OXYGEN THREE-ISOTOPE RATIOS OF SILICATE PARTICLES RETURNED FROM ASTEROID ITOKAWA BY THE HAYABUSA SPACECRAFT: A STRONG LINK TO EQUILIBRATED LL CHONDRITES. D. Nakashima[1], N. T. Kita[1], T. Ushikubo[1], T. Noguchi[2], T. Nakamura[3], and J. W. Valley[1]. [1]WiscSIMS, Dept. Geoscience, University of Wisconsin-Madison, Madison, WI 53706, USA (naka@geology.wisc.edu), [2]College of Science, Ibaraki University, Mito, Ibaraki 310-8512, Japan, [3]Dept. Earth Science, Tohoku University, Sendai, Miyagi 980-8578, Japan

Introduction: The Hayabusa spacecraft returned dust particles from asteroid 25143 Itokawa in 2010. Preliminary examinations revealed that Itokawa particles are genuinely asteroidal surface materials, showing evidence of space weathering and solar wind implantation [1-2]. The mineralogy, chemistry, and oxygen isotope ratios of the Itokawa particles are identical to those of LL4-6 chondrites [e.g. 3-4], which is consistent with the results of remote sensing measurements from the spacecraft [e.g. 5]. These initial results suggest S-type asteroids are sources of ordinary chondrites.

While $\Delta^{17}O$ ($=\delta^{17}O-0.52\times\delta^{18}O$) values of the Itokawa particles are very similar to those of LL4-6 chondrites, $\delta^{18}O$ values are highly variable [4]. Values of $\delta^{18}O$ of the Itokawa olivines are lower than those of olivine in LL4-6 chondrites [4,6]. Given that olivine is the most abundant silicate mineral from Itokawa particles (64vol%; [7]), the average oxygen isotope ratios of Itokawa particles would be significantly fractionated compared to bulk LL4-6 chondrites [8] if the published olivine data truly represent that of olivine from Itokawa particles. However, Yurimoto et al. [4] also mentioned the possibility that part of the variation could be caused by instrumental mass fractionation relating to irregularities of the sample surface owing to the small size (<200µm) of the grains.

Here we report new SIMS oxygen three-isotope analyses of six Itokawa particles by using an IMS-1280 at the WiscSIMS laboratory with precision and accuracy of 0.3‰ (2SD; [e.g. 9]). We re-analyze five particles reported in [4], in addition to one new particle.

Analytical Methods: To minimize the effect of surface topography, we used the indium mounting method instead of the multiple-hole disk used in [4], which is known to show a significantly large instrumental fractionation due to surface topography produced by the 100µm thick lip of the 4mm holes [10].

The allocated six Itokawa particles were mounted in the center of 6mm epoxy disks (2mm thickness). All the particles had a polished flat surface. We pressed the 6mm disk into indium inside of a 25mm diameter aluminum disk, without repolishing the surface (Fig. 1). Two small epoxy blocks (~2mm) containing polished San Carlos olivine grains (~1mm) were also pressed into the indium mount for standardization. The surface topography of sample across the indium mounts was less than 40µm. The oxygen isotope analyses were made using ~12µm Cs^+ primary beam under the conditions similar to those in [9].

Samples: Exposed surfaces of the four particles (RA-QD02-0014, -0017, -0023, and -0047) consist mainly of olivine, while those of other two (RA-QD02-0010, and -0030; Fig. 1c) consist of multiple minerals of olivine, low-Ca and high-Ca pyroxene, and plagioclase, showing highly equilibrated textures. Major element compositions of the four mineral phases are within the compositional ranges for LL4-6 chondrites [3].

Results: Oxygen isotope data from 6 Itokawa particles plot around the point of intersection between equilibrated chondrite line (ECL) and LL4-6 chondrite line ([8]; Fig. 2a). The $\Delta^{17}O$ values are indistinguishable within the analytical uncertainty, with the average $\Delta^{17}O$ value of +1.34±0.37‰ (2SD; n=20), which is consistent with preliminary examination data [4]. $\delta^{18}O$ values of olivine in the 6 Itokawa particles range from +3.9‰ to +5.1‰ (n=14), which are systematically higher by an average of +4.5‰ than those (+1.4‰ to +4.7‰; Fig. 2a) in [4]. Low-Ca pyroxene in RA-QD02-0030 shows $\delta^{18}O$ values of from +4.9‰ to +5.2‰ (n=3). The $\delta^{18}O$ values of plagioclase from RA-QD02-0010 are +5.5‰ and +5.9‰, while one spot from high-Ca pyroxene in the same particle shows a $\delta^{18}O$ value of +4.3‰, which is marginally lower than those of coexisting olivine (+4.7‰ to +4.8‰).

Discussion: Oxygen isotope ratios in the three equilibrated ordinary chondrites, Siena (LL5), St. Séverin (LL6), and Guareña (H6) were analyzed using the IMS-1280 [11]. As shown in Fig. 2, the isotope data plot parallel to the TF line in the order of high-Ca pyroxene, olivine, low-Ca pyroxene, and plagioclase, which is clear for Guareña and St. Séverin but less pronounced for Siena. The $\Delta^{17}O$ values of Siena (+1.19±0.84‰; n=28) are more variable than type 6 chondrites; St. Séverin (+1.31±0.49‰; n=32) and Guareña (+0.86±0.59‰; n=32), which is reflected in larger 2SD. The $\Delta^{17}O$ values of olivine and pyroxene in chondrules from Siena are highly variable (–2.4‰ to +1.8‰; [11]), possibly reflecting their primary variations seen in type 3 chondrites [9]. Considering smaller variability in $\Delta^{17}O$ among six Itokawa particles, they may represent highly equilibrated LL chondritic materials closer to petrologic type 6 than type 5.

