

BIMODAL OXYGEN ISOTOPE COMPOSITIONS OF MICRO-PORPHYRITIC CHONDRULES IN THIEL MOUNTAINS 07007 REDUCED CV3 CHONDRITE. S. Goh^{1,2}, B.-G. Choi¹ and J. Kim². ¹Earth Science Education, Seoul National University, 08826, Korea (likeio02@snu.ac.kr), ²Center of Research Equipment, Korea Basic Science Institute, 28119, Korea.

Introduction: High temperature processes in the early solar nebular forming refractory inclusions, Ca-Al-rich Inclusions (CAIs) and Amoeboid Olivine Aggregates (AOAs), and chondrules must have been extensive but remains enigmatic [1]. Since they are different in mineralogy, textures and oxygen isotope composition, there is a consensus that they formed under different physicochemical conditions [2]. Relicts in chondrules could be materials of CAIs, AOAs or earlier generations of chondrules. Oxygen isotopic compositions along with petrological characteristics of such relicts could shade a light on our understanding of genetic correlation between refractory inclusions and chondrules and evolution of oxygen isotopic reservoirs in the early solar system [3, 4]

Relicts having different petrological characteristics and oxygen isotopic compositions with their host minerals are rare but have been identified in various chondrites as summarized in [3-5]. Similar to [4], we searched relicts in porphyritic olivine (PO) chondrules using petrological observation and minor element compositions and measured their oxygen isotopic compositions.

Sample and analytical methods: Thiel Mountains 07007 (TIL 07007) was selected for this study, since it is a CV3 reduced chondrite (S2, W1) [6], which is one of the least metamorphosed or altered group that having high abundances of both refractory inclusions and chondrules.

We focused on olivine (forsterite), since it is the major mineral in both AOAs and chondrules and has higher probability of being relicts than any other chondrule-forming minerals because of its higher melting temperatures and slower oxygen diffusion rate [3, 7, 8]. Chondrules experienced lower degree of melting would have higher chances to preserve relicts. We searched micro-porphyritic olivine (micro-PO) chondrules. In a thin section (SNU-T097), we found four micro-POs having average olivine grain sizes of ~30 μm , while those in typical PO chondrules are > 100 μm . Ten non-micro-PO chondrules and five AOAs were studied and compared with micro-POs.

The polished thin section of TIL 07007 was observed by optical and electron microscopes. Chemical compositions were analyzed by JEOL JXA-8530F field emission electron microprobe at Korea Polar Research. The electron microprobe was also used to obtain X-ray mapping images.

In-situ oxygen isotope measurements were carried out using a newly installed CAMECA IMS 1300-HR³ at Korea Basic Science Institute.

For oxygen isotope measurements, three sets of condition were applied: (1) ~3 nA focused and rastered Cs beam excavating ~25×25 μm^2 craters on sample surface with three-FCs for secondary ion detection to enable high precision ($\delta^{18}\text{O}$, $\delta^{17}\text{O}$ as ± 0.2 , ± 0.4 (2 σ)) analyses, (2) ~200 pA focused and rastered Cs beam making ~7×7 μm^2 craters with FC-EM-EM (± 0.5 , ± 0.8) and (3) ~60 pA Cs beam of Köhler mode making ~3×7 μm^2 craters with FC-EM-EM (± 0.7 , ± 1.4) for higher spatial resolution.

Mass resolving power ($M/\Delta M$) of ~5,500 for $^{17}\text{O}^-$ was employed by combining 50 μm width of entrance slit, 250 μm exit slit and 50 eV energy band. Zero energy electron flooding was adjusted for optimal compensation to charging on the sample surface. An analysis consists of 20 cycles for the condition (1) or 80 cycles for (2) and (3) with 4 seconds for a cycle.

Results and Discussion: In TIL 07007, chondrules occupy 63 vol. %. Majority of them are ferromagnesian type-I PO and porphyritic olivine and pyroxene chondrules, although a few are barred, granoblastic, radial pyroxene, porphyritic pyroxene, Al-rich or type-II chondrules.

