Hayabusa mission: A current summary of return sample analysis

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Itokawa dust particles provide a first opportunity for scientists to analyze return samples from asteroid (Yada et al. 2014, Uesugi et al. 2014). Regardless of small size of the particles, a clear picture that describes formation and evolution of a rubble pile asteroid is obtained from a variety of evidence found from the particles. Here we summarize history of Itokawa from past to present. (1) Formation of Itokawa parent body: Itokawa parent asteroid formed in the early solar system as a S-type asteroid of LL-chondrite composition with a radius of 20km or larger, most likely 2.2Myr after CAIs, the oldest solar system material (Nakamura et al. 2011; 2014, Yurimoto et al. 2011, Ebihara et al. 2011; 2015, Tsuchiyama et al. 2011; 2013; 2014, Mikouchi et al. 2014, Nakashima et al. 2014, Wakita et al. 2014, Takeda et al. 2015). Absolute age of the parent-body formation remains to be clarified. (2) Internal heating: Decay heat of short-lived radionuclides such as 26Al raised the temperature of Itokawa parent asteroid up to 800~900 °C at approximately 5 Myr after CAIs and cooled down slowly (Nakamura et al. 2011, Tanaka et al. 2014, Wakita et al. 2014), which probably developed an onion shell asteroid. The heating made parent-body interior to LL5 and 6 material (Nakamura et al. 2011, Nakashima et al. 2014). (3) Impact break-up: A catastrophic impact occurred, possibly at 1.3 ±0.3 Ga ago (40Ar/39Ar age from Park et al. 2015), and broke the parent asteroid into smaller pieces. Re-accumulation of some pieces would have formed a smaller rubble-pile asteroid (Nakamura et al. 2011), but the size of the first rubble pile asteroid is uncertain. The impact effects are observed in many Itokawa dust particles (Nakamura et al. 2012), but most of evidence indicates small-scale impacts (Matsumoto et al. 2016). For instance, diagnostic shock indicators such as planar fractures and 001 screw dislocations of olivine occur only in a small zone on one concave side of the dust particle (Langenhorst et al. 2014). (4) Formation of current Itokawa: Current-size Itokawa formed recently. Short noble gas (He and Ne) cosmic exposure age of 1.5Ma (Meier et al. 2014) and 8Ma at most (Nagao et al. 2011) indicates that current Itokawa surface is young, which is consistent with the absence of cosmogenic B (Fujiya et al. 2016). Young exposure age was discussed in terms of YORP effect (Connolly et al. 2015). (5) Space weathering: Itokawa surface experienced space weathering for a short period of time. Space-weathered surface of a particle consists of a thin layer of FeS-rich vapor or sputtered deposition, and thick layers of partially amorphous material with abundant Fe-rich nanoparticles formed mainly by solar wind irradiation (Noguchi et al., 2011; 2014a, Keller and Berger, 2014, Thompson et al., 2014). Considering short cosmic exposure ages, incipient space weathering effects appears to have been dominated by solar-wind irradiation. The degree of weathering is variable between particles (Bonal et al. 2015). (6) Accretion of dust particles from other asteroids and comets: Small dust and meteoroids are expected to come from other asteroids and comets and accreted on the Itokawa surface. These outer small bodies are rich in organics and therefore organic-bearing particles are expected to be found from Itokawa dust particles. However, so far, no extraterrestrial organics were detected from soluble organic compounds (Naraoka et al. 2014), IR spectra (Kitajima et al. 2015), H, C, and N isotope signatures (Ito et al. 2014), and Carbon-XANES spectra (Yabuta et al. 2014). Neither carbonaceous matter nor hydrated minerals were detected through Raman analysis (Bonal et al. 2015). Halite, possibly indigenous and came from hydrous asteroids, was detected (Noguchi et al. 2014b).

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