Synchrotron-Radiation X-Ray Analysis of Hayabusa-Returned Asteroidal Samples

The Hayabusa spacecraft successfully captured dust particles on the Muses C Regio of asteroid 24153 Itokawa. Synchrotron-radiation X-ray diffraction analysis indicates that the mineralogy of the Itokawa dust particles is identical to that of the most primitive solar system material, chondrites, and dissimilar to that of terrestrial rocks. Chondrites were meteorites that formed 4.5 billion years ago and have a chemical composition close to that of the Sun. The similarity of Itokawa particles to chondrites proves that asteroids are the most primitive solar-system bodies formed in the early solar system. Further transmission and scanning electron microscope analyses indicate that most particles have experienced long-term thermal annealing, suggesting that Itokawa is an asteroid made of broken pieces of an inner part of a larger asteroid [1]. Computer simulations suggest that the original Itokawa asteroid was at least 20 km in radius and formed approximately 150 million years after the birth of the solar system.

Approximately 40 particles ranging in size from 30 to 180 microns that were collected during the first and second touchdowns on the surface of Itokawa were analyzed by various analytical methods. First we used synchrotron X-ray diffraction at BL-3A by applying high-intensity X-rays to identify crystal species in the Itokawa dust particles. Unfortunately the particles are very small (Fig. 1), but we must extract the maximum information from the particles. For this purpose, synchrotron radiation X-ray is the most powerful tool, because it enables us to identify crystal species in such a small particle without any destructive treatment. A variety of destructive analyses can then be performed after non-destructive X-ray analysis.

The X-ray diffraction analysis of individual particles indicates that most abundant mineral is highly crystalline olivine, and the next most abundant minerals are low- and high-Ca pyroxene. Plagioclase is also abundant, but crystallinity differs between particles.

Major and minor element concentrations in all constituent minerals in all dust particles were determined by electron-probe analysis. Chemical compositions of olivine, low-Ca pyroxene, and Co and Ni concentrations of FeNi metals in Itokawa particles are within the range of LL chondrites, indicating that the surface of the Itokawa asteroid is covered with LL-chondrite dust particles. Olivine, pyroxene, and plagioclase in the Itokawa dust particles show homogeneous chemical compositions, indicating that these crystals have undergone intense thermal metamorphism. The metamorphic temperatures experienced by highly equilibrated particles are estimated based on two-pyroxene geothermometry to be approximately 800°C.

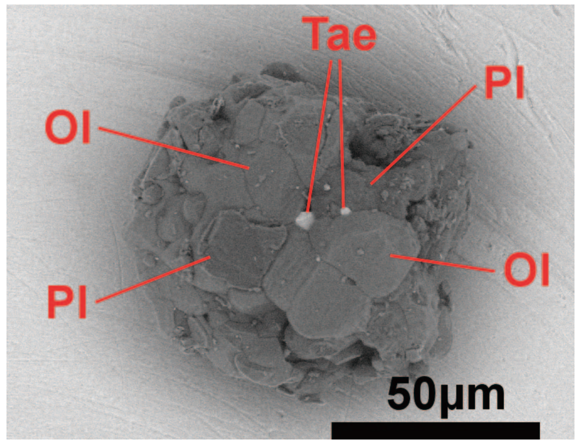

Figure 1
Itokawa dust particle returned by the Hayabusa mission. The particle consists of olivine (Ol), plagioclase (Pl) and FeNi metal taenite (Tae). It shows a smooth surface that was likely formed by sputtering due to solar wind radiation [1].

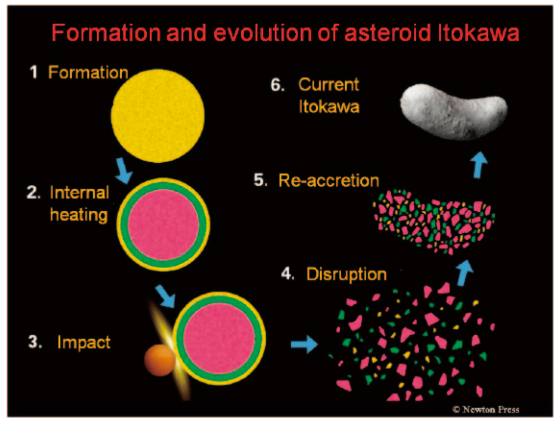

Figure 2
Model of formation of the Itokawa asteroid. (A modified figure appeared in Newton Magazine, 2011).

During thermal metamorphism, temperatures increase with depth and the high petrologic type lay deeper in the parent body than the lower type, assuming internal heating due to decay energy of the short-lived radioisotope ^{26}Al. The metamorphic temperature of 800°C experienced by the Itokawa particles requires the asteroid to have been larger than 20 km in radius and formed approximately 150 million years after the birth of the solar system, i.e., after the formation of the oldest solar system material called CAIs (Ca- and Al-rich inclusions). The current size of Itokawa (approximately 0.5 km in diameter) is much smaller than the initial size, suggesting that the parent Itokawa asteroid was much larger than the current Itokawa. The high abundance of thermally metamorphosed particles, which formed in the interior of the asteroid, on the surface of the asteroid suggests that Itokawa is an asteroid made of broken pieces of an inner part of a larger asteroid (Fig. 2).

REFERENCE

[1] T. Nakamura, T. Noguchi, M. Tanaka, M.E. Zolensky, M. Kimura, A. Tsuchiyama, A. Nakato, T. Ogami, H. Ishida, M Uesugi, T. Yada, K. Shirai, A. Fujimura, R. Okazaki, S.A. Sandford, Y. Ishibashi, M. Abe, T. Okada, M. Ueno, T. Mukai, M. Yoshikawa and J. Kawaguchi, *Science,* **333** (2011) 1113 .

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T. Nakamura (Tohoku Univ.)