THE SURFACE TOPOGRAPHY OF CERES: PRE-DAWN PREDICTIONS FOR EXTENSIVE VISCOUS RELAXATION. M. T. Bland, K. N. Singer, W. B. McKinnon, Department of Earth and Planetary Sciences, and McDonnell Center for Space Sciences, Washington University in Saint Louis. (mbland@levee.wustl.edu).

Overview: Ceres' oblate shape, and lack of large-scale topography suggests that the asteroid might contain a near-surface ice layer tens of kilometers thick [1-3]. The viscosity of water ice at the relatively warm temperatures in the asteroid belt permits rapid viscous relaxation of surface topography. Here we shown that, if Ceres has a near surface ice layer, radiogenic heating alone is sufficient to completely relax (and plausibly erase) even small (4 km diameter) impact craters in the equatorial region over timescales of 10^6-10^9 yrs. Craters at mid-latitudes are expected to be completely relaxed over 10^8-10^9 yrs, whereas small and mid-sized craters in the cold polar regions are largely preserved. We therefore predict low crater densities and highly softened topography in Ceres' equatorial region, with overall crater density and crater depths increasing pole ward. In contrast, if Dawn observations reveal a surface dominated by pristine craters it will indicate the absence of near surface ice, as suggested by [4].

Internal Structure and Surface Temperature: Spectroscopic observations of Ceres indicate that the surface is composed of silicate material [5]. However, the oblate shape of Ceres is inconsistent with a homogeneous silicate body, leading to the inference that Ceres' is differentiated with a silicate mantle of unknown composition [see 6], overlain by a water ice layer that is covered by a relatively thin silicate regolith [1-3] (water ice is unstable on the surface). Simple mass balance calculations indicate that the ice layer is several tens of kilometers thick depending on the assumed silicate density.

For a surface in radiative equilibrium at 2.77 AU (Ceres mean orbital radius) and a bond albedo of 0.1 (roughly appropriate for Ceres' dark surface; see [5]), the equilibrium surface temperature is 163 K (assuming a solar constant of 1370 W m^{-2}, and emissivity of 1), and the theoretical maximum sub-solar (i.e., equatorial) temperature is 235 K. Ceres' mean diurnal temperatures are likely substantially lower, especially at the poles (Ceres' obliquity is near zero): 180 K at the equator decreasing to <120 K at high latitudes [7]. We use these values in the modeling described below. Higher/lower temperatures would lead to greater/less relaxation.

If a near surface ice layer exists, and the temperatures above are typical, relaxation of topography (e.g., impact craters) is inescapable.

Modeling Crater Relaxation: We simulate crater relaxation using the finite element model Tekton2.3 and the techniques described in [8]. To date simulations have been performed for craters with diameter of 4-20 km. These small craters are unaffected by either Ceres curvature or the rocky core at depth, either of which could affect relaxation behavior [9]. Based on icy satellite observations [10], the likely simple-to-complex transition diameter for craters on Ceres is ~20 km (though this is poorly constrained). We therefore assume simple parabolic crater shapes with depth-diameter ratio of 0.2, and ejecta blankets that fall of as $R^{1/3}$, where R is the crater radius [11].

For each crater shape, we simulate viscous relaxation with three different surface temperatures (T_s): 180 K (equatorial), 160 K (mid-latitude), and 140 K (polar). We utilize a time dependent heat flux due only to long-lived radiogenic species (assuming a CI chondrite composition). We assume an ice layer 49 km thick, corresponding to a silicate density of 2700 kg m^{-3}. Maximum heat fluxes 4 billion year ago were 5.6 mWm^{-2}, declining to 0.95 mWm^{-2} today. Heat fluxes are not strongly dependent on the assumed ice layer thickness for reasonable silicate densities. For each crater size and surface temperature combination we simulated relaxation for craters that formed between 10 million and 4 billion years ago. Craters that formed early in solar system history not only have more time to relax, but also experienced higher heat fluxes; whereas craters formed recently have very little time to relax and experience low heat fluxes.

Predicting Ceres' Surface Topography: The relaxation fraction (percent relaxed relative to the initial crater depth), apparent crater depth (depth relative to the surrounding plain), and rim heights for all of our simulations are shown in Fig. 1.

In the polar regions (T_s=140 K) small craters are largely preserved throughout Solar System history, relaxing by only ~10%, larger craters are more relaxed (~70%) but still retain large depths after 4 Ga (500 m, for a 12 km crater). Craters formed in the last 1 Ga are relaxed by less than 50% and maintain depths >1 km. Crater rims heights (which have short topographic wavelengths and thus relax slowly) remain unchanged even for the oldest craters. We therefore expect craters to be largely retained in Ceres polar regions, with small craters appearing relatively pristine (in the absence of True Polar Wander (TPW)).

