ALUMINUM-MAGNESIUM ISOTOPE SYSTEMATICS OF PORPHYRITIC CHONDRULES AND PLAGIOCLASE FRAGMENTS IN CH CARBONACEOUS CHONDRITES. A. N. Krot[1,2*], K. Nagashima[1], and M. Bizzarro[2]. [1]HIGP, U. Hawai‘i at Mānoa, Honolulu, HI 96822, USA *sasha@higp.hawaii.edu. [2]Centre for Star & Planet Formation & Natural History Museum of Denmark, U. Copenhagen, DK-1350 Copenhagen, Denmark

Introduction: The mineralogy, petrology, bulk chemical and isotopic (O and N) compositions indicate that CH and CB metal-rich carbonaceous chondrites are genetically related meteorites [1,2]. We have previously suggested that CBs consist almost entirely of the components formed during a single-stage highly-energetic event, most likely in an impact generated plume: Fe,Ni-metal±sulfide nodules, zoned Fe,Ni-metal grains, non-porphyritic (skeletal and cryptocrystalline) magnesian chondrules, and uniformly ^{16}O-depleted igneous CAIs [3−5]. In addition, the CHs contain ~50% of typical chondritic components: magnesian (type I) and ferroan (type II) porphyritic chondrules and uniformly ^{16}O-rich CAIs [4,5]. Recent U-Pb isotope measurements of magnesian skeletal chondrules from Gujba (CB$_a$) confirmed their late-stage formation, 4562.52±0.44 Ma, ~5 Myr after CV CAIs with the canonical ^{26}Al/^{27}Al ratio [6,7]. High-precision Al-Mg isotope measurements of bulk magnesian skeletal chondrules from Hammadah al Hamra 237 (CB$_b$) revealed no resolvable excess of ^{26}Mg (δ^{26}Mg*): the inferred initial ^{26}Al/^{27}Al ratio [(^{26}Al/^{27}Al)$_0$] is $(4.5\pm8.3)\times10^{-7}$ [8]. The origin and timing of the CH porphyritic chondrule formation are not understood. Based on the mineralogy and O-isotope compositions of the CH porphyritic chondrules, Krot et al. [9] suggested they define their own population. Here we report on the results of *in situ* Al-Mg isotope measurements of porphyritic chondrules and isolated plagioclase grains from the paired CH chondrites Acfer 182 and 214 with the UH Cameca ims-1280 ion microprobe.

Analytical procedure: Mg-isotope compositions were measured using primary ^{16}O$^-$ ion beam accelerated to 13 keV with an impact energy of 23 keV. The measurements were done with a focused ~5 µm ^{16}O$^-$ primary beam with a current of 100 pA. ^{24}Mg$^+$, ^{25}Mg$^+$, and ^{26}Mg$^+$ were measured sequentially in monocollection mode using monocollector EM. ^{27}Al$^+$ was measured using multicollection FC simultaneously with ^{25}Mg$^+$. The mass-resolving power was set to ~4200, sufficient to separate all interfering hydrides and doubly charged ^{48}Ca^{++}. The instrumental mass-fractionation effects were corrected using Miyake-jima anorthite assumed to have terrestrial Mg-isotope compositions. ^{26}Mg excess due to decay of ^{26}Al (δ^{26}Mg*) was calculated using an exponential law with an experimentally defined mass fractionation exponent of 0.514 [10].

Results and Discussion: Al-Mg isotope systematics was measured in plagioclase in 6 Al-rich chondrules containing relict CAIs (Figs. 1a,b), 5 type I and 1 type II chondrules (Figs. 1c,d), and 5 isolated coarse plagioclase crystals (Figs. 1e,f). None of the chondrules measured show evidence for thermal metamorphism or aqueous alteration. Chondrule plagioclase grains are anorthite-rich (An$_{96-99}$). The isolated plagioclase grains show a range of compositions (An$_{99.5}$Ab$_{0.5}$ to An$_7$Ab$_{88}$). One of the Ab-rich grains contains thin exsolutions of K-rich plagioclase and inclusions of Cl-apatite, ferroan olivine (Fa$_{79}$, 1.6 wt% MnO) and pigeonite (Fs$_{69}$Wo$_8$, 1.6 wt% MnO) with thin (~1 µm) exsolution lamellae of ferroan augite (Fs$_{46}$Wo$_{33}$, 0.9 wt% MnO) (Fig. 1f).

