SURFACE PROCESSES AND SPACE WEATHERING AT CERES.

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Introduction: When Dawn arrived at Ceres in 2015 it found a unique and perplexing ice-rock dwarf planet [1]. As anticipated, the overall surface is very dark, but small local areas exhibit unexpectedly bright materials that are likely indigenous in origin [2]. Near-infrared spectroscopic analyses identified the presence of ammoniated phyllosilicates (which are typically associated with the outer solar system) [3], and these were shown to be present everywhere across the surface although their relative abundance varies regionally [4]. The surface is heavily cratered, except for the largest craters [5], allowing relative ages to be derived [6]. The most recent craters often exhibit rays as well as local spectral properties that are relatively blue (440-960 nm) compared to their surroundings [2, 7]. Fresh craters that exhibit regular but distinct optical properties compared to similar but older areas is a characteristic indication that some form of alteration, or space weathering, occurs with time across the surface that transforms freshly exposed material into background soils.

Fresh craters at Ceres. An overview of equatorial Ceres is shown in Fig. 1. This Ceres Color Composite-A is designed to highlight relatively red-blue areas along with overall brightness (green channel). Very young craters such an Haulani (H: 5.7N, 10.9E) exhibit an extensive ray system that appears relatively blue. In addition to two craters used as examples here, Juling & Kupalo [8], other prominent young craters under investigation are indicated with a letter to the right of each.

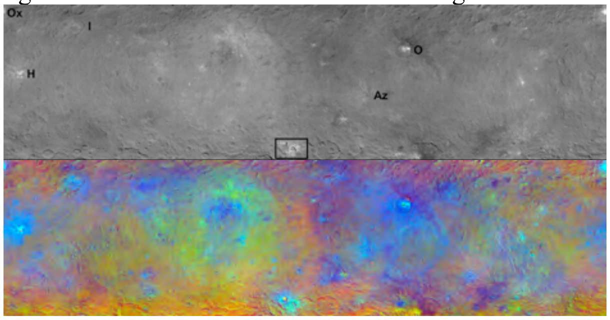

Fig. 1. Ceres equatorial optical properties measured by the Framing Camera (FC) ± 45°. Top: 750 nm albedo; Bottom: CCC-A where R=965/750; G=750; B=440/750 nm. The box indicates craters Juling and Kupalo. Other craters are H: Haulani; Ox: Oxo, I: Ikapati, O: Occator, Az: Azacca.

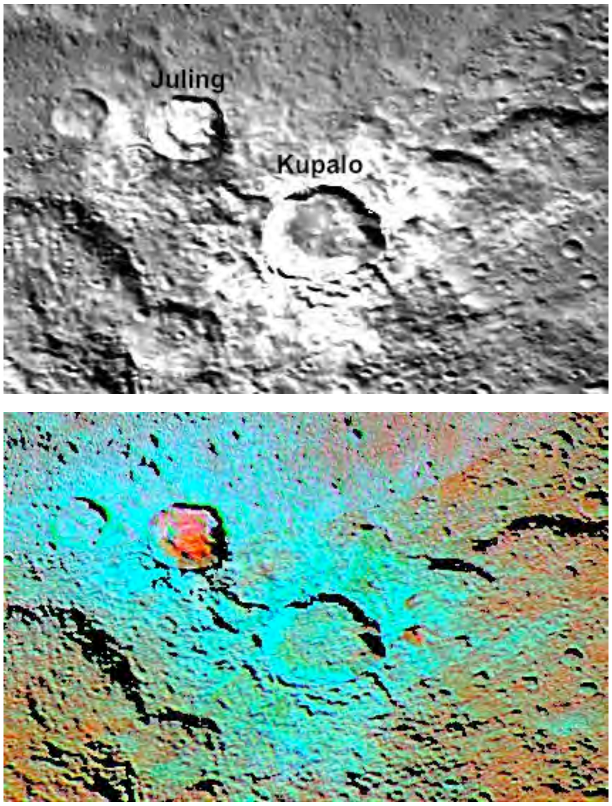

Fig. 2. Craters Juling (20 km @ 35.9 S, 168.4 E) and Kupalo (26 km @ 39.4 S, 173.2 E). Both are relatively young morphologically (see Fig 3 and [7]). Top: Survey FC 750 nm brightness image. Bottom: Survey CCC-R where R=965/750; G=550/750; B=440/750 nm. Kupalo is brighter and has a slightly different visible continuum curvature.

Surface processes. Ceres is an airless body, and its surface is exposed to the harsh space environment apparently for billions of years [6]. The basic principals of space weathering processes and optical effects were first recognized through detailed analyses of the lunar samples [e.g., 9, 10], but recently are found to be more complex. For the Moon, dominant processes include interaction of the silicate surface with micrometeorites and solar energetic particles producing damaged and depositional rims on individual grains that contain optically active npFe^0 (nanophase metallic iron). Samples from the near-Earth S-asteroid Itokawa were found to have similar (but fewer) rims which were also enriched with S as well as Fe nanophase opaques [11], illustrating that surface composition is also an important factor. At Vesta (further from the sun, lower velocity distribution of micrometeorites, no free metal or sulfides) Dawn detected none of the optical effects of lunar-like nanophase-opaque accumulation, but instead found that space weathering of the surface was largely influenced by continuous contamination and mixing of the regolith with minor CC-like material [12], consistent with the larger scale contamination of the surface that resulted in detectible regional OH [13-15]. We thus expect regolith mixing [16] to also be a fundamental process at Ceres.

