TIMESCALE OF THE ASTEROID RESURFACE BY REGOLITH CONVECTION. Tomoya M. Yamada, Kosuke Ando, Tomokatsu Morota, Hiroaki Katsuragi, Department of Earth and Environmental Sciences, Nagoya University, Furocho, Chikusa, Nagoya 464-8601, Japan (yamada.tomoya@a.mbox.nagoya-u.ac.jp).

Introduction: The asteroid Itokawa could be resurfaced by impact-induced seismic shaking. This idea comes from the detailed analyses of the surface observation and the returned sample given by Japanese space probe *Hayabusa*. Migration and sorting of the Itokawa's surface regolith were observed from the high-resolution images [1]. Besides, impact craters on the surface of Itokawa have vague shapes [2, 3]. In addition, the cosmic-ray exposure (CRE) age of the returned sample was estimated as 1.5~8 Myr [4, 5]. These observational findings could evidence the active resurfacing process on small asteroids.

The physical mechanism of the asteroidal resurfacing might be explained by the convective motion of the regolith caused by the impact-induced seismic shaking. Indeed, when the granular matter is subjected to the vertical vibration in the laboratory experiment, the granular convection is readily induced (e.g. [6]). However, it is not obvious whether the granular convection can really contribute to the asteroidal resurfacing or not.

As a first step to ascertain this problem, we performed systematical experiments of the granular convection with glass beads under the steady vertical vibration. From the experimental result, we found a velocity scaling for the granular convection that is almost proportional to the gravitational acceleration [7]. Previous experiments using parabolic flights also showed similar gravity-dependent velocity of the granular convection [8, 9].

The above-mentioned experimental results suggest that the convective velocity would be very low under the microgravity condition. As a consequence of the low convective velocity, the resurfacing timescale might become too long for asteroidal surfaces. Thus, in this study, we aim at modeling the resurfacing process driven by convection to estimate the timescale of asteroidal resurfacing. By comparing the estimated timescale with other ones such as collisional lifetime and CRE age, the feasibility of the asteroidal resurfacing by regolith convection is discussed.

Model: In order to estimate the resurfacing timescale by the regolith convection, we develop a simple model. In the model, we divide the resurfacing process into three phases as follows.

1. Impact phase: An impactor intermittently collides with a target asteroid.
2. Vibration phase: The collision results in a global seismic shaking.
3. Convection phase: The global seismic shaking induces the regolith convection on the asteroid.

The schematic illustration of this model is shown in Fig. 1. At the impact stage (phase 1), we estimate the frequency of impact events per year N_p by using the model of population of the main belt asteroids (MBA) [10]. N_p depends on both the impactor diameter D_i and the target asteroid diameter D_a. To compute the vibration strength induced by each impact, we utilize the global seismic shaking model at the vibration stage (phase 2) [11]. This model includes the inelastic attenuation effect as well as the dependence on D_i and D_a. At the convection stage (phase 3), we use the scaling of the granular convective velocity [7] in order to relate the vibration strength and the regolith convective velocity. By time-integral of the obtained convective velocity form, we can obtain the convective migration length per impact l.

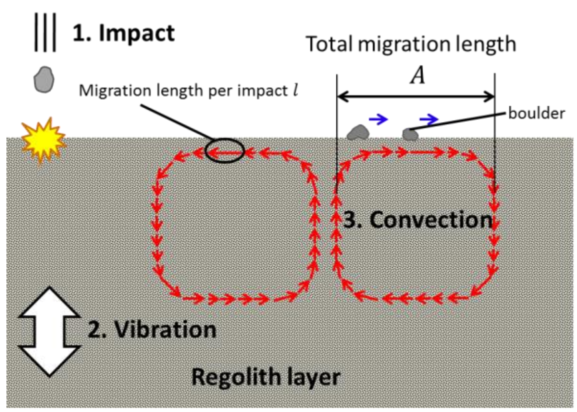

Figure1: A schematic diagram of the asteroidal resurfacing model. Intermittent regolith convection resurfaces the asteroid through three phases: 1: impact phase, 2: vibration phase, and 3: convection phase. Each red arrow's length schematically shows surface migration length per impact l. We assume that the convective roll size A corresponds to the total migration length on the surface.

Multiplying l by N_p, and integrating the product by D_i, the mean migration length per year can be estimated. Dividing the horizontal convective roll scale A by the mean migration length per year, we can numerically compute the resurfacing timescale T as a function of the asteroid diameter D_a. The above-mentioned process is expressed as follows,

$$\mathrm{T}(D_\mathrm{a}) = \frac{A}{\sum_{D\mathrm{i}=D\mathrm{i,min}}^{D\mathrm{i,max}} l(D_\mathrm{i}, D_\mathrm{a}) N_\mathrm{p}(D_\mathrm{i}, D_\mathrm{a})}. \quad (1)$$

In the summation of Eq. (1), the upper limit $D_\mathrm{i,max}$ and the lower limit $D_\mathrm{i,min}$ are determined by the disruption limit [12] and the minimum migration length limit parameterized by the index n as $l_{min} = nA$ (0< n < 1) [13], respectively.

