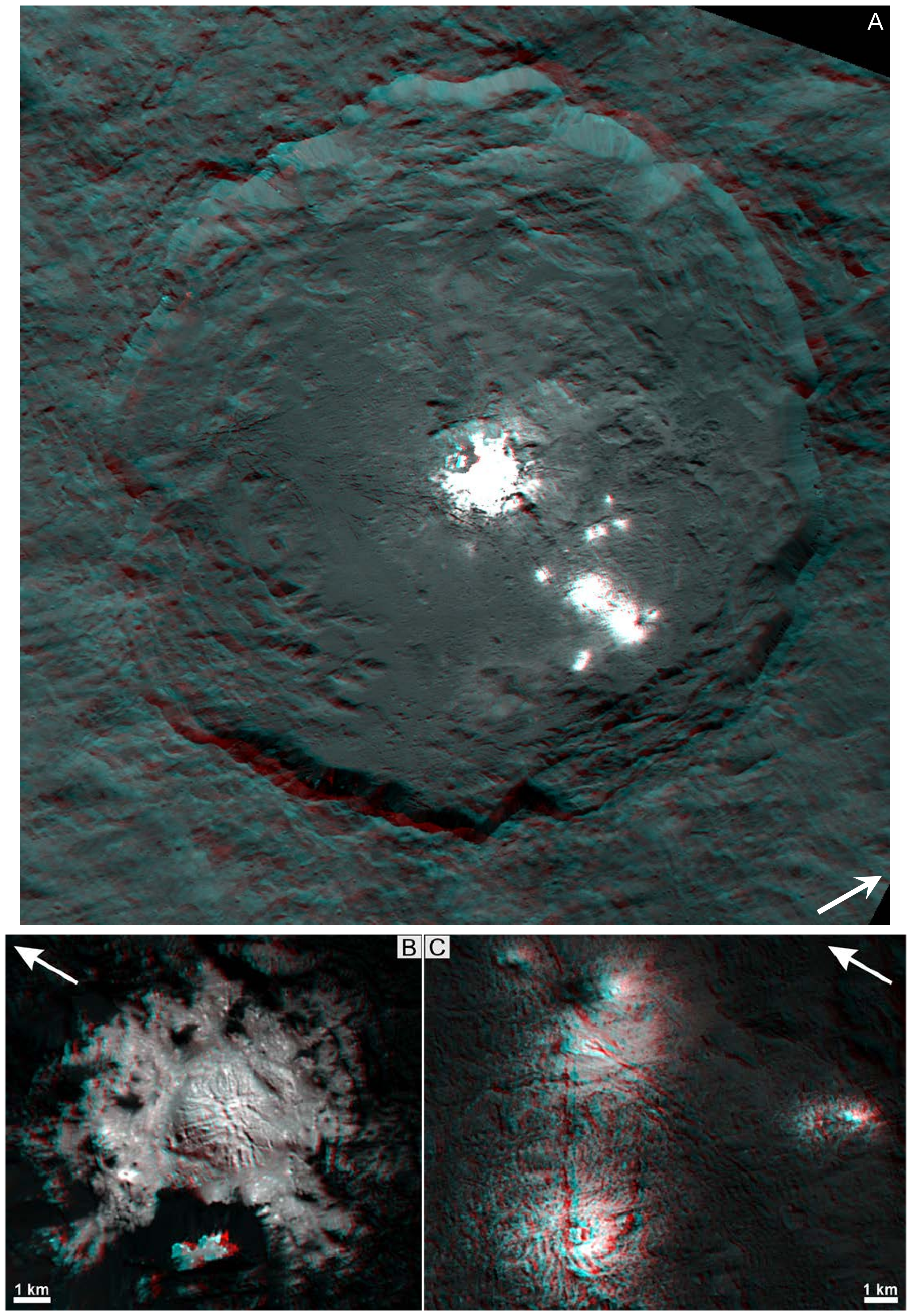

Fig. 1: 3D anaglyphs of Occator.

