Rock piles on Itokawa observed by the highest resolution images. Hideaki Miyamoto[1,2], Hajime Yano[3,4], Akiko M. Nakamura[5], Daniel J. Scheeres[6], Ryosuke Nakamura[7], Masateru Ishiguro[8], Shinsuke Abe[5], Tatsuaki Hashimoto[3,4], Naru Hirata[9], Takashi Kubota[3,4], Tatsuhiro Michikami[10], Tomoki Nakamura[11], Takaaki Noguchi[12], Jun Saito[3,13], Sho Sasaki[14], Akira Tsuchiyama[15], Yasuhiro Yokota[3], [1]Department of Museum Collection Utilization Studies, The University Museum, University of Tokyo, Tokyo, Japan (hm@um.u-tokyo.ac.jp), [2]Planetary Science Institute, 1700 E. Ft. Lowell Rd., Suite 106, Tucson, AZ 85719, [3]Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, [4]Department of Space and Astronautical Science, School of Physical Sciences, Graduate University for Advanced Studies, [5]Graduate School of Science and Technology, Kobe University, [6]Department of Aerospace Engineering, University of Michigan, [7]National Institute of Advanced Industrial Science and Technology, [8]Astronomy Department, Seoul National University, [9]Department of Computer Software, University of Aizu, [10]Fukushima National College of Technology, [11]Department of Earth and Planetary Sciences, Faculty of Science, Kyushu University, [12]Department of Materials and Biological Sciences, Ibaraki University, [13]School of Engineering, Tokai University, [14]Mizusawa Astrodynamics Observatory, National Astronomical Observatory of Japan, [15]Department of Earth and Space Science, Osaka University

Introduction: In November, 2005, the Hayabusa spacecraft performed touch-down rehearsals, imaging navigation tests, and two touchdowns [1], which provided close-up images with the range distance [2] between 63 m and less than 2 km, where the telescopic camera pointed almost vertically to the surface. By rectifying the close-up images into images from higher altitudes, we determine the exact locations for all of the close-up images, which are confirmed by the spacecraft's attitude and orbital information. We find that the size and distribution of particles covering the surface are difficult to be resolved from images whose resolutions are below the size of particles (Fig), which proves the significance of high-resolution images to study the surface of the asteroid.

In distant images the rough terrains generally show a similar appearance with numerous boulders [3] that mostly appear to be buried in smooth, homogeneous materials (Fig). This gives an impression that boulders may have been completely buried by fine materials. Contrary to this, close-up images have revealed that gravel are typically piled on each other without being buried with fines; this is also vividly suggested by the collapse of a rim-like feature of a possible crater. Thus, the surface of Itokawa is likely covered with unconsolidated gravel, which leads us to use terminology of sedimentary deposits (pebble, cobble, and boulder represent objects whose sizes range in 4mm-6.4cm, in 6.4cm-2.6m, and in >2.6m, respectively; gravel includes all of them) [4] to describe surface appearances.

Deficiency of powdery materials: The finest particles observed in the close-up images are centimetre-sized pebbles, whose concentrations are found in the smooth terrains (Fig). The deficiency of powdery materials on the surface is surprising because they are thought to be created [5-7] through impacts onto the present surface of the asteroid, surface degradation due to micrometeoroid impacts, and catastrophic disruption of Itokawa's parent body. If the fine particles are buried, the surface might remain features related to the movements of these particles [8], such as drainage pits [9]. Although we do not observe any clear drainage features on Itokawa, there are series of evidences indicating that the surface of Itokawa is not formed by a simple accumulation of gravels; their positions and orientations were clearly reallocated after their accumulations. For example, none of the smaller gravels is placed on the surfaces of boulders, except when gravels fill gaps between larger boulders. Furthermore, larger gravels do not protrude from each other and their orientations always appear to be gravitationally stable.

