AL-MG CHRONOLOGY OF FEO-RICH (TYPE II) CHONDRULES FROM ACFER 094.

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Introduction: Chondrule ages, determined by ^{26}Al-^{26}Mg chronometry, range from ~ 1 to 3 Ma after CAI formation for pristine (type 3.0) chondrites, excluding CR chondrites [e.g., 1, and refs therein; 2]. In the case of the Y-81020 CO3 chondrite, initial ^{26}Al/^{27}Al ratios of FeO-poor (type I) chondrules are systematically higher than those of FeO-rich (type II) chondrules [3, 4], i.e., type II chondrules tend to be younger in Y-81020. This could represent a gradual change of redox conditions in the CO chondrule-forming region with time [4]. However, Y-81020 experienced some thermal metamorphism (type 3.05, [5]) that, although of very low grade, could have disturbed the Al-Mg systems of type II chondrules. This is because the diffusion coefficient of Mg in albite-rich plagioclase typical for type II chondrules is higher than that in the more anorthite-rich plagioclase of type I chondrules [6].

In contrast, chondrules in Acfer 094 (ungrouped, type 3.00, [5]) are unaffected by thermal metamorphism and initial ^{26}Al/^{27}Al ratios are likely undisturbed. Initial ^{26}Al/^{27}Al ratios of type I chondrules in Acfer 094 range from $(4.2 \pm 2.0)\times10^{-6}$ to $(9.0 \pm 1.5)\times10^{-6}$ with the majority of chondrules possessing initial ratios of ~ 5×10^{-6}, as determined by [7]. It should be noted that the chondrule with the highest ^{26}Al/^{27}Al ratio was relatively FeO-rich (Mg# ~92) chondrule fragment (G39) with a significantly higher Δ^{17}O value (~ –0.5‰) compared to the typical range for chondrules in Acfer 094 (from –6‰ to –2‰, [7, 8].

Taking advantage of the new RF plasma source [9], we performed Al-Mg isotope analyses of type II chondrules in Acfer 094 that were not analyzed previously because of small mesostasis areas (≤5 μm) with plagioclase. Our goals are to assess whether type II chondrule ages are resolvable from those of type I chondrules and whether there is a correlation of initial ^{26}Al/^{27}Al and oxygen isotope ratios.

Sample and Methods: Seven type II chondrules (6 IIA, Mg#: 70-87; 1 IIB, Mg#: 87) were selected for Al-Mg isotope analysis using the IMS 1280 at WiscSIMS, which was upgraded with the RF Plasma ion source. Before SIMS analyses, crystallinity of a representative subset of plagioclase grains was confirmed by Laser Raman analysis (JASCO NRS 1000 at NIPR) and the mineral chemistry of plagioclase (An: ~10-65 mol%) determined by EPMA analysis (Cameca SXFive, UW-Madison). To help aiming small plagioclase grains, areas of interest were first marked by depositing a thin Pt film (3×3 μm) and, subsequently, both underlying C coating and Pt film were removed by FIB milling by using the FEI Helios PFIB G4, UW-Madison. The resulting FIB mark (1 × 1 μm, Fig. 1a) was visible by ^{27}Al ion imaging and the primary beam was finely adjusted using the NanoDeflector of the SIMS instrument [10-12].

Plagioclase was analyzed using a 50 pA primary O_2^- beam (~3 μm diameter, critically illuminated) with 1 μm or 3 μm raster. This resulted in small roundish ~4 μm (Fig. 1b) or rectangular ~5 μm spots. Secondary ions were collected using three EMs; ^{24}Mg and ^{25}Mg on small EMs on multicollection array and ^{26}Mg on the axial EM detector. The $^{24}Mg^+$ intensities were typically at ~2-6 × 10^4 cps for both standard and unknowns. The $^{27}Al^+$ was measured on Faraday Cup (FC) on axial detector by peak switching. A single spot analysis took approximately 50 min. Analyses of olivine or pyroxene were obtained using a 1 nA O_2^- primary beam (~7 μm) and multicollection FCs with a secondary ^{24}Mg intensity of typically ~2 × 10^8 cps. Typical external reproducibility for excess δ^{26}Mg* (2SD) of the bracketing standard analyses was 1.5‰ (labradorite, 0.1 wt% MgO) for plagioclase and 0.1‰ (San Carlos olivine, En_{85}) for olivine/pyroxene analyses. Further analytical details are provided by [9].

