HYDROGEN ISOTOPE SYSTEMATICS IN ORDINARY CHONDRITE PARENT BODIES. Z. L. Jin[1*] and M. Bose[1], [1]Center for Isotope Analysis, School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-6004. *Ziliang.jin@asu.edu

Introduction: In a recent study, we showed that the water incorporated into orthopyroxene minerals from the S-type asteroid Itokawa has comparable hydrogen isotopic signatures to that in terrestrial minerals [1]. This evidence allowed us to discuss the possibility that collisions of S-type asteroids, like Itokawa, could have provided water and other elements, e.g, Os to Earth [2]. S-type asteroids are considered as the parent bodies of H, L, and LL ordinary chondrites (OCs). To verify if other S-type asteroids show similar hydrogen isotope signatures, we undertook this reconnaissance study on several pristine OCs.

In OCs, the most abundant minerals are the early formed refractory minerals such as olivine and orthopyroxene. Under low pressure conditions, orthopyroxene could incorporate a large amount of water [3]. Thus, orthopyroxene in OCs should have recorded the primitive water signature in the early solar system history.

In this study, we conducted SIMS measurement on orthopyroxenes from four OCs, namely, LL4 Graves Nunataks 06179 (GRA 06179), LL5 Larkman Nunatak 12241 (LAR 12241), LL6 Larkman Nunatak 12036 (LAR 12036), and L6 Dominion Range 10035 (DOM 10035). Itokawa is thought to be the parent body of L/LL OCs belonging to the petrologic type 4-6 [4], and therefore we chose meteorites in the same class and range of petrologic types. We chose Antarctic meteorites for this study because they are suggested to be least affected by terrestrial alteration. We measure the hydrogen isotope compositions and water contents in these meteorites and compare them to terrestrial samples and Itokawa.

Samples and preliminary characterization: All 4 studied OCs are thin-sections from the Johnson Space Center collection. We selected the orthopyroxenes from these OCs based on the wavelength-dispersive spectroscopy on the JEOL Electron Probe Micro-analyzer.

Analytical methods: *NanoSIMS.* D/H ratios and H_2O concentrations of the standards and orthopyroxenes from GRA 06179 and DOM 10035 were measured by the Cameca NanoSIMS 50L at Arizona State University. The detailed protocols are stated in [1].

IMS 6f. The measurements of water contents and D/H ratios in LAR 12241 and LAR 12036 OCs were performed on the Cameca IMS 6f at Arizona State University because they have large pyroxene grains. A 10–13 nA Cs^+ ion beam was rastered on a 35 × 35 μm^2 surface area. The field aperture set the analyzed area to 15 µm diameter. H^- and D^- was measured on an electron multiplier. At the end of each measurement, $^{16}O^-$ was measured using a faraday cup. The electron gun was used to compensate the sample surface charge during the measurements. The area of interest was sputtered for 120 seconds prior to the analysis. The data collection takes ~7 mins.

Results: Hydrogen isotope compositions normalized to standard mean ocean water (δD_{SMOW}) and water contents of the orthopyroxenes from the OCs are plotted in Figs. 1 and 2.

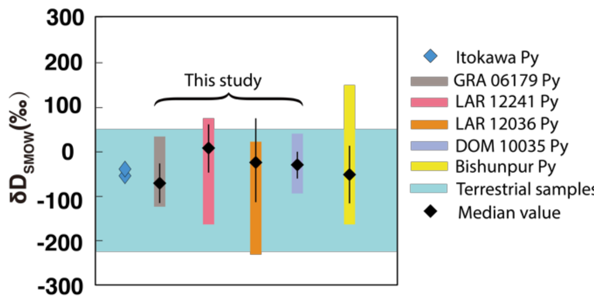

Fig. 1. δD_{SMOW} (‰) of pyroxenes from Itokawa and ordinary chondrites, and terrestrial minerals. The black diamonds indicate the median δD_{SMOW} of each group. The errors are 2SM. Py: pyroxene.

The δD_{SMOW} of 11 orthopyroxene grains from GRA 06179 vary from -95 ‰ to 41 ‰, with a median δD_{SMOW} = -27 ± 30 ‰ (2 standard error of the median or 2SM). These pyroxenes contain 458–1388 ppm water, with a median value of 838 ± 237 ppm (2SM).

In LAR 12241, the δD_{SMOW} of 10 measured grains are from -154 ‰ to 88 ‰ (Median = -2 ± 56 ‰, 2SM). Their water contents range from 298 ppm to 1483 ppm (Median = 814 ± 296 ppm, 2SM).

The δD_{SMOW} of 6 orthopyroxenes from LAR 12036 range from -241 ‰ to 12 ‰ with a median value of -33 ± 92 ‰ (2SM). They have water contents ranging from 565 ppm to 1303 ppm (Median = 801 ± 335 ppm, 2SM).

Ten orthopyroxenes grains from DOM 10035 are measured for δD_{SMOW}, which range from -123 ‰ to 36 ‰ (Median = -67 ± 44 ‰, 2SM). The water contents of these orthopyroxene are 542–1273 ppm, with a median value of 1022 ± 228 ppm (2SM).

