GRAVITY EVIDENCE FOR POST-MAGMA OCEAN SERIAL MAGMATISM ON PROTOPLANET VESTA. C. A. Raymond[1], H. Y. McSween[2], R. S. Park[1], A. S. Konopliv[1], S. W. Asmar[1], E. Ammannito[3], M. C. De Sanctis[4], T. H . Prettyman[5], D. L. Buczkowski[6], R. Jaumann[7], C. T. Russell[3], M. J. Toplis[8], and M. T. Zuber[9], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA (carol.a.raymond@jpl.nasa.gov), [2]Univ. Tenn, Knoxville, USA, [3]UCLA, Los Angeles, CA, USA, [4]INAF/IAPS, Roma, Italy, [5] Planetary Sci. Inst., Tucson, AZ, USA, [6]APL, Laurel, MD, USA, [7]DLR, Inst. of Planetary Res., Berlin, Germany, [8]Uni. de Toulouse, France, [9]MIT, Cambridge, MA, USA.

Introduction: The gravity field of Vesta as measured by the Dawn mission [1] includes small, but significant density anomalies [2, 3] consistent with intra-crustal density contrasts of hundreds of kg/m^3 relative to a three-layer core-mantle-crust model. The pattern of the density anomalies and their geologic and compositional associations suggest a crustal architecture that includes discrete plutons of diogenitic (lower crustal/upper mantle) composition emplaced within the dominantly eucritic crust.

Density Variations: Crustal density variations were determined relative to a three-layer model that employed a 110-km radius core of density 7400 kg/m^3 [4] and a mantle whose density was held constant at the best-fit average value (3160 kg/m^3). Density within the crustal layer defined by the uncompensated topography was solved for by minimizing the power in the residual gravity field. The crustal layer thickness, defined to be zero at the deepest point within the Rheasilvia impact basin, averages ~18 km thick. The layer thickness is arbitrary but is consistent with geochemical models [6-9]. As shown in Fig. 1, density within this layer varies over 1000 kg/m^3, ranging from less than 2400 kg/m^3 at Feralia Planitia to over 3500 kg/m^3 in the region of between the northern Rheasilvia (RS) basin rim and the Divalia Fossae trough system. There is a general pattern of higher density in the eastern hemisphere and the anomaly pattern there has a periodic nature suggesting discrete density anomalies. The density pattern is robust to variations in the center-of-mass center-of-figure offset, as well as the highest degree of the gravity field used to derive the results.

Variations in crustal porosity are clearly contributing to the density variations, most evident in the negative anomalies at the Saturnalia Fossae trough system in the northern hemisphere, and at the western rim of the RS basin, as well as in the region of overlap between the RS and Veneneia basins, shown in Fig. 2. In these regions the density is below 2800 kg/m^3 suggesting thick ejecta and extensive fracturing of the crust. However, positive density anomalies over the eastern troughs and throughout the eastern hemisphere show little topographic expression. An exception is the high density at the western intersection of the two giant basins (Fig. 2), which is clearly associated with the southern part of the Vestalia Terra highland. Vestalia Terra has been shown to be ancient, and underlain by strong resistant crust [10]. The density of these regions exceeds 3200 kg/m^3, consistent with diogenite.

The positive anomaly over the central mound of the Rheasilvia basin is consistent with its origin as an uplifted lower crustal/mantle block. A weake positive along the RS basin rim near the center of the older Veneneia basin, may represent a disrupted Veneneian central mound. There are several other circular positive density anomalies within the RS basin of similar magnitude to the RS central mound that are not associated with the underlying geology.

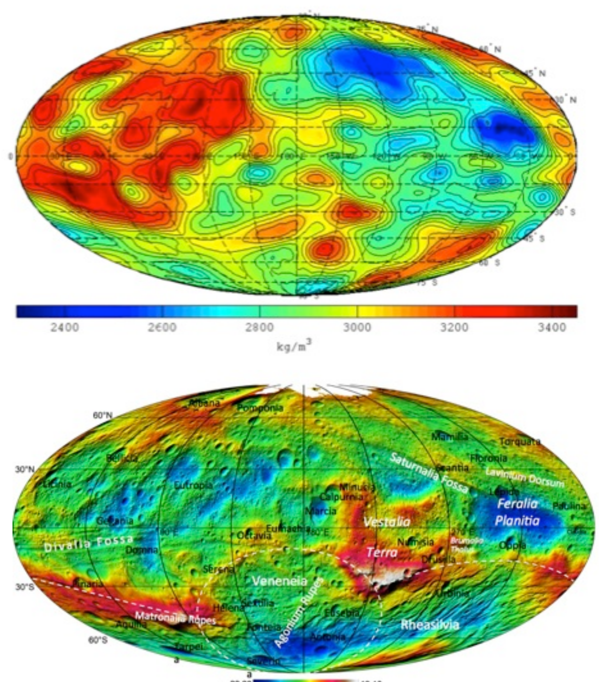

Figure 1. Top: Global crustal density map from [2] in Dawn Claudia system (prime meridian at far left). Bottom: Topography from [5] with annotations of locations discussed in text.

