HOMOGENEITY OF LL5 and LL6 CHONDRITES IN RELATION TO HAYABUSA SAMPLE ANALYSIS

T. Nagano[1] , A. Tsuchiyama[1] , N. Shimobayashi[2] , Y. Seto[3] , Y. Imai[1] , R. Noguchi[1] , T.Matsumoto[1] , J. Matsuno[1]
[1]Department of Earth and Space Science, Osaka University, [2]Department of Geology and Mineralogy, Kyoto University, [3]Department of Earth and Planetary Science, Kobe University.

Introduction: Samples on the surface of asteroid Itokawa were collected and recovered on the Earth by the Hayabusa mission. The chemical compositions of minerals [1,2], oxygen isotopic compositions of minerals [3] and modal mineral abundances [4] obtained in preliminary examination of Itokawa sample show that the surface material of Itokawa is consistent with LL chondrites [1-4]. Textural observation using scanning electron microscopy [1] and x-ray micro-tomography [4] shows that most of the sample particles (~90%) have thermally equilibrated textures (petrologic grade of 5 and/or 6) while some of them (~10%) have less-equilibrated textures (petrologic grade of 4). Homogeneity of the chemical compositions of minerals in particles with equilibrated textures shows that they are similar to LL5 and/or LL6 chondrites [1].

The size of Itokawa particles used in the preliminary examination ranges from about 30 to 180 μm. The total volume of the forty particles examined by the x-ray micro-tomography is 4.0×10^6 μm^3. This corresponds to a sphere of ~200 μm in diameter, which is smaller than the average chondrule size of LL chondrite of ~900 μm. Although the modal mineral abundances are similar to those of LL chondrites, the abundance of olivine is slightly higher and that of high-Ca pyroxene, troilite and metals is slightly lower than those in the average LL chondrite [4]. The bulk chemical composition of the Itokawa particles calculated form the mineral abundance and the chemical compositions of minerals are also slightly different from that of the average LL chondrite [4]. These may be due to the small amount of samples analyzed, but possibility of fractionation by sampling bias during sampling by the spacecraft cannot be excluded. Therefore, it is important to examine how the mineral abundances and chemical composition can be changed by picking a small amount of samples from LL chondrites randomly in connection to the texture of meteorites.

Experiments: Bensour meteorite (LL6) and ALH-78109 meteorite (LL5) were analyzed using an electron-probe micro-analyzer (EPMA: JEOL JXA-8105 at Kyoto University and JAX-8900 at Kobe university). Thirteen elements (Al, Ca, Cr, Fe, K, Mg, Mn, Na, Ni, P, S, Si and Ti) were measured, and images of these elements of 1024 × 1024 matrix with the pixel size of 4 μm (measured area of 4096 × 4096 μm) were obtained. Beam diameter was 3μm and probe current was 4.0×10^{-7} A. Two and one areas were measured for Bensour and ALH-78109 meteorites, respectively. Images of mineral distributions (olivine, Ca-poor pyroxene, Ca-rich pyroxene, plagioclase, troilite, kamacite, taenite, chromite, and Ca-phosphate) were made from the elemental images.

Image analysis procedure: We evaluated homogeneity of the chemical composition of the samples using elemental images as follows: (1) the mean intensity of characteristic X-ray in an elemental image, $\bar{I}$, were calculated for each element, (2) the image was divided into N × N parts (N = 2, 4, 8, … , 1024) to obtain coarse graining images with different sizes, (3) the mean intensities of characteristic X-ray, $I_1, I_2, \ldots, I_{N^2}$, were calculated for each new pixel of a coarse graining image (the total number of the pixel is N^2), (4) the standard deviation of $I_1 \sim I_{N^2}$,σ_N, were calculated, (5) the degree of heterogeneity of the chemical composition, σ_N', defined as σ_N divided by $\bar{I}$,, was obtained, and (6) the relations between N and σ_N' were examined. Homogeneity of the mineral abundances was also evaluated by similar procedure using the mineral images.

Then, we evaluated errors of the mineral abundances of Itokawa samples as follows: (1) Each mineral image was divided into 128 ×128 parts with the size of 51.2 × 51.2 μm, which nearly correspond to the size of Itokawa particles, (2) forty parts were selected randomly and the mineral abundances of these parts were calculated, (3) procedure (2) was repeated by 10000 times and histogram of the abundance of each mineral was obtained, and finally (4) the standard deviation of the histogram, which can be regarded as the error of the Itokawa particles, was obtained.

