GRAVITATIONAL DEFORMATION AND THERMAL HYSTORY OF VESTA.

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Introduction: Gravitational loading in small bodies in the form of stress deviator caused by mass and a nonequilibrium figure of bodies, is constant and actually exists from the moment of their formation [1]. There's no creep in small Solar system bodies. All small Solar system bodies irrespective of their structure from icy to metal including stony bodies are elastic bodies which possess ultimate and yield strength [2]. An analysis of mechanical properties of small stony bodies has been carried out with a model, which uses the elastic theory with ultimate strength for a three-dimensional self-gravity body, and allows the exact solution of differential stresses in a solid elastic body to be received and to carry out their analysis. The value and distribution of stress deviator in small body depends on mass, size, density, figure eccentricity and Poisson coefficient and defined by equation $\tau_{max}=\sigma_0 F(\varepsilon,\nu)$ (1), where dimension factor $\sigma_0=\frac{9}{8\pi}\frac{GM^2}{a^2bc}$, where G - gravitational constant, M – mass ($M=\frac{4}{3}\pi\rho_0 R_m^3$, where R_m – mean radius), a, b and c – main semiaxes, and $F(\varepsilon,\nu)$ – dimensionless function, which depends on figure eccentricity (ε) and Poisson coefficient (ν) [3]. If magnitude of stress deviator is greater than the compressive strength or yield point, the irregular figure of a small body as a result of gravitational deformation is transformed into a spherical equilibrium shape of a planetary body. Gravitational deformation is accompanied by gravitational densification and gravitational strengthening of a material at the entire body due to three-dimensional gravitational compression accompanied by two basic mechanisms of plastic deformation [1, 3].

Small stony bodies: Knowing the physical and mechanical properties of ordinary and carbonaceous chondrites [4], we can estimate (eq. 1) the critical mass and the size of small silicate bodies that undergo gravitational deformation. Small stony bodies composed of ordinary chondrites are characterized by compressive strength in the range of $105\leq\sigma_p\leq203$ MPa [5]. The critical size of a small body with the eccentricity of the figures typical of the small bodies of the S-type with an average axial ratio a/c=0.69 [2, 4], will be in the range of $(862\times595)\leq R_{cr}\leq(1198\times827)$ km, or in terms of the mean radius of a small body of equal volume - $R_{cr}\leq673\leq935$ km.

Small stony bodies of the C-type, consisting of carbonaceous chondrites are characterized by compressive strength in the range of $35\leq\sigma_p\leq70$ MPa [4]. The critical size of a small body with the eccentricity of the figures typical of the small bodies of the C-type with an average axial ratio a/c = 0.80 [2], will be in the range of $(784\times627)\leq R_{cr}\leq(1109\times887)$ km, or in terms of the mean radius of a small body of equal volume - $675\leq R_{cr}\leq956$ km. Thus, the critical radius of a small body of ordinary chondrites exceed 673 km and for carbonaceous chondrites - 675 km. With almost the same size, however, ordinary and carbonaceous chondrites differ significantly from each other in the critical mass and the threshold stress deviator (Fig. 1).

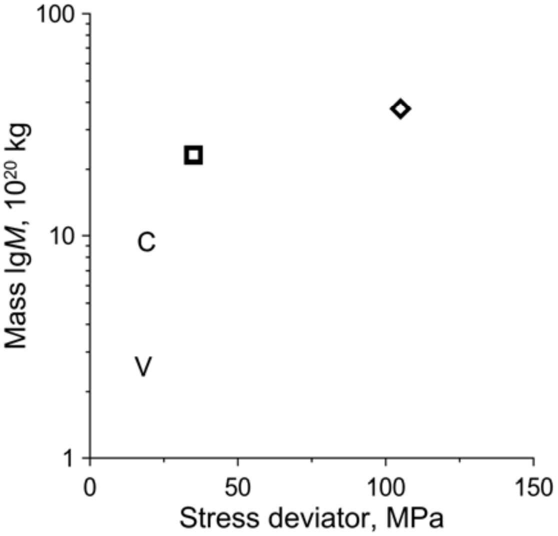

Fig. 1. The critical mass of small stony bodies, depending on the yield strength: ◇ - S-type small bodies (ordinary chondrites); □ - C-type small bodies (carbonaceous chondrites); V – Vesta; C – Ceres.

