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Highly volatile element (H, C, F, Cl, S) abundances and H isotopic compositions in chondrules from carbonaceous and ordinary chondrites

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The partial pressures and isotopic compositions of volatiles present during chondrule formation can be constrained by the highly volatile element or HVE (H, C, F, Cl, S) abundances and isotopic compositions in chondrules. Here we present high spatial resolution and low detection limit SIMS data of the HVE concentrations and H isotopic compositions in type I and II chondrules in primitive ordinary and carbonaceous chondrites (Semarkona (LL3.00), QUE 97008 (L3.05), DOM 08006 (CO3.00)).

The HVEs in the chondrules primarily reside in the glassy mesostases, in which the HVE contents and H isotopic compositions vary significantly (H_2O: 3–10,200 ppm, CO_2: 0.9–1170 ppm, F: 0.3–30 ppm, Cl: 0.07–175 ppm, S: 0.38–3750 ppm, δD: 77–15,000‰). To dissolve such HVE contents in a silicate melt requires significantly higher total pressures (up to 1900 bars) compared to those under canonical chondrule formation conditions (10^{-3} bars). Rather, the HVE enrichments in the mesostases at the chondrule edges suggests secondary influx of HVEs from the surrounding matrix during parent body processes. Consistent with this, melt inclusions sealed in olivine phenocrysts have significantly lower HVE contents than the mesostases in contact with the surrounding matrix. Further, the calculated diffusion distance of H_2O in silicate glass under the relevant conditions is comparable to the chondrule radii. The high δD values in the mesostases could have been generated through isotopic Rayleigh fractionation as a result of the loss of very D-poor H_2 generated from Fe metal oxidation by H_2O in the parent bodies. Based on these results, we hypothesize the secondary origin of most of the HVEs in the chondrule.

A small portion of the HVEs in chondrules could be primary, however, as there are low but measurable amounts of HVEs in the melt inclusions sealed in phenocrysts. We constrain the upper limits of primary HVEs in the chondrules based on the lowest measured HVE contents to minimize the effects of the secondary HVE influxes (type I H_2O: 7–11 ppm, CO_2: 0.3–0.4 ppm, F: 0.1–0.2 ppm, Cl: 0.01–0.03 ppm, S: 0.3–60 ppm, and type II H_2O: 50–85 ppm, CO_2: 0.3–3 ppm, F: <0.2–2 ppm, Cl: 0.04–2 ppm, S: 190–260 ppm).