AL-MG CHRONOLOGY OF ANORTHITE-BEARING CHONDRULES FROM UNEQUILIBRATED ORDINARY CHONDRITES: CLUES ON SHORT DURATION OF CHONDRULES FORMATION. G. Siron[1], K. Fukuda[1], M. Kimura[2], and N.T. Kita[1]. [1]WiscSIMS, University of Wisconsin-Madison, Madison, WI 53706, USA (siron@wisc.edu), [2]National Institute of Polar Research, Tachikawa, Tokyo 190-8518, Japan.

Introduction: The timing and duration of chondrule formation is a key information for the dynamical evolution of the early solar system. Chondrules in ordinary chondrites are considered to form within a short duration (≤0.1 Ma) [1, 2], which would prevent a large extent of mixing of materials in the protoplanetary disk [3]. The ^{26}Al-^{26}Mg chronology ($\tau_{1/2}$ =0.705 Ma) is a powerful means to determine relative ages of chondrules precisely [4]. While an earlier study on ferromagnesian chondrules in unequilibrated ordinary chondrites (UOCs) by [5] shows a short duration of their relative formation ages (<1 Ma), recent studies [6, 7] indicate a longer duration (~1.5 Ma).

Our goal is to determine the UOC chondrule ages with higher precisions (<0.1 Ma) than previous studies by taking advantage of the RF (radio-frequency) Plasma Ion Source at the WiscSIMS IMS 1280 that allow smaller and denser primary beam [8, 9]. Here we focus on anorthite-bearing chondrules in UOCs with low subtypes (3.01-3.05 [10]) to avoid resetting of the chronometer due to parent body metamorphism [4].

Sample and methods: 14 chondrules were selected from 5 UOCs for the study; 4 from QUE 97008 (L3.05), 4 from NWA 8276 (L3.05), 2 from NWA 8649 (LL3.05), 2 from Semarkona (LL3.01) and 2 from MET 00452 (LL3.05). Mineral chemistries were determined prior to SIMS analysis using EPMA.

Oxygen three isotopes and Al-Mg isotopes were analyzed using WiscSIMS IMS 1280 [e.g., 9, 11]. Oxygen three-isotope analyses of olivine, pyroxene, and plagioclase were obtained using 12 µm spots (2.5 nA) on multi-Faraday cup (FC) with a reproducibility (2SD) better than 0.3‰ for $\delta^{17,18}$O and Δ^{17}O. Mg isotope analyses of plagioclases were measured using a 0.2 nA O_2^- primary beam (diameter ~6 µm) with Faraday cup (FC) and electron multipliers (EMs) for simultaneous detection of ^{24}Mg and ^{25,26}Mg isotopes, respectively, which provide a precisions 0.4-0.7‰ δ^{26}Mg*. A few chondrules were also analyzed using 4 nA primary beam (15 µm) with multi-FC detectors with precisions ~0.4‰. Mg isotope analyses of olivine and pyroxene were obtained using a 1 nA primary beam (8 µm) on multi-FC with reproducibility of ~0.05‰ for δ^{26}Mg*. For each chondrule, 5-8 analyses of O isotopes, 6-12 plagioclase and 4 olivine/pyroxene analyses of Mg isotopes were obtained. Details of SIMS Al-Mg analytical conditions are described in [12].

Results: The olivine and pyroxene Mg# (molar [MgO]/[MgO+FeO] %) are between 76 and 97 and are generally in good agreement inside each chondrule. No secondary zoning was observed in olivine compositions. Plagioclase compositions are very close to pure anorthite with only two chondrules below An_{95} (An_{94} and An_{93}). Their MgO contents range is 0.5-1.0%, indicating high $CaMgSi_3O_8$ component in plagioclase. Mean plagioclases compositions from all chondrules exhibit silica excess, similar extents to those in CR chondrites and Acfer 094 [11], except for NWA 8649. Most of these chondrules resemble clast chondrule in [13] and FeO-rich (type II) plagioclase bearing chondrules in [14]. They show a wide range of Mg# and are depleted in Na compared to majority of type-II chondrules in UOCs [14].

The mean oxygen ratios of individual chondrules are shown in Fig. 1, which are similar to previous data from LL3.0-3.1 chondrules [14]. Anorthite-bearing chondrules plot closer to TFL (terrestrial fractionation line) with Δ^{17}O from –0.4 ‰ to +0.5 ‰. Oxygen isotope ratios in plagioclase were obtained from three chondrules and they are in good agreement with those of olivine and pyroxene in the same chondrule.

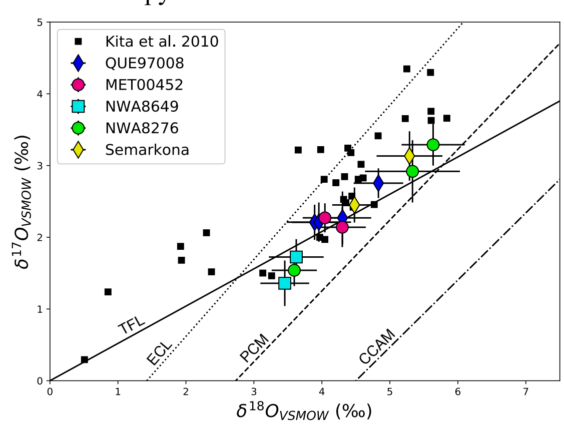

Fig. 1. Mean oxygen three-isotope ratios of individual anorthite-bearing chondrules in this study. Reference lines (ECL, PCM, CCAM) are from [15-17].

