First Looks at Collisional Disruption and Reaccumulation. A. F. Cheng[1], O. Barnouin-Jha[1], N. Hirata[2], H. Miyamoto[3], R. Nakamura[4], H. Yano[5],and the Hayabusa Team. [1]Johns Hopkins Applied Physics Laboratory (11100 Johns Hopkins Rd, Laurel MD, USA, andrew.cheng@jhuapl.edu), [2]Univ. of Aizu, [3]University of Tokyo, [4]National Institute of Advanced Industrial Science and Technology, Japan, [5]ISAS/JAXA.

New analyses of data from the NEAR mission at Eros and from Hayabusa at Itokawa, both S-type near-Earth asteroids, show fundamentally different outcomes for collisional evolution of these objects, producing distinct internal structures. Itokawa has a significantly lower density than Eros, despite similar bulk composition, consistent with a rubble pile structure for Itokawa. A ubiquitous fabric of linear structural features on the surface of Eros indicates a globally consolidated structure beneath its regolith cover. Eros is inferred to be a collisional shard. A similar global fabric is not present on Itokawa and could not have been missed, despite differences in lighting conditions for the two missions. Moreover, Itokawa has significantly more regolith than can be explained in a Eros-like model of internal structure and collisional evolution, and its crater and boulder populations are inconsistent with formation and evolution as a collisional shard. We conclude that Itokawa, unlike Eros, is a rubble pile formed by reaccumulation of fragments after a catastrophic disruption event. Hayabusa has enabled a first detailed examination of the surface geology of an object formed in this way.

Geologic evidence from spacecraft studies of three similar-sized S-type asteroids (mean diameters 31 km for Ida, 16 km for Eros, 14 km for Gaspra) indicates that all of these are mechanically coherent shards rather than rubble piles. Densities for two of these (Eros and Ida) indicate about 25% porosity for both. The most detailed information is available from Eros after NEAR [e.g., 1,2,3]: it is a shattered, fractured body, with at least one through-going fracture system and an average of about 20 m regolith overlying a consolidated substrate, as evidenced by a global fabric of linear structural features (ridges and grooves) and square craters [4]. Eros is not a strengthless rubble pile that was collisionally disrupted and re-accumulated, with jumbled spatial relations between components. The presence of global scale linear structural features that are not geometrically related to any of the large impacts on Eros further suggests that it is a collisional fragment of a larger parent body.

The 53 km, C-type Mathilde has even higher porosity than Eros, at least ~50%, which has led to suggestions that Mathilde may be a rubble pile. However, there is also evidence for a 20-km long scarp, comparable in length to the radius of Mathilde [5], and there are structurally controlled, polygonal craters. If Mathilde is a rubble pile, it has at least one global scale structural component with sufficient strength (cohesion or shear strength) to influence late-stage crater growth. It is also unclear to what extent the high porosity of Mathilde is microscopic, from preservation of a primordial accretion texture.

In this context, the theoretical consensus is that most asteroids larger than ~km size should be rubble piles [6], whereas small asteroids of size <<1 km are predicted to be monoliths. The Hayabusa visit to the 0.32 km, S-type asteroid Itokawa was the first to an object significantly below 1 km size. Would this object be monolithic? Would it have regolith, and how much? Initial reports [7,8,9] indicate that Itokawa, in contrast to the three other S-types so far visited, has a very low density 1.9 g/cc, significantly less than that of the compositionally similar asteroids Eros and Ida, and consistent with a rubble pile structure. Moreover, Itokawa lacks the global fabric (mainly ridges and grooves) that indicates a coherent but heavily fractured structure for Eros. However, there are apparent boulder alignments on Itokawa, suggesting that at least some of its rubble components are larger than 100m size. Likewise Mathilde, if it is a rubble pile, also has at least one large structural component.

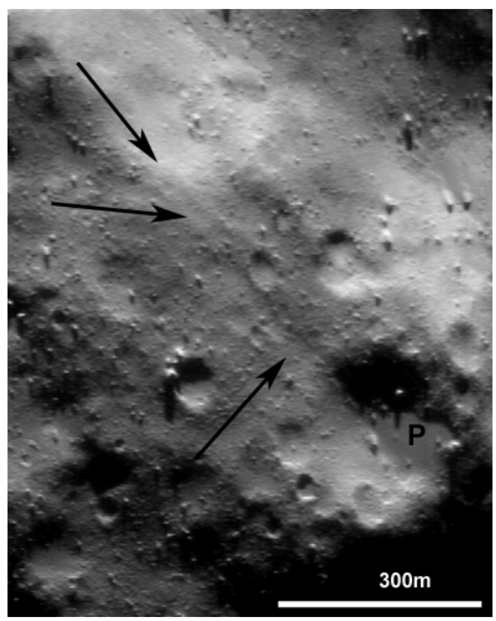

Figure 1. Eros from 19 km, with 300 m scale bar (~mean diameter of Itokawa). Arrows mark linear structural features comprising global fabric. P marks a pond on Eros.

Confirmation that tiny Itokawa is a rubble pile has profound implications for collisional evolution and planet formation processes. Namely, the outcomes of catastrophic disruption must include both of two disparate possibilities: an object as small as Itokawa can reaccumulate, despite surface gravity corresponding to an average escape velocity of only 17 cm s^{-1}, but moreover an object as large as Eros can form as an intact fragment.

