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Surface morphological features of boulders on Asteroid 25143 Itokawa

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ABSTRACT

On the sub-kilometer S-type asteroid, 25143 Itokawa, some boulders on rough terrains seem to be exposed without any powdery material covering. Based on surface morphological features, there are two major types of boulders: one has rounded edges and corners (rounded boulders), while the other has angular edges and corners (angular boulders). The surface features of the rounded boulders suggest that they have hardness heterogeneity and that some may be breccias. The angular boulders appear to be more resistant to impact disruption than the rounded ones, which may be due to a difference in lithology. The major constituents of Itokawa may be LL chondrite-like brecciated lithology (rounded boulders) along with a remarkable number of boulders suggesting that lithology is atypical among LL chondrites (angular boulders). Some of both types of boulders contain intersecting and stepped planar foliations. Comparison with meteorite ALH76009 suggests that the planar foliations may be marks where rocks were torn apart. As lithified breccias cannot be formed on present-day sub-kilometer-sized Itokawa, it is reasonable that boulders with various lithologies on Itokawa were formed on its large ancestor(s). The rubble-pile structure of Itokawa suggested by its low density (~1.9 g/cm^3) indicates that boulders on Itokawa are reassembled fragments formed by catastrophic disruption of large ancestor(s).

1. Introduction

Because of accretion in the early solar nebula, asteroids have experienced various processes such as thermal metamorphism and/or aqueous alteration, impact shock events, catastrophic disruption, and reassembly. It is believed that the majority of meteorites were derived from asteroids; thus, meteorite researchers have estimated histories of asteroids based on petrology, mineralogy, chemistry, and isotopic signatures of meteorites. The in situ observation of rocks on the surface of an asteroid is also a method for estimating its history. However, such direct observation of rock textures by a spacecraft could not be accomplished to date. Even the highest-resolution images obtained by the NEAR Shoemaker spacecraft could not reveal rock textures of the surface material of Asteroid 433 Eros in detail because of limited spatial resolution (Robinson et al., 2002).

The sub-kilometer asteroid, 25143 Itokawa, which is the target asteroid of the Japanese Hayabusa spacecraft, is covered with numerous boulders and cobbles (Saito et al., 2006). Although the finest material observed on Itokawa is resolution-limited (highest resolution: 6.0 mm), typical boulders and cobbles on the rough terrains of Itokawa are stacked without burying by fines (Miyamoto et al., 2007). Miyamoto et al. (2007) also noted the apparent lack of a powdery material covering that obscures the surface morphological features of boulders and cobbles. They proposed some causes of the deficiency of the powdery material: electrostatic levitation and removal of the fines by solar radiation pressure, restricted accumulation after impact due to the higher ejection velocity of the fines, and segregation of the fines into the interior

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of the asteroid. Even though a very thin powdery material covering may exist, it does not conceal the surface textures of boulders and cobbles on Itokawa. Accordingly, we could perform direct observation of the surface morphological features of boulders and cobbles on Itokawa's surface.

The relative abundances of olivine and low-Ca pyroxene and their FeO contents, and elemental abundances of the surface material of Itokawa were obtained by in situ measurements by the near-infrared spectrometer, NIRS-Hayabusa (Abe et al., 2006; Hiroi et al., 2006), and the X-ray fluorescence spectrometer, XRS-Hayabusa (Okada et al., 2006; Arai et al., 2008), respectively. Based on near-infrared reflectance spectra, the surface of Itokawa is estimated to be LL5 or LL6 chondrite-like material (Abe et al., 2006; Hiroi et al., 2006). The XRS-Hayabusa data did not rule out the presence of primitive achondrite-like materials on Itokawa's surface (Okada et al., 2006; Arai et al., 2008). Observation of surface morphological features of large boulders on Itokawa would provide another perspective for discussing its constituents. We used several brecciated LL chondrites, a fragile L/LL chondrite, and an L chondrite with a unique surface morphological feature to discuss the surface morphological features of the boulders on Itokawa. There are no primitive achondrites sufficiently large to facilitate a comparison between their surface features and those of the boulders. From the description on surface features of the boulders and cobbles on Itokawa and comparison with the meteoritic samples, we discuss the lithology of the boulders and cobbles, and their origins.

