HYDROGEN ABUNDANCES AND ISOTOPE COMPOSITIONS OF CHONDRULE MESOSTASES IN CARBONACEOUS AND ORDINARY CHONDRITES. K. Shimizu1, C. M. O’D. Alexander1, E. H. Hauri1, A. R. Sarafian2, J. Wang1, S. D. Jacobsen3, and R. A. Mendybaev4. 1Department of Terrestrial Magnetism, Carnegie Institution for Science, Washington, DC 20015, 2Science and Technology Division, Corning Incorporated, Corning, NY 14831, 3Department of Earth and Planetary Sciences, Northwestern University, Evanston, IL 60208, 4Department of Geophysical Sciences, University of Chicago, Chicago, IL 60637.

Introduction: Hydrogen abundances and isotopic compositions of chondrules may provide important constraints on the partial pressure of H and its isotopic composition during chondrule formation. Low H contents and δD values would be a signature of the H being dominated by nebula gas. On the other hand, if high partial pressures of water were present, as envisioned in some models of chondrule formation by planetesimal collisions [e.g., 1], one might expect high H contents and δD values similar to those of the bulk chondrites, particularly the water-rich carbonaceous chondrites (CCs). For ordinary chondrite (OC) chondrules, this could help trace the timing of migration of outer Solar System objects into the inner solar system, including the delivery of the volatile-rich building blocks of the Earth [e.g., 2,3].

The measurement of H isotopic compositions in chondrules, however, is challenging due to the expected low H concentrations generated during chondrule formation, as well as the potential for parent body overprinting. Previous in situ measurements of H in chondrites have reported highly variable concentrations and isotopic compositions [e.g. 2,4,5,6]. In situ analyses of matrices of OCs and CCs have shown that they are D-enriched, relative to solar and terrestrial values [2,4]. The H contents of matrix are dominated by D-rich insoluble organic matter (IOM) [7,8] and phyllosilicates. The water responsible for the alteration in the CCs has been inferred to have had a δD~450‰ in the CMs, CIIs and Tagish Lake, and ~100‰ in the CRs [3]. However, individual phyllosilicate grains in CRs can have δDs of up to 1600‰ and in chondrule mesostasis up to ~2000‰ [5]. The water in matrix and chondrule mesostases in the OCs may be even more D-rich [2]. This range in water/OH δD values has been interpreted to result from accretion of D-poor water ice and either (1) D-rich water ice that formed in the outer Solar System and/or the presolar molecular cloud [2,4], or (2) D-enrichment in the parent bodies via exchange with IOM and fractionation associated with oxidation of Fe by water [8]. The composition of the low D/H water in CIIs/CMs is difficult to reconcile with the influx of water ice from the outer Solar System, which predicts a high D/H ratio like those of comets. While the water composition of some comets are comparable to the inferred CR water composition, the CRs could have been enriched in D by Fe oxidation [9].

In situ studies of nominally anhydrous minerals in chondrules have reported high H contents [4,6]. If taken at face value, they may require unreasonably high pressure environment in the parent body, and it may also imply extremely high H contents in coexisting mesostases that is not measured (up to 10s of wt% using ol-melt $D_{H2O} = \sim 0.0015$ from [10]). Therefore the high H contents could instead imply parent body modification at lower temperatures.

However, in situ measurements of thin sections can have very high associated blanks due to degassing of the section, H in the C coat, etc. To try to overcome these potential sources of contamination, we have undertaken an initial study to compare separated grains mounted in In with grains measured in situ in the same primitive meteorites.

