MAGNESIUM-ISOTOPE COMPOSITIONS IN A COMPOUND AMOEBOID OLIVINE AGGREGATE – CHONDRULE OBJECT FROM ACFER 094 METEORITE. K. Nagashima[1], G. Libouurel[2], M. Portail[3], and A. N. Krot[1], [1]HIGP, University of Hawai‘i, Honolulu HI, 96822, USA (kazu@higp.hawaii.edu), [2]Observatoire de la Côte d'Azur, Nice, France. [3]Centre de Recherche sur l'Hétéro-Epitaxie et ses Applications, Valbonne, France.

Introduction: The chondrule precursors include Ca,Al-rich inclusions (CAIs), amoeboid olivine aggregates (AOAs), chondrules of earlier generations, and fine-grained matrix-like material [e.g., 1]. As CAIs and AOAs have distinct isotope compositions, including O-isotopes, compared to those in chondrules, compound CAI/AOA/chondrule objects are suitable for investigation of gas-melt interaction including evaporation and condensation during chondrule formation. We have studied a compound AOA/chondrule object (A/Ch#1) from Acfer 094 ungrouped C3.00 chondrite [2]. The O-isotope compositions of this object suggest ~60−85% of oxygen was introduced from the gas, suggesting efficient O-isotope exchange between chondrule melt and gas [2]. In this study, we investigated Mg-isotope compositions in olivines from A/Ch#1 to understand condensation of Mg into chondrule melt as suggested by [3].

Methods: Mg-isotope compositions in olivines were measured using the UH Cameca ims-1280 SIMS. We used ~2 nA primary $^{16}O^{-}$ beam produced by Hyperion-II ion source (installed in August 2019), and 4 Faraday cups (FCs) to measure simultaneously ^{24}Mg, ^{25}Mg, ^{26}Mg, and ^{27}Al. Typical internal precision for δ^{25}Mg is ~0.06−0.08‰ (2-standard-error) and typical external reproducibility of standard measurements is ~0.1−0.15‰ (2-standard-deviation). Since olivines in A/Ch#1 have relatively uniform composition at $Fo_{\sim99}$, we used San Carlos olivine ($Fo_{\sim90}$) and forsterite from Norton County aubrite ($Fo_{\sim100}$) as standards. The Mg-isotope compositions of these olivines in DSM3 scale are reported in [4 and refs. therein]. Instrumental fractionation of Mg-isotopes in olivines changes depending on their forsterite contents [5], generally similar to the observations by [6,7]. We observed ~0.8‰ increase in δ^{25}Mg from Fo_{100} to Fo_{90} and made a correction for $Fo_{\sim99}$ by interpolating values between the two. However, more complex trend with abrupt changes around $Fo_{\sim97}$ was found [6,7] and if we apply this trend, the δ^{25}Mg values reported in this study are decreased by ~0.5‰.

Results and Discussion: Cathodoluminescence (CL) imaging of A/Ch#1 revealed at least 3 CL domains (CL-dark-core, CL-bright-mantle, CL-dark-rim) in olivine crystals. The O-isotope compositions are systematically different among the CL domains [2]. The CL-dark-core and CL-bright-mantle have ^{16}O-rich compositions (Δ^{17}O~ −24‰) similar to typical CAIs and AOAs, while CL-dark-rim region has ^{16}O-poor, chondrule-like compositions (Δ^{17}O~ −11 to −3‰). Thus CL-dark-core and CL-bright-mantle are relicts. δ^{18}O-imaging shows their O-isotope boundaries are sharp, comparable to spatial resolution of the imaging (~1 μm).

We obtained 15 Mg-isotope compositions from different parts of olivine crystals revealed by CL imaging (Fig. 1). Magnesium-isotope compositions are homogeneous in both δ^{25}Mg and δ^{26}Mg* (excess ^{26}Mg) within uncertainty (Fig. 2a) and no systematic differences are seen among the CL domains. The δ^{25}Mg values are ~1−1.2‰, consistent with those for chondrule olivines [8], but inconsistent with negative δ^{25}Mg values reported for AOA olivines [9]. All δ^{26}Mg* values are ~0. Similarly forsterite contents (Fo) are limited to a narrow range around $Fo_{\sim99}$, and not correlated with their δ^{25}Mg values (Fig. 2b).

