SHAPES OF SMALL AND PLANETARY BODIES: CASE OF PHOEBE. E. N. Slyuta. Vernadsky Institute of Geochemistry and Analytical Chemistry, Academy of Sciences of Russia, Kosygin Str. 19, Moscow, Russia. E-mail: slyuta@geokhi.ru

Success of Cassini-Hyugens and the received unique data have shown, that Phoebe despite of a relief roughness possesses surprisingly spherical shape and is not a rocky body as was considered earlier, but is an icy body with unique composition.

Introduction. All solid bodies of Solar system up to the certain size and mass are characterized by an irregular shape, and all solid bodies larger than this size are characterized by a spherical, equilibrium shape [1, 2, 3]. For icy bodies this transition is observed between satellites of Saturn Hyperion and Mimas [1, 3]. For rocky bodies this transition is observed between much larger bodies - asteroids 1 Pallada and 2 Ceres [1, 2, 4]. It is amazing, why Phoebe which is less not only some small rocky bodies, but also less than icy Hyperion possesses such regular sphere-like shape.

Phoebe. What is Phoebe? The mean radius of Phoebe is 110 km [5]. The satellite has sphere-like shape and the *c/a* axial ratio (0.95) corresponds to that for planetary bodies. Phoebe is less than Mimas, and is less than Hyperion. Its volume makes 55% from volume of Hyperion and 17% from volume of Mimas. As Phoebe it is characterized very low albedo (0.06) [5] was considered, that Phoebe is a rocky body. But Phoebe's position among rocky bodies relatively shape parameters could be considered only as anomalous [4].

Discussion. Shapes of small and planetary bodies principal differ from each other. The shape of small bodies is described three-axis ellipsoids with the principal axes $a > b > c$. The small bodies have limb roughness from 2 up to 19% of the mean radius [6]. The roughness of planetary bodies is below 1%. Other basic difference is a relief. The larger the small body size, the higher the maximal relief. And on the contrary, not so expressed, but quite explained inverse relationship at planetary bodies - the larger planetary body, the below maximal relief [7]. It means, that the relief on a planetary body is controlled by gravity, i.e. isostasy works. The distribution of *c/a* and *b/a* ratios for small bodies [2, 4] are in agreement with the experimental data [8], which demonstrated that the *c/a* and *b/a* ratios of fragments created during collisional disruptions follow well-defined distributions. The observed *c/a* ratios for small bodies are within the limits of 0.4-0.85 [2, 4], or within 0.26-0.85 including data on Ida asteroid [6]. The *c/a* ratios for planetary bodies are 0.9-1.0.

It is obvious, that the equilibrium shape of a planetary body is controlled by gravity. The first and main is the gravitational force, the second is the centrifugal force, the third is the tidal force. As a result of interaction of these three forces is a well-known shape – oblate spheroid with a tidal bulb aside an attractive body.

The small body shape is not controlled by gravity and probably completely is determined by a collisional history. To such conclusion mention the following facts: 1) The well-defined distributions of the *c/a* and *b/a* ratios of small bodies, which is determined by collisional evolution. 2) There are no dependence of distribution of the c/a axial ratios of small bodies on the mean radius [1, 3, 4]. 3) There are no geological and morphological indications of large-scale surface deformations, caused even partial relaxation of the non-equilibrium shape and not associated with crater formation [9]. Geological analysis of images of the investigated small bodies (951 Gaspra) [10], (Hyperion) [3], (243 Ida) [11], (253 Mathilde) [12], (433 Eros) [13] shows, that all observed geological features on a surface of these bodies are generated in collisional evolution. 4) The primordial shape of the observed impact craters also can serve as an indicator of the lack of any tectonic activity during the estimated period of exposure of the small body surface [9]. The age of some small bodies is great enough. The age of 243 Ida asteroid is about 2 billion years [14]. The age of 253 Mathilde is also comparable with the 243 Ida age [15]. 5) At last, it is a nonequilibrium shape of small bodies. It follows from a combination of the axial ratios and reasonable values of density in comparison with required for equilibrium shape values [16, 17].

