THE FIRST LOOK OF BLOCKS ON ASTEROID 25143 ITOKAWA BY THE HAYABUSA SPACECRAFT: A COMPARISON OF THE OBSERVED NUMBER DENSITY WITH THE ESTIMATED.

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Introduction: One of the ultimate goals of the AMICA (Asteroid Multi-band Imaging CAmera) mission on board the HAYABUSA spacecraft was to capture images of the very small asteroid 25143 Itokawa at extremely high resolution. Before the arrival of the Hayabusa spacecraft to Itokawa, the number of meter-scale blocks (or the extent of meter-scale flat areas) on the surface was a big concern from the engineering point of view for accomplishing sampling. In general, blocks on small bodies observed by previous space missions are attributed to impact cratering. During impact cratering, only ejecta whose velocities are smaller than the escape velocity can fall back and settle on the surface. Although the escape velocity of Itokawa is too small (sub-meter per second) in comparison with the usually observed ejecta speeds in laboratory cratering experiments [1-3], blocks were still expected on the surface [4]. The images taken by AMICA showed that asteroid Itokawa is covered with numerous blocks. The purpose of this paper is to examine the origin of blocks on the surface of Itokawa, by comparing the observed number of blocks with the calculated values by a model based on impact cratering experiments.

The observed number of blocks on Itokawa: Existence of large blocks on Itokawa surface is one of the most prominent features found on images of Itokawa. The size, the axial ratio, and the location of the blocks were investigated on both print out images and on PC screens. Here we define blocks as both apparently rootless rocks and distinctive positive relief. The number of blocks larger than 5m is roughly 500. Since the surface area of Itokawa is 0.393 km^2 [5], the cumulative number of blocks larger than 5m per unit area is more than 10^3 (km^{-2}), that is larger than the findings for near-Earth S-type asteroid Eros by more than a magnitude [6].

A previous estimate on number of blocks and its assumptions: Outline of the previous block number estimation [4] is as follows. (a) The largest possible crater is the source crater for the ejecta blocks. (b) The ejecta mass distribution is given by a power-law distribution. (c) The total ejecta mass fraction (f_e) having velocity less than the escape velocity (v_e) to the total ejecta mass (M_{total}) from the source crater is assumed to be 0.5%.

(a) *The source crater*. The total ejecta volume from craters are dominated by those from the largest ones, as long as the log-log slope of the differential size distribution of the craters is larger than –4. This is why the largest possible crater was assumed to be the source crater of the blocks on Itokawa. It was assumed that largest crater radius (110m) is ~60% of the mean radius (180m) of Itokawa. This was because similar percentages were observed on Eros and Mathilde[6,7].

(b) *The ejecta mass distribution.* The constant power index of –2/3 for the cumulative ejecta mass distribution was found in previous laboratory cratering experiments of porous sintered glass beads targets [4]. The similar constant exponent was also found for ejecta from the Tycho crater on the moon, based on analyses of the spacial and size distribution of secondary craters [8].

The ejecta mass distribution having velocity less than a given ejection velocity (v) was also given by a power distribution,

$$N(>m,<v)=C(<v)\, m^{-2/3}\,, \qquad \text{eq. (1)}$$

where m is the individual ejecta mass and N is the cumulative number of ejecta block or particle having a mass larger than m. Eq. (1) leads to a differential size distribution $n(m,<v)=2/3Cm^{-5/3}$. The coefficient C in eq. (1) can be determined once the mass of the largest block fallen back to the surface (m_l) is given; the cumulative number of blocks having mass larger than m_l is unity, that is,

$$N(>m_l,<v\_e)=1=C(<v\_e)m_l^{-2/3}\,. \qquad \text{eq. (2)}$$

The mass of the largest block, on the other hand, is derived from the following equation,

