GRAVITATIONAL DEFORMATION OF SMALL KUIPER BELT OBJECTS. E. N. Slyuta[1] and S. A. Voropaev[1], [1]Vernadsky Institute of Geochemistry and Analytical Chemistry, Moscow, Kosygina str. 19, Russia, slyuta@mail.ru.

Introduction: A typical irregular figure of a small body, as well as the usual debris is approximated by a model triaxial ellipsoid with axes $a>b\geq c$. Shape of small bodies is a product of a long collisional evolution, i.e. mechanical processes such as excavation and crushing. Mass of small bodies was not enough for them to become planetary bodies. High porosity of small Solar system bodies also indicates that small bodies have not been subjected to gravitational deformation, otherwise, porosity and fractures would have been destroyed, i.e. "healed". Planetary bodies which belong to another class are characterized by a spherical and equilibrium shape. The all small bodies of the Solar system, depending on the composition are characterized by its own shape [1]. This difference is due, above all, the difference of physical and mechanical properties that depend on composition and structure of these bodies.

Gravitational deformation of irregular shapes of small bodies of the Solar system is determined by the magnitude and distribution of the structural stresses that occur in a small body under the force of its own gravity field. The magnitude and distribution of stress deviator in a small body depend on the chemical and mineral composition, and is determined by such parameters as mass, density, size and shape of a small body, yield strength and Poisson's ratio [2]:

$$\boldsymbol{\tau_{max}=\sigma_0 F(\varepsilon,\nu)}, \qquad (1),$$

where the dimensional factor

$$\sigma_0 = \frac{9}{8\pi}\frac{GM^2}{a^2bc},$$

G - gravitational constant; M – mass ($M = \frac{4}{3}\pi\rho_0 R_m^3$, 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).

Physico-mechanical properties: For comets of Kuiper Belt as Borelli, Wild 2 and for similar in composition Jupiter-family comets Tempel 1 and Churyumov-Gerasimenko, for Neptune-family comet Halley, for which all required data are available [3-7], we can estimate the magnitude of stress deviator, which is two orders lower than the tensile strength (Table 1).

Tensile strength of a cometary nuclei is about 2 kPa [8]. Using the equation (Eq. 1) and assuming the density of the cometary matter to be 300 kg m^{-3} [8] and Poisson coefficient to be 0.31 [9], we may estimate the size of a cometary nucleus at which stress deviator will be equal to the tensile strength (~2 kPa). The estimated radius of the cometary nucleus, taking into account of figure eccentricity is equal to 41×24.6 km, or medium radius - 29 km. Threshold diameter of about 60 km means that up to the size of the largest comet Hale-Bopp (i.e. almost all known comets) tensile strength determined by the composition of the nucleus and has approximately constant value (about 2 kPa) regardless of nucleus size.

Table 1. Stress deviator (τ_{max}) in cometary nuclei

Comet	$a\times c$, km	Mean R, km	Dens., kg/m^{-3}	Eccen. shape, ε_{cp}	τ_{max}, Pa
Borelli	4×1.6	2.17	300	0.917	14.49
Churyumov-Gerasimenko	2.43×1.85	2.03	500	0.648	21.32
Wild 2	2.75×2×1.65	1.96	600	0.800	35.79
Tempel 1	3.8×2.45	2.84	600	0.764	70.70
Halley	8×4×4	5.04	280	0.866	59.54

When tensile strength is reached as a result of tidal disruption, collisions or ram pressure during degassing and sublimation, small bodies less than 50–60 km will easily disrupted, irrespective of their mass, thus increasing secondary population of these bodies. The effective tensile strength of cometary nuclei larger than ~60 km is determined by the body mass and shape parameters and increases according to the quadratic law depending on the body size and mass (Fig. 1).

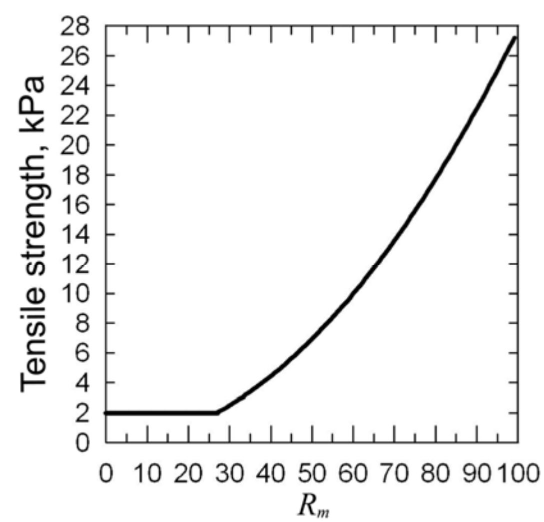

Fig. 1. Dependence of tensile strength on medium radius (R_m) of a cometary nucleus.

