OXYGEN-ISOTOPE COMPOSITIONS OF CHONDRULES AND MATRIX GRAINS IN KAKANGARI CHONDRITE. K. Nagashima[1], A. N. Krot[1], and G. R. Huss[1]. [1]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Mānoa, USA. kazu@higp.hawaii.edu

Introduction: The genetic relationship between chondrules and matrix in primitive chondrites is not well understood. The proposed models include: *(i)* matrix as raw material for chondrules that did not experience chondrule-forming process [e.g., 1], *(ii)* matrix formed by fragmentation of chondrules [e.g., 2], *(iii)* both components formed by thermal processing of dust in the chondrule-forming region [e.g., 3], and *(iv)* the two components are a mechanical mixture and thus not genetically related [e.g., 4]. Oxygen isotopes can potentially provide important constraints on the relationship between chondrules and matrix and on thermal processing of matrix in the solar nebula. Here we report on an *in situ* O-isotope study of chondrules and matrix grains in Kakangari K-grouplet chondrite. The Kakangari matrix has several unique characteristics including mineralogy indicating high temperature processing, enstatite-dominated matrix, and its chemical composition similar to chondrules [5]. Those may imply a genetic relationship between matrix and chondrules. On the other hand, O-isotope compositions of bulk matrix is ^{16}O-enriched by ~2.6‰ compared to bulk chondrules which plot along the terrestrial fractionation (TF) line [6-7, Fig. 1], suggesting they could have formed in different O-isotope reservoirs.

Methods: The mineralogy and petrography of chondrules and matrix grains in Kakangari were studied using the UH field-emission EPMA (JEOL JXA-8500F). Oxygen-isotope compositions were measured with the UH Cameca ims-1280 SIMS. For chondrules, we used ~1 nA primary Cs^+ beam with 7 µm raster and 2 Faraday cups (FCs) for ^{16}O and ^{18}O, and an electron multiplier (EM) for ^{17}O. Matrix grains were measured with ~15 pA beam focused to ~1 µm using FC-EM-EM for ^{16}O, ^{17}O, and ^{18}O, respectively. Analysis spots were marked by focusing the electron beam on the points of interest to produce a spot that is visible as depleted oxygen signal in scanning $^{16}O^-$ ion image, allowing us to identify exact locations of small matrix grains in matrix. In addition to spot analyses, we obtained δ^{18}O isotopographs for some regions in chondrules and matrix using the SCAPS detector [8].

Results and Discussion: Oxygen-isotope compositions of olivine and low-Ca pyroxene grains in 7 type I chondrules (PO, POP, and RP) and 2 FeO-rich POP chondrules were measured. In type I chondrules, olivine and low-Ca pyroxene have very similar and limited compositions, $Fo_{\sim 95-97}$ and $En_{\sim 90-96}$, respectively. The FeO-rich chondrules are very rare in Kakangari (typical type II chondrules are essentially absent [e.g., 9]) and show evidence for reduction [10]. FeO-rich chondrules have larger ranges in compositions, $Fo_{\sim 92-97}$ and $En_{\sim 75-94}$ than type I chondrules. All analyzed chondrules plot near the intersection of the TF line and the Young & Russell line [11] with mean Δ^{17}O values of 0.0±0.8‰ (2SD) and +0.2±0.9‰ for olivine and pyroxene, respectively (Fig. 1). There are no significant systematic differences in O-isotope compositions among chondrules. The Δ^{17}O values of chondrule phenocrysts are in good agreement with bulk chondrules, but the δ^{18}O values are slightly lower than those reported by [6]. This difference might be explained by the presence of ferrihydrite commonly observed at margins of and/or in chondrules, which could have different O-isotope composition from anhydrous minerals in chondrules. One olivine grain in a coarse-grained igneous rim of a POP chondrule Ch#1 is ^{16}O-rich (Δ^{17}O ~ –23‰, Fig. 1). Similar ^{16}O-rich olivines were found in a coarse-grained igneous rim around type I POP chondrule from CR2 chondrite [12]. In order to study the distribution of ^{16}O-rich grains in the rim around Ch#1, two regions in the rim were imaged for δ^{18}O. The δ^{18}O isotopographs show the common presence of olivines with ^{16}O enrichment (Fig. 2). The ^{16}O enrichment is observed only in some portions of these grains, suggesting that these portions are relict and overgrown by ^{16}O-poor olivine crystallized from melt during rim formation.

Based on the textures, the Kakangari matrix is divided into two main groups: relatively large clastic grains, and non-clastic, finer grained aggregates [5]. Clastic grains of olivine and low-Ca pyroxene (5 to 20 µm in size) were measured. Chemical compositions of these grains, $Fo_{\sim 96-98}$ and $En_{\sim 92-97}$, are similar to those in type I chondrules. Oxygen-isotope compositions of matrix grains show a bimodal distribution (Fig. 3): 12 out of 13 olivine and 4 out of 17 pyroxene grains are similarly ^{16}O-rich (Δ^{17}O ~ –23.5±2.9‰), others are similarly ^{16}O-poor (Δ^{17}O ~ –0.1±1.7‰). δ^{18}O isotopographs in several regions of matrix also show the presence of ^{16}O-rich olivine and low-Ca pyroxene grains. No overgrowths of ^{16}O-poor olivine onto ^{16}O-rich olivines are found. Both spot analyses and δ^{18}O isotopographs indicate that ^{16}O-rich grains are not concentrated in specific region or specific type of matrix, instead, they seem to be distributed equally throughout the matrix.