For three chondrules which were not studied by [8] for oxygen isotopes, SIMS oxygen 3-isotope analysis of olivine was performed following procedures described in [13].

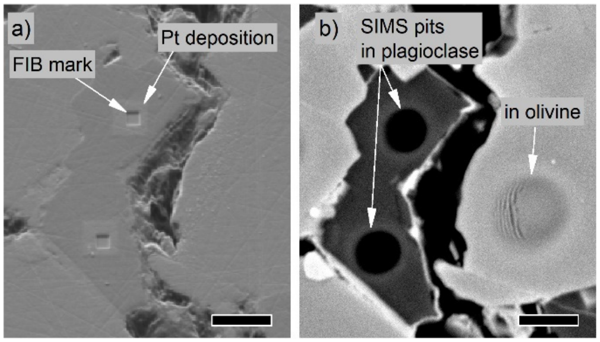

Fig. 1: (a) SE image showing thin film of Pt deposited on sample surface and FIB mark used for aiming primary ion beam by ion imaging and NanoDeflector [e.g., 11]. (b) BSE image showing 4μm (in plagioclase) and 6μm (olivine) SIMS pits. Scale bar: 5 μm.

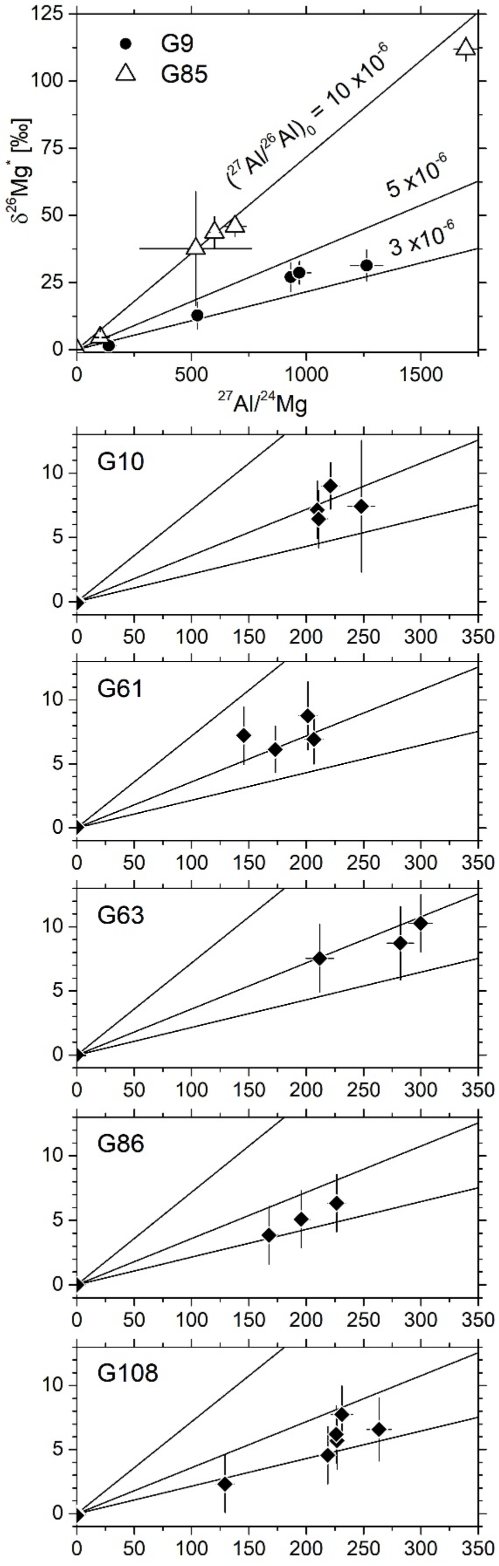

Fig. 2: δ^{26}Mg* (‰) and ^{27}Al/^{24}Mg ratios of plagioclase, olivine, and pyroxene (only G85) in type II chondrules of Acfer 094. Data is preliminary, hence, given initial ^{26}Al/^{27}Al ratios are generic and don't represent internal chondrule isochrones.

