CONTEMPORANEOUS FORMATION OF CHONDRULES IN THE ^{26}AL-^{26}MG SYSTEM FOR ORDINARY AND CO CHONDRITES. E. Kurahashi[1,2], N. T. Kita[2], H. Nagahara[1], Y. Morishita[2], [1]Department of Earth and Planetary Science, University of Tokyo, [2] Micro-scale Isotope Geochemistry Group, Institute of Geoscience, Geological Survey of Japan, AIST, Tsukuba Central 7, Tsukuba 305-8567, Japan (kurahashi-erika@aist.go.jp)

Introduction: Chronometer using the short-lived extinct-nuclide ^{26}Al has been applied to chondrules in order to obtain of their formation ages. Previous studies were mostly performed on Al-rich chondrules [1-4], which constitute only 1% of all chondrules, because of their high Al/Mg ratios. Recently, ^{26}Al ages of major ferromagnesian chondrules in least equilibrated ordinary chondrites (OC) have been obtained [5-7]. However, ^{26}Al ages of ferromagnesian chondrules in least equilibrated carbonaceous chondrites (CC) are very limited [8-10]. Particularly, age data of FeO-poor (Type I) chondrules in CC have been scarcely obtained, because of their fine textures and lack of phases with high Al/Mg (>100) ratios. In order to clarify the origin and formation processes of chondrules, we started systematic investigations on Type I chondrules in the most pristine CC (CO3.0 Yamato-81020) [11, 15, 16], by examining textures, bulk chemical compositions, ^{26}Al ages and oxygen isotopic compositions. We find Type I chondrules in CC formed contemporaneously with ferromagnesian chondrules in OC.

Analytical Techniques: The Al-Mg isotopic analysis was performed using a secondary ion mass spectrometer (SIMS) Cameca IMS-1270 at the Geological Survey of Japan (GSJ). Analytical procedure is similar to [5, 7], except that we used O^- primary ion beam with reduced sizes of 3μm for anorthite in mesostasis (single collector mode), and 5μm for olivine and pyroxene (multi-collector mode). In order to detect a small ^{26}Mg-excess with a few permil levels, most analyses for anorthite took 4-6 hours per position. Petrographic observation of individual chondrules was carried out using an optical microscope and an electron microprobe (EPMA). Bulk chemical compositions of the chondrules were obtained using EPMA by averaging about 500 points per chondrule. More detailed analytical technique is shown in [12].

Mineralogy and Petrography: All Type I chondrules consist of forsteritic olivine (Fo_{91-100}), low-Ca pyroxene with anorthite (An_{84-100}) and high-Ca pyroxene in mesostasis, associated with various amounts of rounded to irregular Fe-Ni metal and/or FeS grains. Y1 is a barred olivine chondrule. Y2, Y3, Y10 are very close to anorthite-rich chondrules in CR chondrites [13], which have anorthite-rich mesostasis at the center containing small forsteritic olivine grains. Y23, Al-rich chondrule (Al_2O_3 23.6wt%), mainly consists of high-Ca pyroxene and anorthite (An_{99}) with small euhedral forsteritic olivine (Fo_{97-99}) grains. Other characteristics of the chondrules are shown in Table 1.

^{26}Al-^{26}Mg ages: We examined eleven Type I chondrules and one Al-rich chondrule for Al-Mg isotopic analysis. Although most Type I chondrules have low Al/Mg ratios (Al/Mg = 20-40), we succeeded in detection of few permil level ^{26}Mg-excesses in all chondrules with sufficient precision (0.5-1‰). The data are summarized in Table 1 and Figure 1. The initial $^{26}Al/^{27}Al$, $(^{26}Al/^{27}Al)_0$, of the chondrules fall in the range between $(5.1+/-2.2)\times10^{-6}$ and $(1.4+/-0.3)\times10^{-5}$ for Type I chondrules and $(3.1+/-1.4)\times10^{-6}$ for Al-rich chondrule. Assuming that the ^{26}Al was homogeneously distributed in the early solar system, the formation ages of the chondrules after CAIs are calculated relative to CAIs with canonical $^{26}Al/^{27}Al$ ratio of 5×10^{-5} [14], resulting in 1 to 2.5 Myr for Type I chondrules and ~3 Myr for Al-rich chondrule.

Discussion: In order to clarify the origin and formation processes of the early solar system, it is very important to study pristine meteorite samples showing unaltered textures and compositions. We chose CO3.0 Yamato-81020 for our ^{26}Al-^{26}Mg systematic investigation, because the sample was known as the least metamorphosed CC by previous studies [11, 15, 16]. Most chondrules in this meteorite show scarce alteration in their mesostasis without nepheline replacing anorthite. This may be a reason that the ^{26}Mg-excesses were preserved in all chondrules analyzed in this work.

^{26}Al ages of Type I chondrules in Yamato-81020 are older than those for Type II (FeO-rich) chondrules in the same meteorite (2.6-3.0Myr after CAIs formation) [9]. Although two ferromagnesian olivine chondrules in Ningqiang (ungrouped CC) have slightly younger ^{26}Al ages of 2-3Myr [10], these data could be affected by mild thermal metamorphism (subtype 3.3) [17]. In fact, one POI in the same meteorite showed the disturbed ^{26}Al-^{26}Mg system [18].

