CHRONOLOGY OF AQUEOUS ACTIVITY AND SOURCES OF WATER ON THE CHONDRITE PARENT BODIES: TESTING THE GRAND TACK MODEL

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Introduction: Most chondrite parent bodies accreted water ices together with anhydrous minerals and subsequently experienced aqueous/hydrothermal alteration and fluid-assisted thermal metamorphism resulting in formation of a diverse suite of secondary minerals [1]. It is currently being debated whether hydrated asteroids formed in the main asteroid belt [2] or whether they formed further away from the Sun and were subsequently implanted into the main belt during dynamical evolution of the Solar System (SS) [3,4]. To test these models, we attempted to constrain the accretion regions of hydrated chondrite parent bodies (CPBs) using ^{53}Mn-^{53}Cr and O-isotope systematics of aqueously formed minerals, thermodynamic calculations, and physical modeling.

Results and Discussion: The ^{53}Mn-^{53}Cr chronology of datable secondary minerals by SIMS with matrix-matched standards – calcite in CM and CI [5], and fayalite in CO3, CV3, and LL3 chondrites [6] – indicates that aqueous activity on the CPBs started ~3–5 Myr after formation of CV CAIs with the canonical ^{26}Al/^{27}Al ratio [7], consistent with ^{26}Al being the major heat source in these bodies. The peak metamorphic temperatures reached by the CPBs [8], the ^{26}Al-^{26}Mg ages of chondrule formation [9,10], the ^{53}Mn-^{53}Cr ages of aqueous alteration [5,6], and the physical modeling suggest that the CPBs accreted ~2.0–4 Myr after CV CAIs [5,6,11]. The inferred water-to-rock mass ratios in ordinary and carbonaceous CPBs range from <0.1 to ~0.6 (could be higher in CIs), which is significantly lower than the solar value of 1.2 [12]. We suggest that most CPBs accreted close to the snow line; CIs may have accreted further away from the Sun than other chondrite groups. Because the snow line for the 2.5–4 Myr-old disk is expected to be within 2–3 AU from the Sun [13,14], we infer that CPBs sampled by meteorites accreted in the main asteroid belt, consistent with the inferred D/H ratio of asteroidal water [2] and near the terrestrial O-isotope compositions (Δ^{17}O from –2‰ to +5‰) of aqueously formed fayalite, magnetite and carbonates. Therefore, the existing meteorite observations provide no clear evidence supporting the predictions of the Grand Tack dynamical model of the SS evolution that hydrated asteroids formed between and beyond the giant planets and were subsequently implanted into the main asteroid belt during migration of the giant planets [3]. We note, however, that there may be other types of hydrated or water ice-bearing planetesimals that were implanted into the main asteroid belt, but have not been sampled by the known meteorites.

References: [1] Zolensky et al. 2008. *Rev. Min. Geochem.* 68:429. [2] Alexander et al. 2012. *Science* 337:721. [3] Walsh et al. 2011. *Nature* 475:206. [4] Levison et al. 2009. *Nature* 460:364. [5] Fujiya et al. 2012. *Nature Commun.* 3:1. [6] Doyle et al. 2015. *Nature Commun.* in press. [7] Connelly et al. 2012. *Science* 338:651. [8] Huss et al. 2006. *MESS II*: 566. [9] Kita & Ushikubo. 2012. *MAPS* 43:1108. [10] Nagashima et al. 2015. this issue. [11] Sugiura & Fujiya. 2014. *MAPS* 49:772. [12] Lodders. 2003. *ApJ* 591:1220. [13] Ciesla & Cuzzi. 2006. *Icarus* 181:178. [14] Martin & Livio. 2012. *MNRAS* 425:L6.