INSOLATION-DRIVEN TOPOGRAPHIC EVOLUTION ON CERES. I. F. Pamerleau[1], M. M. Sori[1], and J. E. C. Scully[2], [1]Department of Earth, Atmospheric and Planetary Sciences, Purdue University, West Lafayette, IN, USA (ipamerle@purdue.edu), [2]Jet Propulsion Laboratory, Californian Institute of Technology, Pasadena, CA, USA.

Introduction: Ceres, the closest icy body to Earth, is the largest object in the asteroid belt. Despite its proximity, the ice fraction in the dwarf planet's crust remains debated, a quantity that is vital to understanding icy body interior processes, differentiation, and habitability. Before any spacecraft visited Ceres, [1] used bulk density measurements to predict the crust's composition to be largely ice and, therefore, be unable to maintain topography (e.g., impact craters) because it would viscously relax (lose topography due to pressure differences).

NASA's Dawn spacecraft revealed a heavily cratered surface on Ceres [2]. This observation was used to argue that the crust could not be purely ice, because ice would be unable to maintain topography over geologic timescales. The Dawn team then constrained Ceres' crust to have a maximum volumetric ice content of 40% based on rheology [3]. They concluded that the crust must be made of strong but light material such as salts and clathrates [4].

However, after the Dawn mission's conclusions were made, experimental laboratory data found that >6% rock content within ice greatly inhibits flow and viscous relaxation [5]. These results have not yet been applied to Ceres, so it is unclear if the crust could retain its cratered topography over geologic time with an ice-rich composition. If viscous relaxation is occurring on Ceres but at a much slower rate than previously expected, it is possible that Ceres' crust is more ice rich than predicted. A potentially icier crust would suggest that our understanding of the dwarf planet's interior processes would need to be revisited.

Here, we seek to quantify the amount of viscous relaxation that has occurred on Ceres. Quantifying viscous relaxation can be complicated due to the non-uniqueness of the process. Surface temperature, geothermal heat flow, composition, topography size, and age all affect the amount of relaxation a feature experiences. Despite the cratered landscape, there is evidence of relaxation happening on Ceres. The polar, colder regions of Ceres have a greater number of craters than the low latitude, warmer regions [2]. There is also evidence of relaxation in the power spectra of topography at different wavelengths [3, 6]. Certain individual features like mountains and large impact basins may be viscously relaxed [7, 8]. We hypothesize that insolation is the main driver of viscous relaxation on Ceres.

Methods: We isolate insolation as a cause of topographic evolution by comparing the poleward and equatorward facing walls of large craters on Ceres. Slopes on Ceres have been mapped in a general sense [9], but focusing on large craters in particular offers advantages when interpreting slopes to quantify relaxation. Studying these craters allows us to eliminate difference in other variables that affect viscous relaxation because the two features (poleward and equatorward crater walls) formed at the same time (i.e., have the same age) and, because they are close to each other, probably have effectively the same geothermal heat flow, composition and topography size.

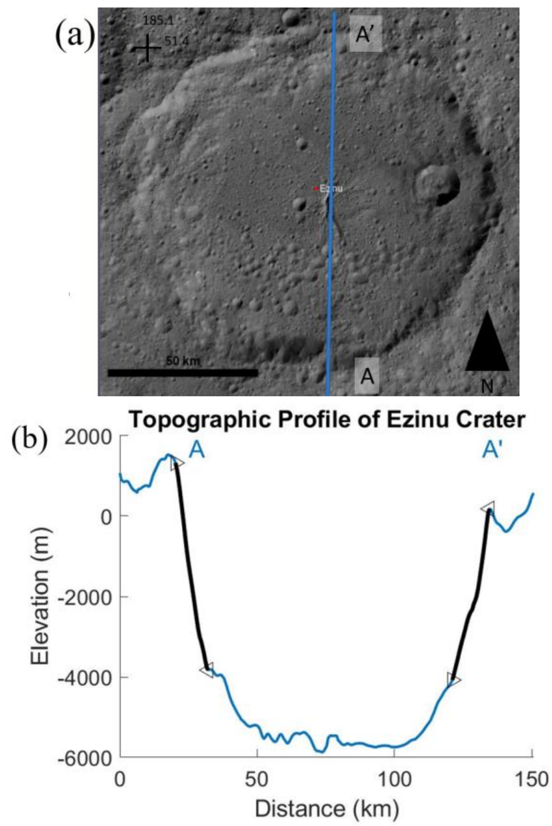

Figure 1: (**a**) Map of Ezinu crater on Ceres and a topographic profile line (A-A') seen in (b). The center of the crater is at about 43°N so the poleward and equatorward facing walls experience very different insolation. (**b**) Profile of Ezinu crater. The left side (A) is the poleward facing wall. The right side (A') is the equatorward facing wall. Thick, black lines bounded by triangles identify what was defined as the crater walls. The slope asymmetry of this crater is about +7.5°. Therefore, the wall with higher insolation evolved more since the crater's formation.

