PRIMITIVE CHONDRULES IN A HIGHLY UNEQUILIBRATED CLAST IN NWA 753 R CHONDRITE.

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Introduction: Rumuruti (R) chondrites are distinct from other chondrite groups by the high abundance of FeO-rich olivine (Fa_{38}) in equilibrated lithologies and high bulk $\Delta^{17}O$ ($=\delta^{17}O - 0.52\times\delta^{18}O$) values (~2.7‰) [1-3]. Many R chondrites are regolith breccias containing clasts with variable petrologic types (R3-6) [3]. R3 chondrites with low petrologic subtypes (<3.5) are not known, except for clasts in brecciated R chondrites [3,4]. Previous oxygen isotope studies of R chondrite chondrules (mainly from R3.6-3.8) suggest a wide range of $\Delta^{17}O$ values from −4 ‰ to +3‰ [1,5,6]. However, the relationship between chondrule types (such as Fa contents of olivine) and $\Delta^{17}O$ values remain uncertain [5]. Based on high precision SIMS oxygen isotope studies of chondrules in the least equilibrated chondrites (LL, CO, CR, and Acfer 094, all with subtypes ≤3.2), group-specific trends between the Mg# (molar MgO/[MgO+FeO]) of mafic minerals and $\Delta^{17}O$ values have been identified [7-10]. These results provide important clues to identify the variety of isotope reservoirs and their evolution in each chondrule forming region. In order to extend similar study to R chondrite chondrules, we performed a detailed petrologic description of a highly unequilibrated R3 clast within the Northwest Africa (NWA) 753 (R3-5) chondrite.

Samples and Methods: The highly unequilibrated clast "Fragment IX", 8 mm × 4 mm in size, was examined from a thin section of NWA 753 (Fig. 1). We selected 69 chondrules and fragments larger than 200µm for detailed petrographic study. BSE images of individual chondrules and EDX semi-quantitative elemental analyses of selected phases were collected with a Hitachi S-3400N SEM. Major element concentrations of olivine and pyroxene in chondrules were measured with a Cameca SX51 EMP.

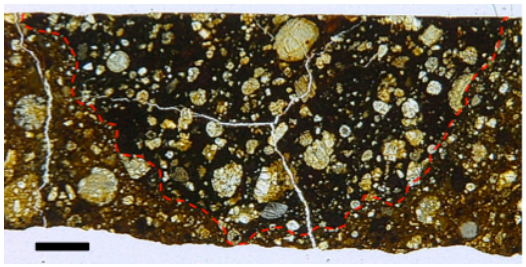

Fig. 1. Transmitted light photograph of the clast NWA 753-IX in thin section. The clast (marked by red dashed line) stands out by the dark fine-grained matrix. The scale bar is 1 mm.

Chondrule Types: Most chondrules show porphyritic textures (n=59), while 6 radial pyroxene (RP), 3 barred olivine (BO), and 1 cryptocrystalline (CC) chondrules were identified (Fig. 2). Mesostasis of chondrules are mostly altered compared to unaltered mesostasis seen in type 3.0 chondrites (such as Semarkona [7]) and often include areas with high Na and Cl contents.

Based on major element analyses of olivine and pyroxene, porphyritic chondrules are divided into 2 Al-rich (e.g., [11]), 29 type I, (Mg#>90) and 28 type II (Mg#≤90). Type I and II chondrules are subdivided into A, AB, and B from the proportions of olivine and pyroxene phenocrysts (A: olivine >80%, B: 20-80%, C: <20%) as shown in Table 1. The proportion of different types of chondrules are very similar to LL3 chondrites [7], especially with respect to similar abundance of type I and II chondrules, while type II chondrules are less abundant in carbonaceous chondrites (~25 % in CO3 and ≤5% in CR3 [10, 12]). All non-porphyritic chondrules are FeO-rich.

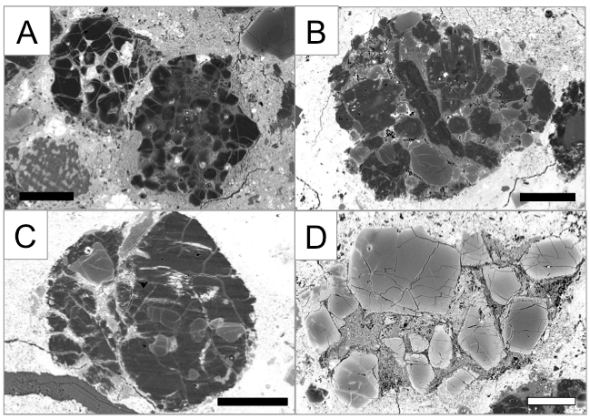

Fig. 2. Major types of chondrules in the R3 clast IX. Scale bars are 100 µm. A: Two type IA chondrules (~$Fo_{99.5}$). B: Type IAB chondrule (pyroxene Mg#~91, Fo_{83-89}). C: Type IB chondrule (pyroxene Mg#~97, Fo_{92-94}). D: Type IIA chondrule (Fo_{77-84}).

Table 1. Classification of chondrules in NWA753-IX.

Porphyritic			Non-porphyritic
	FeO-poor	FeO-rich	
Al-rich = 2	IA = 9 IAB = 11 IB = 9	IIA = 20 IIAB = 7 IIB =1	RP = 6 BO = 3 CC = 1

Distribution of Chondrule Mg#: The average Mg# of olivine and low-Ca pyroxene phenocrysts were calculated for each chondrule. The Mg# of RP and CC chondrules were also estimated from the average of multiple electron microprobe analyses. Results are shown as a histogram of Mg# (Fig. 3), and are very similar to LL chondrites [7]. We note that Mg# of all chondrules in Fig. 3A are higher than Fo contents of equilibrated R chondrite (Fo_{62}). Many type I chondrules contain olivine and pyroxene with Mg# > 98.