Ceres, is located further out in the main asteroid belt than Vesta. As a low bulk-density ice-rock dwarf planet [1], Ceres can, and certainly does, host its own special surface processes and products. For example, over geologic time Ceres is expected to have differentiated to some extent, with the more water-rich materials or ice accumulating near the surface [17]. Water-ice is not stable on the surface [e.g. 18], however, and an ice-bearing surface would sublimate leaving a lag deposit. If a brine is exposed, salts would evolve from dissolved components and any solid/altered minerals present would contribute to the lag. Furthermore, solid state convection of salt rich interior materials may result in upwellings and/or diapirs [17], bringing deeper altered material upward to be exposed by later impact processes. Although details are being investigated and modeled, this description is generally consistent with many of the surface properties observed at Ceres.

Major impacts should excavate below the crustal lag layer. As higher resolution imagery and spectroscopy become available, many of the craters are providing evidence for special forms of mixing and space weathering on Ceres. Equally important are crustal evolution effects from extended mixing of both endogenic and exogenic materials. The character of the ‘continuous ejecta’ surrounding Kupalo in Fig. 3. provides an example where a form of fluidized erosion or deflation has occurred associated with the impact. If the fluid was liquid water/brine, it might have been produced as impact melt or was emplaced as blocks of ice that subsequently melted from the heat of the impact deposits, either of which produced the erosion. Additional ongoing investigations include the origin and nature of crater rays and crater deposits and (perhaps related) salt formation, composition, accumulation, and distribution.

References. [1] CT Russell et al., 2016 *Science* submitted [2] A Nathues et al., 2015 *Nature* 528. [3] MC De Sanctis et al., 2015 *Nature* 528. [4] E Ammannito et al., 2016 *Science* submitted. [5] S Marchie et al., 2016 these volumes [6] H Hiesinger et al. 2016 *Science* submitted. [7] R Jaumann et al. 2015 AGU; 2016 these volumes. [8] S Mest et al. 2016 these volumes. [9] CM Pieters et al. 2000, *MaPS* 35. [10] B Hapke 2001 *JGR* 106. [11] T Noguchi et al. 2011 *Science* 333. [12] Pieters et al. 2012 *Nature* 491. [13] TB McCord et al., 2012 *Nature* 491. [14] De Sanctis et al. 2012 *ApJ* 758. [15] T Prettymann et al. 2012 *Science* 338. [16] T Daly & Schultz 2015 *GRL* 42 [17] TB McCord & Sotin 2005, *JGR* 110. [18] F Fanale & Salvail 1989, *Icarus* 82

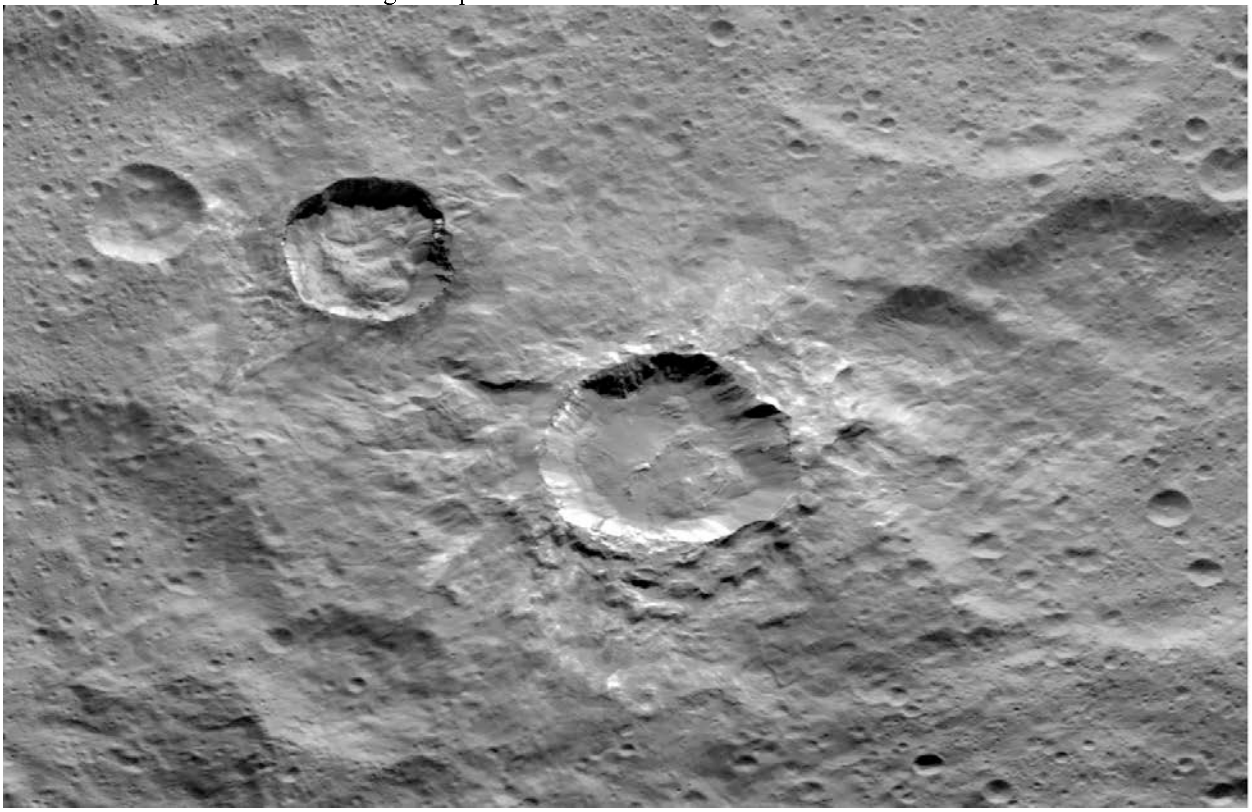

Fig 3. Craters Juling and Kupalo imaged during HAMO with FC clear filter. In addition to the notable erosion/deflation around Kupalo, material filling Juling is distinctly different from anything in the region (see fig 2.).