Discussion: The pyroxene in the OC meteorites or S-type asteroids is one of the earliest refractory minerals that directly condensed from the protosolar nebula. During condensation, water was probably incorporated in pyroxene minerals via adsorption and hydroxylation in the solar nebula [e.g., 5]. Since the S-type asteroids stay undifferentiated, the water that gets incorporated into the pyroxene structure would not be affected by magmatic processes. However, several additional processes could potentially alter the hydrogen isotope compositions in pyroxene. Ionizing irradiation in the protoplanetary disk phase could lead to hydrogen loss correlated with a large deuterium enrichment (< 580 ‰) of the solid residue occurring in the protoplanetary disk within 3 A.U. [6]. However, this process has insignificant effects on grains smaller than 10 µm, as is the subject of this study. The second process is galactic cosmic ray spallation that implants protons in the mineral grains [7]. The contribution from this process is determined by the exposure age of meteorites and production rates for hydrogen and deuterium. The exposure ages of OCs are less than 40 Ma [8]. As a result, the amount of water produced by this process is < 1 ppm for the parent body of OCs; and the isotopic fractionation between hydrogen and deuterium is negligible.

Dehydration at high temperatures caused by thermal metamorphism and impact events on the asteroid bodies could result in the loss of hydrogen, which can affect the hydrogen composition in the host minerals. Based on the thermal-diffusion model [see 1 for details], high temperatures experienced during the thermal metamorphism and after impact events could cause water loss in the asteroid bodies, which is associated with different conditions, such as the highest temperature experienced during the event, duration of metamorphism, cooling rates, and size of the parent body. Although we don't know the sizes of the OC parent bodies, we assume that they are < 50 km in diameter for them to stay undifferentiated. We also assume that the OCs with petrologic types 4–6 experienced thermal metamorphism at 600–1000 ºC during a 10 Ma period and possibly experienced high post-shock temperatures up to 1500 ºC. Based on our simulations, the average fraction of the water loss caused by thermal metamorphism is less than 7 %; the water loss that caused by impact events accounts for < 2 %, because of quick cooling rates (200–600 ºC/ky, [9]). This water loss from the pyroxene structure is coupled with the fractionation of hydrogen isotopes and we estimated that a 10 % amount of water loss would cause an increase of δD by < 50 ‰ [10].

Taking the fractionation of hydrogen isotopes caused by the dehydration into account, the original δD_{SMOW} of the studied pyroxenes from OCs overlap the range of terrestrial samples and indicate a common source of water for Earth and OCs/S-type asteroids. According to the previously estimated water contents of Mars and 4 Vesta [11, 12], the inner solar systems bodies could have incorporated water that preserved in the early formed refractory minerals. The most abundant inner solar system planetesimals, i.e., S-type asteroids, are thus one potential source for water in terrestrial planets.

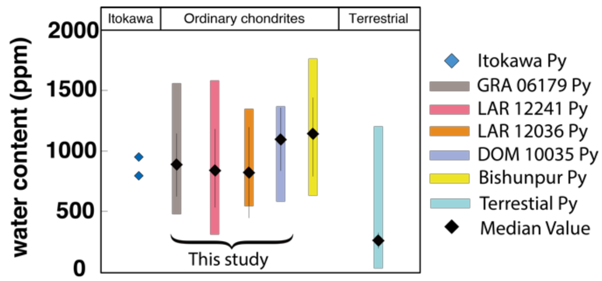

Fig. 2 Measured water contents (ppm) of pyroxenes from Itokawa, ordinary chondrites, and terrestrial rocks. The black diamonds indicate the median water contents in each group. The errors are 2SM.

Although the four studied OCs have different petrologic types, their water contents do not show a sharp distinction, which indicates a surprising result that dehydration is independent of the degree of thermal metamorphism. In fact, the water contents of the studied pyroxenes are similar to those from the highly unequilibrated Bishunpur OC. Besides, the water contents of two previously studied pyroxene grains from the S-type asteroid Itokawa fall within the range of water content of those from OCs. Compared to terrestrial rocks, pyroxenes from OCs contain larger amount of water (Fig. 2). We thus estimate that the pyroxene in OC or S-type asteroid could have incorporated at least 500 ppm water when they condensed from the protosolar nebular. Recent remote observations indicated that two S-type asteroids, 433 Eros and 1036 Ganymed contain 30–300 ppm water [13]. Further studies on the early-formed minerals from OCs, e.g., olivine and clinopyroxene are needed to accurately constrain the water concentration of OC parent bodies/S-type asteroids.

References: [1] Jin Z. and Bose M. (2018) *LPS XLIX, Abstract,* #1670. [2] Drake M. and Richter K. (2002) *Nature*, *416*, 39-44. [3] Mierdel et al. (2007) *Science, 19,* 364-368. [4] Yurimoto et al. (2011) *Science*, *333*, 1116-1118. [5] Asaduzzaman, A. (2015) *ICARUS, 304,* 74-82. [6] Roskosz, M. (2016) *APJ, 862,* 55. [7] Simpson, J. (1983) *Annu. Rev. Nucl. Part. Sci. 66*, 71. [8] Marti, K. and Graf, T. (1992), *Annu. Rev. Earth Planet. Sci.*, *20,* 221-243. [9] Ganguly et al. (2016), *GCA*, *192*, 75-90. [10] Roskosz et al. (2018) *GCA, 233,* 14-32. [11] McCubbin et al. (2012) *Geology, 40,* 683-386. [12] Stephant et al. (2016) *LPS XLVII, Abstract,*#2436. [13] Rivkin et al. (2018) *Icarus, 304,* 74-82.