RELATIONSHIP BETWEEN BULK CHEMICAL COMPOSITION AND FORMATION AGE OF CHONDRULES IN BISHUNPUR AND KRYMKA. S. Tomomura[1], H. Nagahara[1], S. Tachibana,[1] N. T. Kita[2], and Y. Morishita[2]. [1]Department of Earth and Planetary Science, University of Tokyo, 7-3-1 Hongo, Tokyo 113-0033, Japan, [2]Geological Survey of Japan, AIST, AIST Tsukuba Central 7, Tsukuba 305-8567, Japan. (tomo24@eps.s.u-tokyo.ac.jp).

Introduction: Chondrules, the major component of chondrites, were solidified by rapid cooling of molten precursor materials in the early solar system. There still remain some enigmas for the chondrule formation events. Recent studies have shown that ferromagnesian chondrules in unequilibrated ordinary chondrites formed 1-3 Myr later than calcium-aluminum-rich inclusions (CAIs) [1, 2]. [3] reported that there may be a correlation between ^{26}Al-^{26}Mg relative formation ages and bulk chemical compositions, in particular Si/Mg ratios, of ferromagnesian chondrules in unequilibrated ordinary chondrites (Semarkona and Bishunpur). They proposed that younger chondrules tend to have higher Si/Mg ratios. Although such a correlation between ages and chemical compositions may provide an important constraint on chondrule formation events or even the chemical evolution of the early solar system, the number of chondrules reported in [3] is only sixteen, which is not enough for comprehensive discussion. For better understanding of the age-composition correlation of chondrules, we have started a systematic study for bulk chemical compositions and ^{26}Al-^{26}Mg ages of chondrules from unequilibrated ordinary chondrites. Here we report bulk chemical compositions of 89 chondrules and age data for some chondrules as part of a broader study.

Samples and analyses: We chose all the chondrules in two polished thin sections of least equilibrated ordinary chondrites, Bishunpur and Krymka (both LL3.1). The non-biased selection of all the chondrules was to make statistical discussion. Bulk chemical analyses have been done for 52 and 37 chondrules in Bishunpur and Krymka, respectively, with an electron microprobe. For each chondrule, 480-580 point analyses, covering the entire silicate area of the chondrule, were done for oxides (SiO_2, Al_2O_3, TiO_2, FeO, MnO, MgO, CaO, Na_2O, K_2O, and Cr_2O_3 for all chondrules and V_2O_3 and NiO for some chondrules). The mean of the point analyses, except for data of which total wt% is not within the range of 95-105 wt%, is reported as the bulk oxide composition for each chondrule.

A Secondary Ion Mass Spectroscopy (Cameca IMS-1270 at the Geological Survey of Japan) is used for the Al-Mg isotopic analyses. Analytical procedure is similar to [1] except that we used 3 μm beam size for most of the analyses. Two to three spots of glassy mesostasis or plagioclase with high Al/Mg ratios have been measured for each chondrule. The formation ages of chondrules are obtained relative to CAIs formation with canonical $^{26}Al/^{27}Al$ ratio of 5×10^{-5} [4].

Petrography: Four chondrules from Krymka were studied with ion microprobe. A type II chondrule K02 (500 x 400 μm) consists of large olivine phenocrysts (Fo_{84}-Fo_{56}) (100-300 μm), occupying 70% of the entire area, and glassy mesostasis with acicular Ca-rich pyroxene crystals. K16 is a small type I chondrule (200 x 200 μm), which consists of small pyroxene phenocrysts (En_{97}) with a small amount of glassy mesostasis. It contains some metal grains near the rim. A type II chondrule K21 (1.5 x 2.0 mm) is the largest chondrule among the chondrules studied. It contains equal amounts of olivine (Fo_{84}-Fo_{76}) and pyroxene (En_{82}-En_{76}) with a small amount of plagioclase (An_{89}). A type II chondrule K27 (1.0 x 0.8 mm) contains pyroxene (64%) and olivine (20%) phenocrysts, glassy mesostasis (16%) and a few relatively large irregular-shaped troilite grains. There are many small acicular Ca-rich pyroxene crystals in glassy mesostasis.

Results: The 89 chondrules studied consist of 80 ferromagnesian porphyritic chondrules (46 type I (FeO-poor) and 32 type II (FeO-rich)), 8 ferromagnesian non-porphyritic (1 barred olivine and 7 radial pyroxene), and 3 Al-rich chondrules. Olivine/pyroxene ratios and FeO contents of phenocrysts are variable, and bulk chemical compositions of chondrules approximately cover the range of ferromagnesian chondrules in unequilibrated ordinary chondrites reported by [3, 5-8].

The averages of all the chondrules normalized to CI abundances have no difference between Bishunpur and Krymka for both type I and type II porphyritic chondrules.

Bulk compositions (wt%) of major elements of 89 chondrules are shown in the ternary diagram of MgO-SiO_2-(Al_2O_3+CaO) (Fig. 1). Upper scattered data are of Al-rich chondrules. Neither type I nor type II chondrules show a wide range for refractory element contents. However, they have a wide range in MgO-SiO_2 (SiO_2 = 45-65 wt%). The plots do not lead to the kinetic evaporation paths in vacuum [9].

