

## Aqueous activity and sources of water on the chondrite parent asteroids

A. Krot<sup>1</sup>, C. Alexander<sup>2</sup>, K. Nagashima<sup>1</sup>, F. Ciesla<sup>3</sup>, and W. Fujiya<sup>4</sup>

<sup>1</sup>University of Hawaii, USA

<sup>2</sup>Carnegie Institution, USA

<sup>3</sup>University of Chicago, USA

<sup>4</sup>Max-Planck Insitute for Chemistry, Germany

**Ages of aqueous alteration of asteroids:** Most chondrite parent asteroids experienced aqueous alteration resulting in the formation of secondary minerals, including phyllosilicates, magnetite, Fe,Ni-sulfides, carbonates [(Ca,Mg,Fe,Mn)CO<sub>3</sub>], and fayalite [(Fe,Mn)<sub>2</sub>SiO<sub>4</sub>] [1]. Mineralogical observations and thermodynamic analysis suggest that the alteration of the various chondrite groups occurred under different physico-chemical conditions (temperature, redox conditions, pH, water/rock ratio). The chronology of aqueous activity on the chondrite parent asteroids can be inferred from <sup>53</sup>Mn–<sup>53</sup>Cr dating (<sup>53</sup>Mn decays to <sup>53</sup>Cr with half-life of 3.7 Myr) of aqueously-formed carbonates and fayalite measured with secondary ion mass-spectrometry. Recently reported <sup>53</sup>Mn–<sup>53</sup>Cr ages of carbonates in CM [2,3], CI [4], CR [5] chondrites, and fayalite in CV [6], CO [6], and LL [7] chondrites indicate that aqueous alteration on the ordinary and carbonaceous chondrite (CC) parent asteroids occurred nearly contemporaneously, ~3–5 Myr after formation of Ca,Al-rich inclusions (CAIs), the earliest Solar System solids dated [8].

**Accretion ages of chondrite parent asteroids:** Assuming uniform distribution of a short-lived radionuclide <sup>26</sup>Al (decays to <sup>26</sup>Mg with half-life of ~0.7 Myr) in the disk at the canonical level (<sup>26</sup>Al/<sup>27</sup>Al ~ 5 × 10<sup>-5</sup>), the timing of aqueous alteration combined with estimates of peak metamorphic temperatures and thermal modelling of the ordinary and CC parent asteroids suggest that these bodies accreted ~2–3 Myr after CAI formation [2,3,7]. The inferred accretion ages of ordinary and CC parent asteroids are generally consistent with average <sup>26</sup>Al–<sup>26</sup>Mg ages (<sup>26</sup>Al decays to <sup>26</sup>Mg with half-life of ~0.7 Myr) of their chondrules [9,10], suggesting that chondrule formation was rapidly followed by accretion and that <sup>26</sup>Al was the major heating source of aqueous alteration and thermal metamorphism on these bodies. The observed variations in the degree of aqueous alteration within a chondrite group may indicate that water ices accreted heterogeneously or that there was a fluid flow in their parent bodies.

**Sources of water on the chondrite parent asteroids:** According to the Grand Tack and Nice models, the extensively hydrated (C-, D-, and P-type) asteroids formed between and beyond the giant planets and were scattered into the main asteroid belt during a period of giant planet migration [11,12]. Bulk D/H ratio of chondrite water ices can potentially be used for testing this model, but cannot be measured directly. Alexander et al. [13] used the bulk hydrogen and carbon isotopic compositions of chondrites to estimate the water D/H ratio for a number of chondrite groups. The estimated D/H ratio of water in the extensively hydrated CI, CM, CR and ungrouped carbonaceous chondrite Tagish Lake (spectrally similar to D-type asteroids) are significantly lower than in the measured comets from Oort Cloud comets; the D/H ratio of water in CRs, however, is similar to that in the Jupiter Family Comet Hartley 2 [14]. Alexander et al. [13] concluded that CC parent asteroids accreted ~3–7 au from the Sun. These data provide important constraints on the Grand Tack and Nice models.

**References:** [1] Zolensky et al. 2008. *Rev. Mineral. Geochem.* 68:429. [2] Fujiya et al. 2012. *Nat. Commun.* 3:1. [3] Jilly et al. 2014. *MAPS*, in press. [4] Fujiya et al. 2013. *EPSL* 362:130. [5] Jilly et al. 2013. *LPSC* 44:2474. [6] Doyle et al. 2013. *LPSC* 44:1793. [7] Doyle et al. 2014. *LPSC* 45:1726. [8] Connelly et al. 2012. *Science* 338:651. [9] Kita & Ushikubo. 2012. *MAPS* 47:1108. [10] Nagashima et al. 2014. *Geochem. J.*, submitted. [11] Walsh et al. 2011. *Nature* 475:206. [12] Levison et al. 2009. *Nature* 460:364. [13] Alexander et al. *Science* 337:721. [14] Hartogh et al. 2011. *Nature* 478:218.