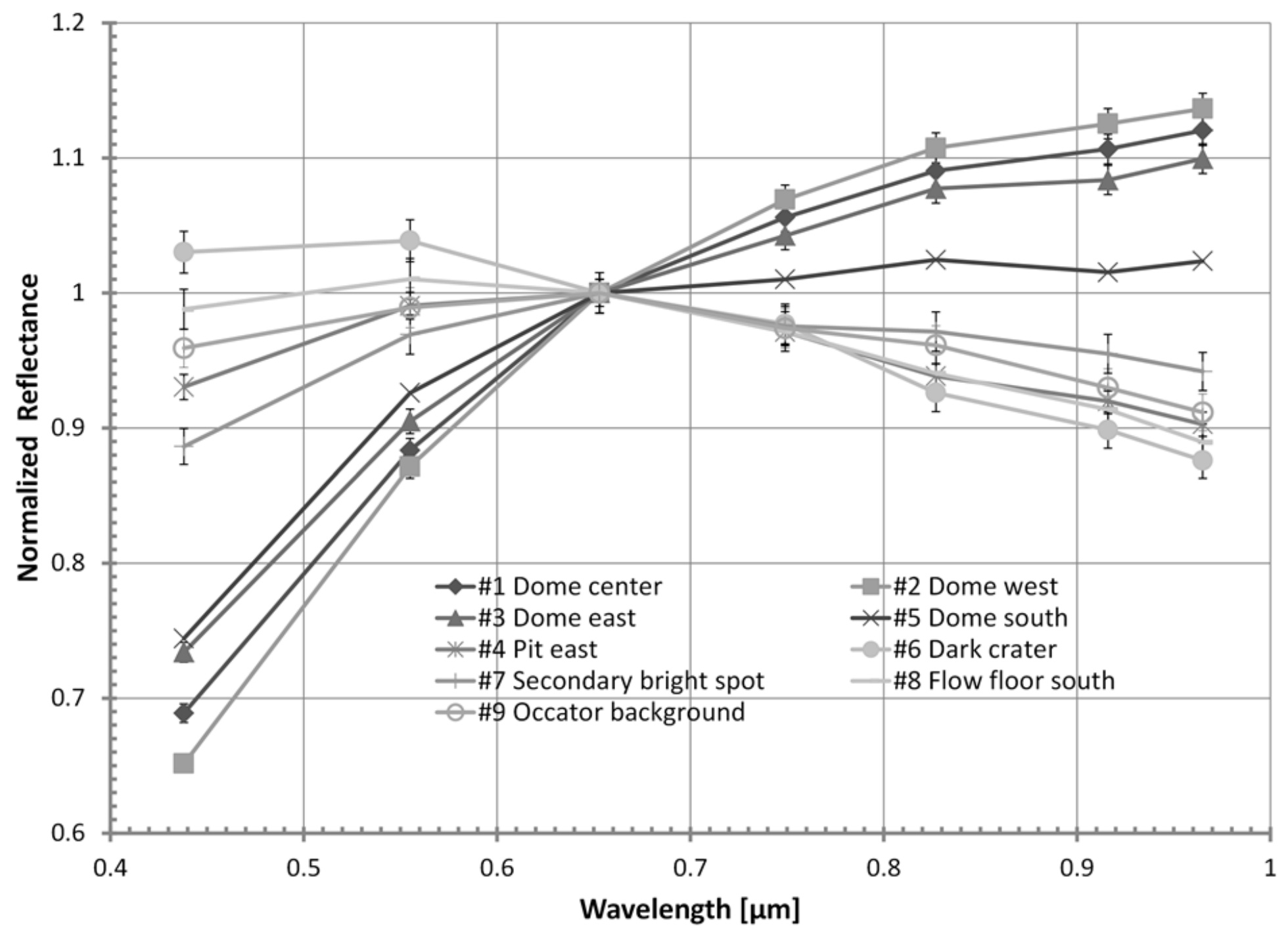

Fig. 3: Relative color spectra of Occator.

