

**Petrology of Two Itokawa Particles: Comparison with Equilibrated LL Chondrites.** M. Komatsu<sup>1,4</sup>, T. Mikouchi<sup>2</sup>, T. Arai<sup>3</sup>, T. J. Fagan<sup>4</sup>, M. Zolensky<sup>5</sup>, K. Hagiya<sup>6</sup>, K. Ohsumi<sup>7</sup>, and Y. Karouji<sup>8</sup>, <sup>1</sup>Graduate University for Advanced Studies, SOKENDAI (komatsu\_mutsumi@soken.ac.jp), <sup>2</sup>University of Tokyo, <sup>3</sup>PERC, Chiba Institute of Technology, <sup>4</sup>Waseda University, <sup>5</sup>JSC, NASA, <sup>6</sup>University of Hyogo, <sup>7</sup>Japan Synchrotron Radiation Institute, <sup>8</sup>ISAS, JAXA.

**Introduction:** A strong link between Itokawa particles and LL chondrites was confirmed by preliminary examinations of Hayabusa particles [e.g., 1, 2]. Both poorly equilibrated and highly equilibrated particles have been found among the grains returned from Itokawa [1], and it is suggested that they correspond to LL4 and LL5-6, respectively. Here we report the petrography of two Itokawa particles and TEM study of one, and compare them to Antarctic LL chondrites with variable petrologic types (LL4-LL7) in order to understand the metamorphic history of asteroid Itokawa.

**Methods:** Two allocated Itokawa particles, RA-QD02-0094 (0094) and RA-QD02-0127 (0127) (Fig.1), were examined in this study. Each particle was embedded in epoxy following the method by [1, 3] and then polished for optical microscope and FEG-SEM observations. After EPMA analyses, two TEM sections were prepared from the particle 0094 by FIB.

## Results and Discussion:

### RA-QD02-0094

This particle is  $50\ \mu\text{m} \times 30\ \mu\text{m}$  in size, composed of olivine and FeS ( $<20\ \mu\text{m}$ ) (Fig.2a). Two submicron-sized chromite grains enclosed in olivine are also observed. A single crystalline olivine is easily recognized under microscopic observation, and minor undulatory extinction was observed indicating low grade of shock. Olivine shows a homogeneous composition ( $\text{Fo}_{70}$ ).

Two FIB sections are made from 0094. TEM analyses show that both olivine and FeS grains are single crystals (Fig. 3). There is no orientation relationship between FeS and olivine. No planar defects are observed in olivine grain, and low abundance of dislocations suggests that 0094 experienced shock stage of S2 [4] (Fig. 3f), consistent with results from other equilibrated Itokawa particles (e.g., [3]).

### RA-QD02-0127

This particle is  $50 \times 45\ \mu\text{m}$  in size and is composed of several fine crystals, which were analyzed by SEM-EDS. The main minerals are olivine ( $\text{Fo}_{72-73}$ ), low-Ca pyroxene ( $\text{Fs}_{19-24}\text{En}_{76-80}\text{Wo}_{0-2}$ ), and plagioclase ( $\text{An}_{7-10}\text{Ab}_{90-94}$ ). Fine-grained high-Ca pyroxene ( $\text{Fs}_{10-12}\text{En}_{58-59}\text{Wo}_{29-32}$ ) and FeS grains are also identified (Fig.4). Particle 0127 shows minor undulatory extinction, indicating low grade of shock (S2).

### Comparison with LL chondrites

#### *Olivine*

One of the most quantitative parameters in the petrologic type classification scheme is the degree of equi-

libration of olivine and pyroxene composition [e.g., 5]. In comparison with LL4-7 chondrites from our previous study [6], FeO and MgO contents of 0094 are similar to those of LL6 and LL7 chondrites (Fig.5). Although we need more data to prove the metamorphic degree for 0127, chemical composition of olivine suggests that 0127 originated from a region corresponding to LL 4-5 chondrite.

