Heterogeneity of LL 5-7 chondrites in relation to HAYABUSA samples.

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Introduction:

In the HAYABUSA mission, the spacecraft succeeded to recover samples from the surface of asteroid Itokawa and these samples were returned to the earth. The chemical compositions of minerals [1] and the mineral abundances [2,3] indicate that the Itokawa samples correspond to LL chondrites. Observation by scanning electron microscopy [1] and x-ray micro-tomography [2] shows that most of the samples (~90%) have highly equilibrated textures (LL5-6), while the rest of them (~10%) have less-equilibrated textures (LL4).

There is a slight difference between the mineral abundances of the Itokawa samples and those of LL chondrites [2,3]. For example, olivine abundance of the Itokawa samples is slightly higher and Ca-rich pyroxene, troilite and metals are slightly lower than those of LL chondrites [4,5] (Fig. 1). These differences show possibility that some fractionation with respect to the mineral abundances occurred on Itokawa's surface. However, the samples examined may not represent the surface material of Itokawa because the samples examined are forty-eight particles of only 30-180 μm in size, which is smaller than a typical size of LL chondrites (e.g., the mean size of chondrules is ~900 μm) although the particles should be randomly collected from a larger area.

In the present study, we estimated the errors of the mineral abundances for the Itokawa samples by statistically examining heterogeneity of LL5-7 chondrites to check weather or not the differences between the mineral abundances of the Itokawa samples and LL chondrites are real.

Experiments:

We used Bensour meteorite (LL6), ALH-78109 meteorite (LL5) and Y-791067 meteorite (LL6-7) as reference samples to check the heterogeneities. We obtained elemental maps of thin sections of the chondrites with an electron-probe micro-analyzer (EPMA: JEOL JAX-8105 at Kyoto University and JAX-8900 at Kobe University). Thirteen elements (Na, Mg, Al, Si, P, S, K, Ca, Ti, Cr, Mn, Fe and Ni) were measured. The image of each elemental map has 1024 × 1024 pixels with the pixel size of 4 μm (area of 4.096 × 4.096 μm). A beam diameter was 3 μm and a probe current was 4.0×10^{-7} A. Two different areas were measured for Bensour and Y-791067 meteorites, while one area for ALH-78109 meteorite.

Image analysis procedure:

Mineral maps of the measured areas were made from the elemental maps. In this procedure, the histogram of the characteristic x-ray intensity of each element was obtained first. Then, a mineral phase was assigned to each pixel based on the histograms by assuming that the minerals have their own peaks and the thresholds of the minerals are determined by the mean value between the neighboring peaks. If all the elemental intensities of a pixel are in the threshold range of a mineral, this mineral was assigned to the pixel. Then, about 70% pixels were identified as each mineral. However, the rest of the pixels (~30%) cannot be identified mainly because a multiple mineral phases should be present in a single pixel. Mineral phases were assigned to the unidentified pixels using the median filter by considering eight neighboring pixels.

It is reasonable to assume that the forty-eight particles examined in the preliminary examination [3] were randomly collected from the smooth terrain named MUSES-C. This random collection process of the small particles was simulated by the following procedures. (1) The mineral and elemental abundances of the entire area measured by EPMA were obtained from the mineral and elemental maps, respectively. (2) Forty-eight square areas with 12×12 pixels (48×48μm), which correspond to the Itokawa particles, were randomly selected from the entire area. (3) The mineral and elemental abundances of whole forty-eight squares were calculated. (4) The steps from (2) to (3) were repeated by 10000 times. (5) Histograms of the mineral and elemental abundances obtained by the repeated process were made to calculate statistical errors of the mineral and elemental abundances.

Results and Discussions:

The comparison between the two measured areas of Bensour meteorite showed that there is no significant difference in the mineral and elemental abundances. This result indicates that the size of the measured area (~4×4 mm) is roughly representative for the mineral and elemental abundances of the meteorite.

The histograms of the mineral abundances obtained by the random selection of small areas can be divided into two groups. One group has a distribution similar to the normal distribution. Thus, the histogram was fitted by the normal distribution, and the peak position and the standard deviation, σ_{RS}, were calculated. Olivine, Ca-poor pyroxene, Ca-rich pyroxene, plagioclase, and troilite belong to this group (Fig. 2). Five different standard deviations (σ_{RS}) were obtained from the five measured areas of the three meteorites. There are not clear differences between the LL6 and LL5 chondrites. The representative standard deviations were calculated from the five standard deviations by considering the error propagation law (olivine 2.9 vol.%, Ca-poor pyroxene 2.4 vol.%, Ca-rich pyroxene 1.2 vol.%, plagioclase 1.4 vol.%, and troilite 1.6 vol.%) and can be regarded as the errors of the mineral abundances of the forty-eight particles. The comparison between the mineral abundances of the examined Itokawa particles and LL chondrites (Fig. 1) shows that differences in the abundances of plagioclase and Ca-poor pyroxene cannot be distinguished if the errors are taken into consideration. In contrast, the olivine abundance in the Itokawa particles is higher than that of LL chondrites and the Ca-rich pyroxene and troilite abundances in the Itokawa particles are lower than those in LL chondrites even if we consider the $2\sigma_{RS}$ errors.