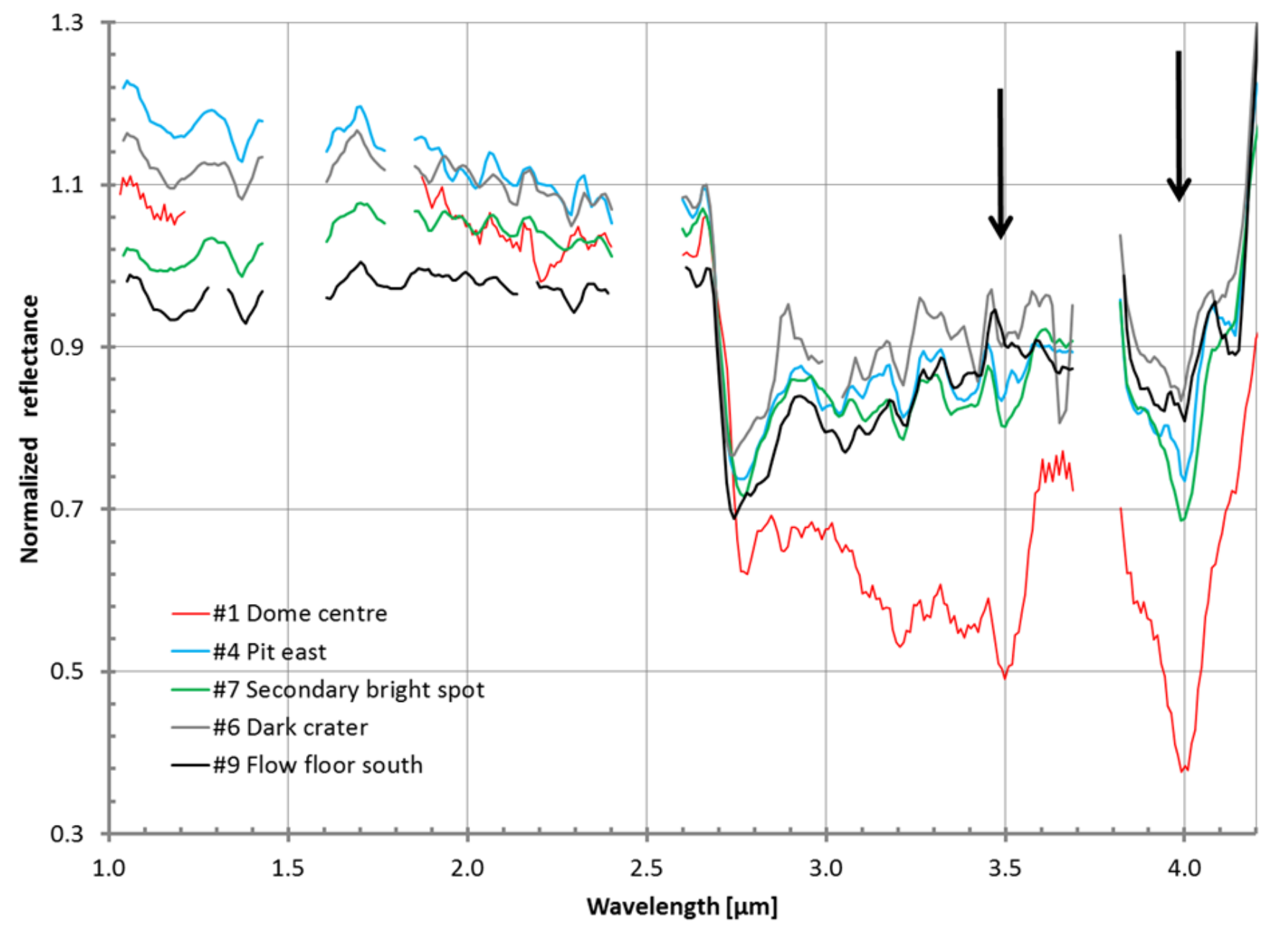

Fig. 4: IR spectra of selected sites.