#### *Plagioclase*

Feldspar grain size increases with petrologic type, and is used as a classification criterion [e.g., 7], and although it cannot be easily applied to the small Itokawa particles, the size of plagioclase ( $<10\ \mu\text{m}$ ) in particle 0127 is within the range of petrologic type  $\leq 5$ .

#### *High-Ca pyroxene*

Crystallization of coarse-grained high-Ca pyroxene is commonly observed in LL5 and LL6 chondrites [8]. The occurrence of micron-sized high-Ca pyroxene in grain 0127 (Fig.4b) might indicate the early stage of crystallization of high-Ca pyroxene.

#### *Chromite*

Chromite in ordinary and carbonaceous chondrites can be used as a sensitive indicator for thermal metamorphism [9, 10]. In LL chondrites, spinel group minerals have a wide compositional range in in type 3, and then they become homogeneous in types 4-6 due to thermal metamorphism [9]. Chromite grains in particle 0094 are too small to be analyzed by EPMA, but low  $\text{Al}/(\text{Al}+\text{Cr})$  and  $\text{Mg}/(\text{Mg}+\text{Fe})$  ratios of chromite in this study are in agreement with those in equilibrated petrologic types (LL4-6) [9].

## Conclusion:

Based on our petrologic study, RA-QD02-0094 and RA-QD02-0127 are similar to LL6-7 and LL4-5, respectively. The shock stage for particle 0094 is likely S2. The low degree of shock in the equilibrated Itokawa particles is consistent with other studies (e.g., [3]). Particle 0127 also shows minor undulatory extinction, indicating weak shock (S2). It should be noted that the Itokawa samples are much smaller than those typically used for meteorite shock degree estimations, and may be biased as is suggested by [11].

The combination of LL6/7-like (highly equilibrated) and LL4/5-like (poorly equilibrated) particles indicates that rocks with different metamorphic histories are in close proximity on the surface of Itokawa, suggesting regolith gardening after metamorphism.

**References:** [1] Nakamura T. et al. 2011. *Science* 33, 1151–1154. [2] Nakashima D. et al. 2013. *Earth & Planet. Science Letters* 379, 127-136. [3] Mikouchi T. et al., 2014 *Earth, Planets & Space* 66, 82. [4] Stöffler D. et al., 1991. *GCA* 55, 3845-3867. [5] Huss G. R. et al. 2006. *MESS II*: 567-586. [6] Komatsu M. et al. 1998. *29th LPS XXIX*, Abstract #1224. [7] Van Schmus W. R. and Wood J. A. 1967. *GCA* 31, 747-565. [8] Kovach H. A. & Jones R. H. 2009. *MAPS* 45, 246-264. [9] Kimura M. et al. *GCA* 70, 5634-5650. [10] Grossman J. N. and Brearley A. J. 2005. *MAPS* 40, 87-122. [11] Zolensky M. et al. 2014. *Hayabusa 2014: 2<sup>nd</sup> Symp. Solar System Materials*, Abstract #P-11.

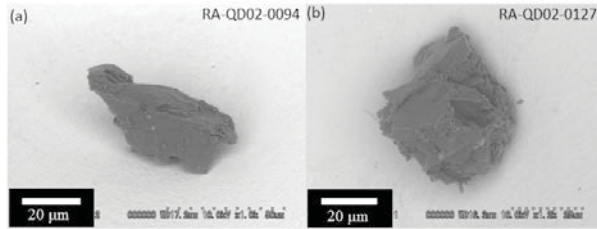


Fig.1. BSE images of original particles.

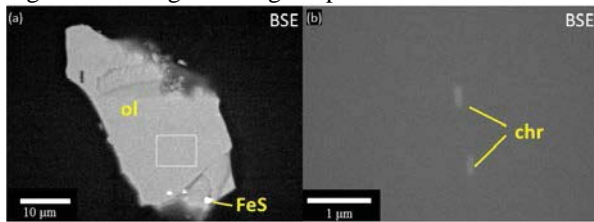


Fig.2. BSE images of polished section of RA-QD02-0094. Submicron-sized chromite is observed in olivine.