4 Vesta: The smallest silicate planetary body in the solar system is the asteroid 4 Vesta. Vesta has a spherical shape of radius R=286.3×278.6×223.2 km (R_m=262.7 km) and a high density ρ_0=3456 kg m^{-3} [6]. From geochemical point of view spectral mineralogical characterization of a surface generally corresponds to almost undamaged basaltic crust of a differentiated body [7]. It is assumed that mantle diogenity were dumped on the surface due to formation of impact basin, which struck eucrites (basaltic) crust of a differentiated asteroid [7]. Vesta's differentiation onto crust and mantle is a result of fairly active and complex magmatic evolution of the asteroid, which is typical for planetary bodies.

If, in accordance with equation (1) we estimate the present value of stress deviator on Vesta, we will find that even in comparison with carbonaceous chondrites strength it is very small and is 18 MPa (Fig. 1). Strength properties of basaltic achondrites, perhaps, are similar to the basic and ultrabasic terrestrial rocks [1], or, at least, ordinary chondrites [5]. Such significant difference between the magnitude of the stress deviator and the yield strength of silicates confirms that Vesta in the early stages of its existence has subjected to strong heating, and, perhaps, even to complete melting. Otherwise, Vesta would never has acquired be the spherical equilibrium shape and, moreover, it would not has been differentiated.

But this is not the end of Vesta evolution. A very small stress deviator compared with the yield strength of silicates means that at the present time isostatic compensation mechanism, which is a necessary attribute of any planetary body, on Vesta does not work. As the cooling of the body and a corresponding increase in the yield strength of material, Vesta gradually from the category of planetary bodies has moved into the category of small bodies, and currently represents although spherical and differentiated (hot tracks of the past), but ordinary dead "cobble". To Vesta remained as planetary body and, like on other planetary bodies, an isostatic mechanism is continued to operate (i.e. gravitational deformation), the mass of Vesta should exceed its current value is more than an order of magnitude (Fig. 1) [1].

In a few billion years of collisional evolution spherical shape of Vesta without isostatic compensation will change to an irregular shape of a small body. And this process began back 2.1 billion years ago, when impact basin Veneneia in diameter of 400 km and a depth of 12 km has formed, and 1 billion years ago, when impact basin Rheasilvia, in diameter of 500 km and a depth of 19 km has formed [8]. Age of residual magnetization of eucrites (meteorite Allan Hills A81001), which is equal to 3.69 billion years old, suggests that Vesta was already cooled down at the time of formation of these impact basins. Since both the crater formed in South Pole, they are mechanically shortened rotation axis (c) on to 20 km, and oblateness ((a-c)/c) increased from 0.15 to 0.21 [9]. It is likely that formation of two systems of long troughs (graben) in the equatorial region of Vesta, one of which is oriented relative to the center of Veneneia, and the other is associated with Rheasilvia [10], is result of elastic deformation of solid Vesta in process of formation of large impact basins.

1 Ceres: There is another planetary body in the main belt [1], it is asteroid 1 Ceres in radius 487.3×454.7 км (R_{m}=476.2 km) [11]. Mineralogy of Ceres surface according to spectral data corresponds to carbonaceous chondrites, i.e. class C [12]. The diameter of Ceres is twice as much as Vesta, but due to the low density (ρ_0=2077 kg m^{-3}), the mass is only 7 times as much as mass of Vesta. Accordingly, a current value of stress deviator is also low and equal to 19.2 MPa, i.e. is slightly more than that of Vesta. It was assumed that bulk composition of Ceres could really be presented chondrites characterized by low strength [1]. However, the observed value of stress deviator is actually half of minimum compressive strength of carbonaceous chondrites (Fig. 1). Apparently, there is significant amounts even less durable material than carbonaceous chondrites in Ceres. It may be, for example, mixture of carbonaceous chondrites and ice. If strength of carbonaceous chondrites is significantly higher than the stress deviator on Ceres, then the yield strength of the ice, on the contrary, an order of magnitude less than the stress deviator [1]. Low density of Ceres also points to significant presence of ice in Ceres [6].

Summary: Significant difference between the magnitude of the stress deviator on Vesta and the yield strength of stony meteorites confirms that Vesta in the early stages of its existence has subjected to strong heating, and, perhaps, even to complete melting. But this is not the end of Vesta evolution. As the cooling of the body and a corresponding increase in the yield strength of material, Vesta gradually from the category of planetary bodies has moved into the category of small bodies, and currently represents although spherical and differentiated (hot tracks of the past), but ordinary dead "cobble". To Vesta remained as planetary body and, like on other planetary bodies, an isostatic mechanism is continued to operate (i.e. gravitational deformation), the mass of Vesta should exceed its current value is more than an order of magnitude.

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