ITOKAWA IS A REGOLITH BRECCIA, NOT A RUBBLE PILE. D. W. G. Sears, Bay Area Environmental Research Institute/NASA Ames Research Center, Space Science and Astrobiology Division, Moffett Field, Mountain View, California 94035. Derek.Sears@nasa.gov.

Introduction: Fujiwara et al. described Itokawa as a "rubble pile" [1] and it is easy to understand why (Fig. 1). The surface of this tiny 0.535 x 0.294 x 0.209 km near-Earth asteroid is covered with unconsolidated cm-sized and larger gravel and boulders [2]. Its shape suggests that it is bifurcated. The lunar surface is very similar and consists of a thick regolith of fine grained material strewn with boulders of a wide size range (Fig. 2). Thus, I argue that Itokawa is not a rubble pile, but a regolith breccia.

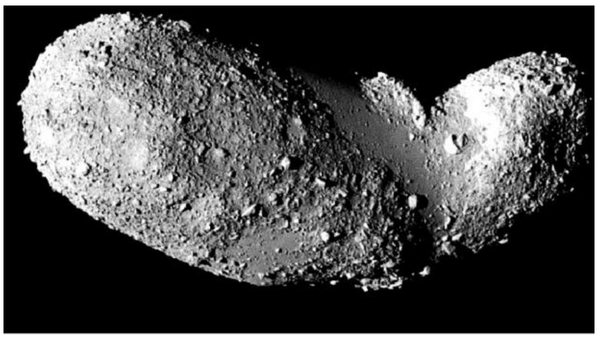

Fig. 1 Image of Itokawa.

Fig.2 Image of the lunar surface. Note similarity yo surface of Itokawa.

The term "rubble pile" was originally intended to mean something very specific, an asteroid formed by the reassembly of fragments produced by impact and that were once free-floating in space [3]. On the other hand, a regolith breccia is a complex assemblage of unconsolidated materials found on the surface of an asteroid or any airless body in space [4].

Properties of Itokawa: Probably the most quoted observational evidence for rubble piles is the relationship between the rotation rate of asteroids and their size (Fig. 2) [5]. It is often argued that the limit for rotation rates of 2.2 hour for asteroids >200 m suggested that these were rubble piles, whereas the faster rotation rates for asteroids <200 m suggests that they are monoliths. With a period of 12 h, Itokawa is the plots near the transition between the purported rubble piles and monoliths, slightly to the rubble pile side. However, recent calculations challenge these conclusions and suggest that <200 m objects have sufficient cohension for them also to be composed of fine particles raher than monoliths [6].

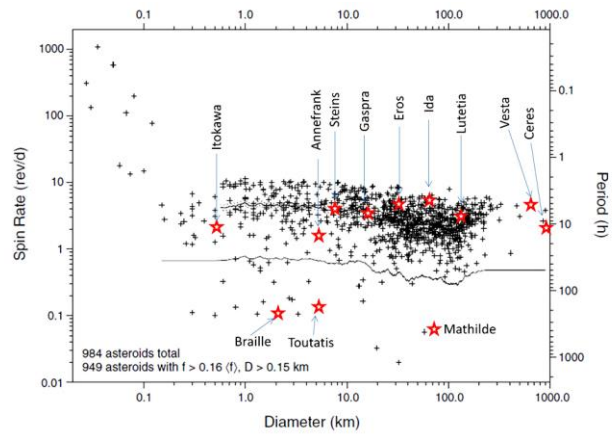

Fig. 3 Spin rate v.s diameter for asteroid Itokawa

Itokawa has a density of 1.9 g/cm^3, a reflectance spectra of an S asteroid, and the mineralogy of the returned grains is that of an LL chondrite. The low densities of asteroids (~2.0 g/cm^3 for C asteroids, ~2.5 g/cm^3 for S asteroids) are ~ 1 g/cm^3 lower than the grain densities of the minerals inferred from spectra. The low density is normally ascribed to porosity. On this basis, Itokawa has one of the highest porosities known, ~45%, much higher than other S asteroids. The often reproduced diagram of mass against postulated porosity appears in Fig. 4a [7]. This is interpreted to reflect internal strength: C indicates "coherent", F = "f ractured", T = "transitional", and LC = "loosely coherent". However, it should be noted that that water content, inferred from the usual meteorite associations, also increases left-to-right in the diagram (from traces to ~20 vol %). Shown in Fig. 4b are mass balance calculations which indicate that internal water can also explain the low density of asteroids. There is now considerable evidence for subsurface water in asteroids inside the "snow line" [8].