At mid-latitudes (T_s=160 K) impact craters relax rapidly. The oldest craters (formed at 4 Ga ago) are almost completely relaxed with depths of just tens of meters. Topography is only retained for craters formed within the last 10^8 yrs. Even with a formation age of 10^8 yrs ago, only a few hundred meters of topography remains. Crater rims are largely preserved; however, rims on the oldest craters are reduced to a few hundred meters or less. We therefore predict that many craters in the mid-latitudes will be highly relaxed though still visible due to their preserved rims. Young and/or small craters will appear relatively pristine.

Near the equator (T_s=180 K) craters relax extremely quickly. Even small craters formed only 10 Ma ago are effectively completely relaxed, with crater depths of only ~10 m. On craters older than 1 Ga, even crater rims are largely relaxed, with rim heights of a few meters. Such older craters may be obscured beyond recognition. These simulations indicate that Ceres' equatorial latitudes may have relatively low crater densities, and any craters present will appear extremely softened.

Synthesis and Further Predictions: Our simulations indicate that, if Ceres' near-surface is largely water ice, crater densities and crater depths should both be low in the equatorial region and increase toward the poles. These results utilized the simplest plausible assumptions: conservative surface temperatures, plausible ice layer thickness, realistic radiogenic heating, and typical crater shapes. We therefore suggest that if craters on Ceres are *not* relaxed then Ceres must have a purely silicate composition as suggested by [4]. Alternatively, extensive viscous relaxation in the polar regions might suggest one or more past episodes of TPW (perhaps by a mechanism similar to [12]).

Current ground based observations of Ceres have revealed several large-scale albedo features, that have (in some cases) been interpreted as impact craters [e.g., 3]. At the scale and location of the features observed we predict that, if these features have an impact origin, they are morphologically rather more similar to palimpsests on icy satellites – large-scale circular features that exhibit almost no topographic signature, but can have a distinctive albedo contrasts relative to surrounding terrain.

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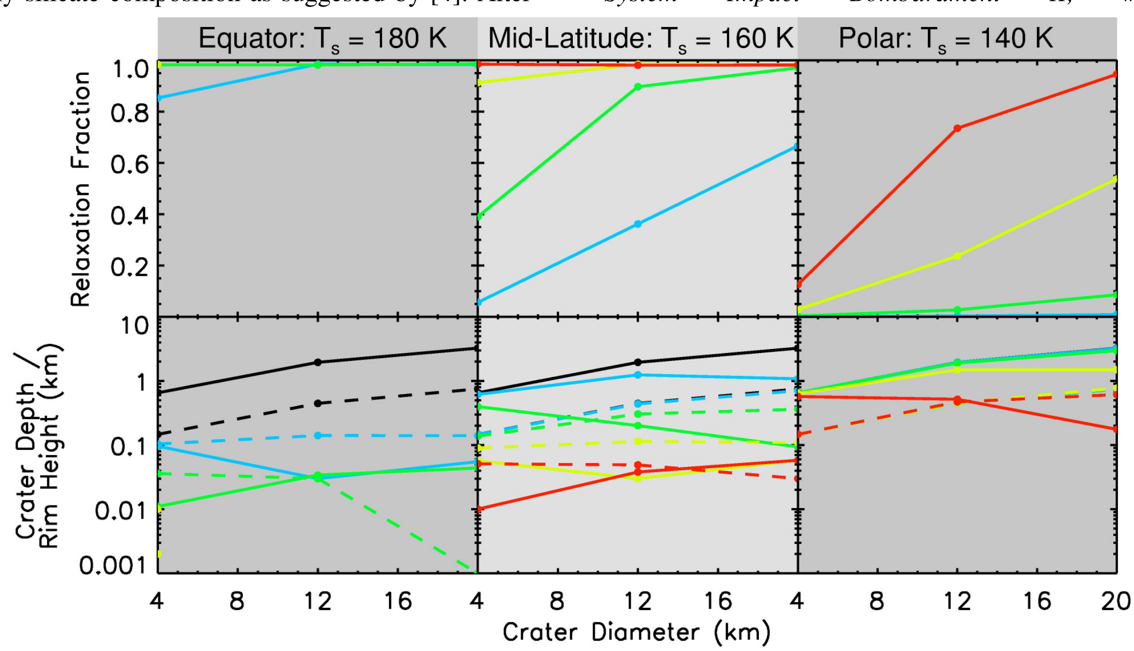

Figure 1: The relaxation fraction (decrease in crater depth relative to the initial depth, top row), apparent crater depth (bottom row, solid lines), and rim heights (bottom row, dashed lines) for crater in the equatorial region (left), mid-latitudes (center), and polar regions (right) of Ceres. Blue, green, yellow, and red lines correspond to craters that formed 10, 100, 1000, and 4000 million years ago, respectively. Black line are initial crater depths/rim heights.