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Dawn Data Reveal Ceres' Complex Crustal Evolution

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Abstract

Dawn mapped Ceres using its framing camera (FC), visible and infrared mapping spectrometer (VIR) and gamma-ray and neutron detector (GRaND) during its primary and extended mission, while deriving Ceres' gravity by high-precision navigation data and topography from multi-angle images. These observations show that Ceres' surface has a heterogeneous crater dsitribution, whereas its ammoniated-phyllosilicate rich surface composition is remarkably uniform [1, 2, 3]. Dawn's gravity and topography observations show that Ceres is close to hydrostatic equilibrium and its topography appears to be compensated [4, 5]. However, there are deviations from isostasy that, together with composition and morphological data sets, reveal processes shaping the evolution of Ceres' crust and mantle.

1. Global Interior Structure

Dawn's gravity and topography data are consistent with a partial physical differentiation into a volatile-rich shell (crust) overlying a denser interior of hydrated silicates [4, 5, 6]. Estimates of crustal density and layer thicknesses assuming a two layer model constrained by assuming meteorite grain densities for the hydrated silicate interior range from 1680 kg/m^3 (~70 km thick) to 1900 kg/m^3 (~190 km thick) corresponding to CI (2460 kg/m3) and CM (2900 kg/m3) class meteorites, respectively [4]. Complementary constraint from admittance modeling yields a best-fit crustal density of ~1250 kg/m^3 in a layer ~40 km thick under assumption of Airy isostasy [5], with a corresponding mantle/core density of ~2400 kg/m^3. Preservation of craters <300 km in diameter on Ceres' surface indicate that the outermost layer, here called the crust, is of order 1000x stronger than water ice. A mixture of silicates, salt hydrates and methane clathrates, with no more than ~30% water ice, is consistent with crater morphologies [7], the global topographic power spectrum [6] and the crustal density estimates. However, variability in crater morphology indicates local variability in crustal rheology. While infrared VIR spectra show only a few small patches of water ice, GRaND data show a shallow ice table with ~10% water ice in polar latitudes; water table retreat yields a drier regolith in equatorial latitudes [8]. While the density and thickness of the strong crustal layer is not tightly constrained, a consistent picture has emerged of a layer of mixed ice, silicates and light strong phases best matched by hydrated salts and clathrates, overlying a mantle of hydrated silicates. This partially differentiated interior, combined with the ubiquitous presence of ammoniated phyllosilicates [3] and carbonates [9] on the surface points towards pervasive aqueous alteration. The absence of an ice-dominated layer in the subsurface (from ocean freezing) may indicate partial loss of the ice shell by impact-induced sublimation [10], and mixing with the salts and silicate rich material present near an ancient seafloor.

2. Regional Anomalies

While much of Ceres topography appears to be isostatically compensated, there are significant residual anomalies that likely reflect density variations and/or dynamic processes in the subsurface. The major anomalies at Hanani Planum, Ahuna Mons, and Kerwan crater are discussed by [5], and may indicate emplacement of material of contrasting density into the crustal layer. In addition to these features, there are broad scale correlations between gravity variations, shown as Bouguer and isostatic anomalies, and other surface characteristics. There is a general negative correlation between topography and Bouguer gravity, which is only partially explained by isostatic compensation [4, 5]. One such correlation occurs between the Bouguer gravity and the planitia identified by [11].

Three large shallow basins with degraded rim topography were identified as possible cryptic impact basins, identified as planitiae A-C; Figure 1, top panel shows these planitiae marked on a topographic map. The middle panel shows the Bouguer anomaly field (degrees 3-12) and the bottom panel shows the 3.1-micron band depth [after 12], which indicates lateral variations in the NH_4-phyllosilicate abundance. For planitiae A and C, an enrichment in NH_4 is shown by the light yellow color in the bottom panel. This presents the question of a common process that created the low topography, higher gravity and ammonium enrichment.

3. Implications for Ceres' Evolution

In the context of the global interior structure, the broad-scale regional correlations described above may be explained by impact excavation of the shallow crust, exposing a denser, deeper-seated more ammonium-rich lithology. This interpretation, which is preferred to explain the compositional variations [12], is further strengthened by the gravity-topography correlation, and may provide an explanation for variations in crustal strength and the distribution of volatile-rich deposits on the surface.

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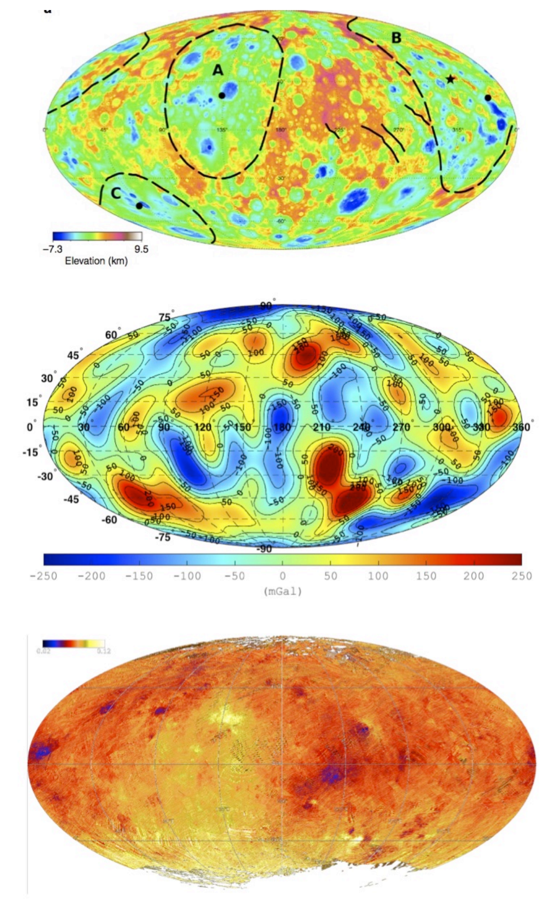

Figure 1. A broad-scale correlation is apparent between topography (and planitiae) shown in top panel from [11], with Bouguer gravity shown in middle panel, and 3.1-micron band depth shown at bottom (after [12]).