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Rounded Boulders on Itokawa as Clues to Geological Processes in the Early Solar System

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Abstract

Large rounded boulders on Itokawa are a surprising find and may be evidence of forceful inter-boulder collisions occurring over protracted periods of time. Surface textures of some boulders are reminiscent of those on terrestrial aeolian sand grains despite five orders of magnitude difference in scale. Using Hertzian analysis and fracture strength data, we calculate that the maximum collisional velocities involved in the comminution process are ~ 6-7 m/s. We hypothesize that boulder rounding could be a product of collisions in a gravitationally stable orbiting debris field in which boulders acquire collisional energy from YORP spin. Collisional paths may be instigated by Yarkovsky drift and gyroscopic effects of rotation. Collisional energy is dissipated by elastic damping, but rapidly renewed by YORP spinup that takes only hundreds to thousands of years to regenerate comminution-strength collisions. The rounded boulders on Itokawa are found amongst angular, unworn material which suggests a mixed origin for Itokawa's regolith.

Keywords: Itokawa, boulder comminution, surface textures, YORP spin, Hertzian analysis

1. Context

In 2005 the Hayabusa mission revealed Itokawa's regolith to be a chaotic assemblage of giant boulders mixed with gravel. Coarse and fine regolith fractions have been crudely sorted such that finer material occupies gravitational wells in the asteroid's geodetic structure. We observe that most boulders are angular or subangular, but occasionally mixed with rounded boulders with morphologically subdued profiles. Fig. 1 shows rounded boulders ranging in size from 0.25 - 6 m with shapes that could not have been produced by mechanical fragmentation during meteorite impact. Whole-rock breakage contributing to terrestrial talus slopes, glacial moraines, impactites, etc, produces angular material as it does in industrial blasting or crushing processes. Each angular clast has a small number of fresh fracture surfaces and a limited amount of edge chipping.

In contrast, some Itokawa boulders have well-rounded profiles and surface textures indicative of a great many chipping events. Shapes and surface textures are suggestive of chaotic collisional processes not unlike those in saltation clouds or stone tumblers. Many boulders, although only crudely rounded, have smoothed or subdued surface textures (Fig. 1) suggesting relatively gentle abrasive action. Here we report on a preliminary examination of several hundred boulders that is part of a longer-term global-coverage analysis of boulder textures and shapes.

2. Analysis

We make the assumption that boulder rounding results from collisions occurring prior to asteroid accretion and not from in situ processes. We attempt to determine boulder collisional speeds as a clue to a likely source of kinetic energy. Rounding is a comminutionally anisotropic process, being selective of edges and corners. Rounding energy does work against protuberances because they are inherently weaker and, in particular, because they are the first to be struck on a spinning or tumbling object; collisional anisotropy enhances rounding when spin is involved.

Boulder shaping on Itokawa is unlikely to have occurred in situ by micrometeorite pitting which