Eros and Itokawa Comparisons: NEAR Shoemaker and Hayabusa A. F. Cheng[1], O. S. Barnouin[2]. [1,2]The Johns Hopkins University Applied Physics Laboratory, Laurel MD, USA 20723 (andrew.cheng@jhuapl.edu).

Introduction: Two asteroids, Eros and Itokawa, have been orbited and landed on by spacecraft, the NEAR Shoemaker spacecraft and Hayabusa, respectively. Both S-type near-Earth asteroids were shown, from their elemental compositions and their mineralogies, to have compositions consistent with ordinary chondrites, but they have distinct internal structures and surface geologies. 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 an 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. Itokawa, unlike Eros, is interpreted as a rubble pile formed by reaccumulation of fragments after a catastrophic disruption event. We shall discuss implications of lineaments for Eros and Itokawa, and we shall discuss constraints on surface properties such as strength and cohesion based on craters and small surface features.

Observational Constraints: Results of the NEAR [1-3] and Hayabusa [4-7] missions suggest that Eros (mean diameter 16 km) is a collisional shard, whereas the much smaller Itokawa (mean diameter 0.324 km) is a rubble pile. The bulk density of Eros indicates a porosity of about 25%, whereas the density of Itokawa indicates a porosity of at least 40%.

Eros displays ubiquitous systems of structural lineaments (e.g., Fig. 1) comprising a global fabric, implying that it is a globally consolidated, cohesive but thoroughly fractured body. Geologic mapping of the lineament systems finds that many, but not all, of them are related to visible impacts [1]. Some lineament systems, such as the twist and a through-going fracture, suggest processes of such a large scale that they probably formed on a parent body of Eros [2,3,10].

Itokawa on the other hand is inferred to be a rubble pile following two main lines of argument [4,10]. The first is that the composition, both mineralogical and elemental, is like Eros and consistent with ordinary chondrites, but the density is much lower. Hence there is a much higher void fraction indicating a rubble pile.

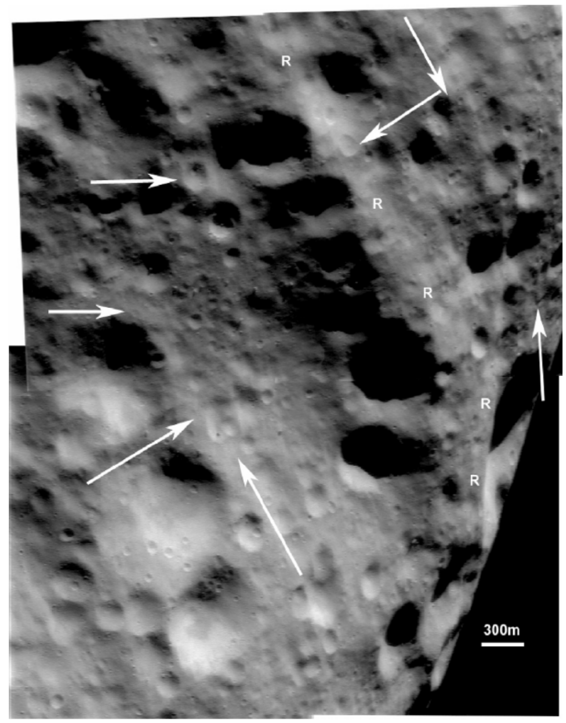

Figure 1. Eros image mosaic, with 300m scale bar (approximate mean diameter of Itokawa). Letters R indicate a ridge 120m in elevation, ~7 km long. Arrows mark three systems of linear structural features with structurally controlled craters. One lineation set trends from upper left to lower right; another trends from lower left to upper right; another trends across. Illumination from top of page.

The second line of argument is based on the surface geology of Itokawa, which shows absence of a global fabric similar to that on Eros, large populations of blocks which are much larger relative to the size of the object than are blocks on Eros, and relatively low crater populations. On Eros, the geometrical relations defining global scale lineament systems were preserved throughout collisional evolution, but not on Itokawa. Many blocks on Itokawa are too large to have formed in any observed impact on Itokawa. It is inferred that Itokawa was catastrophically disrupted and gravitationally reaccumulated as a rubble pile.

If Itokawa were a scaled down Eros, then 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 1/80 the mean diameter, or 4m. An image at the resolution of Fig. 2 would be expected to show on the order of 1000 craters, while only a handful of the largest blocks would be barely resolved. In contrast, far fewer craters are found on the surface of Itokawa, and there are close to 1000 blocks on Itokawa at 3.5 meters size or more. Itokawa's surface is saturated with blocks instead of craters.

The surface geologies on both Eros and Itokawa show abundant evidence for mass motion of regolith (Fig. 2), e.g. on Eros in the form of debris flows [8] and pit drainage systems [3]. This mobile regolith cover is inferred to have a typical depth of about 20m. Regolith on Itokawa is globally segregated [4,10], creating what may be called giant ponds like the area marked Muses Sea in Fig. 2. The migration has also created imbricated cobbles on Itokawa [7]. It appears that regolith motion is stimulated by seismic shaking [7,8,10] on both objects, forming local ponds on Eros, but local and giant ponds on Itokawa. The importance of seismic shaking on Eros is supported by the decrease of crater density with distance from the most recent giant impact (Shoemaker [11]).

