

PHYSICAL AND MECHANICAL PROPERTIES AND GRAVITATIONAL DEFORMATION OF SMALL ROCKY BODIES. E. N. Slyuta¹, ¹Vernadsky 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 destruction. Since small bodies of different composition differ in physical and mechanical properties, it is reasonable to expect that the shape of small bodies of different composition will also differ, which is observed [1]. It should also be noted that regardless of the composition (from icy to metallic bodies) the shape of small bodies, i.e. the average ratio of main semi-axes c/a does not change with an increase in the size and mass of small bodies, which indicates the absence of a creep in small bodies [1, 2]. Due to the lack of the creep, a sharp transition between the small and the planetary bodies is observed, which is especially clearly seen when the size of the largest small body and the smallest planetary body of the same composition are close. For example, this is a transition between Saturn's satellites Hyperion and Mimas, which consist mainly of water ice [3, 4].

Gravity is the only force that can overcome the ultimate strength of a material and reconstruct an irregular shape of small bodies into an equilibrium ellipsoid of planetary bodies. Gravitational deformation occurs when the mass of a small body exceeds the critical, and the stress deviator, respectively, exceed the yield strength. According to the gravitational deformation theory [5] 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:

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

where the dimensional factor

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

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) [5].

Internal structure and physical and mechanical properties of small rocky bodies: Small bodies by their internal structure are divided into three main types - monolithic or coherent, binary and rubble pile [1,

References there in]. Coherent or monolithic bodies consist of one consolidated block of rock. Binary or multicomponent bodies consist of two, and sometimes three or more separate coherent blocks, held together by the force of attraction (multiple systems). The model of a rubble pile, which is an extreme case of a multicomponent system, is a collection of particles or individual fragments that are also held together only by the force of gravity.

At the initial stage, gravitational deformation is accompanied by compaction of small bodies, closure of pores and cracks, i.e. "Healing" defects in the structure. In rocks, these processes are most intensive with increasing pressures ranging from 0.1 to 50 MPa [5, References there in]. Because of volumetric compression, multicomponent small bodies and the rubble pile are transformed into coherent ones. After that, the ultimate strength (compressive strength, yield strength) will be determined by the mineral composition and texture of the coherent rock at a given temperature.

The physical and mechanical properties of ordinary chondrites, of which S-asteroids are mainly composed, and carbonaceous chondrites, of which C-asteroids are mainly composed, have been studied fairly well [6]. Knowing the physical and mechanical properties of ordinary and carbonaceous chondrites, and using equation (1), one can estimate the critical mass and dimensions of silicate bodies, which will undergo gravitational deformation. The yield strength of rocks is usually either the same or slightly less than the compressive strength and is within the ratio of these values as 0.8:1 [3, References there in]. Thus, the compressive strength of ordinary and carbonaceous chondrites can be considered as the upper boundary value with respect to the unknown values of the yield strength of these rocky bodies. Accordingly, the estimated values of the critical masses and sizes of these rocky bodies can also be considered as upper boundary values.

Critical size and mass of small rocky bodies:

The average density of S-asteroids consisting of ordinary chondrites, taking into account their porosity and fracturing, is 2.92 g cm^{-3} [1, References there in]. Poisson's ratio is assumed 0.24, which corresponds to the average value for the Tsarev meteorite, as well as for ordinary chondrites in general [6]. The minimum and maximum values of compressive strength for ordinary chondrites in accordance with the experimental data is 105 and 203 MPa [6]. Taking into account the eccentricity of a shape characteristic of small S-type bodies

with an average axial ratio of $a/c = 0.69$ [1], the critical size (R_{cr}) of a small body consisting of ordinary chondrites will be within $(862 \times 595) \leq R_{cr} \leq (1198 \times 827)$ km, or in terms of the average radius of a small body of equal volume - $673 \leq R_{cr} \leq 935$ km.

For small bodies of carbonaceous chondrites, the density is assumed to the average value of 1.79 g cm^{-3} , which is characteristic of C-asteroids with a known density [1, References there in]. Poisson's ratio for carbonaceous chondrites is unknown. Therefore, as for ordinary chondrites, we take it equal to 0.24. The minimum and maximum compressive strengths for carbonaceous chondrites are 35 and 70 MPa [1]. Taking into account the eccentricity of a figure characteristic of small C-type bodies with an average ratio of semi-axes $a/c = 0.80$ [1], the critical size of a small body consisting of carbonaceous chondrites will be in the range $(784 \times 627) \leq R_{cr} \leq (1109 \times 887)$ km, or in terms of the average radius of a small body of equal volume - $675 \leq R_{cr} \leq 956$ km. If we compare only the minimum critical sizes of small bodies from ordinary and carbonaceous chondrites, then they are almost equal - $R_{cr} \geq 673$ km and $R_{cr} \geq 675$ km, respectively. Having almost the same critical dimensions, however, ordinary and carbonaceous chondrites significantly differ from each other in their critical mass and threshold value of stress deviator (Fig. 1).

Summary: When the size (average radius) of small rocky bodies because of primary condensation or soft (hard) accretion reaches about 500-600 km, regardless of their primary structure (binary, multiple systems, rubble pile) as a result of volumetric compression, they all become coherent. If the size of a small rocky body exceeds a critical value (≥ 675 km), then the stress deviator may exceeds the yield strength and the gravitational deformation of the small rocky body occurs, which converts the irregular shape of the small body into a spherical shape of a planetary body.

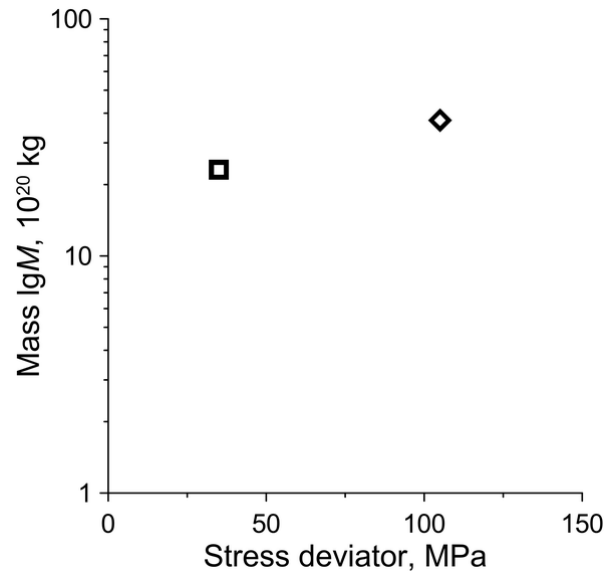


Fig. 1. Critical mass of rocky small bodies depending on the yield strength: ◇ - S-type small bodies (ordinary chondrites); □ - small C-type bodies (carbonaceous chondrites).

References: [1] Slyuta E.N. (2014) Sol. Sys. Res., 48, 217-238. [2] Slyuta E.N. and Voropaev S.A. (2013) LPSC XXXIV, Abstract #1117. [3] Slyuta E.N. and Voropaev S.A. (1997) Icarus, 129, 401-414. [4] Slyuta E.N. and Voropaev S.A. (2014) LPSC XXXV, Abstract #1055. [5] Slyuta E.N. and Voropaev S.A. (2015) Sol. Sys. Res., 49, 123-138. [6] Slyuta E.N. (2017) Sol. Sys. Res., 51, 72-95.