^{26}Al IN CHONDRULES FROM CR CARBONACEOUS CHONDRITES. K. Nagashima[1], A. N. Krot[1], and G. R. Huss[1], [1]Hawai‘i Institute of Geophysics and Planetology, University of Hawai‘i at Manoa, 1680 East-West Road, Honolulu, HI 96822, USA. (kazu@higp.hawaii.edu)

Introduction: The short half-life (0.72 Myr) and the inferred uniform distribution of ^{26}Al in the inner Solar System [1, 2] makes it one of the best chronometers for dating the earliest processes in the solar nebula, including CAI- and chondrule formation. The ^{26}Al-^{26}Mg systematics in chondrules from primitive ordnary (UOC3.0-3.1) and CO3.0 chondrites suggest contemporaneous formation of chondrules from these meteorite groups that started ~1 Myr after formation of CAIs with initial ^{26}Al/^{27}Al ratio [(^{26}Al/^{27}Al)$_0$] of ~5×10^{-5} and lasted for ~2 Myr [3-10]. In contrast, (^{26}Al/^{27}Al)$_0$ of three CR chondrules range from 1×10^{-6} to 6×10^{-6}, corresponding to an age difference of ~2-4 Myr after CAIs [11]. CR chondrites are among the most primitive meteorites in our collections and appear to have avoided thermal metamorphism which potentially dturbed the Al-Mg system. The Al-Mg system in CR chondrules probably has recorded their crystallization ages. The Al-Mg ages of CR chondrules are consistent with their young ^{207}Pb-^{206}Pb ages [12]. In an attempt to further constraining the age and duration of chondrule formation in the early solar system, we extended our study of ^{26}Al-^{26}Mg systematics of CR chondrules.

Samples and Analytical Techniques: Mg-isotopic compositions were measured in four Al-rich and two Type I chondrules (Fig. 1) from El Djouf 001 and Acfer 311 CR chondrites using the University of Hawai‘i Cameca ims-1280 SIMS. A 100–250 pA O$^-$ primary ion beam was focused to ~5-7 µm. The secondary ion mass spectrometer was operated at +10 keV with a 50 eV energy window. Mg isotopes and ^{27}Al were measured with monocollector EM and FC, respectively. The mass-resolving power was set to ~3800, sufficient to separate interfering hydrides and doubly charged ^{48}Ca$^+$. ^{26}Mg* was calculated assuming a linear mass-fractionation law. Note that, with the small degree of instrumental and intrinsic mass fractionation for these measurements and the relatively large isotopic effects, the choice of fractionation law makes no substantive difference in the results. Relative sensitivity factor for plagioclase was calculated based on the measurements on Miyakejima plagioclase standard.

Results and Discussion: The Mg isotopic data from plagioclase grains from 6 magnesium-rich