Results and Discussions: Comparison between two measured areas of Bensour meteorite showed that there is no significant difference in the elemental abundances or $\bar{I}$. This indicates that the measured area with the size of about 4 × 4 mm has almost representative chemical composition of Bensour meteorite. For each element, σ_N' positively correlates with N. If we compare σ_N' at fixed N (e.g., N=8) with $\bar{I}$, two elemental groups can be recognized. One has negative relation between σ_N' and $\bar{I}$ (group A) The other has low σ_N' and $\bar{I}$ values (group B). Si, Mg, Fe, Al, Na, Ca, S, Cr, Ni, P belong to group A. They are contained in minerals as major elements, and if the abundance of a mineral is low, σ_N' becomes large. B group elements are K, Ti, and Mn. They are contained in major minerals as minor elements (K in plagioclase, and Ti and Mn in pyroxene). So these elements have low $\bar{I}$ values, but σ_N' is low because the major minerals exist evenly. The present results suggest that group A elements with low abundance, such as Cr, Ni and P, have large errors in the estimated bulk chemical composition of Itokawa samples of [1] while group B elements have not large errors.

In the histograms of mineral abundances obtained from randomly selected areas, olivine, Ca-poor pyroxene, Ca-rich pyroxene, plagioclase, and troilite have distributions similar to the normal distribution. The standard deviations of the mineral abundances in volume were obtained as follows: olivine 5.7%, Ca-poor pyroxene 4.5%, Ca-rich pyroxene 3.1%, plagioclase 2.7%, and troilite 3.3%. If these deviations are regarded as the error of the mineral abundances of the Itokawa samples, the abundances of Ca-poor pyroxene, troilite and plagioclase fall into LL chondrite data. Those of olivine and Ca-rich pyroxene may be slightly different from the LL chondrite data, but if 2 sigma was taken into consideration, they fall into the LL chondrite data.(Fig.1)

In contrast to the major minerals, the histogram of minor minerals, such as taenite, Ca-Phosphate, and chromite, does not show normal distribution at all, and the peaks of the histograms are located almost at 0% of the mineral abundance. This shows that the mineral abundances of the minor minerals obtained from only forty particles have large errors and cannot be compared with ordinary chondrite data. The image analysis suggests that we should analyze 400 particles particles at least to obtain meaningful errors.

The present results strongly suggest that the difference of the mineral abundance of the Itokawa samples is merely due to statistical errors by picking a small amount of samples. The olivine abundance shows that Itokawa surface material is consistent with LL chondrites.

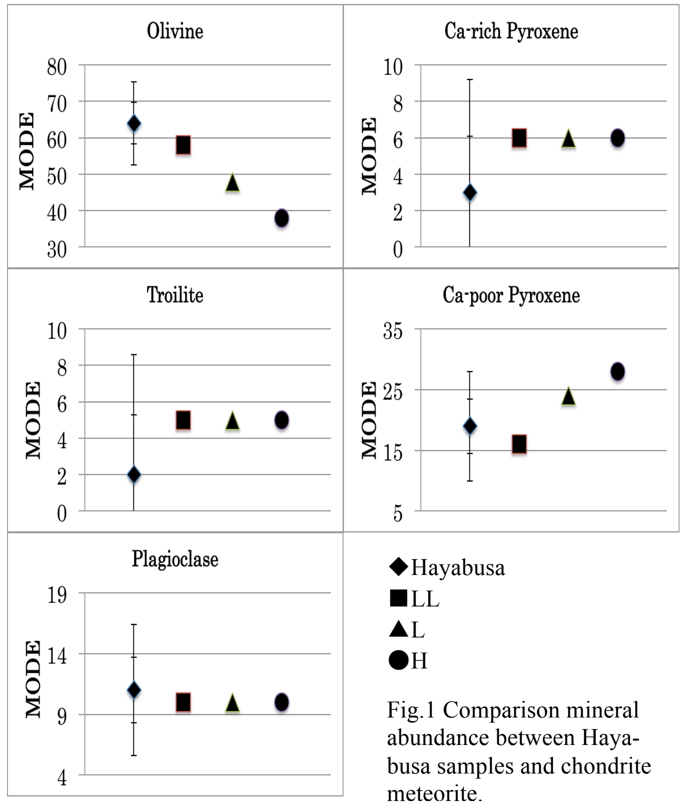

Fig.1 Comparison mineral abundance between Hayabusa samples and chondrite meteorite.

References: [1] Nakamura, T. et al., 2011. *Science, 333*, 1113-1116. [2] Ebihara M. et al., 2011. *Science, 333*, 1119-1121. [3] Yurimoto H. et al., 2011. *Science, 333*, 1116-1119. [4] Tsuchiyama, A. et al., 2011. *Science, 333*, 1125-1128.