SILICATE MINERALS IN CM CARBONACEOUS CHONDRITES MURCHISON AND AGUAS ZARCAS

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Introduction: Asteroids 101955 Bennu and 162173 Ryugu are near-Earth asteroids that originated in the inner part of the main asteroid belt and are the targets of ongoing sample return missions. The spectral features of Bennu (Cb-type) are similar to those of aqueously altered CM-type carbonaceous chondrites (CCs) [1]; likewise, Ryugu is a C-type asteroid [2]. Murchison and Aguas Zarcas are CM2 chondrite falls and potential meteorite analogs for Bennu and Ryugu. Aguas Zarcas is a particularly interesting sample because it was a recent fall (April 2019) in Costa Rica that was collected within hours of its fall, and is a complex breccia consisting of various different lithologies [3]. Here, we studied these two CCs and their components to constrain the evolution of hydrogen in C-type asteroids.

Samples and Methodology: Fresh thick-sections of Murchison and Aguas Zarcas were dry polished, mounted in indium, gold coated, and left in the airlock of the NanoSIMS for ~2 weeks. The D/H ratios and H_2O concentrations of the standards and silicate minerals in the CCs were measured using the Cameca Ametek NanoSIMS 50L at Arizona State University. Two terrestrial standards with known D/H ratios (PMR-53: δD_{SMOW} = -115 ‰; and ALV-519: δD_{SMOW} = -72 ‰) were used to determine the instrumental mass fractionation (IMF) for H isotopes. The water contents were calculated using two mineral and a glass standard with different water contents: (1) orthopyroxene PMR-53, 268 ± 16 ppm (2σ) water; (2) orthopyroxene 116610-18, 119 ± 22 ppm (2σ) water; (3) basaltic glass ALV-519, 1700 ± 86 ppm (2σ) water. A heated San Carlos crystal was used as a blank. All samples and standards were mounted in the same NanoSIMS holder, with a blank and a PMR-53 standard placed next to the samples.

A 16-keV Cs^+ primary beam of ~500 pA (D1-3 aperture, <1 μm in diameter) was rastered over a 25×25 μm^2 area. The secondary ion signal was electronically gated to the internal 50 % of the rastered area. $^1H^-$, $^2D^-$, $^{12}C^-$, and $^{18}O^-$ were measured simultaneously using entrance slit 1 and aperture slit 1 in isotope mode with a fixed counting time of 500 μs/pixel and variable number of cycles (50–250). The electron gun (~500 nA) was used to compensate for the charging of the sample surface. The analysis area was pre-sputtered with 25×25 μm^2 raster at 1 nA for ~10 minutes. The $^1H^-$ and $^{12}C^-$ intensity was monitored using real time imaging to identify surface contamination and cracks. The water contents were estimated using a water calibration determined by a linear regression of $^1H^-/^{18}O^-$ measurements in the standards versus known H_2O concentrations; it has an intercept at 1.51×10^{-2} and a slope of 1.11×10^{-4} (R^2 = 99.4%). Background analytical blank were <18 ppm H_2O, which were subtracted from sample measurements. IMF correction was done using PMR-53 and delta values were normalized to Standard Mean Ocean Water (SMOW).

Results & Discussion: The median H isotopic compositions of silicate minerals in Murchison and Aguas Zarcas are different. The median δD value (of all spots combined) in Murchison is -227 ‰, while that in Aguas Zarcas is -86 ‰ with a maximum error of 46 ‰. The silicates in Aguas Zarcas (median=1,604 ppm H_2O) are ~3 times more hydrated than those in Murchison (563 ppm H_2O). The nominally anhydrous minerals in recent ordinary chondrite falls, Benenitra and Chelyabinsk, and asteroid Itokawa have water contents similar to Murchison [4, 5]. More importantly, the δD median value of meteorites Benenitra and Chelyabinsk (-263 ‰) is also similar to Murchison, within 1σ errors, indicative of common formation conditions of nominally anhydrous minerals in the protosolar nebula. Several measurements on individual grains, from the rim to the core, were undertaken in Murchison and Aguas Zarcas. These grains show the same D/H isotopic ratios within errors, but variable water contents and exhibit no degassing trend.

Isolated silicate minerals in the Murchison matrix have the same water contents relative to Murchison chondrules within errors but have elevated D/H ratios (δD=-162 ‰ vs. -217 ‰). Isolated olivine grains in carbonaceous chondrites have been postulated to have splashed out of chondrules when these were still molten, followed by quick quenching [6]. This process of formation would result in a preferential loss of H from the chondrule melt in its free-floating state and potentially produce the observed D-rich signatures. Alternatively, the isolated silicates could have acquired D-rich water from the surrounding organic-rich matrix with high D/H ratios (δD=777 ‰) [7], although much larger δD values are expected in this case. Based on these observations, we predict that silicate minerals within individual particles collected from the Bennu and Ryugu regolith will show distinct populations of D-poor and D-rich signatures.

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