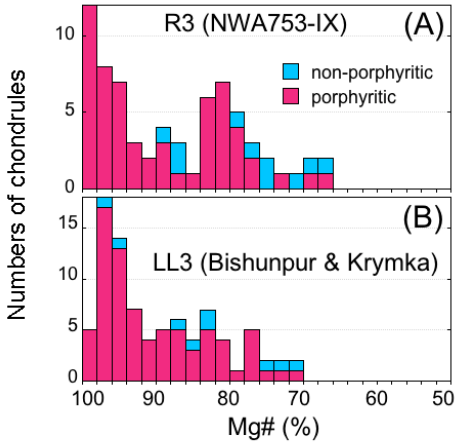

Fig. 3. Histograms of chondrule Mg# in R3 clast NWA 753 IX (this work) and LL3 chondrites [7].

As shown in Fig. 4, most Mg-rich olivine (Mg#>98) in porphyritic chondrules show enrichments of Al_2O_3 and CaO and depletion of MnO when compared to other olivine grains. This indicates that some type I chondrules in R3 are significantly enriched in refractory elements. They could be related to refractory forsterite grains or forsteritic olivine with ^{16}O-rich isotope signatures that were reported previously from R3 chondrites [6,13].

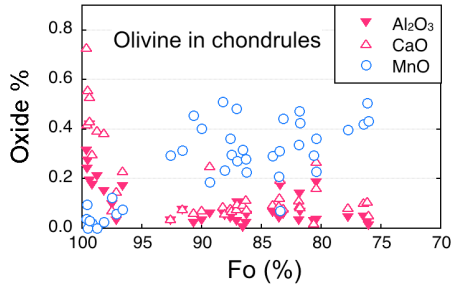

Fig. 4. Minor elements in coarse-grained olivine from porphyritic chondrules in NWA 753 IX. The detection limits of Al_2O_3, CaO, and MnO are 0.04%, 0.03%, and 0.09%, respectively.

Cr_2O_3 Contents in Olivine: Grossman and Brearley [14] suggested that the average and the standard deviation (SD) of Cr_2O_3 wt% in ferroan olivine (Fo<98) grains can be used as an index of very mild thermal metamorphism corresponding to subtypes from 3.00 to 3.15. To index the R3 clast, we selected EPMA analyses of coarse-grained (≥100μm) olivine cores from 32 chondrules with Fo<98. The average and SD of Cr_2O_3 wt% are 0.17 ± 0.11 %. As shown in Fig. 5, data plot close to the subtypes 3.15-3.20 for ordinary chondrites. Although it is not certain if we can apply the same classification scheme established for ordinary chondrites to R chondrites, the data suggest that clast NWA 753-IX is the least metamorphosed R3 chondritic material compared to other R3 chondrites (≥3.6).

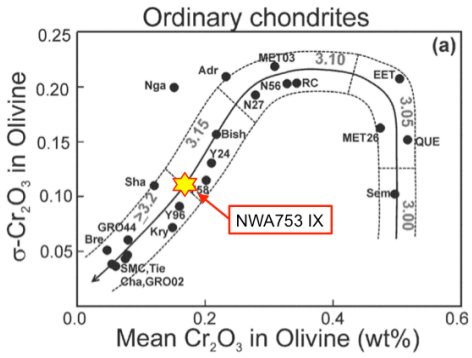

Fig. 5. The average and SD of Cr_2O_3 wt% in olivine (Fo<98) in chondrules from clast NWA 753-IX, superimposed on the diagram published by [14].

Summary: The highly unequilibrated R3 chondritic clast NWA 753-IX contains a variety of chondrules with a wide range of Mg# (100-67). The petrologic subtype estimated from Cr_2O_3 contents of olivine is similar to subtypes 3.15-3.2 for ordinary chondrites. Other similar pristine R3 chondritic materials exist in R3 regolith breccias [4] that need to be examined in detail. These least metamorphosed R3 chondritic materials are suitable for detailed combined petrologic and isotope studies of their chondrules.

References: [1] Weisberg M. K. (1991) *GCA, 55,* 2657-2669. [2] Bischoff A. et al. (1994) *Meteoritics, 29,* 264-274. [3] Bischoff A. et al. (2011) *Chemie der Erde, 71,* 101–133. [4] Bischoff A. (2000) *Meteoritics & Planet. Sci., 35,* 699-706. [5] Greenwood J. P. (2000) *GCA, 64*, 3897-3911. [6] Isa J. (2011) *LPS XLII,* Abstract #2623. [7] Kita N. T. et al. (2010) *GCA, 74*, 6610-6635. [8] Ushikubo T. (2012) *GCA, 90*, 242-264. [9] Tenner T. J. et al. (2013) *GCA, 102*, 226-245. [10] Tenner T. J. et al. (2012) *LPS XLIII,* Abstract #2127. [11] Bischoff A. and Keil K. (1984*) GCA* 48, 693-709 [12] Kunihiro T. et al. (2005) *GCA, 69* 3831-3840. [13] Pack A. et al. (2004) *GCA, 68,* 1135-1157. [14] Grossman J. N. and Brearley A. J. (2005) *Meteoritics & Planet. Sci., 40,* 87-122.