CERES' LARGEST IMPACT CRATER, KERWAN: INFERRING LOCAL INTERIOR STRUCTURE FROM ITS PECULIAR MORPHOLOGY. M. T. Bland[1], C. A. Raymond[2], R. R. Fu[3], A. Ermakov[2], P. M. Schenk[4], S. Marchi[5], S. D. King[6], J. C. Castillo-Rogez[2], C. T. Russell[7]. [1]USGS Astrogeology Science Center, Flagstaff AZ (mbland@usgs.gov), [2]Jet Propulsion Laboratory, Pasadena CA, [3]Columbia University, New York NY, [4]Lunar and Planetary Institute, Houston TX, [5]Soutwest Research Institute, Boulder CO, [6]Virginia Tech, Blacksburg VA, [7]UCLA, Los Angeles CA.

Overview. Below its rocky lag deposit, Ceres' outer layer is likely composed of a mixture of ice (< 35% by volume), salts, clathrates, and silicates [1,2,3]. Gravity and topography data acquired by the Dawn spacecraft [4] suggest that this outer layer is, on average, ~50 km thick, and underlain by a higher density, rock-dominated interior [3,5]. These inferred values apply globally but do not preclude local variations in the outer layer thickness. Here we describe the unusual morphology of Ceres' largest crater, Kerwan, and suggest that it results from viscous relaxation of the crater in the presence of an inner/outer layer boundary uplifted to just ~10 km below the crater floor.

Kerwan's Unusual Morphology. At 284 km in diameter, Kerwan (-10.8º S, 124.0º E) is Ceres' largest clearly identifiable impact crater (Fig. 1a) [cf. 6]. Kerwan is ~5.5 km deep when measured from its center to the surrounding terrain [1], but its topographic profile is unusual (Fig. 1b). Unlike most complex craters (including those on Ceres), which have flat floors and steep, terraced walls [e.g., 7], Kerwan has a deep central depression, and the floor rises concavely toward the rims. Much of the interior is marked by a broad topographic bench with an elevation near that of terrain outside the crater. Thus much of the crater floor sits just 1-2 km below the surrounding terrain. Kerwan's rim is discontinuous, and often marked by a simple scarp or a narrow massif. The morphology of Kerwan is unique, and stands in strong contrast to the more typical morphology of Ceres' second largest crater Yalode (diameter of 267 km).

Is Kerwan's morphology due to viscous relaxation? Despite the apparent strength of Ceres' outer layer [1,2,3], Kerwan's size and relatively warm location make it the most likely crater to have experienced viscous relaxation [1]. To evaluate whether Kerwan's morphology results from viscous relaxation, we performed a series of numerical simulations using the viscoelastic finite element model *Tekton* [8] in axisymmetric geometry. We used an initial crater 5.5 km deep and 280 km in diameter, a surface temperature of 150 K [9], a time-dependent heat flux consistent with radiogenic decay, all viscous flow regimes appropriate for ice I (for the outer layer), a surface gravity of 0.27 m s^{-2}, and a timescale of 1 Ga [1,10].

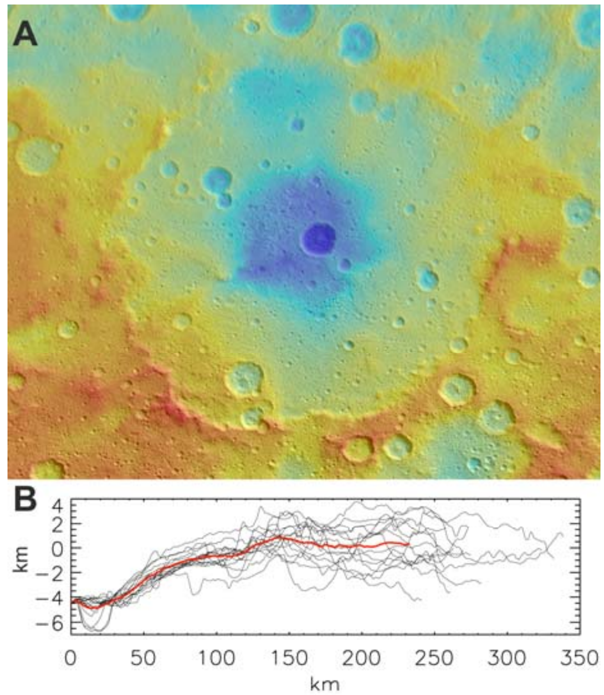

Figure 1: ***A.*** *Color coded topography overlaid on a mosaic of Kerwan (140 m/pixel). Red is high, blue is low.* ***B.*** *15 topographic radial profiles taken from* ***A*** *(spaced every 24º, crater center at left). The red curve shows the average profile.*

Relaxation in thick outer layer. Viscous relaxation of impact craters in an infinite half-space produces a characteristic morphology: up-bowed floors (the longest wavelengths relax the fastest) and retained rims. Our Kerwan relaxation simulations are no exception when a 50 km thick outer layer is assumed (Fig. 2a). The crater center relaxes rapidly, leaving a deeper moat interior to the rim. This morphology contrasts strongly with Kerwan's, which we conclude is inconsistent with relaxation in a thick outer layer.

