Vesta is not an intact protoplanet

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The Dawn mission was designed to explore "remnant intact protoplanets from the earliest epoch of solar system formation" [1]. However, models of Vesta composed of an iron core, olivine mantle, and HED crust in chondritic proportions cannot match the joint constraints from Dawn [1] of Vesta's density, core size, and the extremely limited presence of exposed olivine on its surface. Vesta has a mean density of 3456 kg/m^3 and its surface composition is well matched by howardites. The Dawn gravity data suggest a nickel-iron core of radius 110 km and density 7500–7800 kg/m^3. The Rheasilvia impact basin, formed within a pre-existing large basin, Veneneia, should have excavated material from a depth of 50 km to 80 km or more below Vesta's surface [2]. If the howardite crust were thinner than 50–80 km, a significant amount of olivine-rich material, derived from depth, would have been exposed within this basin; models suggest that olivine would also be distributed both on Vesta's surface and in space as meteorite-source Vestoids. Such olivine is rare on Vesta, among the Vestoids, or in our meteorite collection. Vesta's density is similar to an L chondrite, but the Na and K abundances in Vesta are strongly depleted compared to chondrites and the average metal content of an L chondrite, 8.4% by mass, would give a core radius less than 90 km. A 110 km radius metallic core, via the Dawn data, represents 15% of Vesta's mass. The Mg/Al ratio in cosmic abundances is about 10:1, but roughly 1:1 within the eucrites; thus if Vesta started with cosmic abundances, the eucrites can only represent 10% of the parent body total mass. Likewise the 10 x chondritic rare earth trace elements (REE) abundance seen in most eucrites demands that, regardless of formation mechanism, these basalts were crystallized from a melt representing 10% of the mass of the source region [3]. Thus the howardite crust of a chondritic HED parent body, mixing all the available eucritic and diogenitic material (in a 2:1 ratio), represents no more than 15% of its total mass. This leaves 70% of Vesta's mass as olivine. Assuming no porosity in this mantle, the radius and density of Vesta can be matched only with a howardite crust (average grain density [4] of 3270 kg/m^3) that was 27 km thick with a porosity of nearly 45%, comparable to sand. If the mantle porosity is 8%, similar to Chassigny, the necessary crust porosity would be 30%, but its thickness would drop to 21 km. In both cases, this crust is too thin to accommodate the lack of olivine in Rheasilvia or its ejecta. Absent some unknown process to hide large amounts of olivine on the surface of Vesta and among the Vestoids, chondritic models do not fit the observational constraints. A larger, lower density core of olivine and metal mixed in equal proportions (by mass), of density 5000 kg/m^3 and radius 145 km may also fit the Dawn gravity data [5]. The remaining volume of Vesta would be a 115 km thick howardite crust, thick enough to allow the metal/olivine core to remain unexposed. (In this case Vesta would be composed only of core and crust, but the core would be rich in olivine.) To match Vesta's density, this thick crust only needs an average porosity of 4%. Since 50% of Vesta's mass in this model would be eucrites, the REE abundances for the whole of Vesta would have to be five times chondritic values. Either Vesta accreted from a highly unusual cosmochemical setting, or 80% of its primordial olivine and iron were removed at some time after the REE trace elements were extracted from the bulk proto-Vesta into the eucritic melt. This proto-Vesta would have to have at least three times the mass of the current Vesta, with a radius of at least 375 km (still smaller than Ceres). Either Vesta formed with a very non-chondritic composition or it was subjected to a radical change in composition, presumably due to the intense collisional environment [6,7] where and when it formed. In any event, Vesta is not a remnant protoplanet but a chemically stripped and reaccreted body.

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