VESTA STRUCTURE AND SOME PETROLOGIC CONSTRAINS FROM THE STUDY OF GRAVITATIONAL POTENTIAL BY THE DAWN MISSION.

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Introduction: Space mission Dawn targeted 4 Vesta provides a number of remarkable results concerning as surface coverage as physical parameters of the surviving protoplanet. It was confirmed that Vesta differentiated and Rheasilvia, a giant impact basin at the the south polar region, is the most likely source of howardite-eucrite-diogenite (HED) meteorites [1]. But, degree of Vesta's primary hondritic body melting is not clear till now and depends on the time of its formation at the beginning of the life of the Solar System [2]. So, the core/mantle size and the composition of theirs rocks remains questionable.

Analytical procedure: If the gravitational potential of Vesta is modeled by a spherical harmonic expansion in the body-fixed reference, then the main part in second order is [3]

$$U(r,\theta,\varphi) \approx GM/r \{1 + 1/r^2 [(A+B-2C)/2M \, ½(3 \cos(\theta)^2 - 1) + (B-A)/4M \cos(2\varphi) \, 3\sin^2(\theta)]\}$$

where $A < B < C$ are principal moments of inertia, M is mass and G is the gravitational constant. The unnormalized coefficents (the reference radius of the body is 265 km) are defined as [4]

$$C - (A+B)/2 = J_2^R MR^2, \quad J_2^R = 0.071060892;$$
$$B - A = C_{22}^R \, 4MR^2, \quad C_{22}^R = 0.002818457.$$

Most recent and relevant data from Dawn are [4]
major axes of the best-fit ellipsoid,
a/b/c - 284.5/277.25/226.43 (km);
mass, M - 2.59076×10^{20} (kg);
bulk density, ρ_b – 3456 (kg/m3);
rotation rate, ω - 1617.333119 (deg/day).

For our purpose, the shape of Vesta is reasonably well approximated by a twoaxial oblate ellipsoid, $a_1 = b_1 = 280.85$ (km), $c_1 = 226.43$ (km) and B = A at second harmonic degree.

In this case using equatorial axes **a** as the reference radius is more convenient

$C - A = J_2 Ma^2$ where $J_2 = J_2^R (R/a)^2$ and $J_2 = 0.063266$.

An exact analytical treatment provides for homogeneous twoaxial oblate ellipsoid (with an arbitrary bulk density)

$J_2^{(0)} = 1/5 \, \varepsilon_1^2$, where eccentricity $\varepsilon_1^2 = 1 - c_1^2/a_1^2$.

So, for homogenous Vesta, $J_2^{(0)} = 0.069998$ ($\varepsilon_1 = 0.5916$) and $J_2 < J_2^{(0)}$ is a clear indication of the more dense core relative mantle.

In order to explore the implications of the gravity and shape for the interior structure of Vesta, simple two-layer mass-balance model was explored with an assumed core as twoaxial oblate ellipsoid with major axes $a_2 = b_2 > c_2$ and eccentricity $\varepsilon_2^2 = 1 - c_2^2/a_2^2$. In this case,

$M = M_1 + M_2$,

where $M_1 = 4\pi/3 \, \rho_1 a_1^2 c_1$, ρ_1 is the mantle's density, $M_2 = 4\pi/3 \, (\rho_2 - \rho_1) a_2^2 c_2$, ρ_2 is the core's density. So, mass-balance provides

$$1 = \rho_1/\rho_b + (\rho_2 - \rho_1)/\rho_b \, (a_2/a_1)^2 c_2/c_1$$

or

$$(a_2/a_1)^2 c_2/c_1 = (\rho_b - \rho_1)/(\rho_2 - \rho_1) \quad (1)$$

For two-layer model an exact analytical treatment provides

$$J_2^{(1)} = 1/5 \, [M_1/M \, \varepsilon_1^2 + M_2/M \, \varepsilon_2^2 (a_2/a_1)^2] \quad (2)$$

