Relationship between regolith particle size and porosity on small bodies

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Small planetary bodies are covered by a particle layer called the regolith. The particle size and porosity of the regolith surface of the small bodies are important physical properties. The responses of the surface to solar irradiation depend on the particle size and porosity. The particle size and porosity have influences on the dynamic responses of the surface, such as cratering efficiency. In previous studies, these two quantities were measured or estimated by various methods. Here we propose a semi-empirical relationship between the particle size and porosity for small bodies' surfaces.

An empirical relationship between the porosity of granular materials in loose packing state under $1G$ and the ratio of the magnitudes of the interparticle force and gravity which act on a particle was presented in a previous study [1]. In this study, we assume that the van der Waals force F_V is predominant in the interparticle forces and adopt a model formula [2] which is different from that adopted in the previous study [1]:

$$F_V = \frac{AS^2}{48\Omega^2} r, \tag{1}$$

where A is the Hamaker constant, r is the particle radius, Ω is the diameter of an O^{-2} ion, and S is the cleanliness ratio which shows the smallness of a number of the adsorbate molecules [2]. It was shown that the cleanliness ratio S is approximately 0.1 on the Earth, and is almost unity in the interplanetary space. In addition to the data of the several previous studies, our own measurement result for micron-sized fly-ash particles in atmospheric conditions is used in the present analysis. We calculate F_V using Eq. (1), and obtain a relationship between porosity and the ratio $R_F = F_V/F_g$, where F_g is gravity. An empirical formula used in the previous study [1],

$$p = p_0 + (1 - p_0)\exp(-m{R_F}^{-n}), \tag{2}$$

is applied to fit the data, where p is the porosity and p_0, m and n are constants. We assume that p_0 is 0.36. By substituting Eq. (1) to Eq. 2, we obtain

$$p = p_0 + (1 - p_0)\exp\{-m(\frac{AS^2}{64\pi\Omega^2 \rho g r^2})^{-2}\}, \tag{3}$$

where ρ is particle density and g is the gravitational acceleration. We found that previous data and our own measurement result were fit successfully by Eq. (3) as shown in the figure (left).

We then apply Eq. (3) to the conditions of small bodies' surfaces to derive the relationship between particle radius and porosity for the several objects as shown in the figure (right). For example, in the case of asteroid (25143) Itokawa, the range of porosity is expected to be between 0.55 and 0.8 for the surface area consisting of particles with mm–cm sizes.

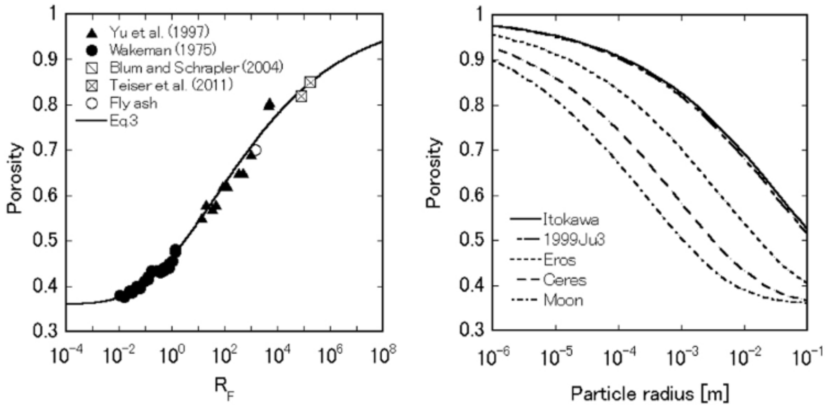

Figure: Porosity of granular media as a function of the ratio R_F of the magnitudes of the van der Waals force and gravity (left) and porosity as a function of particle radius on the surface of small bodies (right).

References: [1] Yu, A. B., et al., 2003. Powder Technol. 130. 70–76. [2] Perko, H. A., et al., 2001. J. Geotech. Geoenviron. Eng. 127, 371–383.