

## WHAT WAS THE SOURCE OF THE WATER IN CHONDRITES?

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**Introduction:** Equilibrium and kinetic factors should have caused the D/H ratio of water in the solar nebula to have increased with radial distance from the Sun [1]. This has apparently been confirmed by the observation of three comets all with water  $\delta D$  values of  $\sim 1000\%$  [2]. Here we explore whether the  $\delta D$  values of water in chondrites can be used to constrain where the water formed. In particular, whether the water retains a record of the influx of ice from the outer into the inner Solar System that has been proposed to explain the non-solar O isotopic composition of the inner Solar System.

**Results:** The H isotopic compositions of water in various chondrites were estimated by subtracting H in insoluble organic matter (IOM) from published bulk H data [3]. The range of estimated water  $\delta D$  values are: CI (-25 to -105 ‰), CM1-2 (-110 to -180 ‰), Bells (CM2, 640 ‰), Tagish Lake (365 ‰), CR (190-510 ‰) and Semarkona (1170-2760 ‰). Measurements of nominally organic-free components in typical CMs are generally slightly lighter than our estimates (-120 to -200 ‰) [4]. The measurements of water compositions in Semarkona are variable, but the most D-rich measurements are consistent with our upper estimate. Measurements of matrix in CR chondrites exhibit a considerable range (-200 to 400 ‰), with large scatter within a single meteorite [5]. To avoid potential contamination by D-rich organics, we have begun a survey of H isotopes of hydrous phases in chondrites that should be free of organics, beginning with Al Rais the CR with the most D-rich estimated water composition. To date we, have found a bimodal distribution of compositions (-200 ‰ and  $\sim 500$  ‰) in two distinct phases that covers that range of estimates for CRs.

**Discussion:** The variations in Al Rais minerals may indicate either exchange of one mineral with terrestrial water or an evolution of the H isotopic composition of its water during alteration. Even greater variation has been found in Semarkona, which contains water with a D-enrichment that exceeds those of the three measured comets. [6, 7] interpreted this water as being interstellar. However, D enrichments could be due to isotopic fractionation associated with  $H_2$  generation when Fe was oxidized by water during aqueous alteration [3]. The same process is likely to have occurred in all altered chondrites, but particularly the most oxidized ones – e.g., CRs, Bells and Tagish Lake that also happen to contain the isotopically heaviest water. If correct, all the estimated water  $\delta D$  values are upper limits on initial water compositions. Estimates of the amount of water consumed by the oxidation of CI chondrites suggest that the initial  $\delta D$  values of their water may have been close to the bulk solar value (about -840‰). Even the current compositions of water in CIs and CMs show that it did not form in the outer Solar System (i.e., they are not fragments of outer Solar System comets). High temperature events, such as chondrule formation, would have locally re-equilibrated water and  $H_2$ , but if anything the H isotopic compositions are positively correlated with chondrule abundance which is the opposite of what would be expected if this was an important process. We are currently exploring ways to estimate how much water was consumed in the alteration of other chondrites. Nevertheless, at present we find no compelling evidence for the preservation of outer Solar System water in chondrites.

**References:** [1] L  cluse C., Robert F., (1994) *Geochim. Cosmochim. Acta* **58**, 2927. [2] Bockel  e-Morvan D. *et al.*, in *Comets II*, M. C. Festou *et al.*, Eds. (University of Arizona Press, Tucson, 2004), pp. 391-423. [3] Alexander C. M. O'D. *et al.*, (2010) *Geochim. Cosmochim. Acta* **74**, In press. [4] Eiler J. M., Kitchen N., (2004) *Geochim. Cosmochim. Acta* **68**, 1395. [5] Bonal L. *et al.*, (2010) *Lunar Planet. Sci.* **41**, #1442. [6] Deloule E., Robert F., (1995) *Geochim. Cosmochim. Acta* **59**, 4695. [7] Deloule E. *et al.*, (1998) *Geochim. Cosmochim. Acta* **62**, 3367.