Geologic evidence for a rubble pile Itokawa is summarized as follows. Itokawa has no giant craters and few craters of any size. Blocks as large as those found on Itokawa could not have formed as crater ejecta on a body the size of Itokawa, and the volume of mobile regolith on Itokawa is also too great to be consistent with its craters. There is no global fabric of linear structural features.

If Eros and Itokawa had similar collisional histories, at least one giant crater would be expected on Itokawa, and the crater density would be close to equilibrium saturation down to crater sizes of about 4 m diameter. An image at the resolution of Figure 2 (~400 px across the mean diameter) would be expected to show on the order of a thousand craters. Moreover, in an Eros image at this resolution in terms of pixels across the object, only a handful of the largest blocks would be barely resolved. In contrast, far fewer craters are found on the surface of Itokawa, and the rough areas on Itokawa are covered with blocks at several m size.

The smooth areas of Itokawa consist of coarse, gravel-sized regolith as shown by data obtained from the Itokawa landings. The individual cobbles are resolved in close-up images, and moreover a high coefficient of restitution is inferred from the (unplanned) spacecraft bounces off the surface of the asteroid. True fines are apparently absent. The coarse regolith on Itokawa is mobile, as evidenced by the global segregation into rough and smooth areas. Direct evidence of such mass motion is found in close-up images showing imbricated boulders. The effective cohesion of Itokawa material must be extremely small to permit such mass motion.

The rough areas of Itokawa are close to saturated with meter-size blocks, and regolith there may also consist of coarse, angular material. This is suggested by the unusually high gravitational slope of about 40° within the southern "neck" region of Itokawa. No significant area of Eros has such a large slope. The friction angle of coarse, angular cobbles can approach such high values. Talus and flow fronts are not evident in this region.

Itokawa's mobile regolith volume, if it contains gravel-sized particles, is consistent with extrapolation of its boulder size distribution, suggesting a fragmentation size distribution. Blocks and regolith may have formed on a larger parent body, which was subsequently disrupted catastrophically such that some of the fragments reaccreted to form Itokawa. Fines may have dispersed due to non-gravitational forces without being incorporated into the forming rubble pile, or they may have settled into the interior. Gravitational sedimentation of coarse regolith to produce the globally segregated smooth areas in areas of low geopotential occurred subsequently.

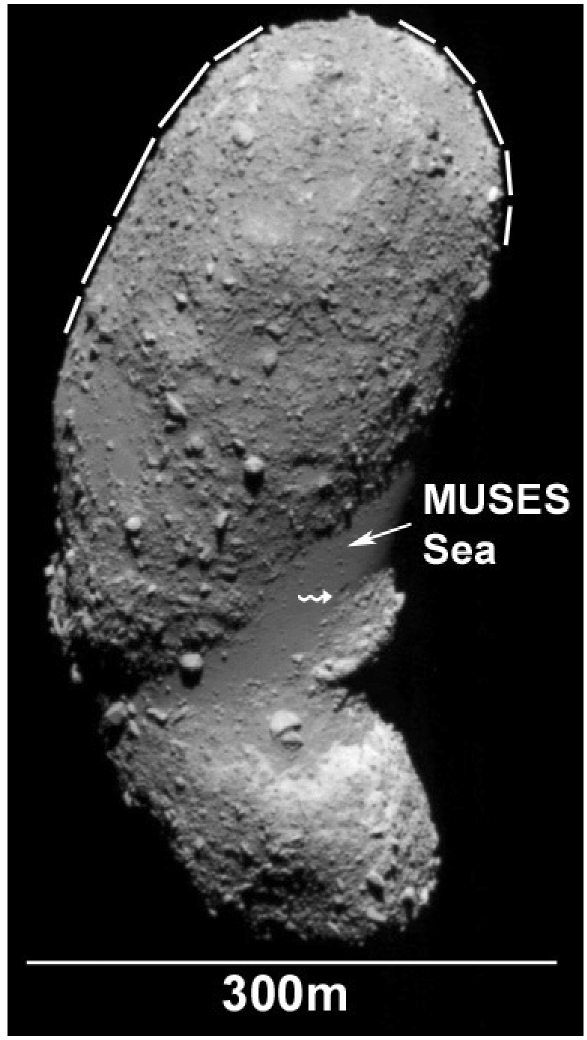

Figure 2. Itokawa from 8.5 km range (0.86 m/px), with 300m scale bar. Global segregation into blocky and smooth areas (e.g., the "MUSES Sea"). Wiggly arrow marks a 10m bowl-shaped crater. White bars around limb have thickness corresponding to 2.6 m, so that added depth of regolith fill would bury all but the tallest blocks in the region.

In summary, the surface geology of Itokawa is distinct from that of Eros, indicating formation and evolution as a gravitational aggregate rather than a collisional shard.

[1] Cheng A.F. (2002). *Asteroids III (ed. W. Bottke et al., U of AZ Press)*, 351–366. [2] Thomas P. C. et al. (2001) *Nature*, *413*, 394. [3] Prockter L. et al. (2002) *Icarus*, 155, 75-93. [4] Thomas P. C. et al. 2002 *GRL*, 29, 10.1029/2001GL014599. [5] Thomas P. C et al. 1999 *Icarus*, 140, 17-27. [6] Asphaug E. et al. (2002). *Asteroids III (ed. W. Bottke et al., U of AZ Press)*, 463–484. [7] Fujiwara A. et al. *Science*, 312, 1330-1334. [8] Abe S. et al. *Science*, 312, 1344-1347. [9] Saito J. et al. *Science*, 312, 1341-1344.