Relaxation in a thin outer layer. Parmentier and Head [11] used analytical models of crater relaxation to show that the relationship between wavelength and relaxation rate becomes inverted when relaxation occurs in a thin (relative to the crater diameter) layer underlain by an immobile substrate. In such a case, long wavelengths are retained while short wavelengths relax. The crater morphologies derived by [11] bear similarities to Kerwan. We simulated the viscous relaxation of Kerwan in a thin outer layer to test whether such an internal structure reproduces Kerwan's morphology (Fig. 2b). As found by [11], long wavelengths are indeed retained while the shorter wavelengths are removed. The resulting morphology is more similar to that observed for Kerwan (the best fit is for a layer just 10 km thick), but our results would require the initial crater to be shallower and smaller – inconsistent with Kerwan's rim diameter. We therefore do not favor this explanation of Kerwan's morphology.

Relaxation in a layer with variable thickness. Large lunar impacts are known to uplift the mantle below the crater reducing the thickness of the crust directly below [e.g., 12]. It's plausible that a Kerwan-sized impact could produce similar uplift of the inner/outer layer boundary on Ceres. We investigated the effect such an uplift would have on subsequent long-term viscous relaxation. Our best-fit model used an inner/outer layer boundary that was uplifted to a depth of 10 km below the crater floor. The outer layer thickness is uniform beneath the crater to a radius of 50 km, and then increases rapidly (via a second order polynomial) to a thickness of 50 km. Our simulations show that this geometry inhibits relaxation of the central portion of the crater floor, while simultaneously permitting rapid relaxation of the floor further than 50 km from the crater center. The result is a crater with a deep center and an uplifted bench interior to the crater rim. The simulated morphology bears a striking resemblance to that of Kerwan (Fig. 2c).

Discussion: The morphology of Kerwan is consistent with relaxation in the presence of an inner/outer layer boundary uplifted to just ~10 km below the crater floor; however, because Ceres' inner layer is higher density than the outer, an uplifted floor should create a positive Bouguer anomaly beneath the crater, which is not observed. This suggests that the structure below Kerwan is not higher in density than its surrounding, just higher in viscosity. This could result from the concentration of strong but low density material directly beneath the crater during the impact event.

Similar structures might occur beneath several of Ceres' largest craters, and that substantial "local" topography on the layer boundary may persist. Yalode in particular might have such a deflection beneath it; however, because it is located at much higher latitudes (~45° S) viscous relaxation is less likely to have occurred. That is, their interiors may be similar, but one has relaxed and one has not. The difference in morphology between Yalode and Kerwan also argues that Kerwan's morphology is not the result of some unique process occurring during impact into Ceres' complex outer layer.

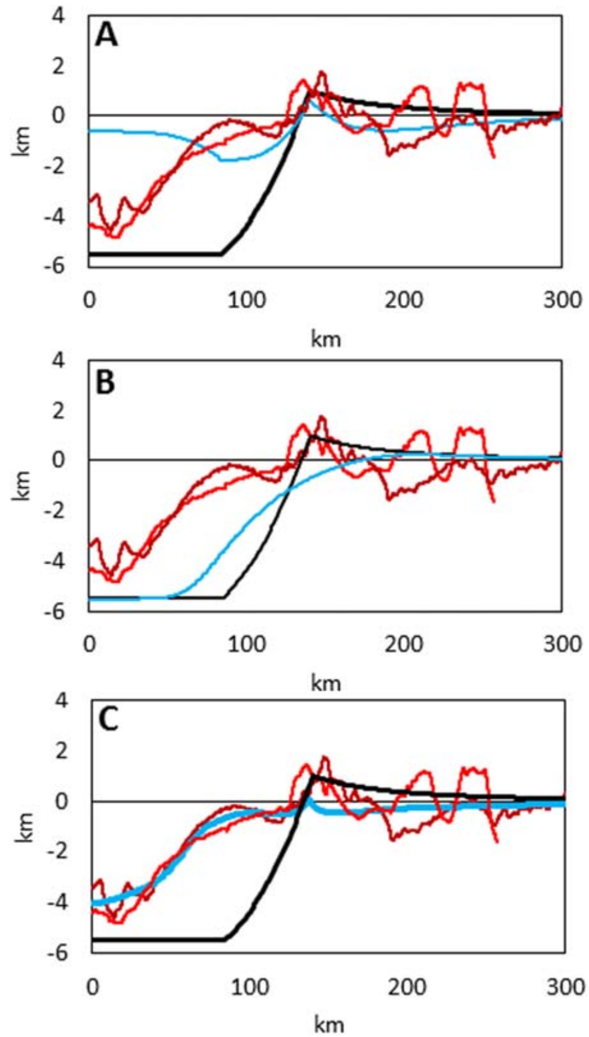

*Figure 2: Simulations of the viscous relaxation of Kerwan using a thick (**A**), thin (**B**), and variable layer thickness (**C**). In each, the black curve is the initial crater, the red/maroon curves are two profiles of Kerwan's topography, and the blue curves are the simulated topography.*

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