The inferred (^{26}Al/^{27}Al)$_0$ in CH chondrules and isolated plagioclase grains studied are given in Table 1. Because minerals with low ^{27}Al/^{24}Mg ratio in chondrules have not been measured yet, these ratios represent model isochrons forced through the origin (^{27}Al/^{24}Mg = 0, ^{26}Mg/^{24}Mg = 0.13932). Only two out of 14 chondrules measured (~15%), 1 Al-rich and 1 type I, show resolvable δ^{26}Mg* corresponding to (^{26}Al/^{27}Al)$_0$ of $(4.9\pm2.6)\times10^{-6}$ and $(6.2\pm5.2)\times10^{-6}$ ($\pm2\sigma$). This is the lowest number of chondrules with resolvable δ^{26}Mg* among all unmetamoprhosed ordinary and carbonaceous chondrites studied so far (Fig. 2). For a comparison, ~35% of CR chondrules and virtually all chondrules in type 3.0 ordinary, CO, and Acfer 094 (ungr.) show resolvable δ^{26}Mg* [11−18]. Assuming uniform distribution of ^{26}Al in the protoplanetary disk after epoch of CAI formation, these observations together with the common presence of very refractory ^{16}O-rich relict CAIs (grossite-rich and hibonite-rich) in CH porphyritic chondrules [19; Fig. 1b] suggest that they may represent the youngest population of chondrules formed by melting of isotopically diverse solid precursors in the disk. The nature of the late-stage melting event(s) that produced CH porphyritic chondrules is unclear. Based on the presence of the uniformly ^{16}O-depleted igneous CAIs in CH and CB chondrites, Krot et al. [5] suggested that they formed by remelting of typical (^{16}O-rich) CAIs in an impact generated plume having an ^{16}O-poor composition. If this the case, some of the porphyritic chondrules could have been melted or remelted in the plume as well.

In contrast to CH chondrules, 3 out of 5 coarse plagioclase grains measured [*1573 2-10* (An$_{99.5}$Ab$_{0.5}$), *1573 1-3* (An$_7$Ab$_{88}$), and *1579 4-1* (An$_6$Ab$_{89}$)] show resolvable δ^{26}Mg*, corresponding to the inferred (^{26}Al/^{27}Al)$_0$ of $(1.4\pm1.2)\times10^{-6}$, $(8.9\pm2.8)\times10^{-7}$, and $(7.4\pm4.2)\times10^{-7}$, respectively. These data together with the mineralogy, chemical compositions and sizes of the plagioclase grains appear to preclude their formation as a result of fragmentation of chondrules or metamorphosed chondrites. Instead they probably represent fragments of differentiated bodies. The high Al/Mg ratio (3000–5000) in Ab-rich grains and the observed antiperthite texture and pyroxene exsolutions in one of them (Fig. 1f) suggest relatively slow cooling after crystallization. The similar texture was described in Ab-rich plagioclase in the Watson IIE iron meteorite [20]. Oxygen-isotope and trace element measurements of these plagioclase grains may help to elucidate their origin.

In addition to the mineralogically pristine non-porphyritic and porphyritic chondrules [5,8,this study], CH chondrites contain thermally metamorphosed porphyritic chondrules (Figs. 1g,h) and several kinds of hydrated lithic clasts [21,22]. These observations may indicate that CH chondrites accreted diverse types of materials, suggesting they represent accretionary breccias that sampled the protoplanetary disk, possibly, during a debris stage of its evolution.

References: [1] Weisberg et al. 1995. *Proc. NIPR Symp. Antarct. Meteorites* 8:11. [2] Krot et al. 2002. *Meteorit. Planet. Sci.* 37:1451. [3] Krot et al. 2005. *Nature* 436:989. [4] Krot et al. 2010. *Geochim. Cosmochim. Acta* 74:2190. [5] Krot et al. 2012. *Geochim. Cosmochim. Acta* 83:159. [6] Bollard et al. 2013. *Goldschmidt Conf.*:732. [7] Connelly et al. 2012. *Science* 358:651. [8] Olsen et al. 2013. *ApJ* 776:1. [9] Krot et al. 2008. *Chem. Erde* 67:283. [10] Davis et al. 2005. *LPSC* 36:2334. [11] Kita et al. 2000. *Geochim. Cosmochim. Acta* 64:3913. [12] Rudraswami et al. 2008. *Earth Planet. Sci. Lett.* 274:93. [13] Villaneuve et al. 2009. *Science* 325:985. [14] Kurahashi et al. 2008. *Geochim. Cosmochim. Acta* 72:3865. [15] Nagashima et al. 2007. *Meteorit. Planet. Sci.* 42:5291. [16] Nagashima et al. 2008. *Lunar Planet. Sci.* 39:2224. [17] Schrader et al. 2013. *Meteorit. Planet. Sci.* 76:5141. [18] Ushikubo et al. 2013. *Geochim. Cosmochim. Acta* 109:280. [19] Krot et al. 2011. *LPSC* 42:1226. [20] Olsen et al. 1994. *Meteoritics* 29:200. [21] Bonal et al. 2010. *Geochem. Cosmoch. Acta* 74:2500. [22] Bonal et al. 2010. *Geochem. Cosmoch. Acta* 74:6590.