$$\int_0^{m_l} n(m,<v\_e)dm = f_e M_{total}\,. \qquad \text{eq. (3)}$$

(c)*The mass fraction of ejecta fallen back to the Itokawa surface*. The mass fraction of ejecta having speed less than a given ejection velocity (v) was found to be dependent upon the strength of the surface in the strength regime of the cratering process [3]. This dependency was likely consistent even with the results of porous targets and a number of ejecta with very low velocities (<1m/s) were observed[4][9]. The material strength of an S-type asteroid Eros was estimated to be ~10 MPa [10]. If the material strength of Itokawa, which was also categorized as S (or Q)-type asteroid [11], is similar to that of Eros, the fraction of the fallen back ejecta mass is estimated to be 0.5% based on the laboratory experiments of sintered glass beads targets with various compressive strengths ranging from 0.5 MPa to 250 MPa [9]. Accordingly, the fallen back ejecta mass was estimated to be $(110)^3 \times 0.005 \times 2500$ kg, where density of Itokawa was assumed to be uniform throughout the whole body and 2500 kgm^{-3}.

The above parameters substituted into the model lead to $C=4.1\times10^4$ and the mass of the largest block of 8.3×10^6 kg, which is compatible with those estimated from the empirical relationship between the total ejecta mass (or crater size) and the largest block mass (or the largest block size) [6,12,13]. The number of the blocks larger than 1 m was thus estimated to be ~340 like the number of the observed blocks larger than 5 m. In turn this estimate is therefore much smaller than the number of blocks larger than 1 m on Itokawa surface.

Revised parameters for Itokawa and results: Since there is a large discrepancy between the previous estimation and the observed data, we reconsider the size of the source crater of the blocks and the material strength of Itokawa. The radius of the maximum crater (Little Woomera) is about 50m [14], which is less than the half of the previously expected radius. Several craters (or circular depressions) larger than 30m are also observed. The bulk density determined for Itokawa is ~2100 kgm^{-3} [15], which is less than that (~2600kgm^{-3}) of the other S-type asteroids previously explored, Ida and Eros. The smaller bulk density may indicate that Itokawa has a larger macroporosity. Therefore, it is quite likely that the material strength of Itokawa is less than 10 MPa.

We revised the parameters and recalculated the number of blocks on Itokawa. The parameters adopted in this study are given in Table 1. Some of the parameters, such as bulk density and the radius of the source craters are based on the observed data. As another interest is to evaluate the effects of the material strength, we test a range of plausible values. In this paper, the minimum material strength is assumed to be 0.1 MPa. Weak surface with material strength less than 0.1 MPa would produce only a small amount of ejecta due to compaction [16].

The results are also shown in Table.1. The number of blocks increases with decreasing material strength. This is because the mean velocity of ejecta decreases with decreasing material strength. In this model the size of the largest block also slightly increases with decreasing material strength. Such a tendency was found in some of the experiments of one of authors [9], whereas a model of impact spallation predicts complicated material dependency of the thickness of spall fragments [17].

One can see from Table 1 that the estimated number of blocks is very small compared with the observed data and the largest block size is smaller than those found on the surface of Itokawa. Even if Itokawa has several 50m-sized craters, this tendency does not change. Note that the empirical relationship between the largest block size and the source crater diameter predicts similar largest block-size, e.g. 6.3 m for a 50m-radius crater [6]. These results probably mean that it is difficult to produce as many blocks on the surface as were observed considering only impact cratering as the source; it is possible that the blocks of Itokawa were originated from other process.

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Table 1. Itokawa's parameters used for this study and the results.
Density: 2100 kgm^{-3} [15], Escape Velocity: 0.20m/s
Radius (R) of source craters: 50 m[14] ,
Crater Volume: $V=R^3$ (m^3).

Material strength	10MPa	1MPa	0.1MPa
Mass fraction of ejecta fallen back to the surface (f_e)	0.45 %	1.41 %	4.43%
Size of the largest block from the largest crater	8.1 m	11.9 m	17.4m
Estimated number of blocks larger than 5m	2.6	5.7	15.4