Samples and Methods: The meteorites selected for this study are the least altered/metamorphosed available: ALH 77307 (CO3.0), Kaba (CV3.1), Semarkona (LL3.0) and QUE 97008 (L3.05). To minimize the effect of analytical background from degassing of epoxy/glue, we picked olivine grains from powdered meteorite samples that were then directly mounted into In. The grains were then polished in In along with an internal standard for volatile contents and H isotopic compositions (ALV519-41 basaltic glass), as well as Suprasil and Herasil to monitor the analytical background. The olivine grains are ~50-500 μm across, and glasses are variably present within the grains. While we lack petrological context for the grains, they most likely originated from chondrules. Also, it is difficult to evaluate whether or not the glasses that were analyzed in this study were originally enclosed melt inclusions or embying mesostasis, and as such we refer to the glasses as mesostases.

The major element compositions of the mesostases and olivines were measured by EPMA. Volatile (H, C, P, S, F, Cl) concentrations were measured using the Cameca 6F following the technique of [11]. A 10 nA Cs+ primary beam was rastered over a 25×25 μm² area for 300 s, after which analyses were conducted by rastering the primary beam over a 20×20 μm² area from which the central 3×3 μm² of the secondary beam was collected using a circular field aperture. The vacuum in
the sample chamber was $8 \times 10^{-10}$ Torr. The H isotopic compositions were measured using the Cameca NanoSIMS 50L following the technique of [12]. A 1 nA Cs⁺ primary beam was rastered over a 25×25 µm² area for 300 s after which analyses were performed using the “image” mode rastering the primary beam over a 20×20 µm² area. Images were then processed using the L’image software to select regions of interest and avoid contamination from surface features such as cracks and bubbles. The vacuum in the sample chamber was $6 \times 10^{-10}$ Torr.

**Results and Discussion:** H₂O concentrations in the chondrule mesostases range from 9–104 ppm (Fig. 1) significantly lower compared to previous studies (1000 ppm to several wt.%) [2,6]. The measured H₂O concentrations are, however, significantly higher compared to the concurrently determined background of H₂O concentration using Suprasil (3.9±0.7 ppm). Given the relatively small number of our analyses, the discrepancy in the H₂O concentrations between our study and previous studies [2,4,6] may arise from natural variation. Alternatively, while analytical backgrounds were not reported in previous in situ studies, part of the discrepancy could arise from higher analytical backgrounds in previous studies. The H₂O concentrations of 4–27 ppm measured in the chondrule olivines (Fig. 1) are also significantly lower than previously reported values (76–2100 ppm, [4,6]). The combined mesostasis and olivine data certainly suggest that blanks may be much higher in previous in situ studies.

Nevertheless, the H₂O concentrations measured in the olivine are higher, relative to the coexisting mesostases ($D_{HDO} = 0.05–0.9$), than would be expected if they were in equilibrium at igneous temperatures (expected $D_{HDO} = -0.0015$ from [10]). However, the H₂O contents in olivines are upper limits due to the possible overlap of the 6f SIMS analyses spots with mesostases, and future NanoSIMS analyses with greater spatial resolution may help better establish the distribution of H₂O between olivines and mesostases.

The H isotopes can help determine if the olivine and mesostasis exchanged with the same reservoirs and what the sources of the reservoirs might be. The H isotopic compositions of the chondrule mesostases range from 780–5600 ‰ (Fig. 2). These $D$-enrichments in mesostases may have been inherited from water ice that formed in the presolar molecular cloud [2,4]. However, this requires that the inner Solar System OCs accreted proportionately more interstellar water than the outer Solar System CCs and even many comets. Nor is it clear why there is an apparent covariance with the H isotopic composition in IOM [7,8]. The alternative scenario is that IOM and mesostases may have approached isotopic equilibrium with D-rich water generated through an isotopic Rayleigh distillation process during oxidation of Fe by water and loss of D-poor H₂ [8].

![Figure 1](image1.png)  
**Figure 1:** H₂O concentration in the chondrule mesostases (filled circles) and olivines (open diamonds) from carbonaceous and ordinary chondrites.

![Figure 2](image2.png)  
**Figure 2:** H isotopic composition in the chondrule mesostases (filled circles) and IOMs (open circles) [7,8] from carbonaceous and ordinary chondrites.