Table 1. Inferred initial $^{26}Al/^{27}Al$ ratios in porphyritic chondrules and plagioclase fragments from CH chondrites.

object	$(^{26}Al/^{27}Al)_0$	object	$(^{26}Al/^{27}Al)_0$
Al-rich chondrules		**Type I chondrules**	
1579 1-103	$(4.9\pm2.6)\times10^{-6}$	*1579 x5*	$(6.2\pm5.2)\times10^{-6}$
1579 2-8	$<0.6\times10^{-6}$	*1573 2-201*	$<6.4\times10^{-6}$
1573 2-3	$<3.2\times10^{-6}$	*1579 x3*	$<6.0\times10^{-6}$
MB1 1-1	$<2.8\times10^{-6}$	*1579 x2*	$<6.2\times10^{-6}$
MB1 2-4	$<1.6\times10^{-6}$	*1579 x4*	$<4.8\times10^{-6}$
MW 10	$<1.5\times10^{-6}$	*MW 54*	$<4.0\times10^{-6}$
plagioclase fragments		*MW 55*	$<3.2\times10^{-6}$
1573 2-10	$(1.4\pm1.2)\times10^{-6}$	**Type II chondrules**	
1573 1-3	$(8.9\pm2.8)\times10^{-7}$	*1573 2-202*	$<2.5\times10^{-6}$
1579 4-1	$(7.4\pm4.2)\times10^{-7}$		
1573 1-9	$<4.4\times10^{-6}$		
1573 2-9	$<1.4\times10^{-6}$		

Fig. 1. BSE images of the representative (a–f) porphyritic chondrules and plagioclase fragments measured for Al-Mg isotope system, and (g,h) metamorphosed chondrules from the CH carbonaceous chondrite Acfer 214. Yellow ellipses in a–f indicate locations of SIMS spots. aug = augite; cpx = high-Ca pyroxene; grs = grossite; hib = hibonite; mes = mesostasis; met = Fe,Ni-metal; ol = olivine; pg = pigeonite; pl = plagioclase; px = low-Ca pyroxene; sf = sulfide; sp = spinel.

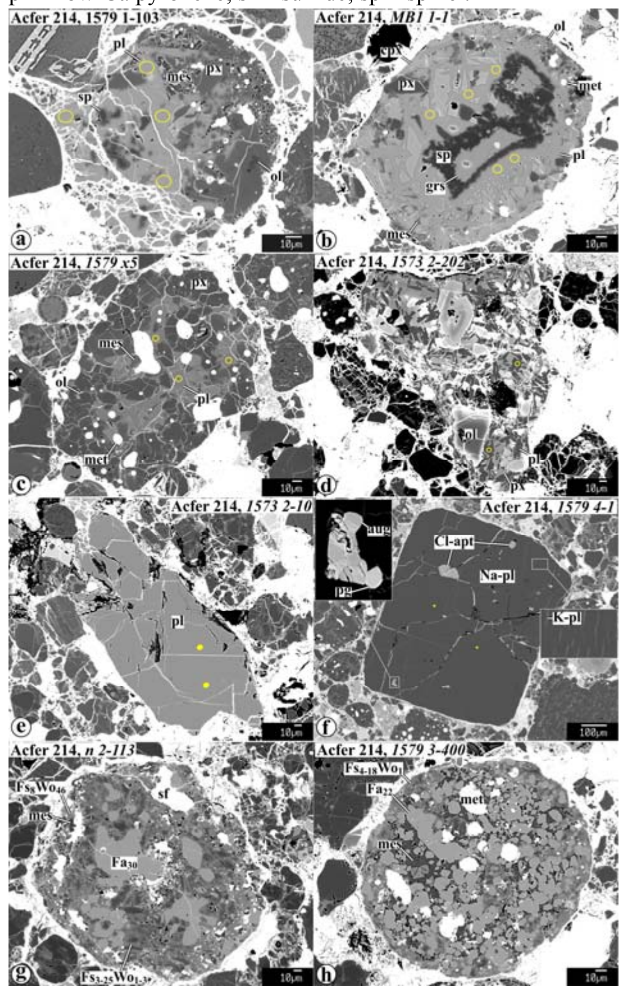

Fig. 2. Inferred initial $^{26}Al/^{27}Al$ ratios in chondrules (chds) and plagioclase fragments (plag fr) from unequilibrated ordinary (UOC) [11–13] and carbonaceous (CO [14], CR [15–17], Acfer 094 [18], and CH) chondrites.