Such strength increase can explain the observed lack (or deficiency) of cometary nuclei larger than ~60 km, since it will significantly affect the parameters of parent body disruption and, consequently, the quantity of secondary population objects.

Gravitational deformation: In contrast to the cometary nuclei, which are small in size and characterized by irregular shape, Saturn's moon Phoebe is a large enough body with shape close to spherical. The mean radius of the satellite is 106.5 km [10]. Since the satellite is characterized by a very low albedo (0.06), it was believed that Phoebe is a rocky body. But among small rocky and icy bodies Phoebe differed by anomalous shape [11]. The explanation that followed the model of critical mass was the fact that Phoebe composition and physico-mechanical properties of the material should differ not only from rocky bodies, but also from ordinary icy bodies. It turned out that the composition of Phoebe really significantly different from conventional icy bodies, consisting mainly of water ice, and generally corresponds to the composition of comets and Kuiper Belt objects [12]. Phoebe has an anomalous reverse orbital revolution and has been captured by gravitational field of Saturn [12, 13]. Low albedo is due to the presence of chondritic dust layer on a surface of Phoebe.

By its shape parameters Phoebe belongs to planetary bodies [14, 15]. This means that the stress deviator in the case of Phoebe exceeds the yield stress of the material, and Phoebe passed the stage of gravitational deformation. Gravitational deformation is accompanied by the densification and hardening of material. Cometary nuclei are characterized by high porosity and low density (Table 1). If cometary material tightly packed to the lack of porosity, the maximum average density of the cometary nucleus will be about 1650 kg m^{-3} [16]. Phoebe's density is 1638 kg m^{-3} [17], and corresponds well to the value of tightly packed cometary nucleus after gravitational deformation.

Taking into account the satellite semiaxes of a=109.3±1.4 km, b=108.5±0.6 km, c=101.8±0.3 km [10], density - 1638 kg m^{-3} [17] and Poisson's ratio - 0.31 [9] and using (Eq. 1), we can obtain the stress deviator of 0.49 MPa for Phoebe. Hence, the yield strength of a material of Kuiper Belt objects is within the range $0.002<\sigma_p<0.49$ MPa, where the lower limit corresponds to a cometary nucleus tensile strength (~2 kPa) and the upper limit - Phoebe’s stress deviator.

If to take yield strength of 0.49 MPa, then radius of a small body which has not undergone gravitational deformation (i.e. with a density of about 300 kg m^{-3} and figure eccentricity of ε=0.8) (Table 1), may reach of 643×386 km. Thus, among Kuiper Belt objects there may be small bodies with dimensions much larger than Phoebe, but distinguished by low density and a smaller mass. For example, the object 1994 VK_8 of 280×190×190 km in diameter, or the object 1998 SM_{165}, which has a highly elongated shape of 600×360×360 km in diameter [18] (Fig. 2). The irregular shape of these small bodies is far from the spherical shape of planetary bodies.

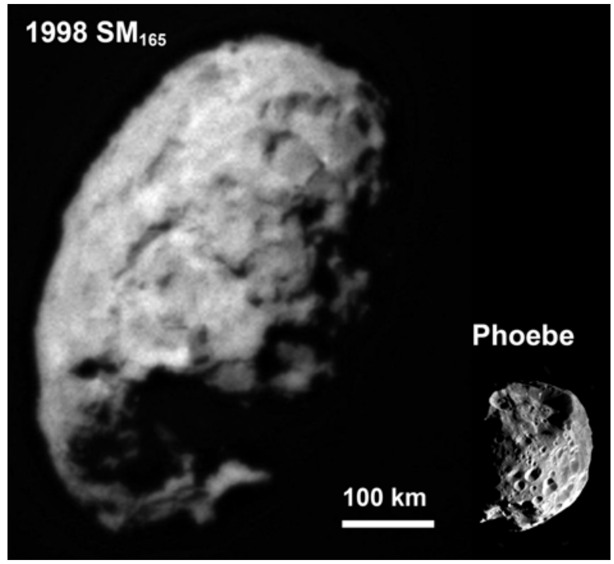

Fig. 2. The comparative dimensions of Kuiper Belt object 1998 SM_{165} (on the left) and Phoebe (on the right) shown at the same scale. To visualize 1998 SM_{165} the image of Wild 2 comet was used. Photos by «Srardust» and «Cassini», NASA.

Summary: If the yield strength is ≤0.49 MPa (Phoebe's stress deviator), eccentricity - ε=0.8 and Poisson's ratio - ν=0.31, we can estimate based on the equation (Eq. 1) the upper limit for the density of the object 1998 SM_{165}, which is estimated as ρ_0<647 kg m^{-3}. This is the case when it is impossible to make by any other means. The density agrees well with the cometary nuclei's density lying within the range from 180 to 800 kg m^{-3} [8], as well as with known density of some transneptunian objects, which varies in the range from 110 up to 670 kg m^{-3} [19].

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