Interiors of Vesta and Ceres as constrained by the Dawn mission

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Introduction: Protoplanets Vesta and Ceres are the two most massive bodies in the asteroid belt. The planetary formation process had frozen for these bodies just before the run-away accretion, as they could not accrete enough mass. Gravity and topography data provide insight into internal structure of these bodies, which gives important clues to understanding the planetary formation process.
Data: Pre-Dawn shape models of Vesta [1] revealed substantial deviations from hydrostaticity, whereas for Ceres observed shape was consistent with a hydrostatic ellipsoid of revolution [2,3]. Images from the Framing Camera of the Dawn spacecraft have been used to construct shape models of Vesta and Ceres independently using stereophotogrammetry [3] and stereophotoclinometry [4] techniques, while the gravity field of these bodies has been determined via radio-tracking to a spherical harmonic degree n=18 and n=16, respectively [5,6].
Discussion: We find that Vesta was once hot and hydrostatic [7] and is no longer either. It was despun by two giant collisions [8,9] that produced the two largest basins on the asteroid's surface –Rheasilvia and Veneneia. These two basins in the southern hemisphere represent the largest deviation of Vesta from a hydrostatic equilibrium shape. On the other hand, the northern hemisphere is well approximated by an ellipsoid and represents the fossil shape of Vesta prior to the giant impacts [8,9]. Based on the gravity-topography admittance analysis, Vesta's topography is not compensated. The two most characteristic features in the Bouguer anomaly map are the region of highest topography –Vestalia Terra –with the strongest positive anomaly and the central peak of Rheasilvia, which is also associated with a positive anomaly which likely represents the deeper and denser layers excavated by the Rheasilvia impact. It is possible that the porosity variations control a substantial fraction of the remaining gravity signals. Unlike Vesta, Ceres possesses plenty of gravity anomalies that can be associated with geomorphologic units. Gravity/topography admittance analysis reveals that Ceres' topography is isostatically compensated [10]. We combine the gravity/topography data and finite element modeling to constrain Ceres' rheology and density structure. We find that Ceres' crust is light and mechanically strong with the volumetric water ice content <30%. Ceres has experienced limited viscous relaxation as evidenced by the deviation of its topographic power spectrum from the power law at low degrees [10,11].
Conclusions: The divergent geodynamic evolutions of Vesta and Ceres may be attributed to three main factors: size, location and time of accretion. The latter two factors determine the properties of the accreted material and subsequently affect the type of heat transfer. Being smaller, Vesta cooled more quickly than Ceres and developed an elastic lithosphere before acquiring most of its topography. Ceres, on the other hand, had a longer cooling time and has not developed an appreciable lithosphere at a 4.5 Gy timescale. Consequently, Ceres is an order of magnitude closer to hydrostatic equilibrium than Vesta and its topography is isostatically compensated. Additionally, having accreted further out in the asteroid belt Ceres accreted and subsequently retained more volatiles, unlike mostly silica-dominated Vesta. This compositional difference affects the rate viscous relaxation of topography making Ceres’ near surface viscosities several orders of magnitude lower than those of Vesta. Inferred low mantle density for Ceres implies strong hydration, which favors accretion with a lower ^{26}Al abundance and/or efficient early heat transfer due to hydrothermal circulation.

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