Association with Compositional Variations: 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 [10 -12], predominantly in the region

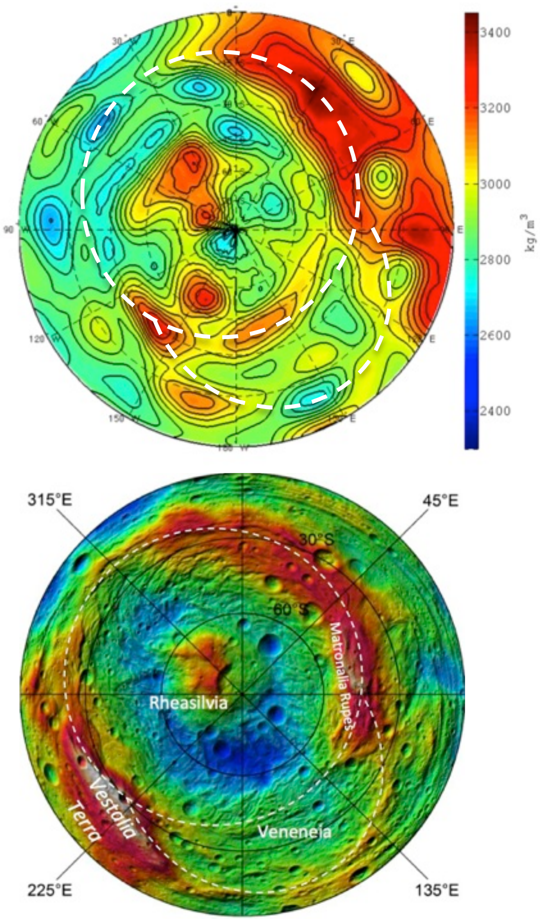

Figure 1. Top: Crustal density map of the southern hemisphere from [2]. Bottom: Topography from [5].

of overlap between the Rheasilvia and Veneneia basins and the along Rheasilvia's eastern rim at Matronalia Rupes. Although the dominantly low density seen in the RS basin seems to contradict such a finding, it can be explained as a result of deep excavation of the crust and mantle by these two major impacts. The higher density diogenite within the near surface materials is offset by the extensive fracturing in this location.

Southern Vestalia Terra and the central mound show some evidence of diogenite enrichment, but the composition is dominated by basalt [11-13], likely due to thick ejecta. The association of Vestalia Terra with denser, ancient crust argues for a primodial origin of the dense layer, reflecting the original crustal architecture. The region of positive gravity anomalies extending north from the RS basin within the eastern hemisphere corresponds broadly to a longitudinally-restricted region of diogenite enrichment that connects to the diogenite concentration within Rheasilvia. Most notably, the area in which olivine has been detected [14] lies at the edge of the region of strong positive anomalies and diogenite enrichment. One hypothesis for the 'lane' of diogenite is that it is an ejecta deposit from the RS impact. While RS ejecta may be present in this lane, the association of diogenite with the positive density anomalies indicates that the source of the lane extends to depth and argues for a fundamentally different crustal structure in this hemisphere. Furthermore, the derived density values, consistent with unfractured diogenite, indicate a largely diogenitic crust in this broad region, in contrast to the less dense crust associated with the eucrite-rich region to the west [11-13].

Implications for Vesta's evolution: The pattern of density anomalies is best explained by post-magma ocean serial magmatism in which diogenitic plutons were emplaced into the vestan crust. Such serial magmatism appears to be a natural consequence of magmatic evolution on a small body [9, 15] and trace element patterns in diogenites appear to require multiple magma bodies, supporting the hypothesis that diogenite plutons were emplaced into the crust [16, 17]. The occurrence of olivine within the region of positive density is also consistent with the heterogeneity implied by discrete magmatism. Overall, the density distribution is consistent with a dominantly diogenitic lower crust that has intruded the eucritic layer heterogeneously. Such a diogenitic lower crust is predicted by recent 1D modeling [18] that accounts for migration of Al^{26} melts to form an early magma ocean. Such a scenario is the simplest explanation of all the observations.

References: [1] Konopliv A. S. et al. (2013) *Icarus,* 240, 103-117. [2] Park R. S. et al. (2013) *Icarus*, 240, 118-132. [3] Ermakov, A. et al., *Icarus*, 240, 146-160. [4] Russell C. T. et al. (2012) *Science*, 336, 684-687. [5] Preusker F. et al. (2012) *LPS XLIII.* [6] Righter K. M and M. J. Drake (1997) *MAPS*, 32, 929-944. [7] Ruzicka, A. et al. *MAPS*, 32, 824-240. [8] Toplis et al, (2013), MAPS, 48(11), 2300-2315 [9] Mandler, B.E and L.T. Elkins-Tanton (2013), *MAPS*, 48, 2333-2349. [10] Buczkowski, D. et al. (2013) GRL, 39, L18205. [11] Ammannito E. et al. (2013) *MAPS*, 48, 2185-2198. [11] Prettyman T.H. et al. (2012) *Science*, 338, 242-246. [12] Prettyman et al. (2013) *MAPS*, 48, 2211-2236. [13] de Sanctis, M. C. et al., *Science*, 336, 697-700. [14] Ammannito E. et al. (2013) *Nature*, 504, 122-125. [15] Wilson L. and Keil K. (2012) *Chemie der Erde* 72, 289-321. [16] Barrat J. A. et al. (2008) *MAPS* 43, 1759-1775. [17] Mittlefehldt D. W. (1994) Geochim. Cosmochim Acta, 58, 1537-1552. [18] Mizzon, H. et al (2015) this conference.

Acknowledgements: A portion of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration.