THE SUB-SURFACE DISTRIBUTION OF VOLATILES ON CERES. M. Hoffmann[1], A. Nathues[1], T. Platz[1], M. Schaefer[1], G. S. Thangjam[1], K. Mengel[2], E. A. Cloutis[3], P. Gutierrez-Marques[1], J. Ripken[1], C. T. Russell[4], [1]Max Planck Institute for Solar System Research, Justus-von-Liebig-Weg 3, 37077, Göttingen, Germany, [2]Institute of Displosal Research, Clausthal University of Technology, Adolph-Roemer-Str. 2a, 38678 Clausthal-Zellerfeld, Germany, [3] Department of Geography, University of Winnipeg, 515 Portage Ave., Winnipeg, Manitoba, Canada R3B 2E9,[4]Institute of Geophysics and Planetary Physics, University of California, 3845 Slitcher Hall, 603 Charles E. Young Drive, East, Los Angeles, CA 90095-1567, USA.

Introduction: Extended ray systems and bluish visual colors characterize fresh impact craters on Ceres [1]. Evidence from images by the Dawn Framing Camera (FC) [2] links this also to recent activity [3] from exposed former ice/volatile-rich sub-surface layers. Morphology, crater counts, and distribution of material of distinct color properties trace a consistent sequence of evolution on short and long time scales depending on the internal distribution of materials exhumed during impacts. Thus, not only the subsequent alteration can be identified by comparison of features of different age, but also very old distribution and content of materials at crustal depths becomes evident. Consequently, the three dimensional distribution and correlation of the bluish material of the young craters can be studied analyzing the global distribution and by measuring the crater depth and thickness of the exposed layers in each of them.

Color ratio parameters: Diagnostic spectral parameters for this bluish material are the slope over the full range of the FC colors (0.96 µm / 0.44 µm, ratio “A”) and a spectral ratio which describes the relative depths of the absorption at the extreme ends of this range relative to the maximum of reflectance at the middle of this range (ratio “B”):

(0.55 µm *0.75 µm)/(0.44 µm *0.96 µm)

This parameter has values between 1.08 (weathered background) and 1.22 (at the center of the Occator crater).

Results: The distribution of exposed bluish material, displayed by blue color in a mosaic of these parameters, is quite diverse (Fig.1). Material appears bluish in this stretch if it has values <.96 of the first and >.95 of the second parameter described above. These limits will be used for the term “bluish” in the subsequent discussion. The distribution ranges from craters with many blue spots inside their walls but missing blue-colored ejecta outside, to crater floors completely cleared of blue material while the outside shows a contiguous cover. In many cases only the crest of the crater wall appears bluish. In other cases the most prominent exposure of blue material is a central peak. No corresponding dependence on crater size has been detected. We have studied the distribution of different patterns of bluish inner-crater exposures and the ejecta.

Although bluish craters are concentrated near the equatorial region, they are very sparse near larger impact structures in the southern hemisphere (Kerwan, Yalode, Urvara). While at young craters the source of the bluish material can be localized, increasing age does not only change the spectral properties and crater morphology, but also the identifiable volume of volatile-rich deposits, likely due to mixing with the altered carbonaceous chondritic surface material of the pre-impact crust. Areas of blue material without a specific structure appear weak in contrast and may be either old or widely covered by thin distant ejecta. Independent from the impact velocity, the distribution of bluish material demonstrates that recent impacts encounter a mottled distribution of apparently un-processed sub-surface material on a global scale at lower latitudes. Some secondary impact deposits (caused by far-flung blocks of distant primary impacts) of such material is also scattered at higher latitudes. In longitude, bluish exposures cluster grossly at the two prominent craters Occator and Haulani. Scattered additional sites, including the outstanding bright Dantu crater, only emphasize an apparent deficit in bluish material around the longitudes 120°±90° and 300°±40°.

The patterns of the location and thickness of the layers indicate in situ exposure or impact distribution of the bluish material. A bluish crater floor is consistent with the presence of blue material at the bottom level of the layer exposed by the impact, indicating the presence of the bluish material prior to the impact. If the distribution of blue areas inside craters follows their morphology (floor, wall), it can be concluded that they show the original distribution of depth and thickness of primary layers. Inner walls without bluish exposures in a crater with a bluish ejecta pattern and a bluish floor indicate a sizeable original upper layer free of bluish material. A radial increase of bluish small spots towards a crater with an extended thick

