DEGRADATION AND EJECTA MOBILITY OF IMPACT CRATERS ON CERES. J. H. Pasckert[1], H. Hiesinger[1], C. A. Raymond[2], C. T. Russell[3], [1]Institut für Planetologie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany (jhpasckert@uni-muenster.de); [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA; [3]University of California, Los Angeles, California, USA.

Introduction: Ceres is the largest and most massive body in the asteroid belt and the largest dwarf planet in the Solar System. Recent Dawn Framing Camera (FC) images show that the surface of Ceres is heavily cratered and exhibits a complex geologic history [1-4]. This is in contrast to some previous geophysical models [5] predicting a relatively craterless surface as the result of relaxation, as Ceres was thought to be a differentiated body with a water-rich shell. Consequently, the limited relaxation of craters implies that the cerean crust has a lower ice content than previously thought [6]. Furthermore, the Dawn mission was able to confirm the presence of a water ice-rich crust including water-hosting minerals, and geologic features (lobate flows, pits, etc.) possibly related to water ice in the subsurface [7-10]. In addition, the simple-to-complex transition diameter on Ceres is similar to that of other icy bodies (Dione and Tethys) in the Solar System. However, rampart craters thought to be related to a water-rich surface or sub-surface are very common on Mars, Dione, and Ganymede, but are absent on Ceres. Thus, detailed investigation of the crater shape and the style of ejecta emplacement are important to explain the controversial behavior of impact craters on Ceres, and to test the ice-rich nature of the cerean crust.

Here we present our first results of a global study investigating the distribution, timing, and ejecta mobility (EM) of cerean impact craters, based on Framing Camera (FC) images of NASA's Dawn mission. The ejecta mobility is a common parameter to categorize rampart craters throughout the Solar System and is thought to be related to the water content of the target. It describes the ratio between the ejecta extent and the diameter of the parent crater. The EM has already been studied in great detail for rampart craters on Mars and icy satellites [11-13]. According to these studies [12], on Mars EM increases with increasing latitude, and thus increasing ice content.

Methods: We mapped the proximal ejecta blankets of 252 craters with a visible ejecta blanket. Small craters often have thin ejecta blankets, making it difficult to identify them. Thus, only craters with clearly recognizable ejecta blankets were mapped. Furthermore, we classified these 252 craters into 3 classes. Class I includes the freshest and smoothest ejecta blankets, sometimes showing flow-like lobes. In Class II, craters show more degraded ejecta blankets, where the ejecta extent has been reduced by subsequent degradation (e.g., impact cratering). Class III includes the most heavily degraded craters, where ejecta blankets are barely visible

To calculate the mean extents, we calculated the equivalent radii of the measured shape areas of the mapped ejecta blankets by the following equation:

$$E = \sqrt{\left(\frac{A}{\pi}\right)} - r$$

where E (km) is the mean extent of the ejecta blanket, A (km²) is the area of the mapped crater including the ejecta blankets, and r (km) is the radius of the respective crater. The ejecta mobility (EM) ratio has been calculated as follows [e.g., 11-13]:

$$EM = \frac{E}{r}$$

To understand the timing of the mapped craters, we derived absolute model ages (AMAs) of 24 mapped craters by performing crater size-frequency distribution (CSFD) measurements using the lunar derived production and chronology functions from [2]. To augment our CSFD measurements, we also included AMAs form other studies [14-18].

In addition, we studied potential correlations of the calculated parameters with the latitude of the investigated craters. We also compared our results for Ceres with rampart craters on other icy surfaces and with craters on dry surfaces. For this, we calculated the EM, for example, for 15 lunar craters (diameter range: 1-200 km) located on both, mare basalts and highlands.

Results: The largest crater that shows a clearly defined ejecta blanket is Urvara crater (46°N/112°W) with a diameter of ~170 km. Based on CSFDs, Achita crater with an AMA of 570 Ma [14] is the oldest crater still showing an ejecta blanket. It has been classified as class II, but close to the transition to Class III. The maximum extent of Yalode's ejecta blanket is extremely difficult to map. Thus, we excluded Yalode from our EM studies. If included in our study, Yalode crater (730 to 850 Ma) would be the oldest crater that still shows an almost continuous ejecta blanket. The youngest dated crater with an ejecta blanket is Haulani crater (5.6°N/10.7°E) with an AMA of 1.2 Ma.

The calculated EM ratios vary from 1.2 to 7.3 with a mean value of 2.8. This is a relatively wide range compared to Mars or Ganymede (Fig.1a), but similar to the average of craters throughout the entire Solar System (2.35 [13]). There seems to be no correlation between the EM ratio and the crater diameter (Fig. 1a). Similar to other planetary bodies, there is a clear trend indicating that the ejecta run-out distance is directly proportional to the crater diameter (Fig. 1b). Yet, the slope of the increase seems to be shallower than on Mars or Ganymede (Fig. 1b), possibly caused by the lower gravity.