The other group does not show any normal distribution at all. Minor minerals, such as taenite, kamacite, chromite and Ca-phosphate (the abundance of these minerals are less than ~5 vol.%), belong to this group (Fig. 3). Therefore, the errors of these mineral abundances cannot be evaluated. This is because the forty-eight areas (or particles) are not enough to obtain statistical information on the abundances of the minor minerals. A simulation suggests that we should analyze more than 400 particles to obtain a meaningful error.

The present results indicate that the abundances of olivine, Ca-rich pyroxene and troilite of the Hayabusa sample are statistically different from those of LL chondrites although the chemical compositions of minerals in the Itokawa particles are clearly within the ranges of those in LL chondrites [1]. There are three possibilities for the differences. First, the material in the parent body of Itokawa originally has different mineral abundances from the typical abundances of LL chondrites. Second, the original material has the typical LL chondrite abundances, but fractionation with respect to the mineral abundances occurred during the formation process of Itokawa as a rubble pile asteroid and/or the formation process of the smooth terrain, such as particle movement from a rough terrain to the smooth terrain [6]. Third, the regolith material in the smooth terrain originally has the typical LL chondrite abundances, but fractionation occurred during the sampling process by the HAYABUSA spacecraft. In particular, if sampling of electro statically levitated particles [2, 6] was made, some fractionation might be expected although the sampling mechanism is still not known.

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References:

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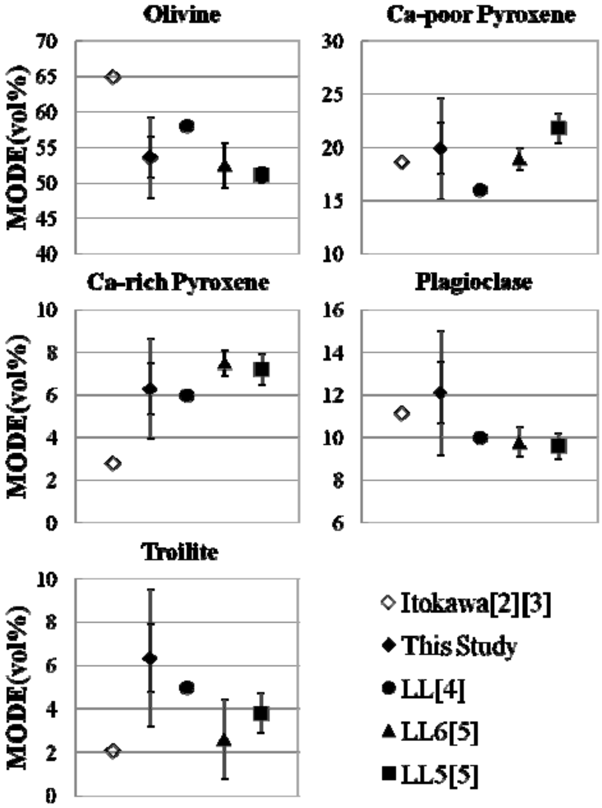

Fig.1

Figure1. Differences of the modal abundances of minerals between Itokawa sample and those of LL chondrites. The mean values of the five measured areas in the present study are shown with the standard deviations, which correspond to the errors for the Itokawa sample. Reference data for LL chondrites [4, 5] are also shown.

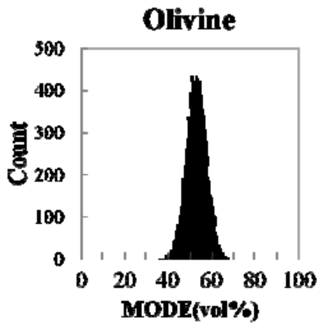

Figure 2 A histograms of the olivine abundance by the random sampling simulation.

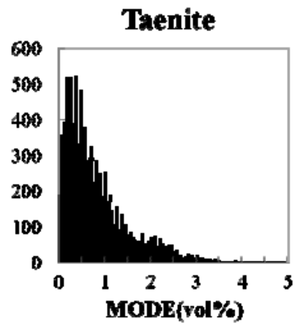

Figure 3 A histograms of the taenite abundance by the random sampling simulation.