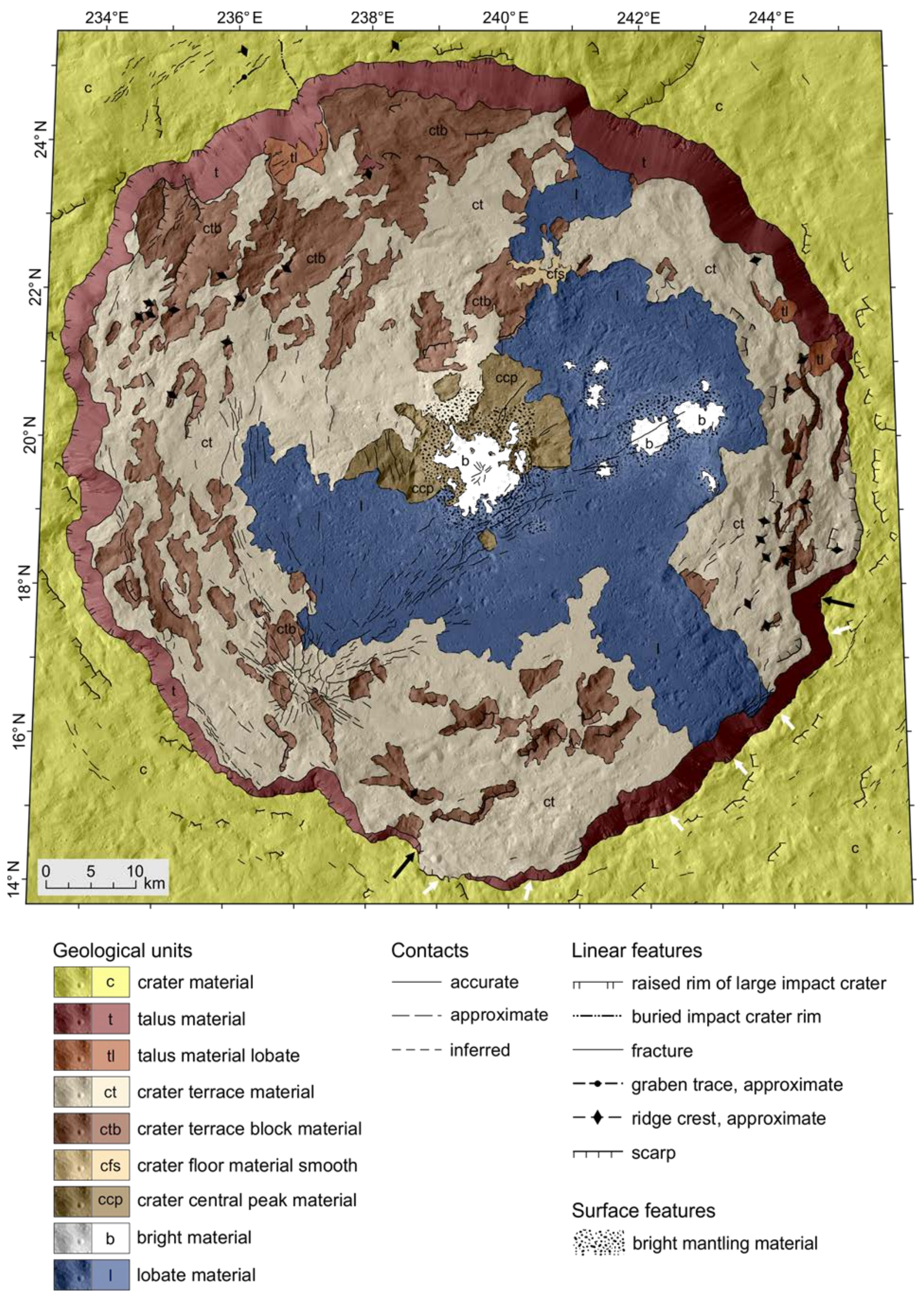

Fig. 2: Geologic map of Occator.

