REFRACTORY INCLUSIONS RECYCLED DURING FORMATION OF PORPHYRITIC CHONDROLES FROM CH CARBONACEOUS CHONDrites. Alexander N. Krot1,2, Kazuhide Nagashima1, Elishevah M. M. E. van Kooten3, and Martin Bizzarro4. 1HIGP/ SOEST, University of Hawai‘i at Mānoa, USA. 2Centre for Star and Planet Formation, Natural History Museum of Denmark, Denmark.

Introduction: It is inferred that CAIs formed during initial stages of our Solar System evolution, in high-temperature (>1350 K) region of the protoplanetary disk (PPD), probably near the proto-Sun, were subsequently transported radially away and accreted together with chondrules into chondrite parent bodies throughout the disk [1]. Most CAIs in unmetamorphosed chondrites are uniformly 16O-rich (Δ17O ∼ −5‰) and have an inferred initial 26Al/27Al ratio ([26Al/27Al]0) close to the canonical value of −5.2×10−5 [2,3]. 26Al-poor CAIs are rare [4]. In contrast, most chondrules are 16O-poor (−7‰ < Δ17O < −4‰); individual CAIs are isotopically uniform, have no resolvable 26Mg* excess, and lack Wark-Lovering (WL) rims; instead, igneous forsterite rims are common [9–11]. Most CB chondrules are magnesium, have non-porphyritic textures (skeletal olivine and cryptocrystalline), 16O-poor compositions (~5‰ < Δ17O < −2‰) and no resolvable 26Mg* excess [12,13]. It is inferred that CB chondrules formed in an impact-generated gas-melt plume ~5 Myr after CV CAIs [13,14]; CB CAIs experienced melting and isotope exchange in the plume [11].

Most CH CAIs are characterized by very refractory mineralogy (rich in grossite, hibonite, perovskite, and gehlenitic melilitite; anorthite is typically absent) and are surrounded by WL rims [15]. They have variable (~Al/Al)0 (~85% of CAIs show no 26Mg* excess [15,16]) and a large range of Δ17O values (from ~−35‰ to ~−5‰); individual CAIs, however, are isotopically uniform [15,16]. Some CH CAIs are texturally, mineralogically and isotopically (uniformly 16O-depleted) similar to CB CAIs. There are two major populations of CH chondrules: (i) CB-like magnesian non-porphyritic and (ii) magnesian, ferroan, and Al-rich porphyritic. It is suggested that the former originated in the impact plume inferred for the origin of CB chondrules, whereas the latter formed by incomplete melting of solid precursors, possibly prior to impact plume event [12]; the CB-like CAIs were completely melted in the plume [11].

Results: Incompletely melted CH CAIs, most likely during formation of porphyritic chondrules, can be divided into three major groups: (i) polymorphic relic CAIs and clusters of relic spinel grains inside porphyritic chondrules (Figs. 1a,b); (ii) CAIs surrounded by chondrule-like igneous rims composed of anorthite, high-Ca pyroxene, ±low-Ca pyroxene, ±olivine, ±Fe,Ni-metal (Figs. 1c,d); and (iii) Type C-like CAIs. Relict CAIs and CAIs surrounded by igneous rims are dominated by grossite-, hibonite-, and spinel-rich types, and often contain anorthite replacing melilitite. WL rims around relict CAIs are either lacking or incomplete as a result of dissolution by host chondrule melt. Type C-like CAIs consist of anorthite, Al,Ti-diopside, ±olivine, ±low-Ca pyroxene, and relic spinel and mellellite. Minerals in most of individual relict CAIs and spinel clusters have similar O-isotope compositions (Fig. 2). There is, however, a large range of Δ17O values, from ~−37‰ to ~−4‰, between individual relict CAIs and spinel clusters. They are systematically 16O-enriched relative to the host chondrules and igneous rims which have Δ17O values ranging from ~−10‰ to ~+4‰. These observations provide little evidence for O-isotope exchange of relict CAIs with the host chondrule melts. None of the relict CAIs or their host chondrules measured for 26Al-26Mg systematics shows evidence for 26Mg* excess.

Discussion: The mineralogy, petrology, 16O- and Al-Mg-isotope systematics of relict CAIs in CH porphyritic chondrules and CH CAIs surrounded by chondrule-like igneous rims are similar to the CH CAIs surrounded by WL rims and are apparently unaffected by chondrule melting. We infer that (i) CH CAIs were present in disk region(s) where CH porphyritic chondrules formed, but most of them avoided melting, suggesting highly localized nature of chondrule-forming events. (ii) Porphyritic chondrules in CH chondrites and other chondrite groups formed by incomplete melting of isotopically diverse precursors, including CAIs. Because CH CAIs are mineralogically and isotopically distinct from CAIs in other chondrite groups, the CH porphyritic chondrules must have formed from a distinct precursor material. It is suggested that (a) 26Al-poor CAIs formed prior to addition of stellar 26Al to PPD [18] and were transported to larger radial distances from the Sun (>100 AU) than the 26Al-rich CAIs [16], and (b) radial transport of dust in accretionary disks rapidly decreases with time [19]. If this is correct, the high abundance of initially 26Al-poor CAIs in CH chondrites suggests that CH porphyritic chondrules formed by melting of dust predominantly from the outer part of PPD, supporting [20]. (iii) Common presence of relict CAIs inside porphyritic chondrules precludes their formation by splashing of differentiated bodies [21] and probably by impacts [7]; bow shocks [22] and current sheets [23] in PPD are more likely mechanisms. (iv) CH chondrites contain chondrules of multiple generations formed by at least two different mechanisms.

Fig. 1. BSE images of (a, b) relict grossite-rich CAIs inside porphyritic chondrules and (c, d) spinel-melilitel-hibonite-perovskite CAIs surrounded by igneous rims (IR) from CH chondrites Acfer 182 and Acfer 214. CAIs shown in "a" and "c" are $^{16}$O-rich, those in "b" and "d" are $^{16}$O-poor (for details see Fig. 2).

Acfer 214, MB4-1-5

Acfer 214, MB4-2-6

Acfer 214, MB1-T-1

Acfer 182, C-4

Fig. 2. $\Delta^{17}$O values of CAIs (b, d) recycled during formation of CH porphyritic chondrules. Color & black-and-white symbols correspond to CAI & chondrule minerals, respectively. cpx = high-Ca pyroxene; grs = grossite; hib = hibonite; mel = melilitel; ol = olivine; pl = plagioclase; px = low-Ca pyroxene; sp = spinel; unk = unidentified.