TOPOGRAPHIC DIFFUSION AS A CAUSE OF VARIATIONS IN CRATER DENSITY ON CERES. M. Hirabayashi[1], C. I. Fassett[2], D. A. Minton[3], G. S. Collins[4], and T. M. Davison[4], A. I. Ermakov[5], [1]Auburn University, Auburn, AL 36849, USA, (thirabayashi@auburn.edu), NASA Marshall Space Flight Center, Huntsville, AL 35805, USA, [3]Purdue University, West Lafayette, IN 47907, USA, [4]Imperial College London, SW7 2AZ, UK, [5]NASA/JPL Caltech, Pasadena, CA 91109, USA.

Introduction: The surface of Ceres has been modified by impact cratering events [1] and post-impact processes [2] over its lifetime. Due to a relatively strong crust of Ceres, craters larger than ~ 250 km in diameter are also affected by viscous relaxation [3, 4]. The northern region is heavy cratered while the equatorial and southern regions are lightly cratered [5, 6] (Figure 1). While some areas might have been modified by post-impact flow processes, other locations are less affected by such activities and mainly controlled by impacts [2, 7]. If these impact-affected areas were in equilibrium in a similar manner, we would expect the similar crater morphologies and populations. Here, we propose that the observed crater populations in these areas are attributed to a variation in topographic diffusion. We find that a 10-km-diameter crater is completely erased in ~1.5 Ga in the equatorial and southern regions and ~4.0 Ga in the northern region. A possible explanation is that the mechanical conditions on the surface might have evolved differently, possibly due to emplacements of large craters in the past [6].

Topographic diffusion: When impact cratering is a main contributor to degradation, existing craters are gradually erased because of exposure to new crater generations. Although one emplacement of a crater smaller than a formally existing crater may not affect crater degradation immediately, small craters are generated so often that existing craters are progressively erased [8]. This process, known as topographic diffusion, plays a significant role in crater erasure on rocky, airless planets [9, 10, 11].

Crater population on Ceres: Using publically available Dawn HAMO images, we count craters with a diameter ranging between 1 km and 100 km in the northern, equatorial, and southern regions (Figure 2). We avoid locations affected by large-scale flow features such as distinctive material distributions [3, 4] only to consider impact cratering to be a primary degradation process. We choose four sites with an area of 150 km by 150 km in each region. The cumulative size-frequency distributions (CSFDs) of the equatorial and southern regions are similar, while the northern region is distinctly higher in density. At smaller crater sizes, the slopes in log-log space are approximately -1.4 in all cases. This trend is consistent with an R-plot analysis [5] and a spectral power density analysis of topography [3]. As impact cratering is considered to be primary in these locations, slopes shallower than -2 and the probable crater production SFD slope imply that these regions are in crater equilibrium [12].

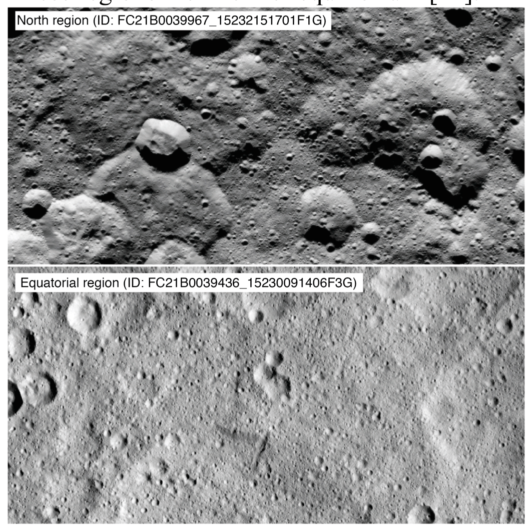

Figure 1. Crater morphologies in the northern (top) and equatorial (bottom) regions in the same scale.

Crater equilibrium modeling: The information of interactions between generated and erased craters give constraints on the crater equilibrium condition [12]. This statistical model can specify the time evolution of the crater number. Also, because crater equilibrium is only dependent on a cratered surface condition, the effect of topographic diffusion can be characterized without a crater production function in this model [12].

In the present work, we extend this statistical model to compute the lifetime of a crater at a given diameter due to topographic diffusion. Given a currently observed equilibrium slope, the original model outputs how many craters are to be generated to erase old ones entirely. Incorporating a crater production model, the new model can describe the absolute timescale of the degradation processes. We use a crater production function derived based on a model-based population of the main asteroid belt [13].

Using the developed technique mentioned above, we find degradation timescales on Ceres (Figure 3). Based on the evolution of the crater population, craters at 10 km in diameter may be erased at a 99 % level in ~4.0 Ga in the northern region while 1.5 Ga in the equatorial and southern regions (the top in Figure 3). This result is reasonable because a larger crater population indicates that a cratered surface keeps more craters visible, implying that craters on that surface remain longer. We also describe how the degradation timescale changes due to the crater size (the bottom in Figure 3). The results are consistent with works proposed that crater degradation processes are dependent on crater sizes and surface conditions, which is called anomalous diffusion [10, 11]. Note that when a new crater is large, its ejecta blanket may immediately cover small craters [14]. However, it does not contribute to topological diffusion in a long timescale [15]. From Figure 3, we obtain the lifetime of a 100-m-diameter in the northern region as ~ 30 Ma and that in the equatorial and southern region as ~ 10 Ma. These crater degradation timescales are much shorter than those on other rocky planets like the Moon and Mercury [9, 16].