The main difference between the two features is the surface temperature (i.e., insolation). The equatorward facing wall receives more insolation than the poleward facing wall. Because of this temperature difference and the sensitivity of rheology to temperature, the equatorward facing wall should experience more viscous relaxation than the poleward facing wall. Therefore, we should be able to quantify viscous relaxation on Ceres by comparing the equatorward and poleward facing walls of large craters.

To quantify the amount of viscous relaxation on Ceres, we computed the difference between poleward and equatorward facing slopes of large craters. Using Dawn topography that was referenced to the best fit ellipsoid, we identified craters with diameters >100km using an established Cerean crater catalogue [5]. We took three profiles running north-south of these >100km diameter craters and measured the poleward and equatorward facing slopes for each profile to compute an average measured slope (Fig. 1).

The final quantified amount of topographic evolution is found by subtracting the average equatorward facing slope from the average poleward facing slope. A positive difference corresponds to an equatorward facing wall that shallowed more than its poleward counterpart, as we would expect from relaxation.

Preliminary Results: There are 16 craters with diameters >100km that we were able to confidently make slope measurements of poleward and equatorward facing walls. Of those craters, 2 had asymmetries <1° which we interpreted as not displaying enough topographic evolution to be considered. 10 of the remaining 14 craters displayed a positive slope asymmetry while 4 displayed a negative slope asymmetry (Fig. 2). There are 4 craters with positive asymmetries from low latitudes (<30°), 6 from mid latitudes (>30°, <65°), and none in high latitudes (>65°). The maximum slope asymmetries occurred in the mid latitude regions where the poleward and equatorward facing walls have the highest insolation difference which supports the hypothesis that topographic evolution is insolation driven. In these latitudes, the poleward-facing walls are as much as 12.5° steeper than equatorward-facing walls.

The probability of 10 or more craters having steeper poleward slopes by random chance is <10%. Therefore, we conclude that some process related to insolation is responsible for asymmetric topographic evolution on Ceres. Plausible insolation-related processes that could modify topography on Ceres are viscous relaxation, sublimation, and thermal stresses. We favor viscous relaxation as the most likely process to create asymmetries this large, but quantitative tests of this hypothesis is the subject of ongoing work.

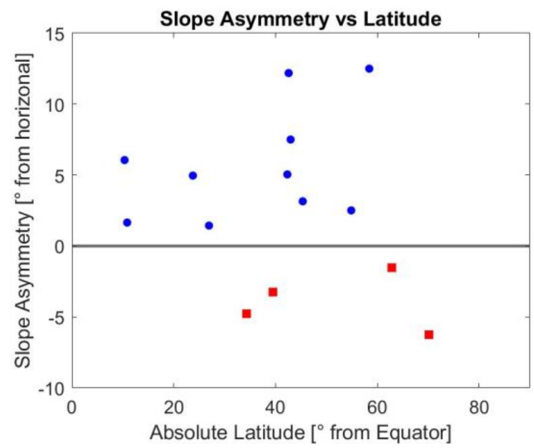

Figure 2: Scatter plot of slope asymmetry as a function of latitude. Red squares are craters that displayed negative slope asymmetries (colder, poleward slopes evolved more than warmer, equatorward slope) and blue circles are craters that displayed positive slope asymmetries (warmer, equatorward slopes evolved more than colder, poleward slopes). The highest positive slope asymmetries occur at mid latitudes where the difference in insolation of the two slopes is greatest.

Conclusions: Our results show that insolation is likely a major driver of the topographic evolution on Ceres. There are three mechanisms that are most likely causing this to occur: viscous relaxation, sublimation of crustal ice, and thermal stress. We currently favor viscous relaxation as the dominate mechanism for larger craters. In ongoing work, we are testing this hypothesis using Finite Element Method modeling. We will test whether we can recreate these large craters with asymmetries from an initial crater shape using viscous relaxation mechanics.

References: [1] Bland, M. T. Icarus 226, 510–521 (2013). [2] Hiesinger, H. et al. Science 353, (2016). [3] Bland, M. T. et al. Nature Geoscience 9, 538–542 (2016). [4] Ermakov, A. I. et al. Journal of Geophysical Research: Planets 122, 2267–2293 (2017). [5] Qi, C. et al. Geophysical Research Letters 45, 12,757-12,765 (2018). [6] Fu, R. R. et al. Earth and Planetary Science Letters 476, 153–164 (2017). [7] Sori, M. M. et al. Nature Astronomy vol. 2 946–950 (2018). [8] Bland, M. T. et al. Geophysical Research Letters 45, 1297–1304 (2018). [9] Ermakov, A. I. et al. Journal of Geophysical Research: Planets 124, 14–30 (2019).