Results and Discussion: Oxygen isotope analysis of three type II chondrules (Mg# ~50-70) yield mean chondrule Δ^{17}O values of ~ –2‰ and are in line with preexisting data [8]. All analyzed chondrules contain plagioclase with resolvable excess δ^{26}Mg*. Plagioclase shows ^{27}Al/^{24}Mg ratios in between 100 and 300, except for Na-rich plagioclase (An: ~10-30 mol%) in chondrules G9 and G85 (up to 1700, Fig. 2). According to preliminary data reduction, initial ^{26}Al/^{27}Al ratios range from ~3×10^{-6} to ~5×10^{-6} for 6 chondrules; only G85 shows an initial ^{26}Al/^{27}Al ratio of ~1×10^{-5} that is significantly higher than 5×10^{-6} (Fig. 2). These ranges are within those previously reported for type I chondrules in Acfer 094 [7]. Interestingly, G85 (IIB) and G39 (IA fragment) both show similarly high ^{26}Al/^{27}Al ratios, high Δ^{17}O values (0‰ and –0.5‰, Fig. 3), and intermediate Mg#s (87 and 92). These 2 chondrules are minor constituents among Acfer 094 chondrules, in terms of redox state and oxygen isotopes, and might be derived from a distinct chondrule forming environment in respect to most chondrules in Acfer 094. Finally, in contrast to observation made in Y-81020 [3, 4], formation ages of type II chondrules are indistinguishable from those of type I chondrules in Acfer 094.

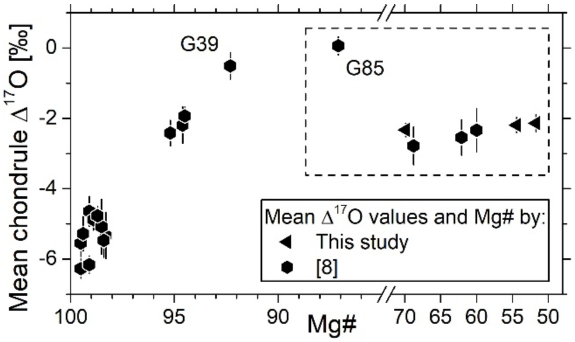

Fig. 3: Mean chondrule (host) Δ^{17}O values and Mg#s of dated type I and type II chondrules in Acfer 094. Dashed box marks chondrules dated by this study. Error bars represent propagated uncertainties of chondrule means (95% confidence level).

References: [1] Kita N. T. and Ushikubo T. (2012), *Meteorit. Planet. Sci.*, 47, 1108–1119. [2] Villeneuve J. et al. (2009), *Science*, 325, 985–988. [3] Kunihiro T. et al. (2004), *GCA*, 68, 2947–2957. [4] Kurahashi E. et al. (2008), *GCA*, 72, 3865–3882. [5] Kimura M. et al. (2008), *Meteorit. Planet. Sci.*, 43, 1161–1177. [6] van Orman J. A. et al. (2014), *EPSL*, 385, 79–88. [7] Ushikubo T. et al. (2013), *GCA*, 109, 280–295. [8] Ushikubo T. et al. (2012), *GCA*, 90, 242–264. [9] Kita N. T. et al. (2018), *this meeting*. [10] Nakashima D. et al. (2013), *EPSL*, 379, 127–136. [11] Nakashima D. et al. (2015), *EPSL*, 410, 54–61. [12] Defouilloy C. et al. (2015), *LPS 46*, #1415. [13] Kita N. T. et al. (2010), *GCA*, 74, 6610–6635.