AQUEOUS ACTIVITY ON CHONDRITE PARENT ASTEROIDS. A. N. Krot[1,2], P. M. Doyle[1,2], K. Nagashima[1], K. Jogo[3], S. Wakita[3], F. J. Ciesla[4], and I. D. Hutcheon[5]. [1]HIGP, U. Hawai'i, USA. [2]U. Hawai'i NASA Astrobiology Institute, USA. [3]Tohoku U., Japan. [4]U. Chicago, USA. [5]Glenn Seaborg Institute, LLNL, USA.

Introduction: Aqueous alteration is a fundamental process in the early solar system that affected most groups of chondritic meteorites. Type 1 and 2 CI, CM, and CR carbonaceous chondrites experienced aqueous alteration at lower temperatures (T < 100°C) and higher water/rock ratios (W/R ~ 0.2–1) than type 3 ordinary (UOC), CO, and CV chondrites (T ~ 100–300°C, W/R ~0.1–0.2) [1]. As a result, these meteorites have different assemblages of aqueously-formed minerals: phyllosilicates (*phyl*), carbonates (*crb*), magnetite (*mgt*), and Fe,Ni-sulfides (*sf*) in CIs, CMs, and COs, and fayalite (*fa*), hedenbergite, andradite, *mgt*, *sf*, and *phyl* in UOCs, COs, and CVs (Figs. 1, 2). Mineralogical observations, isotopic data, and thermodynamic analysis suggest that the alteration resulted from interaction between a rock and an aqueous solution in an asteroidal setting [1,2]. The ages of aqueous alteration [3] and the sources of asteroidal water (inner *vs.* outer solar system) remain poorly-known [4]. In this talk, we will summarize recent results on the mineralogy, petrology, O and Cr-isotope compositions of aqueously formed minerals (*fa*, *crb*, and *mgt*) in UOCs and CCs.

Oxygen-isotope compositions of aqueously-formed minerals: On a three-isotope oxygen diagram, compositions of *fa* and *mgt* in UOCs and CCs measured *in situ* by SIMS, plot along mass-dependent fractionation lines with a slope of ~0.5 and Δ^{17}O values of +4.5‰ and –1‰, respectively; they are in disequilibrium with chondrule olivines and bulk compositions of their host meteorites (Fig. 3a). Because Δ^{17}O values of *fa* and *mgt* are equal to Δ^{17}O of a fluid, we infer that during formation of *mgt* and *fa* the fluid experienced insignificant exchange with ^{16}O-enriched anhydrous silicates. In CMs and CIs, O-isotope compositions of *crb* and *mgt* plot close to the terrestrial fractionation line (Δ^{17}O ~ ±1.5‰); with increasing degree of aqueous alteration, and the Δ^{17}O values of *crb* approach those of bulk meteorites. We suggest that Δ^{17}O values of *fa* and *mgt* in UOCs, CVs, and COs, and *mgt* and *crb* in CIs and CMs, can be used as a proxy for Δ^{17}O values of water ices that accreted into their parent asteroids. We note, however, that Δ^{17}O of water prior to the formation of *mgt* and *fa* is not known.

Mn-Cr isotope systematics of fayalite and carbonates. ^{53}Mn-^{53}Cr ages of fayalite formation, anchored to D'Orbigny angrite [9,10] and compared with the U-corrected Pb-Pb age of CV CAIs [11], are 4.6 and 5.1 Myr after CAIs, respectively [12]. These ages are indistinguishable from ^{53}Mn-^{53}Cr ages of calcite and dolomite formation in CI and CM chondrites reported by [13-15]. These observations indicate that aqueous alteration on several carbonaceous chondrite asteroids occurred nearly contemporaneously.

The CO and CV chondrites define metamorphic sequences of petrologic subtypes between 3.0 and 3.7 with a peak metamorphic temperature of about 600°C [16]. ^{26}Al is the major heating source of asteroids. The initial ^{26}Al/^{27}Al ratio in the protoplanetary disk is unknown, but after epoch of CAI formation could have been uniform at ~5×10^{-5} level [17]. Therefore, peak metamorphic temperatures experienced by CV and CO chondrites can be used to constrain accretion ages of their parent asteroids. Numerical modeling of thermal history of the CV and CO-like asteroids with radius of 50 km, water/rock ratio of 0.2, and peak metamorphic temperature of 600°C suggests that these asteroids must have accreted within < 2.6 Myr after CAIs. Fayalite could have precipitated < 5 Myr after CAIs in the outer portions of these asteroids, which have never been heated above 300°C. For a comparison, the inferred accretion ages of the CI and CM parent bodies are 3–4 Myr after CAIs [13,14].

