CORRELATION BETWEEN ALUMINUM-26 AGES AND BULK SI/MG RATIOS FOR CHONDRULES FROM LL3.0-3.1 CHONDRITES. N. T. Kita[1, 2], S. Tomomura[3], S. Tachibana[3], H. Nagahara[3], S. Mostefaoui[4] and Y. Morishita[2], [1]Department of Geology and Geophysics, University of Wisconsin-Madison (1215 W. Dayton, Madison, WI 53706-1692 (noriko@geology.wisc.edu), [2]Geological Survey of Japan, AIST, Tsukuba 305-8567, Japan, and [3]Department of Earth and Planetary Science, University of Tokyo, Hongo, Tokyo 113-0033, Japan, [4]Max-Planck-Institute for Chemistry (Otto-Hahn-Institut), Becherweg 27, D-55128 Mainz, Germany.

Introduction: Recently, the ^{26}Al-^{26}Mg analyses were performed for many chondrules from least equilibrated chondrites by using ion microprobe [e.g., 1-3]. The initial ^{26}Al/^{27}Al ratios of these chondrules are between 1.5×10^{-5} and 3×10^{-6}, 1-3 million years (Myr) younger than CAIs with the canonical initial ratios of 5×10^{-5} [4]. Similar age differences between CAIs and chondrules are also reported from absolute Pb-Pb ages [5]. Thus, the initial ^{26}Al/^{27}Al ratio of the solar system is considered to be homogeneous for applying the ^{26}Al-^{26}Mg chronometer.

In the systematic study of chondrules from LL3.0-3.1 chondrite, Mostefaoui et al. [2] first indicated that olivine-rich chondrules tend to be older than pyroxene-rich ones. This was the first observation of a correlation between ^{26}Al ages and chondrule compositions. Bulk analyses of the same chondrules lead Tachibana et al. [6] to further concluded that the ^{26}Al ages correlate with chondrule bulk Si/Mg ratios as well as with volatile element (Mn, Cr, and Na) contents. However, many analyses done by the previous studies [1-2] have large errors (≥1 Myr) compared to the whole range of age variation (1-2Myr), which made the correlation less convincing. In this study, we have improved analytical precisions of ion microprobe analyses and obtained both new and re-measured data in order to better constrain the age-composition correlation. A part of the new data set was reported in [7].

Ion Microprobe analyses of chondrules: We made efforts in reducing analytical errors of the ^{26}Al-^{26}Mg system by (i) increasing secondary ion sensitivities, (ii) careful evaluation of detector dead time, and (iii) reducing the beam sizes down to 3 μm in order to analyze narrow mesostasis areas with high Al/Mg ratios [3]. In order to obtain higher primary oxygen ion beam, we now use O^- instead of O_2^- even though secondary Mg ionization efficiency is known to be higher by using O_2^- primary beam [1].

We analyzed seven chondrules from two thin sections of Bishunpur and Krymka (M3816 and L3802, respectively, allocated from Natural History Museum in Vienna). Three chondrules from Bishunpur (B1C4, B1C18, B1C56) are those analyzed previously by [2] and four from Krymka (K02, K16, K21. K27) are newly described by [7]. They are mostly type II chondrules with variable Si/Mg ratios (0.86-1.5×CI chondrites; Table 1).

Results: The results of the analyses are shown in isochron diagram (Fig. 1). Both new and re-measured chondrule data show well-resolved ^{26}Mg-excesses ranging between 2 and 17‰, with better precisions compared to the previous work [2]. Exceptions are data from K02 and one point in K16, which show no detectable ^{26}Mg-excess. Data from K16 show a negative slope, suggesting the Al-Mg system was disturbed after ^{26}Al had decayed. These chondrules are located within 1mm from the fusion crust, and so that it could be disturbed recently during the fall of the meteorite on earth.

For five other chondrules, the initial ^{26}Al/^{27}Al isotopic ratios were calculated from data including those obtained in [2] by assuming normal Mg isotopic ratios at the origin. These results are within a range of previous measurements. The re-measured chondrule data agrees with those in [2] within the analytical errors. Because of reduced primary beam size in order to avoid Mg-rich phase, re-measured chondrules show ^{27}Al/^{24}Mg ratios higher than in [2], which also helped improve the precision of the slope. The errors of initial ^{26}Al/^{27}Al ratios are 10-20% for most cases, significantly reduced from previous studies (30-50% in [1-2]). The ^{26}Al ages of chondrules relative to CAI formation (5×10^{-5} [4]) are between 1.5-2.2 Myr (Table 2).

Discussion: These ages as well as other ion microprobe Al-Mg ages (e.g., [3]) are significantly younger than those recently suggested by [9] from the bulk ICP-MS analyses of chondrules in Allende (0-1.5 Myr after CAIs [9]). One exception is Bishunpur B2C1 showing an age of ~0.8Myr younger than CAIs [2], though data were obtained from low ^{27}Al/^{24}Mg phases (~30) and needs to be re-measured. The ion microprobe data are from mesostasis glass and/or plagioclase, which might be solidified from melt during the last chondrule melting. The chronological interpretation of bulk chondrule data is not clear; there might be a mechanical mixing of old CAI components or it may correspond to the time of closure for isotopic exchange with external environments. If there were early-formed chondrules as suggested by [9], the ion microprobe results would indicate that they were nearly completely recycled by later formed chondrules after 1.5 Myr.