Four chondrules were classified as micro-POs. Except their grain sizes, petrological characteristics of them are very similar to those of the other POs (hereafter we call typical type I PO as simply PO). The average forsterite contents of PO and micro-PO chondrules are 99.1 and 98.9 mol. %, respectively. Some olivine grains in both POs and micro-POs show zoning in minor element contents that core areas are lower in Al and Ti (below detection limit) than peripheries ($\text{TiO}_2 < 0.15$ wt.%, $\text{Al}_2\text{O}_3 < 0.25$ wt.%), similar to previous studies [4].

AOAs take ~3 vol. % in TIL 07007. They are made up with irregular aggregation of fine grained (~10 μm) olivine nodules enclosed by thin (~1 μm) layers of Al-rich diopside and anorthitic feldspar. Fe-Ni metal is very rare and occurs as a tiny (<10 μm) grain if any.

As a whole, O isotope compositions of olivine from chondrules and AOAs nicely fall along near-slope 1 mixing line, *i.e.*, carbonaceous chondrite anhydrous mineral (CCAM) or primitive chondrule mineral (PCM) lines, ranging from -46.6 to 1.9 ‰ in $\delta^{18}\text{O}$ and -48.1 to -0.6 ‰ in $\delta^{17}\text{O}$ (Fig. 1).

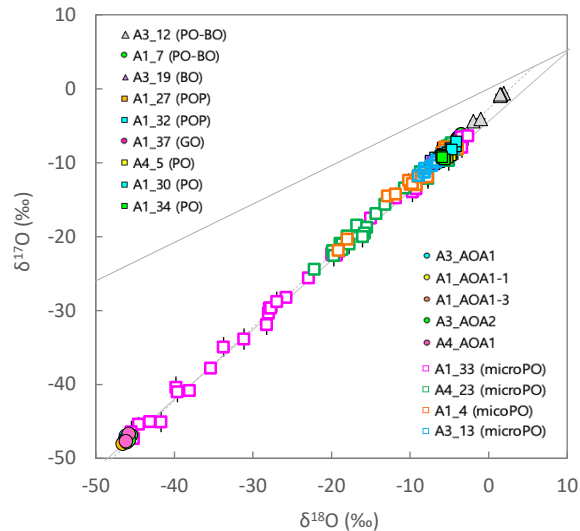


Figure 1. Oxygen isotopic compositions of olivine grains in AOAs and chondrules using CAMECA IMS 1300-HR³. Note that compositions of AOAs and typical chondrules fall at each end of the range while those of micro-POs fall in between them.

AOA and chondrules (except micro-PO) are internally homogeneous in oxygen isotope compositions. Four AOAs are isotopically identical ($\delta^{18}\text{O}$: -46.0 ± 0.6 ‰, $\delta^{17}\text{O}$: -47.4 ± 0.9 ‰, 2σ , $n=14$ ($\Delta^{17}\text{O}$: $\sim -23.5 \pm 0.7$)) and three PO chondrules are internally uniform but slightly different each other: (1) $\delta^{18}\text{O}$: -4.4 ± 0.7 ‰, $\delta^{17}\text{O}$: -7.8 ± 1.0 ‰, 2SD , $n=4$ ($\Delta^{17}\text{O}$: -5.4 ± 0.7), (2) $\delta^{18}\text{O}$: -5.4 ± 0.7 ‰, $\delta^{17}\text{O}$: -9.0 ± 0.3 ‰, $n=4$ ($\Delta^{17}\text{O}$: -6.2 ± 0.2) and (3) $\delta^{18}\text{O}$: -5.8 ± 0.5 ‰, $\delta^{17}\text{O}$: -9.3 ± 0.5 ‰, $n=3$ ($\Delta^{17}\text{O}$: -6.3 ± 0.8).

