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Block distributions on Itokawa

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ABSTRACT

Asteroid 25143 Itokawa is a small elongated asteroid with two distinct parts. The evolution of this two-part body has been the source of speculation. The scenarios for the formation of this asteroid include: two-body capture, catastrophic disruption and rapid reaccretion, YORP spin-up and mass shedding, and disruption (or partial disruption) with two-body reaccretion. In this paper we use the global and regional analyses of block populations and size–frequency distributions as evidence of the probable evolutionary history of Itokawa. The block sample used in this study is believed to be complete for blocks of size >6 m and consists of a sample more than twice as large as previous known studies.

Although block size-frequency distributions hint at different evolutionary paths for the head and the body, their differences are not statistically significant. The distribution of blocks across each body provides clues as to the histories of each body. The head is populated in a spherically symmetric fashion while the body has a distinct equatorial peak. When considering that the head and the body may have been separate entities for a period of time and estimating a rotational axis using minimum rotational energy considerations, the preferential equatorial distribution becomes even more pronounced. We interpret this as excellent evidence for the partial disruption of a proto-Itokawa, subsequent planarization of a debris field and reaccretion of the head and the body into its present configuration.

1. Introduction

Asteroid 25143 Itokawa is a 535 × 294 × 209 m (Fujiwara et al., 2006) Apollo and Mars-crossing asteroid that was sampled by Japan's Hayabusa mission. The surface morphology of Itokawa suggests a complex evolutional history (Fujiwara et al., 2006). The main body of the asteroid appears to be formed by the assimilation of two separate pieces – commonly referred to as the head (the smaller and more spherical section) and the body (larger and elongated). Approximately 80% of the surface is rough terrain that is covered with numerous blocks while the remainder of the surface is dominated by regolith (Saito et al., 2006). The smooth terrain on Itokawa is divided into two areas: the Muses Sea, which extends around the "neck" between the head and body and Sagamihara, which is the north polar region (Fig. 1).

A variety of approaches have been used to gain greater insight into the formation and evolution of this asteroid. These include orbital dynamic assessment (Michel and Yoshikawa, 2006; Ksanfomality, 2011), a study of the surface mineralogy (Abe et al., 2006b; Kitazato et al., 2008), evaluation of the asteroid morphology (Fujiwara et al., 2006; Saito et al., 2006; Abe et al., 2006a); and investigation of crater morphology and size–frequency distributions (Hirata et al., 2009; Michel et al., 2009). These studies indicate that Itokawa is a rubble pile, derived from a common type of LL-5 asteroid, that made its way from the main belt via one of the Jupiter resonances (Michel and Yoshikawa, 2006). It possesses a surface age of ∼75 MYrs, but could be as old as 1 GYr (Michel et al., 2009). Orbit dynamical analyses also show the possibility that the head and body could have evolved separately for some significant time prior to combining (Scheeres et al., 2007). Spectral data show no significant heterogeneity in mineralogy across the asteroid surface, which indicates that Itokawa is probably derived from one parent body. The presence of a population of rounded and angular blocks has been attributed to two rock lithologies being present on Itokawa's parent body (Noguchi et al., 2010), although other origins of block roundedness are possible. They could result from block migration and/or erosion on Itokawa's parent body or Itokawa itself.

Block distributions provide another tool that can be used to explore the evolution of an asteroid and its surface (e.g., Lee et al., 1996; Thomas et al., 2001; Michikami et al., 2008, 2010). Because only a few large craters are visible on the surface of Itokawa (Hirata et al., 2009), it is unlikely that the current block population is dominated by these impacts. It is more likely that the global and regional size–frequency distribution of blocks across the surface of Itokawa provide constraints on the original disruption of the asteroid (Michikami et al., 2008, 2010). This study expands upon

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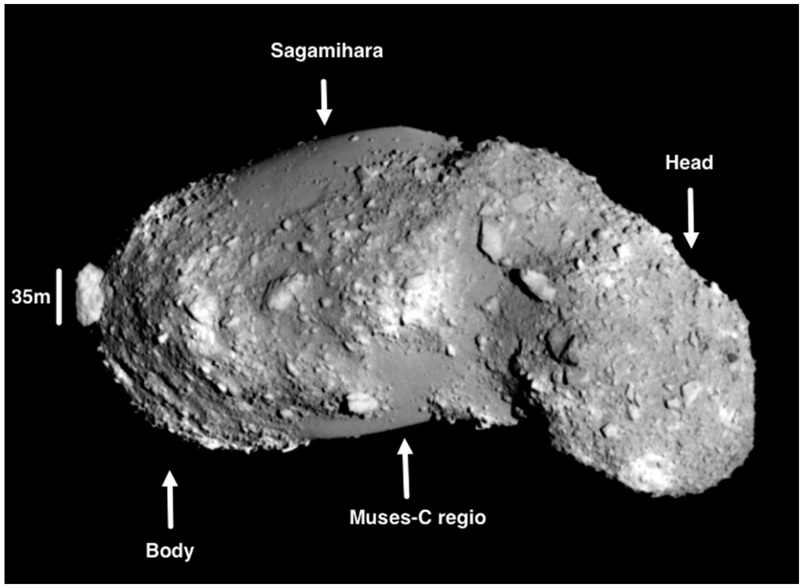

