PETROLOGICAL STUDIES OF TYPE I CHONDRULES IN PRIMITIVE CR CHONDRITES.

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Introduction: Systematic diversities in physical, chemical and isotope properties of chondrules among different chondrite groups are still a puzzle. In order to get a better understanding of the evolution of chondrule formation, systematic investigations of petrology and isotope studies of individual chondrules are required. Precise chondrule formation ages have been obtained from primitive chondrites using ^{26}Al-^{26}Mg systematics (a half-life 0.73 Ma), ranging 1-3 Ma for L, LL and CO [1-3], and 2-4 Ma for CR chondrites [4, 5] after CAI formation with the initial ^{26}Al/^{27}Al of 5×10^{-5} using Secondary Ion Mass Spectrometry (SIMS). However, ^{26}Al ages of bulk chondrules in a CV chondrite with Inductively Coupled Plasma Mass Spectrometry (ICPMS) show older formation ages (0-1 Ma after CAIs) [6] than the data by SIMS. In the SIMS studies, Al-rich phases in mesostasis, such as glass and plagioclase, were measured for Mg isotopes, which times the final solidification event. On the other hand, Mg isotopes of bulk chondrules have a possibility of timing of the formation of chondrule precursors. Our goal is to determine timing of formation of chondrule precursors and chondrule final heating in the same chondrule. Systematic Mg isotopes and petrological studies of chondrules in primitive ordinary and carbonaceous chondrites have been carried out. Before isotope studies, we have performed detail petrologic studies of individual chondrules to evaluate whether each chondrule was suffered secondary metamorphism and/or alteration after chondrule formation or not. In the present study, we show petrologic properties including bulk chemical compositions of individual chondrules from CR chondrites and compare the results with those of other carbonaceous chondrites (CO3.0 Yamato-81020 and CV3 Efremovka [7]).

Samples and methods: Four CR chondrites are used in this study; CR2 Elephant Moraine (EET) 92174, CR2 Northwest Africa (NWA) 1567, CR2 NWA 852 and CR/CV3 Sahara 00182. Petrological observation of chondrules was carried out under SEM and EPMA. The bulk chemical compositions of chondrules were obtained by quantitative analysis with EPMA by averaging around 500 points per chondrule at the acceleration voltage of 15kV using a focused beam current of 12nA [7, 8].

Petrological descriptions: Observation of textures, mineral composition, and bulk elemental abundance of 8 chondrules from NWA 1567, 2 chondrules from NWA 852, 2 chondrules from EET 92174 and 7 chondrules from Sahara 00182 have been obtained so far. All chondrules observed are magnesium-rich (Type I) chondrules and contain forsteritic olivine, orthopyroxene, Ca-pyroxene, plagioclase, metal and mesostasis consisting of fine textures of plagioclase, high-Ca pyroxene and glass (Figure 1). There are no alteration phases in the obsereved chondrules. Olivine composition of chondrules from Sahara 00182 show slightly lower Fo# (Fo_{91-92}) than those from other CR chondrites (Fo_{93-97}), which is consistent with the previous study [9].

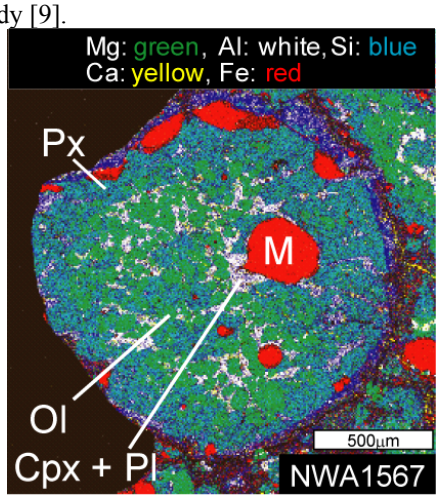

Figure 1. BSE image of chondrule from CR2 NWA 1567.

Mineralogy of plagioclase: Primitive Al-rich phases (e.g. plagioclase) without any secondary disturbance after chondrule formation are required to determine formation ages of chondrules using ^{26}Al-^{26}Mg systems. To evaluate primitiveness of chondrules, we performed careful observation of plagioclase with combining of textures and chemical compositions. [3] reported detail petrological study of plagioclase in chondrules in a primitive CO3.0 chondrite and concluded that plagioclase grains containing relatively high MgO abundance (~1 wt %) in chondrules are igneous origin meaning primitive. If individual chondrules are suffered alteration, MgO contents of plagioclase would decrease, resulting in an increase in the Al/Mg ratio. For example, partial-disturbance of Al-Mg systems of plagioclase-olivine inclusions (POIs) have been reported for the Ningqiang carbonaceous chondrite, in which plagioclase shows both a clear ^{26}Mg excess with low Al/Mg ratios and less ^{26}Mg excess with high Al/Mg ratios in a single inclusion

[10]. In the previous studies of Al-Mg systems, Al/Mg ratios of plagioclase of chondrules from primitive chondrites are less than 81 in LL3.0 Semarkona [1], less than 60 in CO3.05 Yamato-81020 [3] and less than 47 in CR2 Yamato-793495 [5]. Figure 2 shows a summary of Al/Mg ratios of plagioclase in Type I chondrules from the CR2 chondrites measured in this study, suggesting 8 to 46 in NWA1567, 13 to 32 in NWA852 and 9 to 39 in EET92174. Chondrules from Sahara 00182, however, show various ratios from 5 up to 5400. These extremely higher values are similar to those of chondrules from metamorphosed LL3.4 [11] and H4 [12] chondrites (Al/Mg ratio = less than 5500). These higher Al/Mg ratios of plagioclase indicate that Sahara 00182 would be slightly metamorphosed, which is consistent with results by [13]. In conclusion, we suggest that Sahara 00182 is not suitable for Al-Mg isotope studies, though they are classified into petrologic type 3 [9].