It should be noted that the range of ^{26}Al ages is almost the same as those of ferromagnesian chondrules in the least equilibrated OC (LL3.0 Semarkona and LL3.1 Bishunpur), that is 1-2.5Myr [5-7]. Thus, Type I chondrules in CC formed contemporaneously with ferromagnesian chondrules in OC. We do not observe any correlation among ages of Type I chondrules and their textures or compositions, such as mineral assemblages, size distributions, bulk chemical compositions, and abundance of metal grains. This suggests that chondrule formation occurred by random sampling of their precursors during 1-2.5Myr after CAIs formation in Type I CC chondrule forming region. This is different from the case of OC ferromagnesian chondrules, which show correlation of ^{26}Al ages with their bulk Mg/Si ratios, though the data are obtained mostly from Type II (FeO-rich) chondrules [12]. On the basis of the similarity in bulk chemical compositions, Type I chondrules in CC can be related to amoeboid olivine aggregates (AOAs) [19]. Considering that AOAs from the same meteorite with $(^{26}Al/^{27}Al)_0=(2\text{-}3)\times10^{-5}$ (0.1-0.5Myr) [20], Type I chondrules in CC could evolved using AOAs as one of their precursors. On the other hand, forming age of Y23 Al-rich chondrule is 2.9(-0.4/+0.6)Myr, which is clearly younger than those of Type I chondrules. An Al-rich chondrule from Axtell (CV3) AXCH-1471 [4] has very close bulk composition to Y23 with indistinguishable ^{26}Al age of 2.8(-0.4/+0.6)Myr after CAIs formation. Bulk chemical compositions of these Al-rich chondrules are close to those of Type C CAIs and plagioclase-olivine inclusions (POIs) [21, 22]. The initial $^{26}Al/^{27}Al$ ratios were $(3\text{-}6)\times10^{-6}$ (2-3Myr) [14, 22], which is similar to or slightly older than the Al-rich chondrules. Therefore, Al-rich chondrules in CC might evolve from Ca-Al-rich objects, likely Type C CAI and POIs, later than the formation of Type I chondrules. Variations of oxygen isotopic compositions among ferromagnesian chondrules, Al-rich chondrules, AOAs, POIs, and CAIs in CC [20, 23-25] indicate Type I and Al-rich chondrules in CC might form by mixing of ^{16}O-poor Si-rich gas with AOAs and CAIs/POIs, respectively.

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Table 1 Summary of petrology and Mg isotopic data for individual chondrules in Yamato-81020

Chondrule	Chondrule type	Size [μm]	Mineral*	$^{27}Al/^{24}Mg$	$(^{26}Al/^{27}Al)_0$ [10^{-5}]	Relative age to CAIs [Myr]
Y10	Type I	230	Ol, Hpx, Lpx, An, metal	21-32	1.41+/-0.33	1.3(-0.2/+0.3)
Y20	Type I	290	Ol, Hpx, Lpx, An, metal	37-39	1.18+/-0.12	1.5(-0.1/+0.1)
Y24	Type I	650	Ol, Hpx, Lpx, An, metal	29-32	1.20+/-0.15	1.5(-0.1/+0.1)
Y29	Type I	590	Ol, Hpx, Lpx, An, metal	23-27	1.05+/-0.20	1.6(-0.2/+0.2)
Y8	Type I	100	Ol, Hpx, Lpx, An, metal	23-28	1.09+/-0.24	1.6(-0.2/+0.3)
Y3	Type I	380	Ol, Hpx, Lpx, An, metal	25-27	1.11+/-0.35	1.6(-0.3/+0.4)
Y12	Type I	230	Ol, Hpx, Lpx, An, metal	33-35	0.95+/-0.22	1.8(-0.2+/0.3)
Y9	Type I	315	Ol, Hpx, Lpx, An, metal	41-63	0.73+/-0.20	2.0(-0.3/+0.3)
Y2	Type I	230	Ol, Hpx, Lpx, An, metal	28-29	0.58+/-0.20	2.3(-0.3/+0.4)
Y1	Type I	435	Ol, Lpx, An, metal	91-128	0.57+/-0.17	2.3(-0.3/+0.4)
Y17	Type I	280	Ol, Hpx, Lpx, An, metal	29-35	0.51+/-0.22	2.4(-0.4/+0.6)
Y23	Al-rich	180	Ol, Lpx, An	145-167	0.31+/-0.14	2.9(-0.4/+0.6)

*Ol: olivine, Hpx: high-Ca pyroxene, Lpx: low-Ca pyroxene, An: anorthite

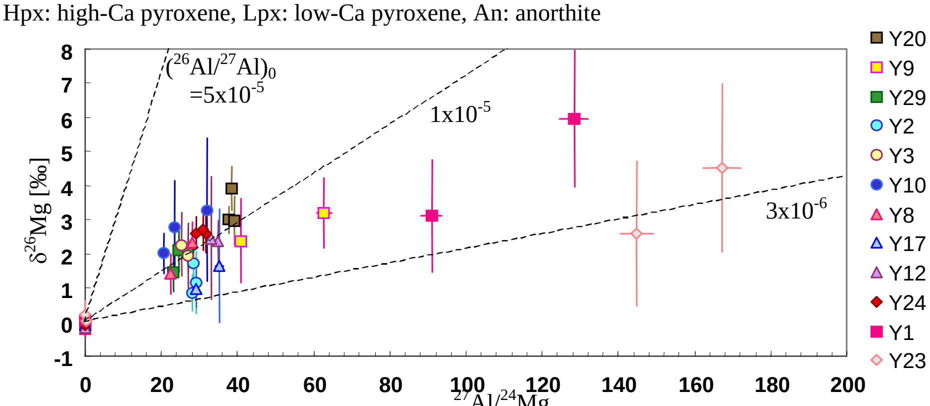

Figure 1 ^{26}Al-^{26}Mg diagram for Type I chondrules and Al-rich chondrules in Yamato-81020.