On the other hands, 4 micro-PO chondrules occupy wide isotopic ranges from -45.2 to -2.6 ‰ in $\delta^{18}\text{O}$ and -47.3 to -6.4 in $\delta^{17}\text{O}$ ‰ (from -23.8 to -4.3 ‰ in $\Delta^{17}\text{O}$). Such ^{16}O -enrichment and large variation ($\delta^{18}\text{O}$ around -50 ‰) in ferromagnesian chondrules are rare, but reported in several chondrites including Mokoia [9] and Kaba [4].

Four micro-POs have very similar ^{16}O -poor ends which similar to compositions of the other (non-micro-PO) chondrules, however, their ^{16}O -rich ends differ: (1) from -45.7 to -2.6 ‰, (2) from -22.2 to -4.1 ‰, (3) -19.1 to -3.9 ‰ and (4) from -8.9 to -4.5 ‰ in $\delta^{18}\text{O}$. The isotopic heterogeneities in micro-POs are found within a grain as well as grain-to-grain. No relationship observed between O isotopes and spatial locations of olivine within a chondrule. The degree of ^{16}O -enrichment and O-isotope heterogeneity from a micro-PO chondrule seems to have a weak correlation with mineral abundances. ^{16}O -enrichment show a positive relation-

ship with olivine and/or mesostasis abundance, and negative relationship with troilite and/or low-Ca pyroxene abundances in chondrules.

Within a single micro-PO olivine grain, ^{16}O -enrichments are correlated with minor element contents; the Ti-Al-depleted core is more ^{16}O -riched, which is consistent with previously reported [4]. When we use smaller-sized primary beams, there seems to be a compositional gap between ^{16}O -rich and ^{16}O -poor values in each microPO: (1) from -27.0 to -9.7 ‰, (2) from -15.8 to -9.0 ‰ and (3) from -7.8 to -4.6 ‰ in $\delta^{18}\text{O}$ (Fig. 2), which implies that oxygen diffusion with relict grains during and after chondrule formation was limited. We suspect that the gaps could be the larger with the smaller primary beams.

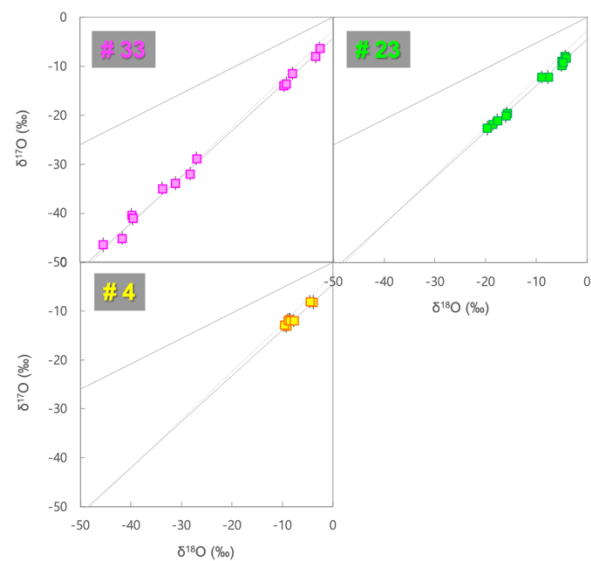


Figure 2. Oxygen isotope compositions of olivine in three micro-POs measured with the smallest primary beam in this study. Each chondrule shows bimodal compositions.

References: [1] Ireland, T.R. et al. (2020) *Space Science Reviews* 216, 25. [2] Russell, S.S. et al. (2005) *Chondrites and the Protoplanetary Disk* 317-353. [3] Tenner, T.J. et al. (2018) *Chondrules - Records of Protoplanetary Disk Processes* 196-247. [4] Marrocchi Y. et al. (2019) *GCA* 247: 121-141. [5] Ushikubo T. et al. (2012) *GCA* 90: 242-264. [6] Weisberg M.K. et al. (2010) *The Meteoritical Bulletin*: No. 98. [7] Ustunisik, G. et al. (2014) *GCA* 142: 27–38. [8] Soulié, C. et al. (2017) *Meteoritics & Planet. Sci.*, 32 52: 225–250. [9] Jones, R.H. et al. (2004) *GCA* 68: 3423-3438.