Lack of gravitational deformations on small bodies, i.e. on bodies with mass less than some critical value, probably, is connected to some physical and mechanical properties of material. Dependence of parameters of the observed transition between small and planetary bodies on composition of these bodies also confirms this assumption. The theory of gravitational compression and the subsequent plastic deformation of a body has been submitted and in detail considered by Slyuta and Voropaev [1, 2, 4, 9]. The basic consequences of this theory below are resulted. 1) As fundamental strength, capable to resist to gravitational compression, the elastic limit or yield stress which characterizes physical and mechanical properties of material is considered and depends on composition. 2) Strain and a relaxation of a body shape occur only when the differential stresses reach value of a yield stress. The body ceases behaving like elastic and becomes plastic. The differential stresses cannot be greater than a yield stress as any increase in applied stress would immediately be relaxed by strain. 3) The differential stresses depend on gravity. The body deformation is possible only when the body mass is equal or exceeds some critical value, i.e. critical mass. 4) The radial gradient of the stress deviator is very small and plastic deformation occurs simultaneously throughout the entire body. If the body mass exceeds critical value, deformation of a body shape will occur up to achievement of a full equilibrium condition (the spherical form). 5) Stress deviator is always equal to a yield stress in a planetary body as the body mass exceeds the critical one. Therefore at any deviation of an equilibrium planetary body shape caused or with change of rotation speed, or with change of tidal forces, or with large impact event the planetary body shape would immediately be relaxed by strain to a new equilibrium condition with new shape parameters. 6) According to the dependence of a yield stress on temperature, an increase in temperature implies growing differential stress, corresponding to a relative decrease in the required critical mass. At high temperatures the body materials can reasonably be considered as perfectly plastic solids. 7) Strain rate is minimal and is established naturally depending on a differential stress, temperature and the dominating mechanism of strain.

Plastic deformation is accompanied by two basic strain mechanisms: a) the internal crystal deformation through mechanical twinning and translational gliding including subordinated intergrain sliding; б) the mechanical granulation including fragmentation and rotation of crystals (cataclasis) which is accompanied by significant intergrain sliding and moving. Perhaps, consequence of such plastic deformation in planetary bodies would be gravitational densification which actually is an initial stage of gravitational density differentiation. It may explain absence radial density inhomogeneity at small bodies [3] where according to the considered theory gravitational deformation is impossible.

The critical mass model well explains the observed dependence of transition on composition of small and planetary bodies. For rocky bodies this transition is observed between asteroids 2 Pallas and 1 Ceres where 2 Pallas (570 × 525 × 482 km in diameter) is a small body, and 1 Ceres (932.6 km) is the smallest rocky planetary body [1]. The spectral characteristics of 2 Pallas and 1 Ceres place it in the C class of asteroids, which have been computed with carbonaceous chondrites [18]. According to the received value of a yield stress (σ <60.2 MPa) for 1 Ceres the material on the physical and mechanical properties differs from chondrites and is much weaker [4]. Last data [19] show, that 1 Ceres really is the smallest and perhaps differentiated rocky planetary body in the Solar System.

For icy bodies transition is observed between satellites of Saturn Hyperion and Mimas where Hyperion (328 × 260 × 214 km in diameter) is the largest icy small body, and Mimas (400 km) the smallest icy planetary body [1, 3]. Hyperion is a homogeneous body [3]. As against Hyperion Mimas has density differentiation with depth [20, 21].

According to last data Phoebe is an icy body, but Phoebe's icy composition is very different from that of the icy satellites of Saturn and is like to that of Kuiper objects [22]. The orbital properties of Phoebe is allowed to suggest that it was captured by the Saturn's gravitational field. Phoebe's composition [23] is close to that of a comet 9P/Tempel 1 [24] which is also a Kuiper object. But if comets are small bodies with an irregular shape, Phoebe is enough large body with a sphere-like shape. Probably, this is one more example of dependence of small and planetary body transition on composition. These are bodies with the most primitive material in the Solar System. It is in agreement with estimated strengths properties of comets [25] which are much weaker than values, characteristic for usual icy bodies and especially for rocky bodies [4].

Conclusion. Now Phoebe occupies the true position in a number of small and planetary bodies. Phoebe on the shape parameters is not a small body and belongs to planetary bodies. Phoebe’s volume is almost six times less than volume of Mimas. But due to the composition and accordingly to strength properties already not Mimas, but Phoebe is probably the smallest planetary body in the Solar System.

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