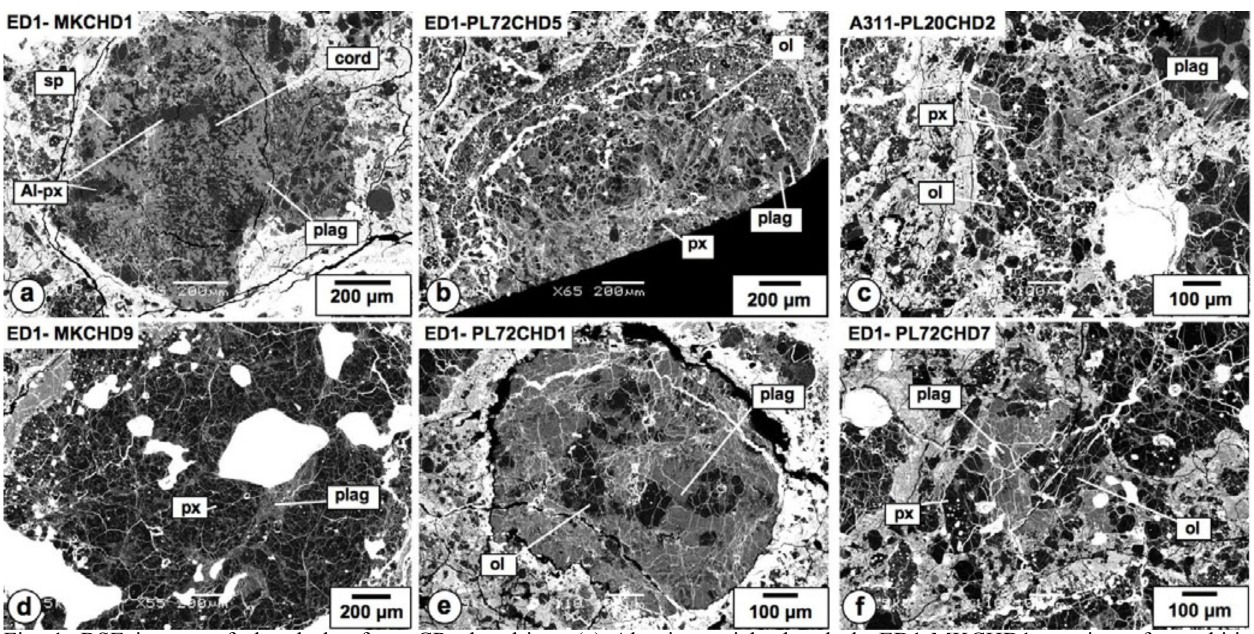

Fig. 1. BSE images of chondrules from CR chondrites. (a) Aluminum-rich chondrule ED1-MKCHD1 consists of anorthitic plagioclase enclosing spinel grains, aluminous low-Ca pyroxene, and cordierite. (b) Aluminum-rich chondrule ED1-PL72CHD5 has a microporphyritic texture and consists of olivine, low-Ca pyroxene, high-Ca pyroxene, anorthitic plagioclase, silica-plagioclase mesostasis, and Fe,Ni-metal nodules. (c) A fragment of a Type I porphylitic olivine-pyroxene chondrule, A311-PL20-CHD2 consists of olivine, low- and high-Ca pyroxene, anorthitic plagioclase, and silica-plagioclase mesostasis. (d) Type I porphylitic pyroxene chondrule ED1-MKCHD9 consists of low-Ca pyroxene, Fe,Ni-metal nodules, and minor high-Ca pyroxene, olivine, anorthitic plagioclase, and silica-plagioclase mesostasis. (e) Al-rich chondrule ED1-PL72CHD1 consists of anorthitic plagioclase, olivine, high-Ca pyroxene, and silica-plagioclase mesostasis. (f) A fragment of an Al-rich chondrule ED1-PL72CHD7 anorthitic plagioclase, olivine, high-Ca pyroxene, Fe,Ni-metal nodules and silica-plagioclase mesostasis. Al-px: aluminous low-Ca pyroxene; cord: cordierite; ol: olivine; px: low-Ca pyroxene; sp: spinel.

chondrules are plotted on Al-Mg isochron diagrams in Fig. 2. Al/Mg ratios in plagioclase range from 40 to 160. Apparent $^{26}Mg/^{24}Mg$ excesses are resolved at the 2σ level in 3 out of 6 chondrules suggesting that live ^{26}Al existed at the time these chondrule melts crystallized. Model Al-Mg isochrons (fitted lines are forced through the origin) yield estimates for $(^{26}Al/^{27}Al)_0$ of $(4.5\pm1.1)\times10^{-6}$ for ED1-MKCHD1, $(3.2\pm1.3)\times10^{-6}$ for ED1-PL72CHD5, and $(3.2\pm1.4)\times10^{-6}$ for A311-PL20CHD2. The remaining chondrules have no resolvable $^{26}Mg^*$ and only upper limits of $(^{26}Al/^{27}Al)_0 <3\times10^{-6}$ are indicated for analyses of ED1-MKCHD9, ED1-PL72CHD1, and ED1-PL72CHD7.

The inferred $(^{26}Al/^{27}Al)_0$ in the CR chondrules are summarized in Fig. 3. The $(^{26}Al/^{27}Al)_0$ in CO3.0-3.1 [3-7] and CO3.0 [8-10] are also shown. In UOC3.0-3.1 chondrules, $(^{26}Al/^{27}Al)_0$ range from $\sim0.4\times10^{-5}$ to 2.3×10^{-5} ($\sim0.9\times10^{-5}$ in average). In CO3.0 chondrules, $(^{26}Al/^{27}Al)_0$ range from $\sim0.2\times10^{-5}$ to 1.4×10^{-5} ($\sim0.8\times10^{-5}$ in average). No systematic differences were found between UOC3.0-3.1 and CO3.0 chondrules. In contrast, most CR chondrules have lower initial $(^{26}Al/^{27}Al)_0$: $(0.1\text{-}0.4)\times10^{-5}$. The average of $(^{26}Al/^{27}Al)_0$ calculated from 6 chondrules having resolvable $^{26}Mg^*$ is 0.3×10^{-5}, significantly lower than those in UOC3.0-3.1 and CO3.0.

Figure 3 shows relative age differences between CAIs with the canonical $^{26}Al/^{27}Al$ ratio and chondrules in UOC3.0-3.1, CO and CR chondrites. Relative ages of UOC3.0-3.1 and CO3.0 chondrules are ~1-3 Myr inferred from their $(^{26}Al/^{27}Al)_0$. On the other hand, CR chondrules have ages of 2-4 Myr inferred from their $(^{26}Al/^{27}Al)_0$. The majority of CR chondrules give younger ages than the majority of UOC and CO chondrules, which could imply formation of most CR chondrules postdated the formation of most OC and CO chondrules. The range of relative ages of CR chondrules is consistent with an age difference (2.5±0.9) Myr between CV CAIs and CR chondrules inferred from $^{207}Pb\text{-}^{206}Pb$ isotope systematics [12]. However, most of the Al-Mg ages in CR chondrules fall at the younger end of that range (>3 Myr after CAIs) and appear to be systematically yournger than those inferred from $^{207}Pb\text{-}^{206}Pb$ system (Fig. 3). This could indicate either that the absolute ages of CV CAIs are older, or absolute ages of CR chondrules are younger than inferred from the $^{207}Pb\text{-}^{206}Pb$ system.

