MINERALOGY, PETROGRAPHY, AND OXYGEN ISOTOPIC COMPOSITIONS OF ULTRAREFRACTORY INCLUSIONS FROM CARBONACEOUS CHONDRITES.

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Introduction: Fine-grained CAIs with Group II rare earth element (REE) patterns condensed from a gaseous reservoir from which the ultrarefractory (UR) REEs had been removed. The carriers of UR REEs are poorly known. Here we report on the mineralogy, petrography and O-isotope compositions of 25 CAIs, presumably UR (REEs have not yet measured), from CR2, CM2, C3.0, CO3.0–3.6, CV3.1–3.6, and CH3.0 carbonaceous chondrites (CCs).

Mineralogy and Petrography: The UR CAIs studied are dominated by Zr, Sc, Ti, and Y-rich oxides (allendeite, kangite, lakargite, panguite, Y-perovskite, tazheranite, warkite, zirconolite) and silicates (davisite, eringaite, thortveitite) and often contain refractory metal alloy nuggets; most are surrounded by rims of Sc-pyroxene, ±eringaite, Al,Ti-diopside, and ±forsterite. These CAIs occur as (*i*) individual objects, (*ii*) constituents of amoeboid olivine aggregates and Fluffy Type A CAIs, and (*iii*) relict objects in forsterite-bearing Type B CAIs and chondrules.

Oxygen-isotope compositions: Nearly all UR CAIs from the least metamorphosed CCs [Murchison (CM2), Y-793261 (CR2), Acfer 182 (CH3.0), and DOM 08006 (CO3.0)] have uniform O-isotope compositions ($\Delta^{17}O \sim -24\pm2$‰ and $\sim -6\pm2$‰) (Fig. 1a,b). In contrast, most UR CAIs from CCs of petrologic type ≥3.1 (CVs: Kaba, Vigarano, Efremovka, and NWA 3118, and COs: DOM 08004, Moss, and Ornans) are isotopically heterogeneous: spinel, hibonite and forsterite are ^{16}O-rich ($\Delta^{17}O \sim -24$‰), but warkite, eringaite, kangite, Y-perovskite, and davisite are ^{16}O-depleted to various degrees (Fig. 1b,c).

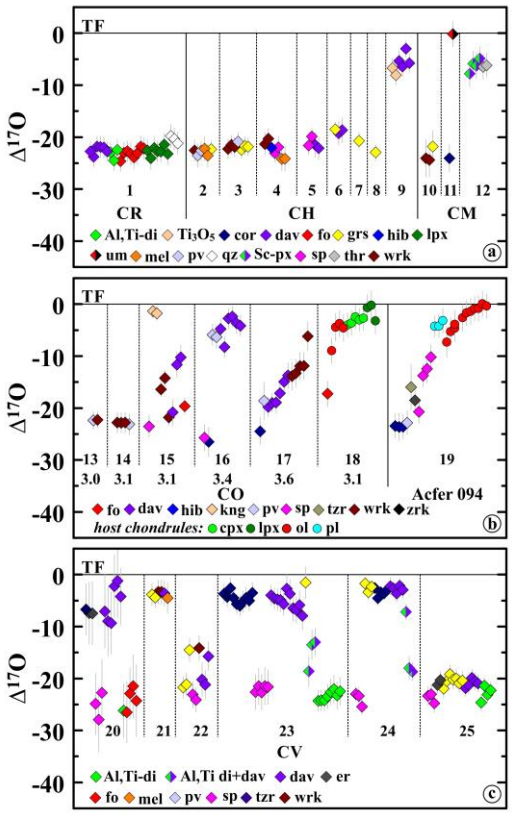

Figure 1. $\Delta^{17}O$ ($=\delta^{17}O-0.52\times\delta^{18}O$) of UR CAIs from (a) CM2, CR2, and CH3.0 chondrites; (b) CO3.0–3.6 chondrites and Acfer 094 (C3.0 ungrouped); (c) CV3 chondrites. 1 = *4* from Y-793261; 2 = *5-2* from NWA 470; 3 = *418/P* from Acfer 182; 4 = *1573-1* from Acfer 214; 5 = *35* from ALH 85085; 6 = *6* from PCA 91326; 7 = *3* from PCA 91452; 8 = *MB 111-1* from Acfer 214; 9 = *A0031* from SaU 290; 10 = *M11*; 11 = *M80-1*; 12 = *M10* from Murchison; 13 = *100-1* from DOM 08006 (CO3.0); 14 = *22-4* and 15 = *YY* from DOM 08004 (CO3.1); 16 = *Oscar* from Ornans (CO3.4); 17 = *1* from Moss (CO3.6); 18 = *50-1* from MAC 88107; 19 = *17* from Acfer 094; 20 = *V3*, 21 = *V7*, and 22 = *V13* from Vigarano; 23 = *3N* from NWA 3118; 24 = *33E* from Efremovka; 25 = *Al-2* from Allende. Abbreviations: Al,Ti-di = Al,Ti-diopside; cor = corundum; cpx = Sc-bearing high-Ca pyroxene; dav = davisite; er = eringaite; fo = forsterite; grs = grossite; hib = hibonite; kng = kangite; lpx = Sc-bearing low-Ca pyroxene; um = unidentified Sc-, Zr-, and Y-rich oxide; mel = melilite; ol = Fe-Mg olivine; pl = plagioclase; pv = perovskite; qz = quartz; Sc-px = Sc-bearing Al,Ti-diopside; sp = spinel; TF = terrestrial fractionation line; thr = thortveitite; Ti_3O_5 = Sc-rich Ti_3O_5; tzr = tazheranite; wrk = warkite; zrk = zirkelite. Diamonds and circles indicate minerals in CAIs and host chondrules, respectively.

Discussion: Most UR CAIs formed in a ^{16}O-rich gaseous reservoir; some subsequently experienced incomplete melting and O-isotope exchange in the CAI- and chondrule-forming regions. UR CAIs from CCs of petrologic type 2–3.0 largely retained their original O-isotope compositions, whereas those from CV and CO chondrites of higher petrologic type that experienced fluid-assisted thermal metamorphism, recorded mineralogically-controlled O-isotope exchange mostly with a ^{16}O-depleted aqueous fluid on the host chondrite parent asteroids. UR CAIs melted during chondrule formation (CAIs 18 and 19 in Fig. 1b) and possibly a relict UR CAI in a FoB CAI (CAI 23 in Fig. 1c) appear to have experienced O-isotope exchange with a ^{16}O-depleted nebular gas during melting.