The four mineral phases that we analyzed for oxygen isotope ratios are major constituents of the Itokawa particles [7]. Based on the volume fractions and average $\delta^{18}O$ values of respective mineral phases, the bulk $\delta^{18}O$ value of the Itokawa particles is calculated as +4.8‰ (concentrations of oxygen atoms in the four minerals are taken account). Similarly estimated bulk $\delta^{18}O$ values for the three meteorites (volume fractions are from [12]) are consistent with the measured bulk $\delta^{18}O$ values, respectively [8]. The estimated bulk $\delta^{18}O$ value of the Itokawa particles is within the $\delta^{18}O$ range of bulk LL5 and LL6 chondrites (+5.0±0.2‰ and +4.9±0.2‰; 1SD; [8]). To summarize, although the number of data is limited (n=20) and only highly equilibrated particles were analyzed, the Itokawa particles resemble equilibrated LL chondrites, especially LL6 chondrites in terms of oxygen isotope systematics based on in-situ multiple spot analyses and estimated bulk $\delta^{18}O$ values, which strengthens the link between asteroid Itokawa and equilibrated LL chondrites that fell to Earth.

From the $\delta^{18}O$ difference between plagioclase and high-Ca pyroxene in RA-QD02-0010 (1.6‰), oxygen isotope equilibrium temperature is estimated as 730°C, which is consistent with those for the three equilibrated ordinary chondrites within the uncertainties [11].

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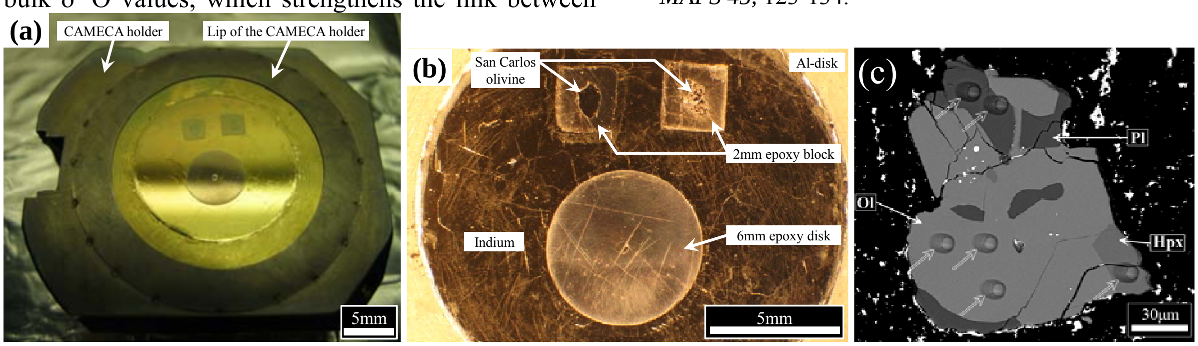

Fig. 1: Photograph of the indium mount in a CAMECA holder (a) and an expanded view of the center of the holder containing Itokawa particle RA-QD02-0017 mounted in an epoxy disk (b). Backscattered electron image of Itokawa particle RA-QD02-0010 (c). Arrows in panel (c) show spots sputtered for oxygen isotope analyses.

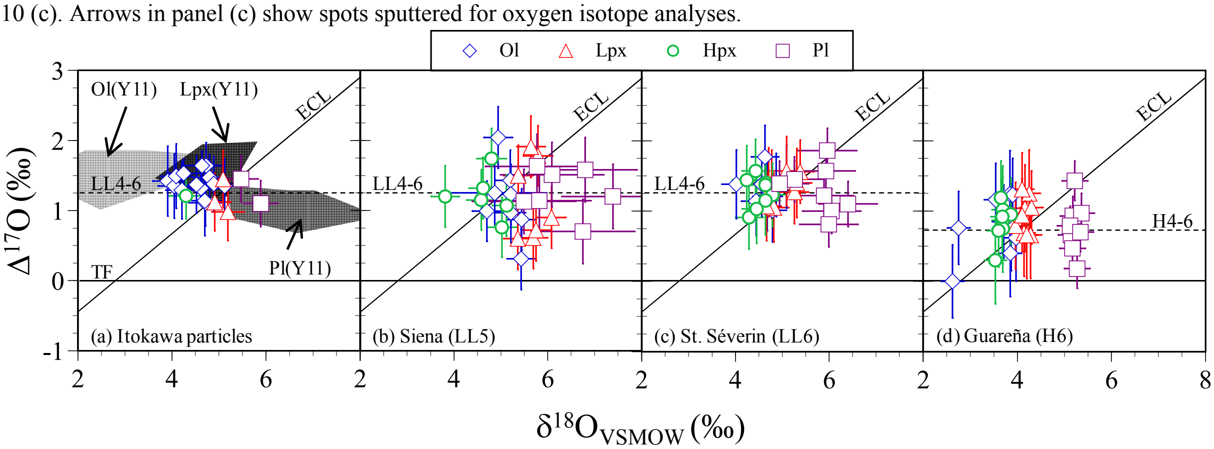

Fig. 2: Oxygen isotope ratios of the six Itokawa particles (a), Siena (b), St. Séverin (c), and Guareña (d). TF, ECL [8], and LL4-6 [8] lines are shown as reference. Oxygen isotope data of the three equilibrated ordinary chondrites from [11] and Itokawa particles (Y11; grey hatched areas) from [4] are shown for comparison.