References: [1] Bizzarro M. et al. (2004) *Nature*, *431*, 275. [2] Thrane K. et al. (2006) *ApJ*, *646*, 159. [3] Kita N. et al. (2000) *GCA*, *64*, 3913. [4] Huss G.R. et al. (2001) *MAPS*, *36*, 975. [5] Mostefaoui S. et al. (2002) *MAPS*, *37*, 421. [6] Rudraswami N.G. and Goswami J.N. (2007) *EPSL*, *257*, 231. [7] Huss G.R. et al. (2007) *MAPS*, *42*, 5005. [8] Kunihiro T. et al. (2004) *GCA*, *68*, 2947. [9] Kurahashi E. et al. (2004) *LPS*, *35* #1476. [10] Kurahashi E. et al. (2007) In *Chronology of Meteorites and the Early Solar System*, 100. [11] Nagashima K. et al. (2007) *MAPS*, *42*, 5291. [12] Amelin Y. et al. (2002) *Science*, *297*, 1678.

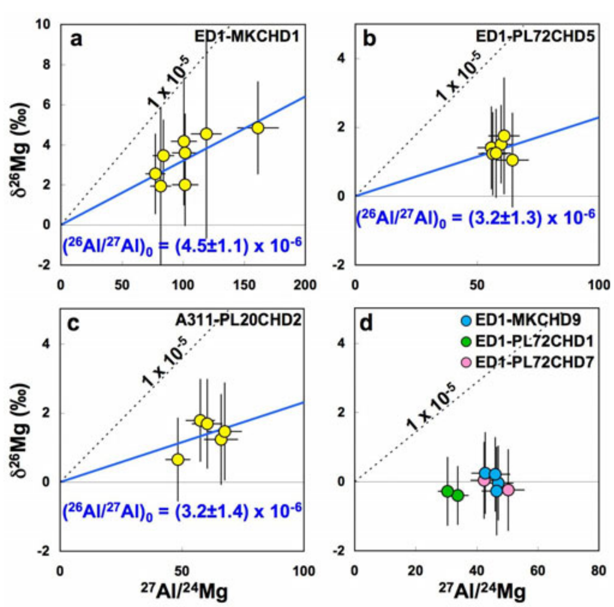

Fig. 2. Al-Mg isochron diagrams for six chondrules from CR chondrites: (a) ED1-MKCHD1. (b) ED1-PL72CHD5. (c) A311-PL20CHD2. (d) ED1-MKCHD9, ED1-PL72CHD1, and ED1-PL72CHD7. Correlation lines in (a-c) are forced through the origin. No resolvable excess of $\delta^{26}Mg$ was found in three chondrules in (d). Reference lines corresponding to initial $^{26}Al/^{27}Al$ isotope ratios of 1×10^{-5} are also shown as dotted lines. Errors are 2σ.

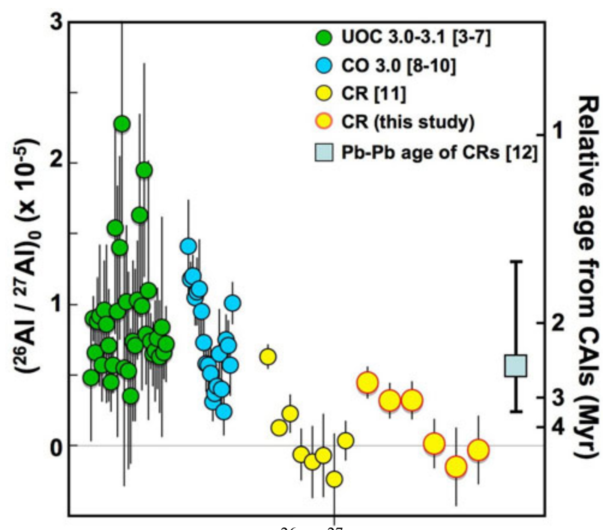

Fig. 3. Comparison of $(^{26}Al/^{27}Al)_0$ in chondrules from UOC3.0-3.1 [3-7], CO3.0 [8-10], and CR chondrites [11, this study] and their relative ages after formation of CAIs with $(^{26}Al/^{27}Al)_0$ of $\sim5\times10^{-5}$. Inferred $(^{26}Al/^{27}Al)_0$ in UOC3.0-3.1 and CO3.0 chondrules range from $\sim0.2\times10^{-5}$ to 2.3×10^{-5}, corresponding to relative age of ~1-3 Myr after CAIs. In contrast, CR chondrules range from 0.1×10^{-5} to 0.6×10^{-5}, corresponding to relative age of ~2-4 Myr after CAIs. The age difference (2.5±0.9) Myr between CV CAIs and CR chondrules inferred from $^{207}Pb\text{-}^{206}Pb$ isotope system [12] is also shown.