We have to assume the specific parameter values to compute T. Here, we use the following values: collision probability $P_\mathrm{i} = 2.9 \times 10^{-24}$ m^{-2}yr^{-1}, the seismic quality factor $Q = 2000$, the impact seismic efficiency factor $\eta = 10^{-4}$, the seismic vibration frequency $f = 10$ Hz, the impactor velocity $v_\mathrm{i} = 5.3$ kms^{-1}, the mean impactor density $\rho_\mathrm{i} = 2500$ kgm^{-3}, the asteroid density $\rho_\mathrm{a} = 1900$ kgm^{-3}, the regolith particle diameter $d = 10$ mm, $A = 1.0$ m, and $n = 0.10$. The values of Q, η, v_i, f, ρ_i, P_i, are the typical ones used in the previous work [10, 11]. The measured values for Itokawa were adopted for the values of d and ρ_a [1]. The details of this model will be presented in [13].

Result: The computed $T(D_\mathrm{a})$ is shown in Fig. 2. We find that the timescale necessary to resurface the asteroid (red circles) is shorter than the mean collisional lifetime of MBA (black squares) [10, 12]. Moreover, at the Itokawa's scale ($D_\mathrm{a} = 400$ m), $T = 9.4$ Myr is longer than the CRE age (1.5~8 Myr [4,5]). This relatively young CRE age is consistent with the regolith convection model. Therefore, the regolith convection can be a plausible mechanism for the asteroidal resurfacing.

Discussion: As already mentioned, T depends on the various parameters. Some of them are actually very uncertain. For instance, the value of η, which indicates the energy-transformation efficiency from the impact kinetic energy to the seismic energy, ranges from 10^{-6} to 10^{-2} [11]. Because this uncertainty spreads over four orders of magnitude, it affects significantly to the estimation of T. However, we find that T is still comparative to the collisional lifetime even in the worst case, $\eta = 10^{-6}$. This means that the regolith convection is able to resurface the asteroid almost within its lifetime.

We obtain an approximated scaling of T expressed by a simple combination of the power-law forms. The obtained form is written by,

$$T(D_\mathrm{a}) \sim \frac{n^{0.97} A^{0.35} f^{1.97} d^{1.56} {\rho_\mathrm{a}}^{0.87}}{Q^{1.97} \eta^{1.93} {v_\mathrm{i}}^{1.85} {\rho_\mathrm{i}}^{0.87} P_\mathrm{i} G^{0.06} C_1} {D_\mathrm{a}}^{0.72}, \quad (2)$$

where C_1 is the coefficient of the approximated cumulative number distribution of the MBA and G is the gravitational constant (6.7×10^{-11} m^{3}s^{-2}kg^{-1}). Equation (2) is shown as a red solid line in Fig. 2. This approximated form shows a good agreement with the numerically computed timescale. In addition, Eq. (2) allows us to evaluate various parameters dependence of the resurfacing timescale.

At the large D_a range, the numerically computed T becomes a decreasing function. Although this is a kind of typical scale-dependent cross over of the scaling, the estimate of T in this regime is not so reliable because the target asteroid is too large to generate *global* seismic shaking [13].

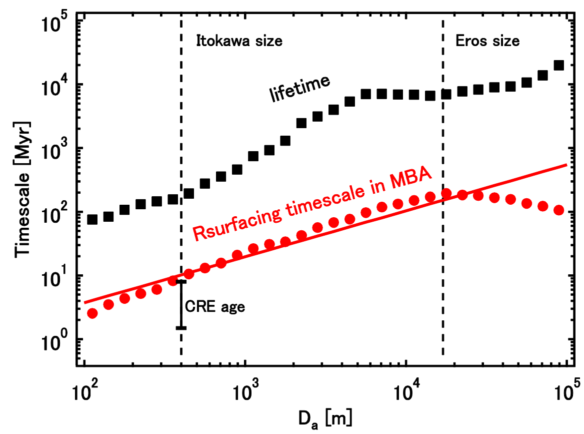

Figure2: Various timescales in the main belt. Red circles show the timescale necessary for the regolith convection to resurface the asteroid. The solid red line shows the approximated resurfacing timescale computed by Eq. (2). Black squares show the mean collisional lifetime of MBA [10, 12]. The CRE age of Itokawa's returned grains is indicated by an error bar [4, 5].

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