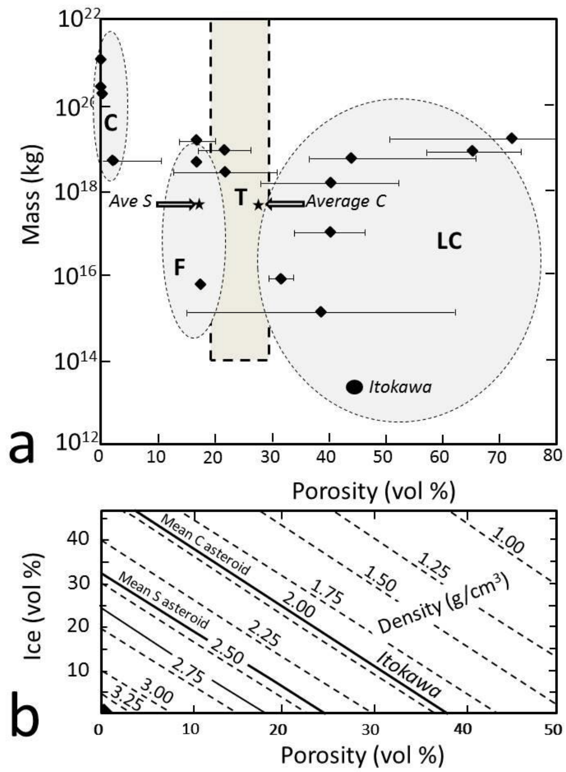

Fig. 4 Relationship between mass, density, porosity and water content for asteroids [8]. Red stars refer to objects explored by spacecraft.

How Common are Rubble Piles?: Detailed observations of asteroid surface properties by robotic space missions have suggested that most asteroids of all sizes are not rubble piles [8]. Examples are:

Grooves on Gaspra [9]
Fractures in the Pola Regio region of Ida [10]
Rahe Dorsum and other grooves on Eros [11].
The catena on Steins [12].
Grooves on Lutetia [13]

Thus five out of seven small asteroids for which sufficient imagery is available suggest that these objects are coherent bodies. See [8] for further details.

The returned Hayubsa samples are from a regolith: Regolith breccias also have a number of properties that result from their exposure to space; implanted solar gases, charged-particle tracks, xenolithic material from impacts, and debris materials from impact such as melts. These effects are all present in the returned Itokawa samples [14].

Is Itokawa too large to be from an Asteroid Regolith?: Photometry [16] and thermal inertia [17] also suggest that regoliths on small asteroids are ubiquitous. Regoliths have been observed on all asteroids for whch we have useful data [8]. In fact evidence of a regolith in one form or another can be found in nearly every one of the 30,000 high-resolution images of Eros [15]. A deficiency of craters <200 m on Eros [14] and <0.6 km on Steins [12] and Lutetia (locally) [13] suggest that their regoliths often may be this deep. Itokawa could well be a piece of the regolith of a, say, 50 km asteroid.

Implications for science, exploration, planetary defense, and resources: *Science.* The internal nature of asteroids is a question of considerable importance in understanding the origin and history of the asteroid belt [e.g. 8].

Exploration. The internal texture of asteroids, especially small asteroids, will affect the way in which spacecraft and humans can function on an asteroid. A coherent monomlith, a rubble pile and a regolith breccia may well have different requirements for tethering, for example.

Planetary Defense. An important element of understanding the behavior of objects entering the atmosphere is knowing their internal texture. Atmospheric behavior is dominated by fragmentation processes and these will differ markedly between monoliths, rubble piles and regoliths.

Resources. As with "exploration" above, the mechanics of surface operations will depend on internal texture. The presence of water is also important because this is probably the most important resource to be obtained from asteroids.

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References: [1] Fujiwara A. et al., 2006. Science 312, 1330-1334. [2] Miyamoto H. et al., 2007. Science 316, 1011-1014. [3] Love S.G. and Ahrens T.J., 1996. Icarus 124, 141-155. [4] McKay D. S., 1991. In *Lunar Sourcebook (Eds*. Heiken G. H. et al.), pp. 285-356. [5] Pravec P. and Harris A.W., 2000. Icarus 148, 12-20. [6] Sanchez P. and Scheeres D.J., 2014. MAPS 49, 788-811. [7] Britt D. T. et al., 2002. In Asteroids III, (eds W. F. Bottke Jr. et al.) p.495-500. [8] Sears D.W.G., 2015. Space Science Reviews 194, 139-235. [9] Veverka J. et al. 1994. Icarus 107, 72-83. [10] Asphaug E. et al., 1996. Icarus 120, 158-184. [11] Prockter L. et al., 2002. Icarus 155, 75–93. [12] Keller H. U. et al., 2010. *Science* 327, 190-193. [13] Sierks H. et al., 2011. Science 334, 487- 490. [14] Noguchi T. et al., 2014. MAPS 49, 188-214. [15] Robinson M. S. et al., 2002. MAPS 37, 1651-1684. [16] Helfenstein P. et al., 1996. Icarus 120, 48–65. [17] Emery J.P. et al., 2014. Icarus 234, 17–35.