Bulk chemical compositions of Type I chondrules: In order to investigate the chondrule formation environment, we measured bulk chemical compositions of a total of 19 Type I chondrules in CR chondrites so far, using the same method as that used in [7]. The bulk compositions do not include Si-rich rim on the surface of chondrules. Figure 3 shows bulk elemental abundance patterns of silicate minerals of Type I chondrules in the CR chondrites by comparison with those of CO3.0 Yamato-81020 and CV3 Efremovka chondrites. There is no significant difference in refractory elements (Al, Ti and Ca) among CR, CV and CO chondrules though the abundance ranges of CO Type Is show slightly wider distribution relative to those of CR and CV chondrules. The patterns of CR chondrules appear to be volatility controlled. The elemental abundance ranges of CR Type I chondrules are similar to those of CO Type Is except iron though the average of CR Type Is shows slightly enriched in the moderate volatile elements (Cr, Mn, K, Na). The iron abundances of CR chondrules have less variation (0.08 to 0.20) relative to those of CO chondrules (0.02 to 0.25) and the average is clearly higher (0.13) than that of CO chondrules (0.07). This unique behavior of iron abundances implies that CR chondrules formed in higher oxidizing region relative to CO chondrules. We also found bulk compositions of Type I chondrules of Sahara 00182 have different patterns from those of both CR and CV chondrites (Figure 3). The moderate volatile elements of chondrules in Sahara 00182 are distributed between the ranges of CR and CV chondrites except Na and Fe, and the abundances of Mn have much less variations (0.31-0.42) relative to other chondrites (0.17-1.21 in CR, 0.09-0.37 in CV). Considering mineralogy of the chondrules, the bulk chondrule compositions of Sahara 00182 could be influenced by chemical alteration with the surrounded matrix phases after chondrule formation.

References: [1] Kita N. T. et al. (2005) In *Chondrites and the Protoplanetary Disk*, 558-587. [2] Rudraswami N. G. and Goswami J. N. (2007) *EPSL* 257, 231-244. [3] Kurahashi E. et al. (2008) *GCA* 72, 3865-3882. [4] Nagashima K. et al. (2007) *MPS* 42, A5291. [5] Kurahashi E. et al. (2008) *GCA* 72, A504. [6] Bizzarro M. et al. (2004) *Nature* 431, 275-278. [7] Kurahashi E. et al. (*2003) The international symposium, Evolution of Solar System Materials, NIPR*, 63-64. [8] Tachibana S. et al. (2003) *MPS* 38, 939-962. [9] Smith C. et al. (2004) *MPS* 39, 2009-2032. [10] Kita N. T. et al. (2004) *LPSXXXV* abstract #1471. [11] Huss G. et al. (2001) *MPS* 36, 975-997. [12] Zinner E. and Göpel C. (1992) *MPS* 37, 1001-1013. [13] Kakazu Y. et al. (2007) *LPSXXXVIII*, abstract #1508. [14] Anders E. D. and Grevesse N. (1989) *GCA* 53, 197-214.

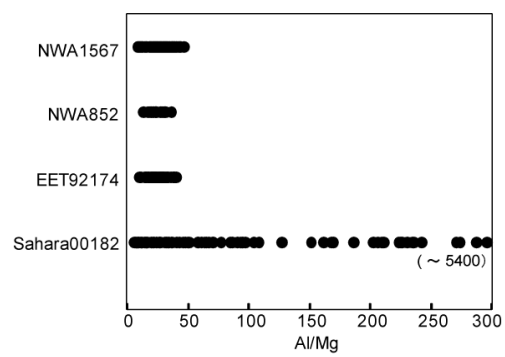

Figure 2. Al/Mg ratios of plagioclase of Type I chondrules from CR chondrites.

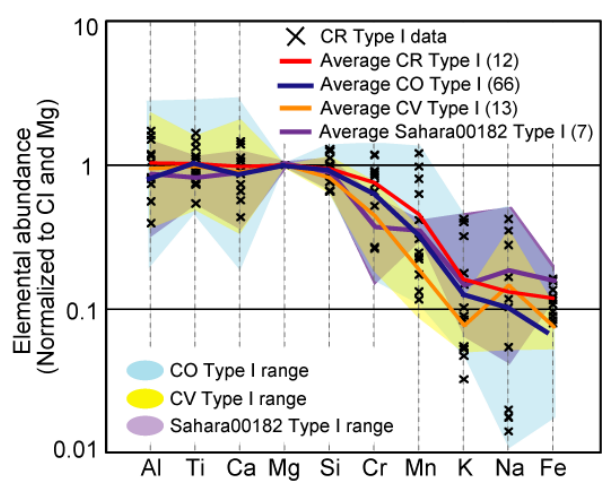

Figure 3. Bulk elemental abundance patterns of Type I chondrules from CR, CV and CO [7] chondrites. Data are normalized to Mg and CI compositions [14]. Total numbers of chondrules obtained bulk compositions are shown in reference with brackets.