The reallocation of gravel is also evidenced by the bright areas, which have relatively higher brightness than the surrounding rough terrains [3]. In a high-resolution image, we find an enigmatic brighter part, which most likely corresponds to a bright area in lower resolution images [3]. The bright areas are explained by specific geological settings, consistent with optical maturation with increasing exposure age [3, 10], as proposed for Gaspra [11], Ida [12], and Eros [13, 14]. In this sense, the brighter part may represent a relatively fresh surface, which was covered with rough particles and eventually exposed when the overlying gravel were removed. Note that the brighter part shows somehow fragmental texture composed of centimetre-scale white patches surrounded by relatively brighter matrix. Some gravel inside are probably consolidated in the brighter matrix whose grain-size is not resolved, giving an impression that the brecciated debris fragments are cemented by finer materials. If this brighter part is lithified, it could not be formed on a small asteroid (such as Itokawa) because of its low internal pressure. On the contrary, it is also plausible that this brighter part is merely aggregates of fine particles, which may remain on the surface even after the removal of overlying gravels because the finer particles have larger cohesion per unit mass.

Diverse histories of boulders: The above observations indicate that the gravels on the surface likely have experienced dynamic processes through the evolutionary history of Itokawa. In addition to this, they are likely to have diverse histories prior to their accumulations to Itokawa, which is suggested by intriguing features of gravels. For example, large gravels include those with unambiguously “bright spots”, such as typically cm-order, relatively circular “bright dots”, elongated and scratch-like “bright scars”, and irregularly-shaped “bright patches”. The high brightness could be due to chemical anomalies at some extent (such as large inclusions) or to coating of fine particles, however the bright dots and scars appear to expose the internal fresh materials of individual boulders or to have the different surface roughness. Furthermore, the distribution of the bright spots varies from one boulder to another but it is independent from roundness or surface smoothness of the boulders, indicating that the formation of these bright spots may not be related to physical properties of the boulders. Thus, we interpret that the high brightness comes from the freshness in optical maturity [3, 10] in most cases. In this sense, the bright dots and scars may be caused by micrometeoroid impacts and by scratch due to gravel collisions, respectively. If this hypothesis is true, the distributions of brighter dots should represent the different exposure age to micrometeoroids impacts. Thus, a boulder with a larger number density of bright spots should have longer residential time either on the surface or in orbit before landing on Itokawa. The random distributions of the bright dots and scars may represent the different ages of these boulders, which do not seem to systematically vary by locations.

The roundness of gravels widely varies even within the same location. Angular boulders can have fresh-looking smooth textures while rounded boulders show rough and sometimes wavy textures. The existence of rounded boulders with non-smooth surface textures suggests either (1) the boulders have experienced degradation processes (either on Itokawa or not) to reduce both their angularity and surface smoothness or (2) these boulders have formed essentially in different processes from the fresh-looking boulders because of the difference in the strength or the degree of lithification. Note that the roundness is independent from the number of the brighter dots and that the fresh-looking boulders with relatively larger numbers of bright dots seem to have experienced a very limited degree of degradation. These indicate that the degree of degradation is not a simple function of the age of boulders. Importantly, both fresh-looking and degraded boulders are found in proximity of each other within the same close-up image, which is difficult to explain only with common surface processes on the present Itokawa. These observations conclude that gravels found in the close-up images are likely to have considerably different histories from each other prior to their reaggregation onto Itokawa.

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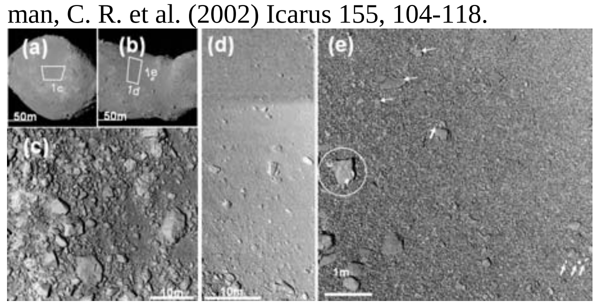

Fig. Images show the different appearances with different resolutions. (a) The Little Woomera region; (b) Muses C region; (c) Higher resolution image of the Little Woomera; (d) Muses C region; (e) Close-up of the Muses C region. Arrows, circle, thick arrows indicate bright dots, bright patch, and bright pebbles, respectively.