2. Images used in this study

Three close-up images of regions of rough terrain were taken by the telescopic Optical Navigation Camera with the V-band filter (also known as the asteroid multiband image camera, AMICA; Saito et al., 2006) from heights of 60 to 160 m from Itokawa's surface during the touch-down rehearsal on November 12, 2005, Coordinate Universal Time (UTC). These images were used for the observation of the surface morphological features of unconsolidated boulders and cobbles in the rough terrain of Itokawa (Fig. 1). The squares labeled "2A", "2C", and "2E" in Fig. 1 correspond to the fields of view of three high-resolution images shown in Fig. 2A, C, and E, respectively. The high-resolution images corresponding to squares "2A", "2C", and "2E" are ST 2539437177, ST 253944467, and ST 2539451609, respectively (Table 1). They are situated at the east side of a smooth terrain (MUSES-C region) and near the rim or the inside of a crater candidate #4 (LINEAR region) proposed by Hirata et al. (2009) (Fig. 1). North is downward

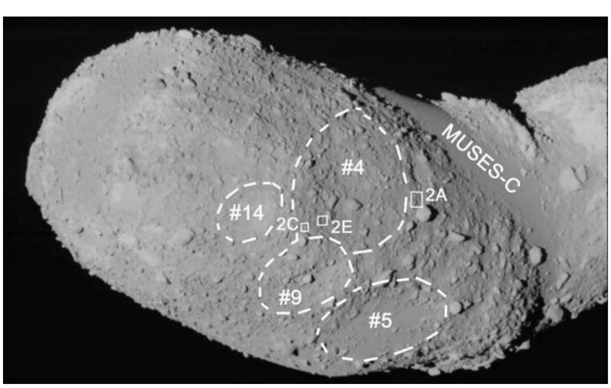

Fig. 1. Positional relationships of high-resolution images used in this study plotted on a part of the global image of Itokawa. Three boxes with numbers correspond to the areas in Fig. 2. The image IDs of Fig. 2A–C are ST 2539437177, ST 2539444467, and ST 2539451609, respectively. In this figure, the geographic north of Itokawa points downward. The MUSES-C region and four crater candidates #4, 5, 9, and 14 by Hirata et al. (2009), is also indicated. The image ID of this figure is ST 2506694595.

in all the images used in this study. A single pixel in each of the original images corresponds to about 11.3, 6.0, and 7.8 mm, respectively. The image resolutions are sufficiently high to allow a description of the surface morphology and texture of ~40-cm-sized boulders. The brightness and contrast of the images are modified to enhance the visibility of the particles (Miyamoto et al., 2007). The top parts of the original images are obscured because of the polarizer (Saito et al., 2006).

3. Surface morphological features of boulders

3.1. Major surface morphological features of boulders on Itokawa

Three high-resolution images of Itokawa's surface used in this study are shown in Fig. 2. The fields of view of all the images are covered with unconsolidated boulders and cobbles. Miyamoto et al. (2007) reported the following two characteristics about the unconsolidated boulders and cobbles in the three images: (1) the smaller boulders and cobbles are not isolated on the top of boulders without being supported by other boulders and cobbles. (2) As may be suggested by the majority of the boulders having wide and relatively flat surfaces facing upward, their position and orientation are stable against local gravity (Fig. 2). Miyamoto et al. (2007) proposed reallocation of boulders and cobbles after their accumulation and/or deposition. Therefore, we could observe surface morphological features of boulders using these images.

Boulders on Itokawa's surface can be categorized into two major types based on their surface morphological features: rounded and angular boulders. Boulders having rounded edges and corners and wavy surfaces in Fig. 2A, C, and E, respectively, are depicted in light gray in their corresponding schematic line drawings (Fig. 2B, D, and F). We call them "rounded" boulders, although they may be classified as subangular to rounded if we use the terminology of sedimentary geology (e.g., Pettijohn, 1974). Rounded boulders occupy about 80% of the total area in Fig. 2A and C and about 50% of the total area in Fig. 2E, for which the corresponding line drawing is shown in Fig. 2F. Typical rounded boulders are shown in Fig. 3.

Boulders with sharp edges and corners are depicted in dark gray in their corresponding line drawings (Fig. 2B, D, and F) and are prominent (about 40% of the total area) in Fig. 2E and F (Table 2). We use the term "angular" for boulders with sharp edges and corners. Typical angular boulders are shown in Fig. 4. By comparing surface morphological features of a large rounded boulder in Fig. 3C and a large angular one in Fig. 4A, it is observed that the latter has sharper edges and corners than the former.

3.2. Surface morphological features of rounded boulders

Some rounded boulders show remarkable surface morphological features (Fig. 3). Protrusions are obvious in the boulders in Fig. 3A and E. The majority of the rounded boulders have surface morphological features similar to those shown in Fig. 3B and C. The boulders in Fig. 3C and D show patches with areas ~50 cm × 50 cm across, indicated by arrows. We can delineate the outline of the patch on the boulder in Fig. 3C, although its surface morphology is similar to its surroundings. A patch on the boulder in Fig. 3D is darker than its surroundings, which suggests different chemical composition and/or different abundance of material that causes darkening. The boulder shown in Fig. 3E, which has surface morphological features similar to those in Fig. 3A, seems to be overlaid by other boulders (two examples are labeled "a" and "b").

In Fig. 2E, rounded boulders seem not to be predominant; however, the center to the middle-right edge of the image is occupied by an area with features similar to those of the boulders in Fig. 3A and E. This area is brighter than the surroundings, and its