Sources of water in chondrite asteroids: In the CO self-shielding models of [18,19], water ice in the outer disk is highly-enriched in ^{17}O and ^{18}O relative to solids in the inner disk. This is consistent with heavy O-isotope compositions of iron oxides in Acfer 094 reported by [20]. In contrast, the inferred Δ^{17}O values of the chondrite water ices are close to the terrestrial value, i.e., very different from the suggested Δ^{17}O values of water ices in the outer Solar System. We conclude that chondrite water ices had a local, inner Solar System origin, which is consistent with the inferred D/H ratio of chondritic water that is different from the isotopically heavy water in the Oort Cloud comets [4].

References: [1] Zolotov et al. (2006) *MAPS* 41:1775. [2] Zolensky et al. (2008) *Rev. Mineral. Geochem.* 68:429. [3] Krot et al. (2006) *MESS II*:525. [4] Alexander et al. (2012) *Science* 337:721. [5] Krot et al. (2013) *Mineral. Mag.* 77:1515. [6] Rowe et al. (1994) *GCA* 58:5341. [7] Benedix et al. (2003) *GCA* 67:1577. [8] Clayton (1999) *GCA* 63:2089. [9] Amelin (2008) *GCA* 72:221. [10] Glavin et al. (2004) *MAPS* 39:693. [11] Connelly et al. (2012) *Science* 338:651. [12] Doyle et al. (2013) *LPSC* 44:1793. [13] Fujiya et al. (2012) *Nature Commun.* 3:1. [14] Fujiya et al. (2013) *EPSL* 362:130. [15] Jilly et al. (2013) *MAPS* submitted. [16] Huss et al. (2006) *MESS II*: 566. [17] Krot et al. (2013) *MAPS* 47:1948. [18] Yurimoto & Kuramoto (2004) *Science* 305:1763. [19] Lyons & Young (2005) *Nature* 435:317. [20] Sakamoto et al. (2007) *Science* 317:231.

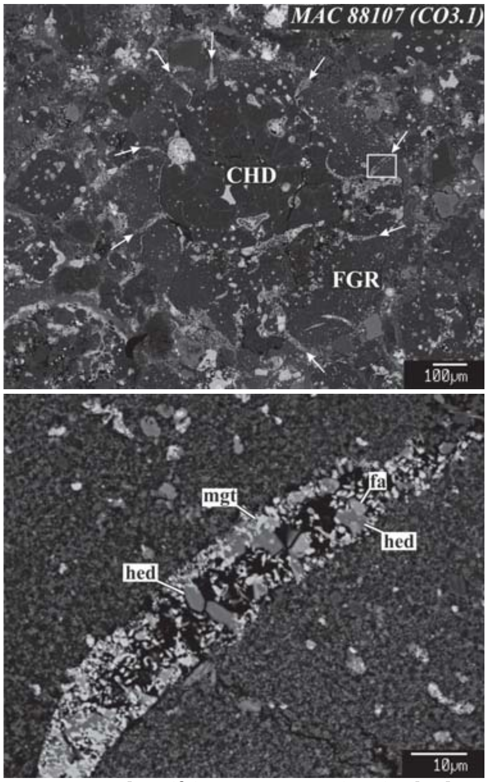

Fig. 1. Fayalite (fa) – magnetite (mgt) - hedenbergite (hed) veins crosscutting fine-grained rim around chondrule in MAC 88107 (CO3.1).