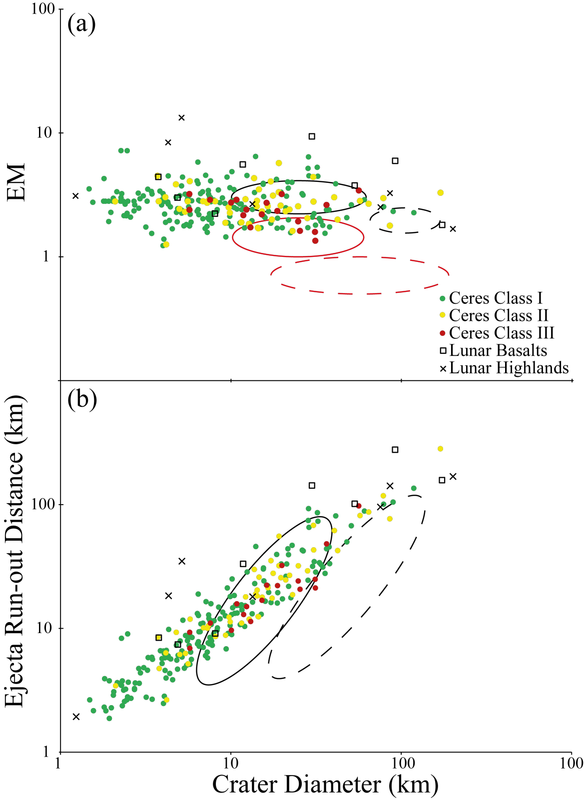

Figure 1: *(a) Comparison between the ejecta mobility (EM) ratio and the crater diameter. The two solid (Mars) and dashed (Ganymede) ellipses represent the results from [13] for inner (red) and outer (black) ejecta layers of rampart craters on Mars and Ganymede (b) Comparison between the ejecta run-out distance to the crater diameter. The ellipses mark the position of the results from [13] for rampart craters on Mars (solid) and Ganymede (dashed).*

Plotting EM ratios versus latitude (Fig. 2), we find that the EM ratios increase with increasing latitude. This can be observed in both hemispheres. The average EM ration between 60° and 90° (30 craters) is by a factor of 1.7 higher than the average EM ratio between 0° and 60° (222 craters).

Discussion and Conclusions: Our CSFD measurements of craters with ejecta blankets show that even the largest craters on Ceres lose their ejecta blankets after ~ 900 Ma, as we observe no older craters having a continuous ejecta blanket. Older craters like Omonga (970 Ma [14]) or Coniraya (1.3 Ga [14]) have already lost their ejecta blankets. The reason for the relatively quick loss/degradation of the ejecta blankets could be caused by the sublimation of volatiles. On the Moon, the ejecta blanket of the Orientale basin might be one of the oldest still visible ejecta blankets. CSFD measurements of [19] reveal an AMA of 3.7 Ga for the formation of Orientale. The oldest lunar crater we used for this study is Tsiolkovsky crater with an AMA of 3.2 Ga [20].

Comparing EM ratios for different planetary bodies, we find that the calculated EM ratios for cerean craters are similar to those of rampart craters on Mars, but higher than those of Ganymede and partially lower than those of lunar craters. This shows that a higher EM ratio is not necessarily the result of only a higher water content, as lunar craters show the highest EM ratios. However, EM ratios of craters in a completely dry target might be different, and not comparable with EM ratios of craters in relatively wet targets, like Mars and Ganymede. Furthermore, also the differences in gravity, and the absence of an atmosphere at Ceres, Ganymede, and the Moon might cause differences in the EM ratios [21].

Looking at the distribution of EM ratios across the surface of Ceres, we observe generally higher EM ratios at the poles than in equatorial regions (Fig.2). A similar increase has also been reported for martian rampart craters and has been related to the higher water content at the poles [10]. An increase in H content to the poles of Ceres has also been observed by Dawn's GRAND instrument [22].

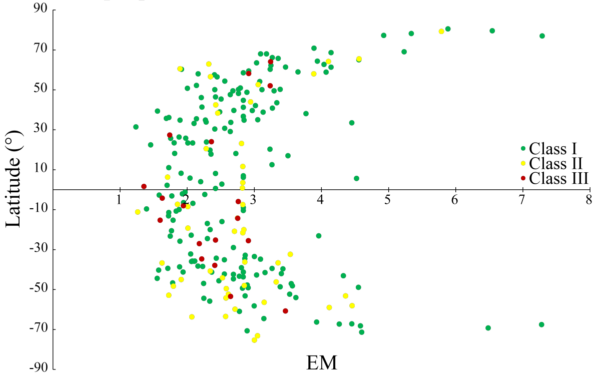

Figure 2: *Latitudinal variation of the EM ratios. The increase of the EM ratios with latitude can especially be observed for Class I and II. Class III craters have not been identified at the poles. This might be related to the poorer illumination conditions at the poles, which make it difficult to identify ejecta blankets in general.*

References: [1] Russell et al. (2016) *Science*, 353. [2] Hiesinger et al. (2016) *Science*, 353. [3] Buczkowski et al. (2016) *Science* 353. [4] Nathues et al. (2016) *Planetary and Space Science,* 134. [5] Bland (2013) *Icarus*, 226. [6] Bland et al. (2016) *Nature Geoscience*, 9. [7] De Sanctis et al. (2015) *Nature,* 528. [8] Combe et al. (2016) *Science*, 353. [9] Schmidt et al. (2016). [10] Sizemore et al. (2017) *Nature,* submitted. [11] Mouginis-Mark (1979) *JGR*. [12] Barlow (2006) *Meteoritics & Planetary Science*, 41. [13] Boyce et al. (2010) *Meteoritics & Planetary Science*, 45. [14] Pasckert et al. (2017) *Icarus*, submitted. [15] Scully et al. (2017) *Icarus*, submitted. [16] Schulzek et al. (2017) *Icarus*, submitted. [17] Ruesch et al. (2017) *Icarus*, submitted. [18] Hughson et al. (2017) *Icarus*, submitted. [19] Whitten et al. (2011) *JGR Planets,* 116. [20] Pasckert et al. (2015) Icarus, 257. [21] Osinski et al. (2001) *EPSL*, 310. [22] Prettyman et al. (2016) *Science*, accepted.