Isochrons for the Al-Mg isotopic system show that the formation ages of chondrules to CAIs are 1.74

(+0.15/-0.13) Myr for K21 and 2.22 (+0.34/-0.26) Myr for K27. Two other chondrules near the fusion crusts show isotopic compositions with disturbance, which are not shown here. We added data from K21 and K27 in the figure of bulk chemical composition-relative formation age by [3] (Fig. 2).

Discussion: The age data from K21 and K27 seem to be consistent with the correlation proposed in [3]. The age-composition (Si/Mg) relationship is newly obtained on the basis of Fig. 2, which gives $\Delta t_{CAI\text{-}chondrule}$= 1.4-2.6 Myr. Silicon to Mg ratios for the 89 chondrules in the present study is converted to relative formation age of those chondrules (Fig. 3). They appeared to have been formed 1.4-2.6 Myr after CAIs and clustered at 1.9-2.0 Myr. If we consider recycling of chondrules, the ages older than the peak may not represent the actual formation frequency. Thus we can conclude that chondrules were formed continuously from about 1.4 to 2.6 Myr after CAIs formation but that it declined significantly after 2.0 Myr after CAIs. The age may well coincide with the evolution of the solar nebula when the turbulent solar nebula got into quiet stages.

Bulk compositions of both type I and type II chondrules (Fig. 1) cannot be explained by a simple evaporation process from the CI composition, suggesting that some other processes are required to produce the chemical diversity of the chondrules [11]. The process proceeded repeatedly with the evolution of the solar system resulting in the relationship shown in the present study.

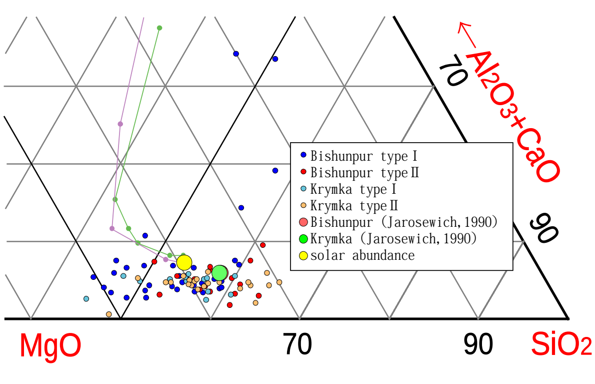

Fig. 1. Bulk compositions (wt%) of major elements of 89 chondrules in the ternary diagram of MgO-SiO_2-(Al_2O_3+CaO). The green and purple lines are kinetic evaporation paths at 1800°C and 2000°C, respectively [9]. The solar abundance and compositions of bulk Bishunpur and Krymka [10] are also shown.

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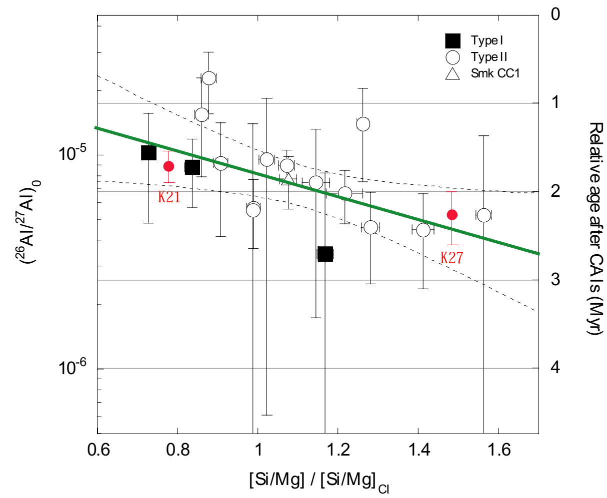

Fig. 2. Relative ages (and initial $^{26}Al/^{27}Al$ ratios) plotted against CI normalized bulk Si/Mg ratios of chondrules from UOCs [3]. Two red circles show data for K21 and K27. The green line is the regression for the correlation between relative ages and bulk Si/Mg.

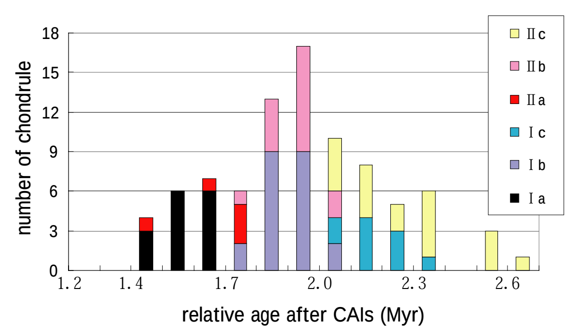

Fig. 3. The estimated age-distribution of chondrules based on the age-composition correlation in Fig. 2. Chondrules show the age distribution ranging from 1.4 to 2.6 Myr after CAIs with a peak at 1.9-2.0 Myr. Subtypes of a, b and c represent $[Si/Mg]_{sample}/[Si/Mg]_{CI}$ of <0.9, 0.9-1.1 and >1.1, respectively.