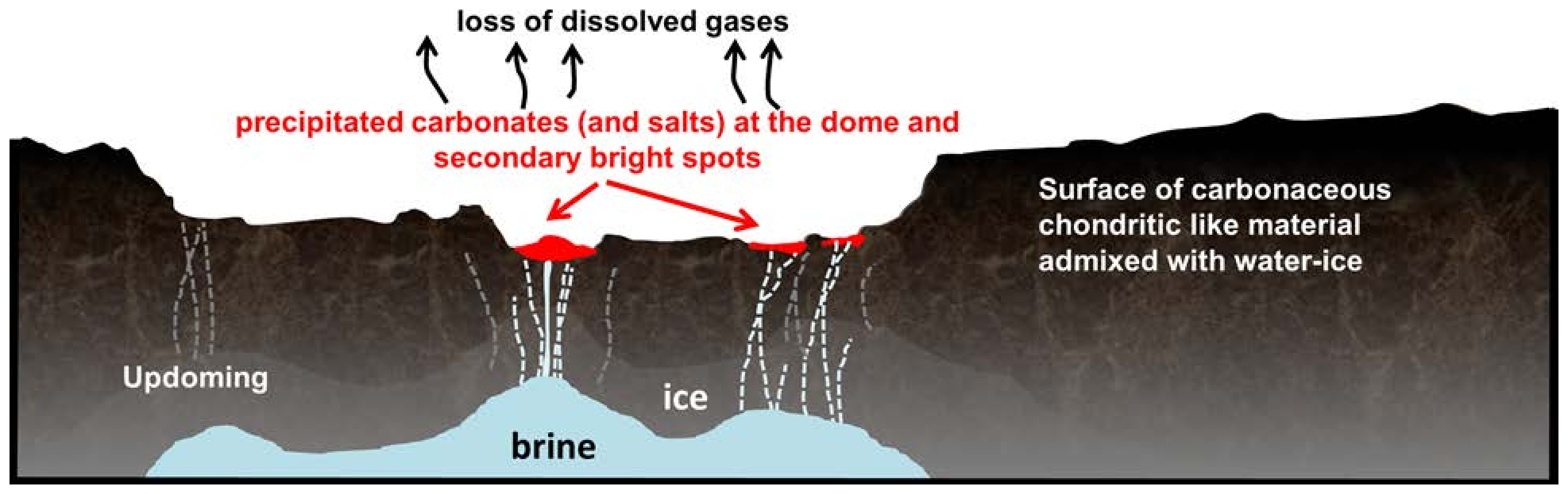

Fig. 5: Inferred cross-section of Occator.

## Discussion

Occator exhibits evidence of present and past endogenic activity, about 30 Ma years after crater formation. The impact event ~34±2 Ma ago obviously delivered sufficient energy to trigger processes that finally led to the present occurrence of bright spots on the surface. The bright dome is essentially uncontaminated by ambient dark material and is fractured, which is indicative of one or more extrusive events. Likely, a long-lasting process appears to be prevalent, whereby periodically or episodically ascending bright material from a subsurface reservoir was deposited, expelled from fractures and extruded onto the surface, forming the present-day central dome. Ballistic transport seems reasonable. However, a sedimentation process and subsequent pit collapse cannot be ruled out.

Ceres today likely contains large amounts of $H_2O$ in the form of an icy mantle and a large liquid reservoir ('ocean') at depth (e.g., ,Castillo-Rogez 2011, Travis et al. 2015). Upon heat loss to space and decay of radio-nuclides (e.g., Travis et al. 2015), an ice-rich outer shell developed and the mass of residual liquid decreased while solute concentrations increased, finally resulting in a high-salinity brine layer or isolated lenses (Nathues et al. 2016). Due to its elevated density, the brine layer must be located between a muddy icy lower crust and a silicate-rich core. Fines, early and continuously precipitated phases, carbonates like $CaCO_3$, and patches of brine got trapped in the growing ice-rich shell. Besides water, methane and carbon dioxide are probably the most abundant gas species dissolved in the pressure regime between core and crust.

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 latter can be triggered by larger impacts where the upper crust is mechanically disturbed such that deep-seated brines are enabled to ascend closer to the surface. The pressure release caused by this upward movement produces significant $H_2O$ losses, thereby oversaturating the liquid in carbonate and possibly with other minor phases of chloride and sulfate minerals. Before the onset of sublimation, methane and carbon dioxide would exsolve from the solution, form vent systems and escape through those vents along with relatively large proportions of water vapor (Fig. 5). Episodic tapping of the hypersaline liquid by pressure release is probably an explanation for the formation of a rather thick salt deposit in the central pit.

**References:** Castillo-Rogez, J. C. 2011, Icar 215, 599; De Sanctis et al. 2015, Nature 528, 241; De Sanctis et al. 2016, Nature 536, 54; Nathues et al. 2015, Nature 528, 237; Nathues et al. 2016, PSS 134, 122; Nathues et al. 2017 ApJ 153; Travis et al. 2015, 46th LPSC, 2360