Based on textures, minor element distributions, and O-isotope compositions, [2] concluded that original AOA materials experienced partial melting and transformation into the AOA/chondrule compound object during chondrule formation, and this transformation was accompanied by condensation of gaseous SiO into the initially ^{16}O-rich AOA melt and O-isotopic exchange with ^{16}O-poor gas. Magnesium-isotope compositions from ^{16}O-rich parts of olivines might be expected to have negative δ^{25}Mg values as all AOAs investigated by [9] have negative δ^{25}Mg (−3.9 to −0.4‰). However, we found all olivines have δ^{25}Mg ~1‰, consistent with those of olivines in Acfer 094 chondrules (+0.2 to +2.3‰) [8]. It seems this can be explained by homogenization of Mg-isotopes and Fo contents in olivine without significant changes in O-isotope compositions. Figure 3a shows diffusion rates of Mg, O and Fe-Mg interdiffusion in forsteritic olivine [10-12]. At high temperature, such as 1400˚C, diffusion rates of Mg and Fe-Mg are comparable, but are ~4 orders of magnitude faster than that of O. Figure 3b shows calculated time required to have diffusion distances of 0.1 and 1 μm for oxygen and 50 and 100 μm for Mg in forsteritic olivine. If olivine overgrowth onto relict AOA olivines crystallized under high temperature, such as ~1600˚C as [3] suggested, the object was kept for several hours to have diffusion distances of Mg and Fe-Mg of ~50−100 μm which are comparable/smaller than the largest olivine grains, while O diffusion distance is only <0.5 µm.

References: [1] Krot and Nagashima (2017) *Geochem. J.*, 51, 45−68. [2] Nagashima et al. (2019) *50th LPSC*, #2167. [3] Libourel and Portail (2018) *Sci. Adv.*, 4, eaar3321. [4] Teng (2017) *RiMG*, 82, 219−287. [5] Nagashima et al. (2020) *51st LPSC*, #1716. [6] Fukuda et al. (2019) *82nd MetSoc*, abstract#6204. [7] Fukuda et al. (2020) *Chem. Geol*. in revision. [8] Ushikubo et al. (2013) GCA, 109, 280−295. [9] Fukuda et al. (2019) *82nd MetSoc*, abstract#6206. [10] Ryerson et al. (1989) *JGR*, 94, 4105−4118. [11] Morioka (1981) *GCA*, 45, 1573−1580. [12] Tachibana et al. (2013) *Phys. Chem. Minerals*, 40, 511−519.

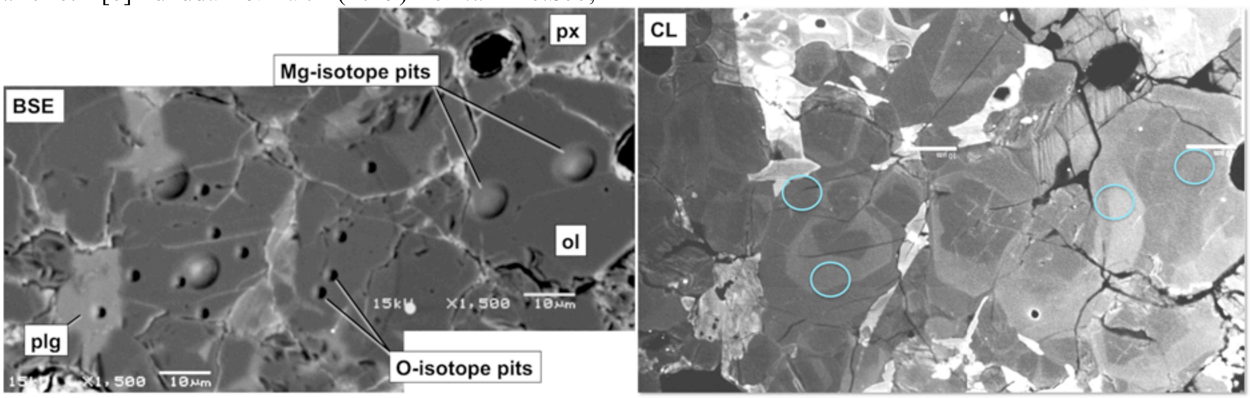

Fig. 1. BSE and cathodoluminescence (CL) images of a compound AOA/chondrule object, A/Ch#1 from Acfer 094 ungrouped type 3.00 meteorite. In the CL image, Mg-isotope analysis locations are indicated by light-blue circles.