We rule out a possibility that these different slopes result from a crater-counting bias at large craters (> 30 km). As seen in Figure 2, the CSFD of craters of this size range is somewhat noisy. This feature results from an artificial cut-off due to the HAMO-image size. For craters less than 30 km in diameter, the population in the northern region is constantly higher than that in the equatorial and southern parts, concluding that this is not a sampling bias.

Interpretations: There are several possible explanations of the obtained heterogeneity. First, viscous relaxation could influence crater degradation. However, because the crust of Ceres has a relatively strong mechanical strength, viscous relaxation only affects large craters (> 250 km in diameter) [3, 4, 17]. Second, Ceres could have experienced a higher impact flux in the northern region than in the other regions. However, due to the current spin period, 9.04 hr, [1] and obliquity evolution [18] of Ceres, this scenario is unlikely to occur. The third explanation, which may be plausible, is that the considered regions might have had mechanical evolutions differently. Topographic diffusion is controlled by the amount of material transport due to impact cratering, which is dependent on mechanical weakness and material conditions. Because impact cratering may control surface material conditions [19] and induce mantle uplifting by which materials in the rocky core [20] reach close to the surface [21], such large craters might have made different evolutions in between the northern region and the equatorial and southern regions. Finally, low-viscous flows in endogenic origin are observed at the centers of craters such as Occator [7]. While the current analysis avoided these features, we note that these processes may help crater degradation processes. Detailed investigations will be necessary.

References: [1] C. T. Russell et al. (2016) *Science* 353, 6303, 1008-1010. [2] D. L. Buczkowski et al. (2016) Sience 02, 353, 6303, aaf4332. [3] A. I. Ermakov et al. (2017) *JGR-Planets* 122, 2267-2293. [4] R. R. Fu et al. (2017) *EPSL* 476, 153-164. [5] R. G. Strom et al. (2018) *Icarus* 302, 104-108. [6] S. Marchi et al. (2016) *Nature Comm.* 7, 12257. [7] K. Krohn et al. (2016) *GRL* 43, 11,994-12,003. [8] L. A. Soderblom (1970) *JGR* 75, 2655-2661. [9] C. I. Fassett and B. J. Thomson (2014) *JGR-Planets* 119, 2255-2271. [10] D. A. Minton et al. (2017) *Proceedings of GSA* 49. [11] D. A. Minton et al. (2018) *Icarus*, in review. [12] M. Hirabayashi et al. (2017) *Icarus* 289, 134-143. [13] H. Hiesinger et al. (2016) *Science* 353, aaf4759. [14] C. I. Fassett et al. (2011) *GRL* 38, 7. [15] D. A. Minton et al. (2015) *Icarus* 247, 172-190. [16] C. I. Fassett et al. (2017) *GRL* 44, 5326-5335. [17] M. T. Bland et al. (2016) *Nature* Geo. 9, 538-542. [18] A. I. Ermakov et al. (2017) *GRL* 44, 2652-2661. [19] T. J. Bowling et al. (2016) *LPSC* 47, 1903, 2268. [20] R. S. Park et al. (2016) *Nature* 537, 515-517. [21] T. M. Davison et al. (2015) *LPSC* 46, 1832, 2116.

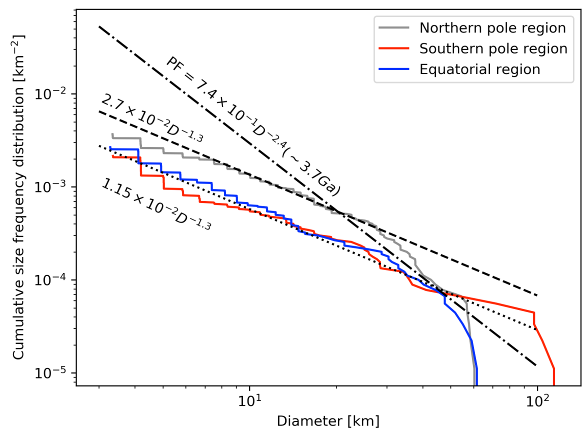

Figure 2. Cumulative size-frequency distributions. The dashed and dotted lines indicate the crater equilibrium slope. The dot-dashed line shows the crater production function at 3.7 Ga [11].

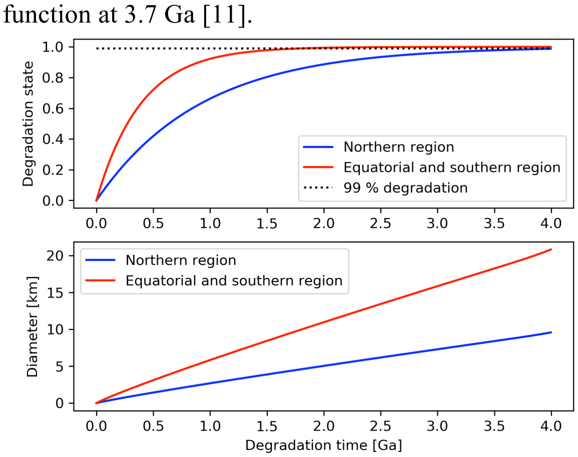

Figure 3. Crater degradation timscales. The top figure shows the degradation evolution of a crater at 10 km in diameter. The bottom figure describes the crater diameter that is degraded at a 99 % level at a given time.