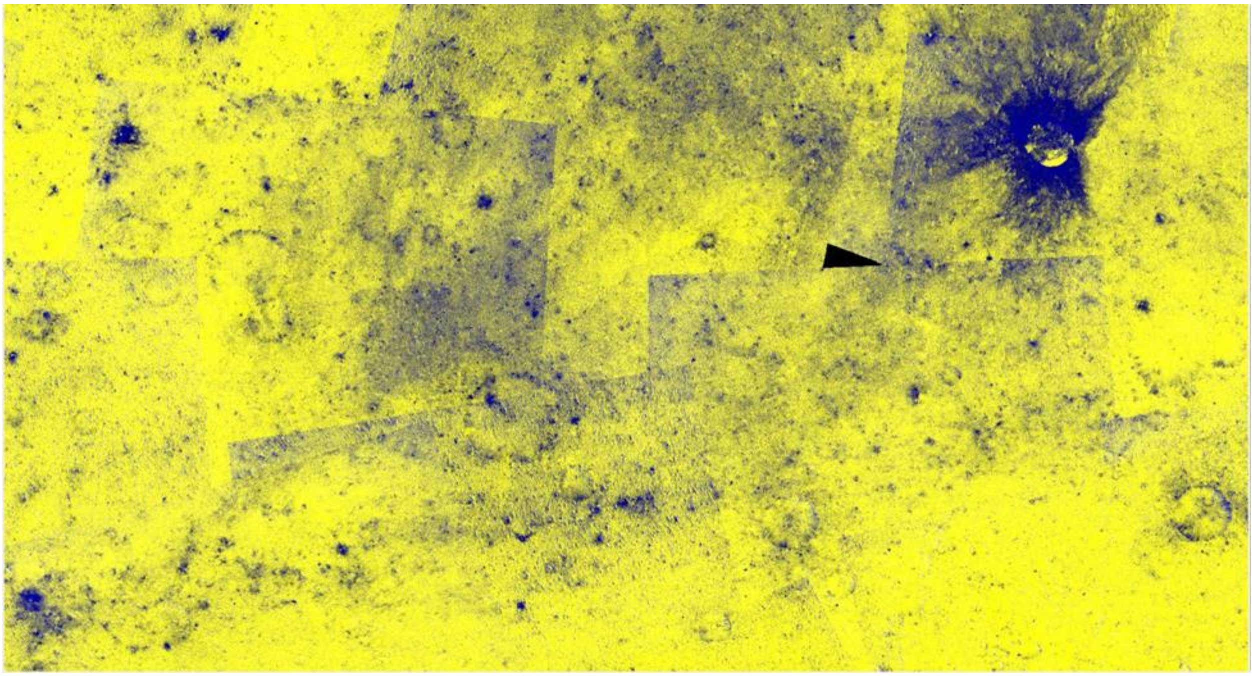

Fig. 1. Many different patterns of "bluish" material in this RGB mosaic (HAMO orbit cycle 5) of the Kerwan basin on Ceres indicate different ages and conditions of exposure. R, G: ratio "A"; B: ratio "B", see text.

bluish ejecta field, e.g. at crater Haulani, is consistent with the assumption of secondary craters. Irregular distribution of larger and smaller bluish patches inside craters is consistent with exposing impacts into a region with a subsurface layer of bluish materials. However, there are areas with bluish and non-bluish craters of similar size and degree of erosion next to each other, where the ambiguity between compositional diversity of the target area or the projectiles is unresolved. While Occator is the largest crater which is covered by bluish material over its full size, the exact thickness of exposed or penetrated bluish layers is difficult to measure because of age-dependent erosion and mixing effects. The low content of bluish material in the largest impact structures indicates a layer thickness much less of their maximum depths during formation. Craters with diameters of about 20 km frequently show complete coverage of their floors and a wide ejecta blanket of bluish material, consistent with a thickness up to 10 km or more.

Conclusion: The observed distribution is a consequence not only of the crater mechanics but also of the initial sub-surface distribution and the chemical stability of the ejected material inside the hot plume [4] associated with formation of the crater. Craters in areas with a high initial content of subsurface volatiles show not only voluminous deposition of bluish materials, but also reveal flow features and different progress of erosion, as well as signs of viscous relaxation. Even in the equatorial zone large areas are only sprinkled by apparently secondary impacts, but are otherwise devoid of craters with indications of primary bluish material. However, in such areas several craters show a weak enhancement of the content of bluish material near the crest of the crater wall. We conclude that at these sites bluish material was available during the time of impact but has been mostly destroyed or subdued by long term alteration.

References:

[1] Nathues et al., in preparation. [2] Sierks et al. (2011) *Space Sci. Rev. 163, 263-327.* [3] Nathues et al. (2015), *Nature 528,237-240.* [4] Pierazzo and Melosh (2000) *Meteoritics and Planetary Science 35, 117-130.*