As a revision of Fig. 4a in [6], we reported ^{26}Al ages of chondrules versus the bulk Si/Mg ratios in Fig. 2. The revised data distribute along a negative slope and are consistent with the previous suggestion that the bulk Si/Mg ratios of LL chondrule increased with time. However, the slope of the negative correlation is smaller than that in the previous work. A time span of less than one million year is found between Mg-rich ones and Si-rich ones. We need more data, especially among the type I chondrules, in order to increase statistics to confirm the present results.

To explain time dependent enrichments of Si and other volatiles (Mn, Cr, and Na) in bulk compositions of chondrules, Tachibana et al. [6] suggested an open system behavior of these elements during chondrule heating events; selective evaporation/recondensation of Si and other volatiles over Mg and physical separations of newly formed volatile-poor chondrules from volatile-rich recondensates and gas. Bulk compositions of 80 randomly selected chondrules in LL3.1 [7] also indicate a fair correlation between Si/Mg and Mn/Cr ratios. Therefore, we may also expect that bulk Mn-Cr system of LL3 chondrules show an isochron consistent with ^{26}Al ages, i.e., a formation age of about 2 Myr after CAIs. So far, bulk Mn-Cr isochron data indicate the ages that are both similar to CAI formation (from Bishunpur and Chainpur [10]) and ~2 Myr younger than CAIs (from Semarkona, Nyquist et al., unpublished), but errors are as large as ~2 Myr. Further comparison between these two systems is a key to understand the chemical fractionation among chondrules in ordinary chondrites.

References: [1] Kita, N. T. et al. (2000) *GCA 64*, 3919-3922. [2] Mostefaoui, S. et al. (2002) *Meteorit. Planet. Sci. 37*, 421-438. [3] Kurahashi, E. et al. (2004) *LPS XXXV*, Abstract# 1476. [4] MacPherson, G. J. et al. (1995) *Meteoritics 30*, 365-386. [5] Amelin, Y. et al. (2002) *Science 297*, 1678-1683. [6] Tachibana, S. et al. (2003) *Meteorit. Planet. Sci. 38*, 939-962. [7] Tomomura, S. et al. (2004) *LPS XXXV*, Abstract# 1555. [8] Hutcheon, I. D. and Hutchison R. (1989) *Nature 337*, 238-241. [9] Bizzarro, M. et al. (2004) *Nature 431*, 275-278. [10] Nyquist, L. et al., (2001) *Meteorit. Planet. Sci. 36*, 911-938.

Table 1. List of chondrules analyzed for Al-Mg system.

Sample	Type and description	Si/Mg*
K02	IIA: Fo_{84-56}, En_{72}, glass	1.02
K16	IAB: Fo_{92}, En_{97}, glass	0.98
K21	IIA: Fo_{84-76}, En_{82-76}, An_{89}	0.77
K27	IIB: Fo_{83}, En_{75}, glass	1.48
B1C4	IIAB: Fo_{83}, En_{83}, An_{91}	0.86
B1C18	IIAB: Fo_{77}, En_{77}, An_{89}	1.02
B1C56	IIB: Fo_{84-78}, En_{88-78}, An_{43-3}	1.26

*Normalized to CI ratios.

Table 2. The ^{26}Al ages relative to CAI formation (Myr).

Sample	This work	Previous work [2]
K21	1.74 (-0.13/+0.15)	
K27	2.22 (-0.26/+0.34)	
B1C4	1.51 (-0.19/+0.23)	1.3 (-0.4/+0.7)
B1C18	1.9 (-0.4/+0.7)	1.8 (-0.7/+2.9)
B1C56	1.74 (±0.10)	1.3 (-0.4/+0.7)

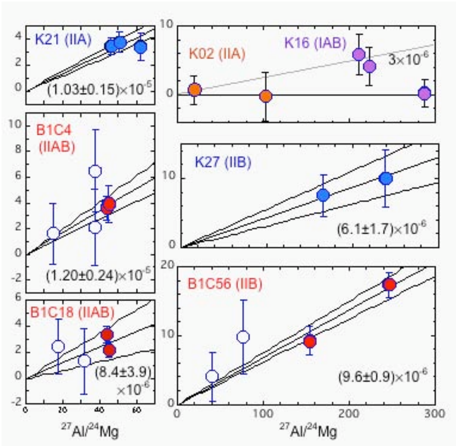

Fig. 1. Al-Mg isochron diagrams and the initial $^{26}Al/^{27}Al$ ratios for chondrules from Krymka and Bishunpur (LL3.1). Filled and open symbols are from this work and [2], respectively.

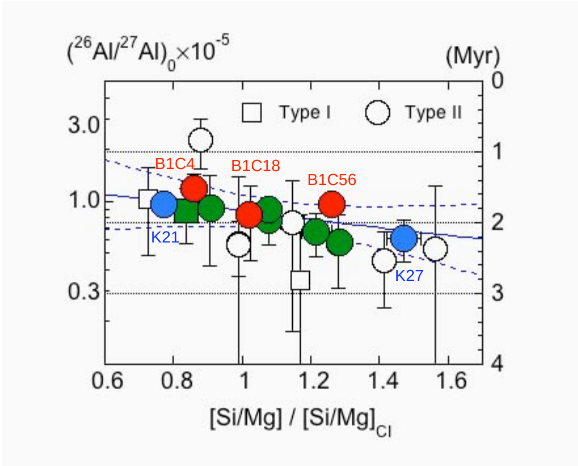

Fig. 2. The correlation of ^{26}Al ages of chondrules with their CI normalized bulk Si/Mg ratios. Filled green; Semarkona [1, 8], filled red and blue; Bishunpur and Krymka (this work), respectively, and open symbols; Bishunpur [2].