AQUEOUS ACTIVITY ON CHONDRITE PARENT ASTEROIDS. A. N. Krot1,2, P. M. Doyle1,2, K. Nagashima1, K. Jogo1, S. Wakita1, F. J. Ciesla1, and I. D. Hutcheon2, 1HIGP, U. Hawai‘i, USA. 2U. Hawai‘i NASA Astrobiology Institute, USA. 3Tohoku U., Japan. 4U. Chicago, USA. 5Glenn 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 CIIs, 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 Δ17O values of +4.5‰ and ~1‰, respectively; they are in disequilibrium with chondrule olivines and bulk compositions of their host meteorites (Fig. 3a). Because Δ17O values of fa and mgt are equal to Δ17O of a fluid, we infer that during formation of mgt and fa the fluid experienced insignificant exchange with 16O-enriched anhydrous silicates. In CMs and CIIs, O-isotope compositions of crb and mgt plot close to the terrestrial fractionation line (Δ17O ~ ±1.5‰); with increasing degree of aqueous alteration, and the Δ17O values of crb approach those of bulk meteorites. We suggest that Δ17O values of fa and mgt in UOCs, CVs, and COs, and mgt and crb in CIIs and CMs, can be used as a proxy for Δ17O values of water ices that accreted into their parent asteroids. We note, however, that Δ17O of water prior to the formation of mgt and fa is not known.

Mn-Cr isotope systematics of fayalite and carbonates. 53Mn-54Cr 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 53Mn-54Cr 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]. 26Al is the major heating source of asteroids. The initial 26Al/27Al 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 17O and 18O 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 Δ17O values of the chondrite water ices are close to the terrestrial value, i.e., very different from the suggested Δ17O 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].

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]).