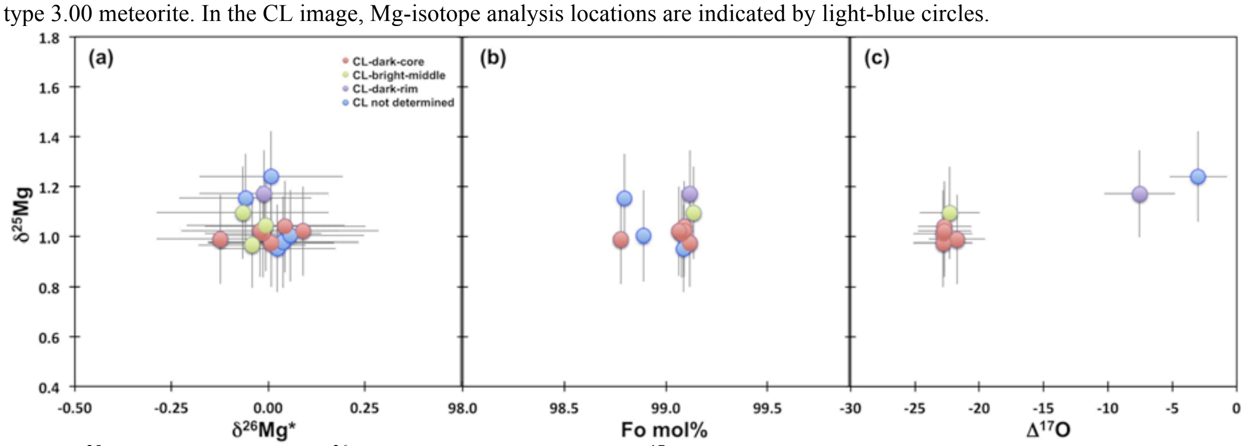

Fig. 2. δ^{25}Mg values against (a) δ^{26}Mg*, (b) Fo content, and (c) Δ^{17}O values in olivines. Note these comparisons are made with values taken from nearest measurement locations, not always from same locations.

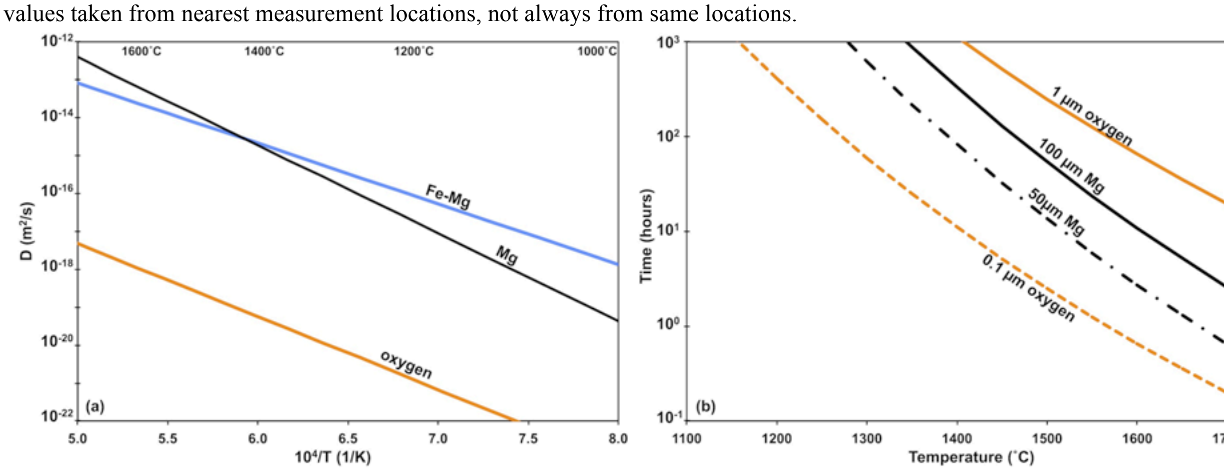

Fig. 3. (a) Diffusion rates of oxygen, magnesium, and Fe-Mg inter-diffusion in forsteritic olivine. The rates are from [10-12]. (b) Calculated time (hours) required to have diffusion distances of 0.1 and 1 µm for oxygen and 50 and 100 µm for Mg in olivine.