Fig. 1. Asteroid 25143 Itokawa (image credit: JAXA). North is up.

previous prior efforts (Michikami et al., 2008) by identifying and measuring more than two times the number of blocks reported in that study. The purpose of this work is to gain new inferences on the processes controlling Itokawa's parent body disruption, its subsequent re-accretion and surface evolution.

This study is split into four sections that include: a discussion of the approach taken to measure the block distributions on Itokawa; a presentation of the results obtained including both global and regional analyses; a discussion of these results in the context of various conceivable parent-body disruption, re-accretion and subsequent surface evolution scenarios; and a few conclusions.

2. Approach

The presence of blocks on an asteroid provides the opportunity to study the geological evolution of the asteroid surface and its collisional history. These blocks are typically formed on asteroids by impact cratering (e.g., Thomas et al., 2001), catastrophic disruption of the parent body, or a combination of the two. The block distributions on the satellites of Mars, Asteroid 243 Ida and Asteroid 433 Eros, suggest that most of the observed block populations were formed by impact cratering (Lee et al., 1986, 1996; Thomas et al., 2001). These studies indicate that the observed blocks are ejecta that fall back on an asteroid when their excavation velocities are smaller than the escape velocity of the asteroid.

The very large (~27 m-diameter) block, Yoshinodai, that is observed by the Asteroid Multi-band Imaging CAmera (AMICA) near the tail of Itokawa (Fig. 1) could not be formed by this impact process. The largest most plausible crater on Itokawa is a 115 m-diameter crater (Hirata et al., 2009). The Yoshinodai block represents ~20% of this crater's volume. Observation of blocks deposited from craters on other asteroids (e.g., Thomas et al., 2001) and planets (e.g., Vickery, 1987), as well as experiments, show that for impacts at 5 km/s (the likely impact velocity in the asteroid belt) the re-deposition of such a large block is unlikely for such a small crater. The probability is much greater that many of the largest blocks observed on Itokawa originate from the disruption of its parent body (Fujiwara et al., 2006; Abe et al., 2006b), especially given this asteroid's measured density of 1.9 g/cm^3, which indicates it is a rubble pile. Measuring the size–frequency distributions of these blocks on this asteroid both regionally and globally, therefore, could provide a means to evaluate Itokawa's re-accretion process.

2.1. Block measurements

Blocks were mapped and measured across Itokawa's surface using the Small Body Mapping Tool (SBMT; Kahn (2013)), a geographic information system for irregular bodies created by the Johns Hopkins University Applied Physics Laboratory (Kahn et al., 2011). The SBMT facilitates the analysis of asteroid data by allowing the user to quickly search through and visualize available datasets in context with an asteroid shape model. We define blocks as rocks and features with distinctive positive relief that are larger than a few meters in size.

We used the SBMT to identify and map blocks in AMICA images obtained by the Hayabusa mission overlain on the most recent shape models of Itokawa (Gaskell, 2008). AMICA had an effective field-of-view (FOV) of 5.83 × 5.69 degrees (Saito et al., 2010) and was the scientific camera onboard the Hayabusa spacecraft. AMICA acquired over 1660 images of Itokawa prior to the "touch and go" sampling, although only about 900 have been accurately geolocated. The data used in our analysis includes the surface location (*x*-, *y*- and *z*-coordinate; or latitude, longitude and radial distance from the center of body).

Visible blocks larger than 5 m in length along their major axis were mapped although, as shown in Fig. 6, there is evidence of under sampling below 6 m. The blocks were measured as ellipses, where the semi-major and semi-minor axes provide a long and short axis for each block measured. The SBMT also keeps track of the orientation of the long axis of each ellipse. This size limit was chosen to ensure that any block counts were not influenced by variable image resolution across the asteroid. Furthermore, multiple images were viewed, to eliminate biases that might occur as a result of the lighting and viewing geometries. To ensure total surface coverage, >100 AMICA images were used, providing multiple views of most locations at several incidence and emission angles. These images were chosen from a range to the asteroid surface of <10 km to take advantage of good image resolution (<1 m/pixel). A total of 1430 blocks were measured over the entire surface area of 0.4011 km^2 (Fig. 2).

2.2. Evaluation of blocks

In assessing the size of blocks for statistical analysis, there are a few approaches that could be considered. For example, Michikami