Oxygen-isotope compositions of chondrules and ^{16}O-poor matrix grains are nearly identical, and consistent with those of bulk chondrules (Fig. 3). This suggests both components could have sampled the same O-isotope reservoirs during chondrule formation, and is consistent with that in Kakangari the clastic matrix grains are chondrule fragments suggested by [5]. Oxygen-isotope compositions of ^{16}O-rich grains are very similar to those in an AOA (Fig. 3). ^{16}O-rich olivine grains could be related to AOAs and formed at a different nebula region prior to chondrule formation. These grains were subsequently transported into the chondrule-forming region, and incorporated into chondrule precursors, at least chondrule rim, and into matrix. Origin of ^{16}O-rich low-Ca pyroxene in Kakangari matrix is unknown. ^{16}O-rich low-Ca pyroxene grains have been observed in AOAs [13] and in isolated grains in matrix of CR2 chondrite [14]. In both cases, ^{16}O-rich low-Ca pyroxene are associated with olivine, and probably formed by a reaction between forsterite and gaseous SiO, suggesting that ^{16}O-rich low-Ca pyroxenes formed in the same ^{16}O-rich gaseous reservoir as forsterite. Since we did not find olivine in the ^{16}O-rich low-Ca pyroxene grains, those low-Ca pyroxene may be direct condensates from fractionated (Mg/Si < solar) gas [15-16]. TEM study of these grains is important to constrain an origin of the ^{16}O-rich pyroxene.

The O-isotope composition of bulk matrix is ^{16}O-enriched compared to chondrules [6-7]. ^{16}O-rich grains in matrix could contribute to O-isotope composition of bulk matrix. Based on detailed X-ray maps of Kakangari matrix, clastic olivine grains can make up 5–10% of the matrix. Considering most olivines and some pyroxene are ^{16}O-rich, it seems possible to make up about 10% of matrix by ^{16}O-rich grains, and therefore, ^{16}O-enriched bulk matrix composition could be due to abundant ^{16}O-rich grains in matrix.

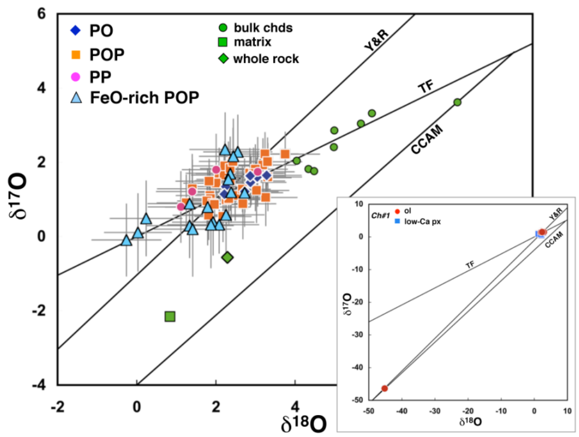

Fig. 1. Oxygen-isotope compositions of olivine and low-Ca pyroxene in 9 chondrules from Kakangari. Also shown are bulk chondrules, bulk matrix, and whole-rock compositions from [6]. The inset shows O-isotope compositions of a POP chondrule Ch#1. TF: terrestrial fractionation line, Y&R: Young & Russell line [11], CCAM: carbonaceous chondrite anhydrous mineral line.

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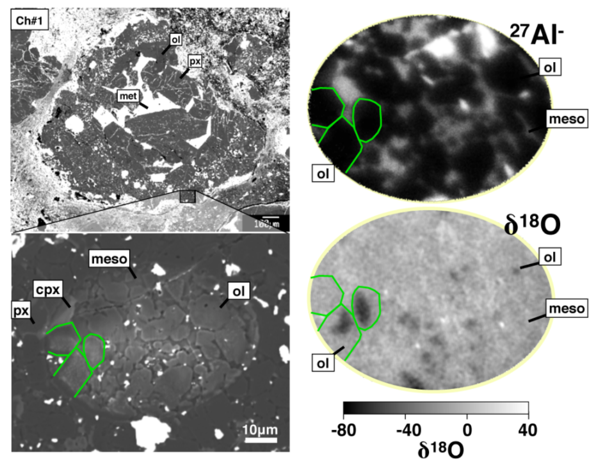

Fig. 2. BSE image, $^{27}Al^-$, and $\delta^{18}O$ isotopograph of a region in the coarse-grained igneous rim of a POP chondrule Ch#1. Distribution of $^{27}Al^-$ signal corresponds to mesostasis. $\delta^{18}O$ isotopograph shows common presence of ^{16}O-rich olivines. Note that only part of olivine grains are ^{16}O-rich in olivine grains outlined by green curves, suggesting that ^{16}O-rich parts are relicts and overgrown by ^{16}O-poor olivine during chondrule rim formation. cpx: high-Ca pyroxene, meso: mesostasis, met: FeNi-metal, ol: olivine, px: low-Ca pyroxene.

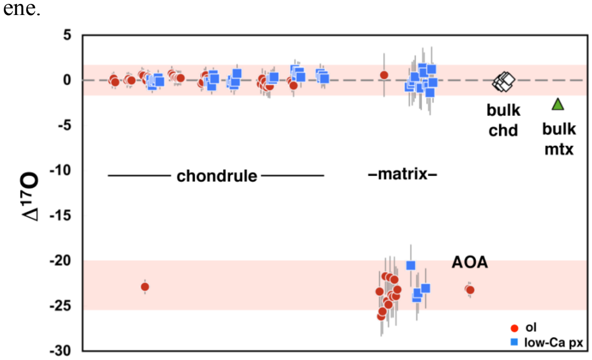

Fig. 3. $\Delta^{17}O$ values of chondrules, matrix grains, and an AOA from Kakangari. Bulk chondrules and bulk matrix data are from [6].