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Geophysical Constraints on Vesta's Evolution

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Abstract

Density anomalies have been derived from gravity data obtained by the Dawn spacecraft. These anomalies and their associations with geologic structures and composition support the presence of crustal heterogeneity indicative of the plutonic nature of the lower crust.

1. Introduction

During its 14-month stay at Vesta, the Dawn mission determined the gravity field of Vesta to degree and order 20, using high-accuracy coherent Doppler tracking of the spacecraft by the Deep Space Network, especially from the ~480 km radius Low-Altitude Mapping Orbit [1]. A residual gravity field, calculated as the difference between the observed gravity field and one calculated under varying assumptions of the internal density structure that minimizes the misfit with the observed field, reveals density variations in the crust and upper mantle of Vesta. These significant gravity anomalies can be interpreted as crustal thickness or density variations, and likely reflect both sources. The residual anomalies are associated with structural features such as the Vestalia Terra highland and the deep Saturnalia Fossae, the diogenitic central mound of the Rheasilvia impact basin, and the eastern rim of the Rheasilvia Basin. As such, these anomalies reflect the modification of the vestan crust and mantle by impacts that have extensively fractured and pulverized it while also exposing deep-seated material and mixing it with the original crust. However, impacts alone can't account for the all of the apparent density (and/or crustal thickness) variations. The presence of significant density anomalies in concert with broad compositional and geologic variations is consistent with heterogeneity in the original crust and mantle of Vesta. Features such as southern Vestalia Terra and similar high-density features appear to be primordial, and suggest intracrustal plutons consistent with evidence from the trace element geochemistry of HED meteorites, and genetic models that include multiple magma chambers.

2. Density Anomalies

Residual gravity anomalies from [1] range from a low of -194 mGal to a high of 244 mGal. A polyhedral model of Vesta's interior was used by [2] to invert the residual gravity data to obtain variations in crustal density in a model with defined layers. The model has a core of radius 110 km following [3], and an ellipsoidal mantle layer of average density 3170 kg/m^3 below a crustal layer whose top surface follows the surface topography and whose base in defined by the deepest point on Vesta, within the Rheasilvia basin. The mantle density is held fixed while the density of the crustal layer is varied until the minimum residual anomaly is obtained. This approach likely overestimates the variations in the crustal layer since the mantle also deviates from the average, and it may co-vary with the crustal density. The resulting crustal density estimate is shown in Fig. 1, in the top panels, with the northern hemisphere on the left and southern hemisphere on the right. Positive density anomalies occur scattered within the Rheasilvia and Veneneia impact basins, while a band of very strong positive anomalies cluster in a longitude sector that extends from ~0 deg to ~120E (in Claudia coordinates). Positive density anomalies are associated with stronger, resistant crust in the southern Vestalia Terra highland, and the eastern portion of the Divalia Fossa troughs. The density of these regions reaches ~3200 kg/m^3, consistent with unfractured diogenite. The positive anomaly over the central mound of Rheasilvia is consistent

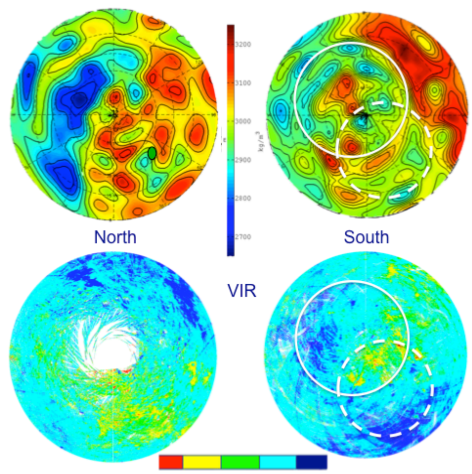

Fig 1. Top: Crustal density maps of the northern hemisphere (left) and southern hemisphere (right) from [2]. Color scale bar shown in kg/m^3. Bottom: Maps of the distribution of howardite (green), eucrite (blue) and diogenite (red) across the surface of Vesta as measured by the VIR spectrometer [4]. Outlines of the Rheasilvia and Veneneia basins are shown as solid and dashed white lines, respectively. The green dot in the upper left panel indicates the location of olivine reported in [5].

with its origin as an uplifted lower crustal/mantle block, and a similar uplifted block appears to be present within the Veneneia basin. Negative density anomalies, strongest in the north, reflect the extensive fracturing and deep excavation of the crust, such as within the Rheasilvia basin, and in the region of overlap between the Rheasilvia and Veneneia basins. In these regions the density is ~2800 - 2900 kg/m^3 [2]. The broad swath of positive density anomalies that extends north from the eastern troughs is associated with compositional variations as discussed below.

Clues to the sources of the density anomalies can be found in their association with compositional variations. Diogenite, representing the vestan lower crust and possibly upper mantle, is found within the Rheasilvia basin, predominantly in the region of overlap between Rheasilvia and the Veneneia basin (Fig 1, bottom right panel). The low density obtained there can be explained as a result of deep excavation of the crust and mantle by these two major impacts, which effectively mixed the deeper-seated diogenite material with the surface material. In the northern hemisphere, the positive gravity anomalies correspond to a longitudinally-restricted region of diogenite enrichment. Most notably, the area in which olivine has been detected [5] lies within the region of strong positive anomalies and diogenite enrichment.

3. Implications for Vesta Evolution

The pattern of residual gravity anomalies and the density variations they imply, together with their associations with diogenite and ancient crust in Vestalia Terra, point to a plutonic origin within the deep crust and possibly upper mantle of Vesta. Vestan crustal genesis and evolution by serial magmatism has been proposed to explain evidence for multiple magma chambers on the HED parent body (Vesta) as shown by varying trace element patterns among diogenites (e.g. [6,7]). Density variations revealed by Dawn's geophysical data favor petrogenetic models that include serial magmatism such as those recently elucidated by [8,9].

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