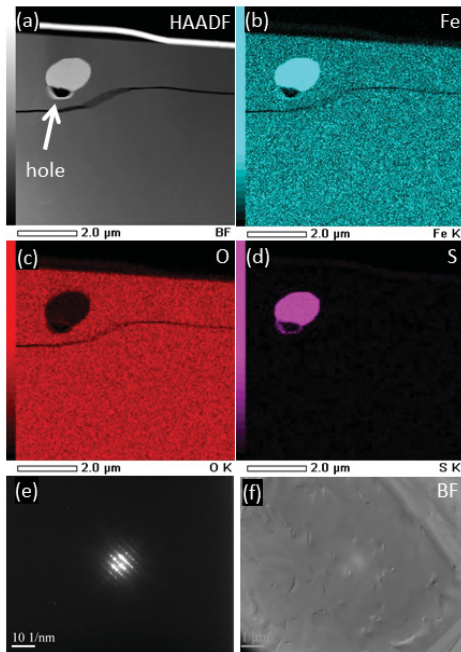


Fig.3. TEM images from FIB section #1 of RA-QD02-0094. (a) HAADF, (b-d) X-ray elemental mappings, (e) SAED pattern of olivine, (f) bright-field TEM image.

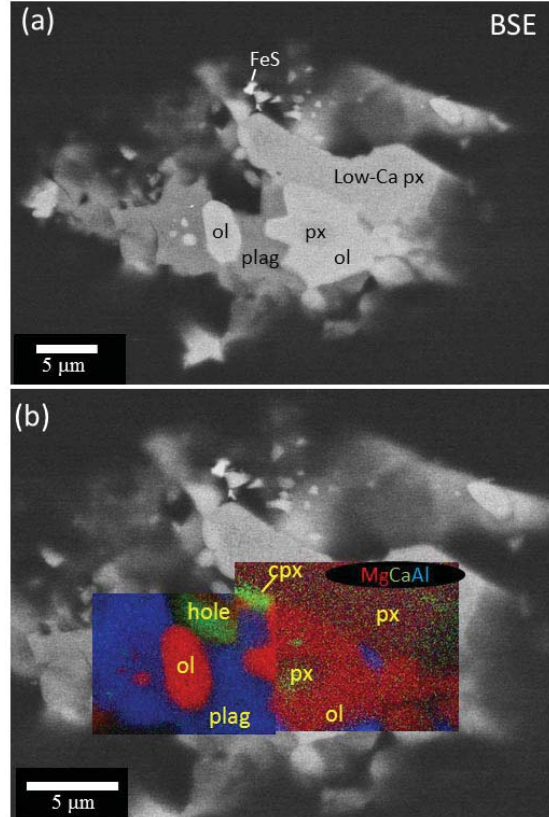


Fig. 4. (a) BSE image of polished section of RA-QD02-0127. (b) High-Ca pyroxene is identified in combined X-ray elemental map of the grain (Red=Mg, Green=Ca, Blue=Al).

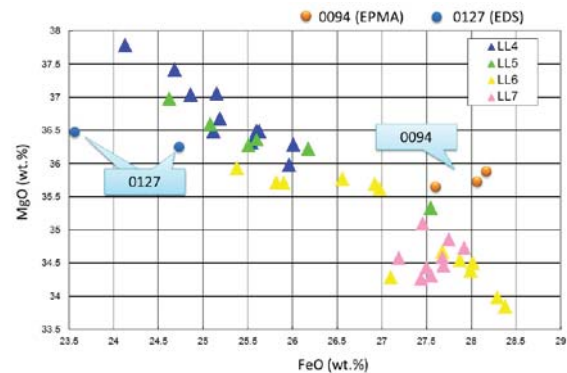


Fig. 5. Olivine compositions of RA-QD02-0094(0094) and RA-QD02-0127 (0127). Average olivine compositions of Antarctic LL 4-7 chondrites are from [6].