Interpretations: These observations strongly support the idea that both Eros and Itokawa are products of catastrophic disruption, while Itokawa (but not Eros) underwent additionally a dispersal and gravitational reaccumulation. However, the physical properties of the putative shard and rubble pile, notably the distributions of void space (macro versus micro) and the strength properties (such as cohesion), are poorly constrained. It has recently been suggested that Eros is not actually a rock shard, but a fine-grained, cohesive rubble pile (not a strengthless rubble pile [12]).

We will discuss constraints on physical properties that can be inferred from surface geology. The strength and cohesion *required* by surface geology are quite low because of the low gravity, no more than for lunar regolith. Some constraints from Eros are: ability to propagate seismic waves (at least compressional waves) globally; drainage of regolith into pits on several tens of m scales (even cohesion less than for lunar fines can stop such drainage [9]; square (strength-controlled) cratering on several hundred m scales; and stability of small, steep-walled collapse features (e.g., at the NEAR landing site) and of crater rim-structures on slopes. However, boulder and block morphologies at Eros and Itokawa are suggestive of rocks, and Hayabusa bounced off the Itokawa gravel. Are there rocks on Eros? Is Itokawa's gravel made of dirt clods?

We thank NASA and the MUSES-C Project for support.

References: [1] Buczkowski, D., et al., 2008.. Icarus 193, 39–52. [2] Cheng, A.F., 2002. In: Bottke, W., et al. (Eds.), Asteroids III. U of Arizona Press, pp. 351–366. [3] Prockter, L., et al., 2002. Icarus 155, 75–93. [4] Fujiwara, A., et al., 2006. Science 312, 1330–1334. [5] Abe, S., et al., 2006. Science 312, 1344–1347.[6]. Barnouin O. et al. Icarus, 198, 108–124. [7] Miyamoto, H., et al., 2007. Science 316, 1011–1014. [8] Cheng, A.F., et al., 2002b. Meteor. Planet. Sci. 37, 1095–1105. [9] Cheng, A.F. 2004. LPSC No. 1350. [10] Cheng, A.F., et al. 2007. Geophys. Res. Lett. 34, L09201. [11] Thomas P., Robinson M. 2005. Nature 436, 366. [12] Asphaug, E. 2008. B.A.A.S. 40, p. 431

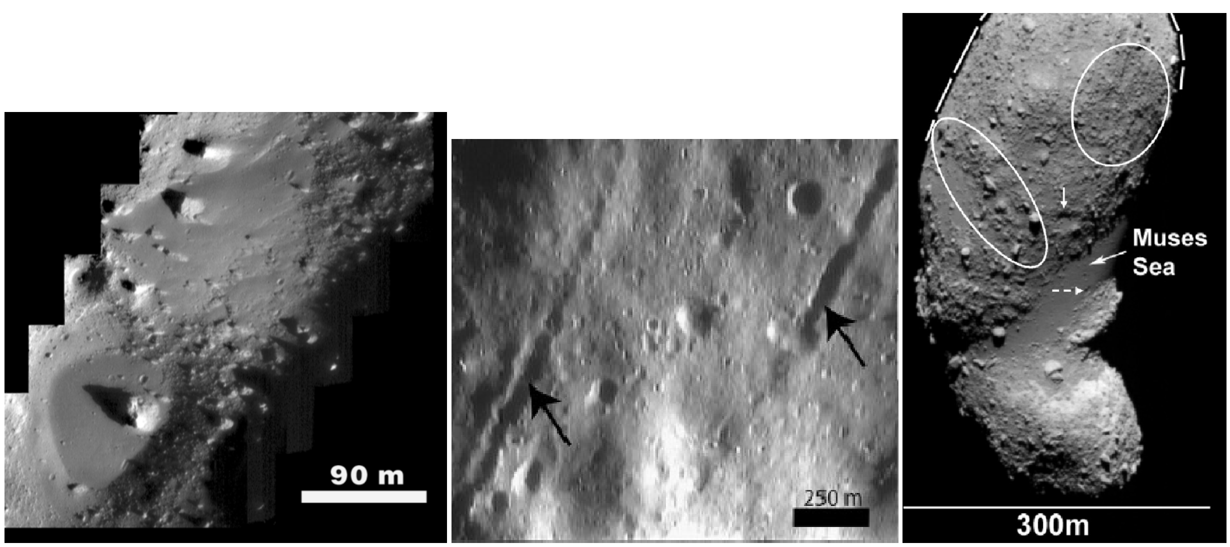

Figure 2. Mobile regolith. (left) mass motion on Eros: a pond with a beach, and above it (topographically as well as in the image) a debris flow, with 90 m scale bar. (Center) pit chain systems on Eros, with 250 m scale bar. (Right) a medium solar phase angle image of Itokawa, east side, with 300m scale bar. Global segregation into blocky and smooth areas. Vertical arrow indicates a crater with pond. Dashed arrow marks a 10m bowl-shaped crater. Possible block alignments are marked with ellipses. White bars around limb have thickness corresponding to 2.6 m, illustrating depth of regolith fill to bury all but the tallest blocks in the region.