Asteroid 4 Vesta: A Fully Differentiated Dwarf Planet

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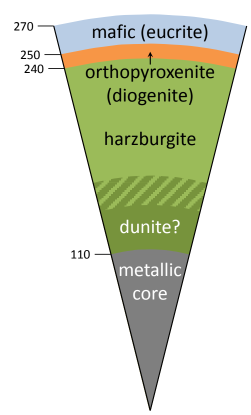
One conclusion derived from the study of meteorites is that some of them – most irons, stony irons, some achondrites - hail from asteroids that were heated to the point where metallic cores and basaltic crusts were formed. Telescopic observations show that there remains only one large asteroid with a basaltic crust, 4 Vesta; present day mean radius 263 km [1]. The largest clan of achondrites, the howardite, eucrite and diogenite (HED) meteorites, represent the crust of their parent asteroid [2]. Diogenites are cumulate harzburgites and orthopyroxenites from the lower crust whilst eucrites are cumulate gabbros, diabases and basalts from the upper crust. Howardites are impact-engendered breccias of diogenites and eucrites. A strong case can be made that HEDs are derived from Vesta [3]. The NASA Dawn spacecraft orbited Vesta for 14 months returning data allowing geological, mineralogical, compositional and geophysical interpretations of Vesta's surface and structure. Combined with geochemical and petrological observations of HED meteorites, differentiation models for Vesta can be developed [e.g., 4].

Proto-Vesta probably consisted of primitive chondritic materials. Compositional evidence, primarily from basaltic eucrites, indicates that Vesta was melted to high degree (≥50%) which facilitated homogenization of the silicate phase and separation of immiscible Fe,Ni metal plus Fe sulphide into a core. Geophysical models based on Dawn data support a core of ~110 km radius [1]. The silicate melt vigorously convected and initially followed a path of equilibrium crystallization forming a harzburgitic mantle, possibly overlying a dunitic restite. Once the fraction of crystals was sufficient to cause convective lockup, the remaining melt collected between the mantle and the cool thermal boundary layer. This melt undergoes fractional crystallization to form a dominantly orthopyroxenite (diogenite) lower crust. The initial thermal boundary layer of primitive chondritic material is gradually replaced by a mafic crust through impact disruption and foundering. The quenched mafic crust thickens over time through magma extrusion/intrusion. Melt from the residual magma ocean intrudes and penetrates the mafic crust forming cumulate eucrite plutons, and dikes, sills and flows of basaltic eucrite composition.

The post-differentiation vestan structure is thus not too dissimilar from that of terrestrial planets: (i) a metallic core; (ii) an ultramafic mantle comprised of a lower dunitic layer (if melting was substantially <100%) and an upper cumulate harzburgitic layer; (iii) a lower crust of harzburgitic and orthopyroxenitic cumulates; and (iv) an upper mafic crust of basalts and diabases (melt compositions) with cumulate gabbro intrusions. Impacts have excavated to the lower crust and delivered howardites, eucrites and diogenites to Earth, but there is yet no evidence demonstrating excavation of the vestan mantle [5].



Structure of 4 Vesta, modified after [4].

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