All chondrules exhibit resolvable δ^{26}Mg* in plagioclases with ^{27}Al/^{24}Mg ratios between 33 and 75. All chondrules but one show well-behaved ^{26}Al-^{26}Mg isochron data (MSWD: 0.37-1.8) with (^{26}Al/^{27}Al)$_0$ between (6.3±0.7)×10^{-6} and (8.9±0.3)×10^{-6}. Examples are shown in Fig. 2. One chondrule from NWA 8649 show a significant scatter in δ^{26}Mg* and with a MSWD value of 4.7, so that the inferred (^{26}Al/^{27}Al)$_0$ was not determined for the chondrule. Formation ages are calculated relative to CAIs between 1.80 ± 0.04 Ma and 2.16 ±

0.11 Ma by assuming homogeneous distribution of ^{26}Al with $(^{26}Al/^{27}Al)_0 = 5.252\times10^{-5}$ at t=0 [18]. The relative ages calculated for two chondrules separately by using Multi-FC and FC-EM plagioclase data gave consistent ages within errors (Fig. 3). The mean relative ages of 13 chondrules are 1.9 ± 0.1 Ma (SD, n=13). Chondrules in QUE 97008 gave systematically younger ages (2.0-2.2 Ma) than the rest of chondrites (1.8-2.0 Ma). No difference in chondrule ages between chondrite groups (L vs LL) nor chondrule types (I vs II) are found (Fig. 3). We do not find systematic changes in $\Delta^{17}O$ with ages.

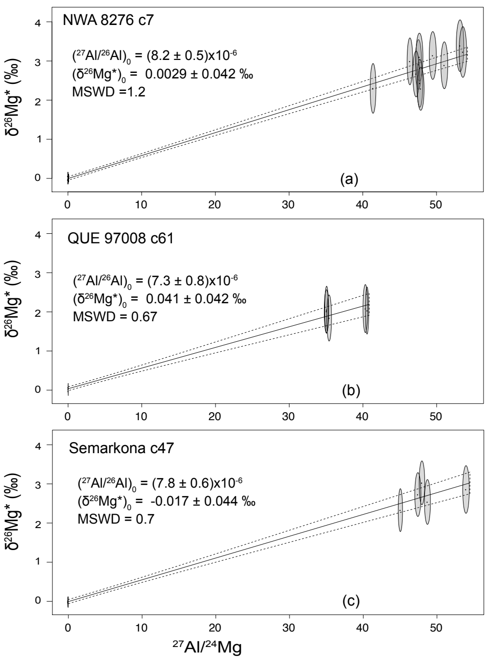

Fig. 2. Example of isochron ^{26}Al-^{26}Mg diagrams for three chondrules.

Discussion: The presence of excess silica for plagioclases in almost all chondrules and well-behaved ^{26}Al-^{26}Mg isochron (MSWD~1) are good indicators that the extent of parent-body metamorphism was not significant. Additionally, the consistency between FC-FC and FC-EM determined ages highlight the accuracy of the present analytical methods. Therefore, the robust and high precision (<0.1 Ma) ^{26}Al-^{26}Mg relative ages clearly show that UOC chondrule formation lasted less than 0.4 Ma and did not exceed 2.2 Ma after CAIs. This range is in agreement with the peak value of the oldest ages among UOC chondrules determined by [6] and [7], respectively. Thus, our new dataset from the anorthite-bearing chondrules may represent the age distribution of UOC chondrules in general. Based on small uncertainties of the relative ages, at least two or possibly more episodes of chondrule formation occurred over a duration of 0.4 Ma. Ages of the youngest two chondrules form QUE97008 (c143 and c150) are resolved from those of eight older chondrules beyond their uncertainties. Relative ages of other chondrules range from 1.8 Ma to 2.0 Ma with significant error overlap. However, data from several chondrules are clearly distinguished beyond the uncertainties. There seems to be no clear gap(s) in the distribution of relative ages.

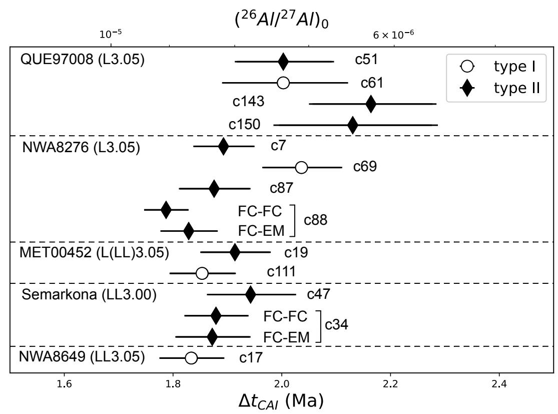

Fig. 3. Inferred $(^{26}Al/^{27}Al)_0$ and relative ages after CAIs for the studied chondrules.

Implication: New high precision SIMS ^{26}Al-^{26}Mg data clearly show that the timescale for UOC chondrule formation was much shorter than previously reported [6-7]. The short duration of these chondrule ages suggests that disk radial transport was very limited for the L/LL chondrite forming regions [3]. New dataset highlight that the timescale is longer than 0.1 Ma, in contrast to the prediction from the extremely high dust density for chondrule formation [1].

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