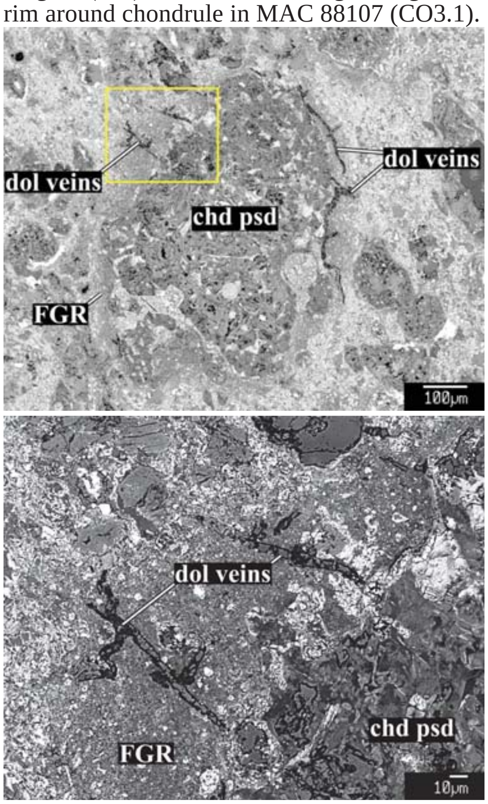

Fig. 2. Dolomite (dol) veins crosscutting fine-grained rim around chondrule pseudomorph (chd psd) in Sutter's Mill (CM2.0).

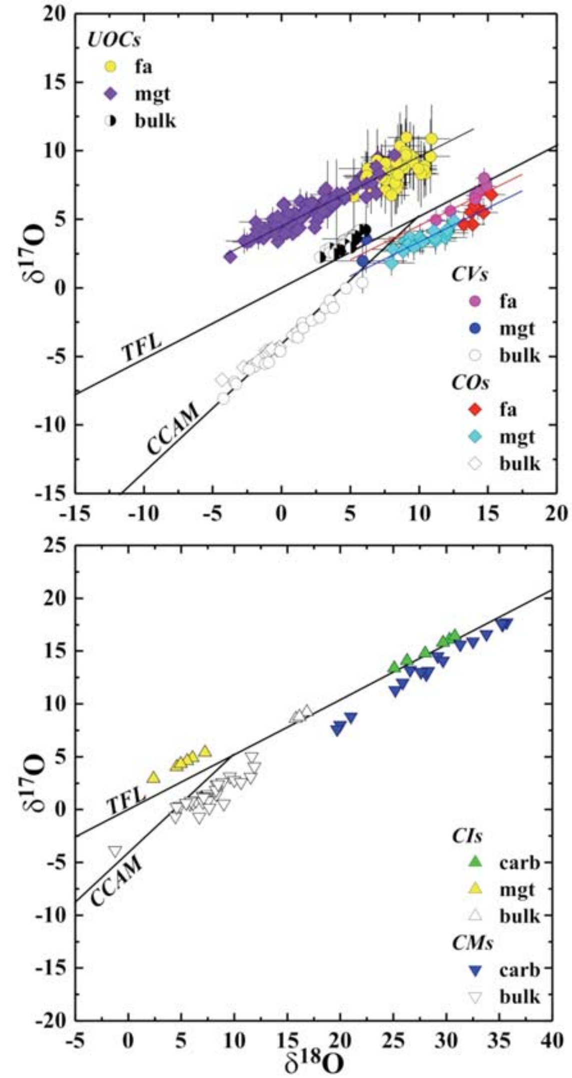

Fig. 3. Whole-rock O-isotope compositions of UOCs and CCs and aqueously-formed fayalite, magnetite, and carbonates in these meteorites (data from [5–8]).

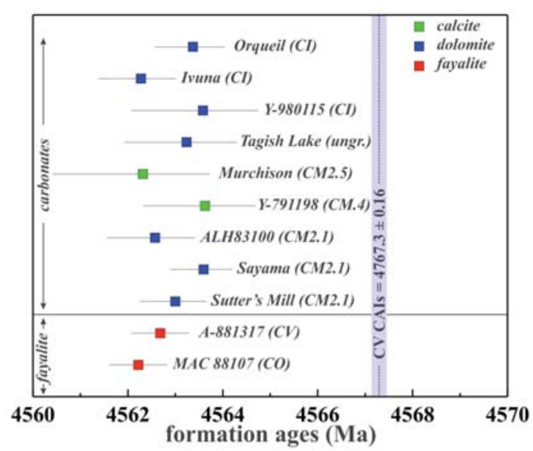

Fig. 4. ^{53}Mn-^{53}Cr relative ages of aqueously formed fayalite, calcite and dolomite in CI, CM, CO, and CV chondrites (data from [12–14]).