After comparison with (1) we have

$$\varepsilon_2^2 (a_2/a_1)^2 = [5J_2^{(1)} - \rho_1/\rho_b \, \varepsilon_1^2]/(1-\rho_1/\rho_b) = D1(\rho_1) > 0 \quad (3)$$

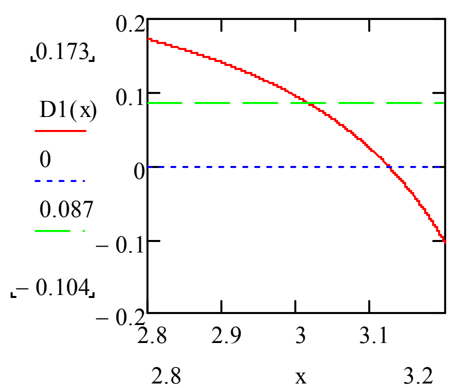

Fig.1

We assume that the core's eccentricity $\varepsilon_2 < \varepsilon_1$ as for more dense rocks relative mantle and $a_2/a_1 < 1/2$. In this case left part of (3) should be less then 0.087. For $J_2^{(1)} = J_2 = 0.063266$, the right part of the later expression - $D1(\rho_1)$ set the following limits for the unknown mantle's density as shown on Fig.1

$3.0 < \rho_1 < 3.13$ (g/cm^3)

At hydrostatic equilibrium, an exact analytical treatment provides for homogeneous twoaxial oblate ellipsoid with bulk density ρ_b , eccentricity $\varepsilon^2 = 1 - c^2/a^2$ and rotation rate ω the following relation

$$\omega^2/2\pi \rho_b G = 1/l^3[\mathrm{arctg}(l)(3 + l^2) - 3l] = F(l),$$

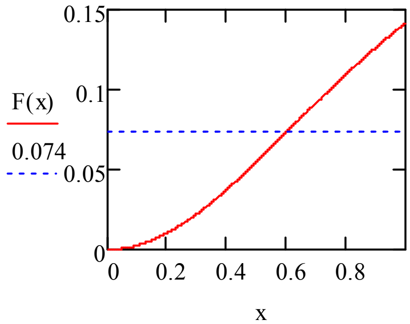

Fig. 2

where $l(\varepsilon) = \varepsilon / \sqrt{1 - \varepsilon^2}$ (see Fig.2).

So, for Vesta with the rotation rate $\omega = 1617.333119$ (deg/day) or rotation period T = 5.342 h and bulk dencity $\rho_b = 3456$ (kg/m3)

$\omega^2/2\pi \rho_b G = 0.074$

and F(l) provides $\varepsilon^{(0)} = 0.518$ while Vesta's eccentricity $\varepsilon_1 = 0.5916$. So, $\varepsilon^{(0)} < \varepsilon_1$ is clear indication of the nonequilibrium figure. The Vesta's Bouguer anomaly mapped to the 290x265-km ellipsoid through harmonic degree 15 [4] shown non-compensated relief as well.

Results and discussion: The above discussed simple core/mantle model provides reasonable value for mean mantle's density. Diogenites are currently believed to originate from deep within the crust of the Vesta and relatively unbrecciated olivine-rich diogenites consist of an equilibrium assemblage of olivine (3.27-3.37 g/cm^3) and magnesian orthopyroxene – harzburgite (2.99-3.2 g/cm^3) [5]. So, we can use this model at analytical treatment for more detailed analyses of the gravity of Vesta and implications for internal stresses [6].

It is clear now that the evolution of Vesta was a complex process and in the initial stage its rocks were more mobile than currently. Additional investigation of the relation between rotation rate and figure of Vesta given its heterogeneity and petrological constraints is required and will be followed.

References:

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[5] A.W. Beck, H.Y. McSween (2010) *Meteoritics & Planetary Science, 45*, 850–872. [6] S.A. Voropaev (2013), 44th *LPSC,* Abstract #1135.